Erik Gawel · Sebastian Strunz
Paul Lehmann · Alexandra Purkus
Editors

The European Dimension of Germany's Energy Transition

Opportunities and Conflicts

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Editors
Erik Gawel
Department of Economics
Helmholtz Centre for Environmental Research – UFZ
Leipzig, Germany

Institute for Infrastructure and Resources Management
Leipzig University
Leipzig, Germany

Sebastian Strunz
Department of Economics
Helmholtz Centre for Environmental Research – UFZ
Leipzig, Germany

Paul Lehmann
Department of Economics
Helmholtz Centre for Environmental Research – UFZ
Leipzig, Germany

Institute for Infrastructure and Resources Management
Leipzig University
Leipzig, Germany

Alexandra Purkus
Department of Economics
Helmholtz Centre for Environmental Research – UFZ
Leipzig, Germany

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Preface

In this volume, we aim to provide an interdisciplinary account of the linkages between Germany's energy transition ("*Energiewende*") and the development of energy policy at the European level. As the title suggests, our goal is to shed some light on both the promises and the pitfalls of moving from national towards European energy policy. Hence, this volume gathers a variety of perspectives: some contributions highlight the possible benefits of a more coordinated approach, and others point to the potential drawbacks of the centralization of energy policy. Moreover, the contributors to this volume come from a variety of disciplines—economics, law, political science, as well as systems science. Several individual chapters explicitly integrate different perspectives; nevertheless, we believe that an overarching merit of this volume is that it also reflects the diversity of opinions that characterizes debates about energy transitions in the context of multilevel governance.

A specific starting point for this book was a workshop held at the Helmholtz Centre for Environmental Research—UFZ in Leipzig, Germany, in December 2016. Contributors from several universities and research institutions joined us at the UFZ to discuss Germany's *Energiewende* within the context of EU energy policy. Needless to say that the latter is constantly evolving: while at the time of the 2016 workshop, the EU Commission's "winter package" of regulative proposals had just been published, by the time of submitting the manuscript, in Summer 2018, the trialogue between Commission, Parliament, and Council is under way or has already been finished for some of the proposals. In other words, a crucial issue for any treatment of the interactions and feedbacks between national and European policies consists in staying up to date with recent developments while not losing sight of the "grand challenges" that characterize the debate in the medium and long run. We hope that the volume balances this requirement by including both analyses of the latest advancements of EU level politics and chapters dealing with more general and conceptual questions.

We would like to sincerely thank all the contributors to this book as well as the reviewers who helped us sharpen the focus. This volume also owes to the Helmholtz

Alliance "Energy-Trans", a project funded by the German Federal Ministry of Education and Research (BMBF) that ran from 2011 to 2015, in that the network of contributors grew out of joint research within this project. In particular, the contributions of several researchers from other EU Member States were enabled through guest professorships funded by "Energy-Trans". Currently, research collaborations on the topic continue within the "ENavi" project, also funded by the BMBF. We are grateful for this support and hope that this volume illustrates the benefit, or rather the necessity of joint research on multifaceted topics such as the one covered here.

Leipzig, Germany
July 2018

Erik Gawel
Sebastian Strunz
Paul Lehmann
Alexandra Purkus

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Towards a European Energy Transition? A Review of Current Policy Challenges and Scientific Debates

Erik Gawel, Sebastian Strunz, Paul Lehmann, and Alexandra Purkus

Abstract This volume addresses the interactions between Germany's energy transition and the EU energy policy framework. Neither the prospects of the proclaimed "Energy Union" nor the future of Germany's energy transition can be fully understood without analyzing the manifold relations between the two. Germany, as an early mover in the transformation of energy systems towards renewables, may hold relevant lessons for the transformation on the EU level. The German energy transition, in turn, needs to be explored within the EU context, because the latter reacts to and influences national energy policies. Specifically, the EU Commission aims to steer Member States' policies towards a more harmonized transition approach. Overall, there are areas of friction as well as synergetic potential between hitherto mostly national sustainability policies and the EU's push towards harmonized policies within a common market. The overall aim of this book, then, is to identify the most critical issues involved in order to avoid the pitfalls and seize the opportunities of the interactions between national and EU level policies.

Germany's energy transition is steadily progressing. According to the latest figures, in 2017, 36.2% of electricity consumption in Germany was generated from renewable sources (UBA 2018: 6). This implies a more than fivefold increase in the renewables share since the year 2000. Yet, the transition process also poses considerable challenges in a variety of fields. For instance, the volatility and regional disparity of feed-in from renewables put a strain on electricity grids and create an urgent need to develop long-term solutions for security of supply. Moreover, the success of the feed-in tariff scheme has also contributed to higher retail electricity

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E. Gawel · P. Lehmann
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

S. Strunz (✉) · A. Purkus
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: sebastian.strunz@ufz.de

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prices which, in turn, has led to intense public debate on whether deployment costs for renewables should be contained. All of these issues have to be addressed in order to keep the energy transition on track.

One important point repeatedly made in these discussions is the "Europeanization" of the energy transition. Basically, it is argued that all of the transition challenges could be mitigated via a more integrated approach on the EU level. By allocating renewable capacities according to maximal geographical productivity around the continent, less renewable capacity would have to be deployed and transition targets could be met more cost-efficiently. In addition, the need for back-up capacity would decrease with rising integration of electricity grids due to better exploitation of complementary weather patterns. Of course, other arguments, such as heterogeneity of preferences and the benefits of decentralized experimentation, caution against rapid centralization and forced harmonization (see Part II for in-depth analyses of these issues). Nevertheless, the EU Commission seizes upon these discussions to promote its vision of an Energy Union (EU Commission 2015). The Energy Union should guarantee "clean energy for all Europeans", as the Commission put it in 2016 when it published a whole array of new regulatory proposals aimed at advancing the Energy Union. From the Commission's perspective, security of supply, climate protection, as well as economic efficiency all benefit from the aspired Energy Union.

Then again, what are the prospects for such visions (cf. Buchan and Keay 2016)? The post-financial crisis turmoil and the upcoming Brexit are examples of the challenges the EU is currently facing. Within the field of energy policy, there are several reasons to cast doubt on high hopes for swift integration. For instance, completely different conceptions of the main purpose of an Energy Union prevail: is the latter to be conceived as a concerted climate protection effort (as northern and western EU Member States maintain) or rather as a collective instrument to safeguard security of supply (as the Visegrád countries maintain)? Furthermore, the extent to which energy policies have already converged in the past is debatable; and where the Commission hopes to take "a significant step towards the creation of the Energy Union",[1] different interpretations of the expected effect of new regulations prevail (see Part I).

Coming back to Germany's energy transition, its position within the EU context seems somewhat ambivalent. While the term *Energiewende* symbolizes the ambition of a "great transformation" towards sustainability, the success of the latter is far from assured. For instance, Germany will fail to meet its greenhouse gas emission reduction targets for 2020 and, the rise of renewables notwithstanding, lignite has lately seen a CO_2-intensive revival. Hence, Germany is currently discussing the need for a coal phase-out following the model of the nuclear phase-out (with the last nuclear plant to be shut down in 2022). Moreover, various side-effects of the rapid deployment of renewables, such as negative environmental externalities from wind energy or biomass production, threaten to taint the public image of renewables (see

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[1] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

Part III). Looking beyond the electricity sector, the picture is not only ambivalent but rather unfavorable: the transformation of the transport and heating sector is clearly lagging behind (see Part VI). Whether Germany serves as a role model and whether its preferred self-image as an EU frontrunner is appropriate, therefore, remains open to debate.

Overall, there is clearly no one-size-fits-all model of a transition process applicable to every national context. In the words of Sovacool (2017: 29), energy transitions are "path dependent and cumulative": that is, various contexts—politico-economic constellations, established infrastructures and technological settings—determine the processes of change and adaptation of the energy policy mix (see Part IV). By implication, energy transitions unfold on different scales and at different speeds (see Part V). So we can neither expect to simply upscale national transition efforts, nor are different transition speeds (both with respect to sectoral and national differences) necessarily problematic (i.e. not necessarily a sign of 'lack of ambition' by laggards).

Against the backdrop of these discussions, the present volume aims to shed some light on the two-way relationship between German and European energy policies:

- What are the current prospects for a more integrated approach within an Energy Union?
- In which ways does the EU context affect Germany's energy transition?
- In what respect can the Energy Union project draw on experience from Germany's energy transition?

Addressing these questions first necessitates an in-depth review of recent developments of the EU energy and climate policy framework for the post-2020 period, as well as an analysis of the potential for bottom-up processes of convergence. Secondly, it requires an exploration of the critical debate on the *Energiewende* in Germany—with an emphasis on possible repercussions beyond Germany. Such spillover effects may, in principle, turn out to be both positive and negative, from "role model" and "frontrunner" on the one hand to "deterrence effects" (e.g., is there a "dark side" to Germany's energy transition, such as inappropriately high electricity prices?) on the other hand.

Summing up, neither the prospects for the proclaimed Energy Union, nor the future of Germany's energy transition can be fully understood without capturing the interactions between both levels. Naturally, these interactions include both challenges and opportunities: in the extreme, one might perceive the vision of a common market with a fully harmonized approach towards sustainability transformation as opposed to the specter of re-nationalization and fragmentation. In reality, frictions and synergetic potential co-exist. The overall aim of this book, then, is to contribute to managing the former and harnessing the latter.

1 Character and Organization of the Book

This volume is essentially characterized by (i) its interdisciplinary approach and (ii) its focus on the interaction between EU level and Germany's *Energiewende*. Its contributors represent all disciplines relevant to the context at hand: economics, law, political science, as well as systems science. Some chapters are written trough an interdisciplinary lens that combines two or more perspectives: thus, an energy systems perspective is coupled with an economic framework or EU climate policy is analyzed with respect to its implications from a behavioral economics viewpoint. By comparison, most similar volumes look at energy transition policies from a narrower disciplinary perspective. For instance, Buchan and Keay (2016) give an economics perspective on the obstacles to the internal market, while Talus (2013) analyzes the development of EU energy policy from a legal perspective. Hager and Stefes (2016), in turn, investigate Germany's energy transition from a comparative perspective, yet they do so mostly via international comparisons (USA, Japan, China) rather than investigating intra-EU interactions. Another distinctive characteristic of the present volume is its focus on the relationships and feedbacks between Germany's energy transition and the EU level. This topic is still understudied: Germany represents an early mover in the transformation of energy systems towards renewables, and the numerous repercussions (political, economic, systemic) of this transition need to be explored within the EU context, which, in turn, reacts to the German transition.

This book is divided into six main parts, each of which has its own theme and consists of several chapters. These are:

1.1 Part I: The European Climate and Energy Policy Framework

The first part of the book explores the current state of the EU's climate and energy policy. To start with, Lehmann et al. review the post-2020 framework, noting that the transition towards sustainable energy comprises more than decarbonization; this further complicates the transformation challenge from an EU perspective, since national approaches in technology-specific areas such as nuclear policy diverge across member states. Smith et al., in turn, assess whether the post-2020 climate and energy target-mix is sensible against the backdrop of its macroeconomic impacts. Subsequently, Resch et al. investigate the prospects for renewables policies in the period from 2020–2030. Part I closes with two legal reviews of the latest developments of the EU energy policy framework: Kahles and Pause address the impact of EU State Aid law, while Ludwig analyzes the EU Commission's "Winter Package" in detail.

1.2 Part II: Unilateralism or Cooperation and Convergence?

Part II focuses on the possibility space in between full harmonization and complete national fragmentation. Grossi et al. discuss the effects of unilateral policy reform on neighboring electricity markets. The prospects and requirements for bottom-up processes of cooperation and convergence are analyzed in two chapters by Knodt and Ringel as well as Strunz et al. Three chapters deal with the multiple aspects of the harmonization debate: Hoffrichter and Beckers discuss the distribution of decision-making competencies in the EU from an institutional-economic perspective. With respect to renewables, explicit cooperation between member states remains scant, so far. The proposal by Busch and Ortner might open a feasible path towards increased cooperation on renewables. At the same time, Strunz et al. argue that a complete and imminent "Europeanization" of energy policy would not be desirable in the first place. Last but not least, Vögele and Ball analyze Germany's role in bottom-up processes: can Germany's reputation as a role model and forerunner be substantiated empirically (for instance, considered that emission reduction targets have been missed in the past)?

1.3 Part III: Is There a Dark Side to Germany's Energy Transition?

This part deals with the challenges that have arisen during the transformation process in Germany and that have been used in public and scientific debates to criticize the rapid expansion of renewables: for instance, rising CO_2 emissions (Kunze and Lehmann), increasing electricity prices (Delzeit et al., Bardt and Schaefer), higher dependence on gas imports from Russia (Gawel and Strunz) and negative environmental externalities from wind power (Ammermann et al.) have all been blamed on the energy transition. However, a more detailed look at these issues shows that strategic motives (such as profit interests of the conventional energy system's incumbent actors) are often a key driver of critiques of the energy transition and causal links are sometimes weaker than contended. Furthermore, the distributive consequences of ambitious climate policy and their effect on consumer behavior is explored and discussed by Heindl et al. Understanding these challenges—and developing adequate solutions to specific problems—is key for the discussion on whether and how the German approach could be scaled up to the European dimension.

1.4 Part IV: The Energy Policy Mix from a Political Economy Perspective

The policy mix for the transformation of the energy system consists of a variety of instruments on different levels of government. Most prominently, the transition process is driven by the emissions trading scheme on the EU level and support policies for renewables on the national level—yet the overlap of these instruments has been at the center of heated debates: has the long-standing "emissions trading vs. support for renewables" controversy been fully resolved (Gawel et al.)? Scholz evaluates possible cost savings from cooperative renewable energy expansion in Europe against the background of import/export dependencies that might be politically highly relevant. Moreover, Sijm et al. investigate how experiences from the Dutch energy transition with regard to system flexibility might inform the refinement of the policy mix in other EU Member States. Finally, the political economy perspective implies that concrete visions and policies, such as the internal market agenda, are always related to specific interests: the EU Commission's push for a common market is a prime example of the combination and interaction of ideological motives and actor-specific self-interest (Strunz et al.).

1.5 Part V: The Spatial Dimension of the Energy Transition

In this part, the spatial effects of the transition are investigated. This includes several interrelated issues, such as decentralization and spatial differentiation between regions (Gailing). At the same time, European electricity market integration requires the transmission of electricity over long distances (Kost and Längle provide an overview of the various implications). Transmission infrastructure poses a particular challenge in that the extension of transboundary interconnectors is a prerequisite for a more integrated energy transition (Brunekreeft and Meyer). Put differently, the more integrated the system, the higher the pressure on existing transmission lines—and this challenge is often viewed merely as a technological issue, while the social, politico-economic and legal restrictions are neglected. Thus, Bovet provides an analysis of the legal aspects of EU transmission line planning.

1.6 Part VI: The Energy Transition Beyond the Electricity Sector

Finally, a European energy transition needs to go beyond the electricity sector. In the transport sector, Germany has hardly been a leading example so far. Lepoutre et al. sketch the overall challenge of supporting electromobility in the transport sector. Achtnicht et al. analyze the prospects of including road transport in the emissions trading scheme as an instrument to initiate the transition of this sector. Furthermore, sector coupling will become an increasingly important topic as the transition proceeds; the experiences from bioenergy (Horschig et al.) and biofuel (Purkus et al.) policies provide relevant lessons on how to prevent undesired side-effects and how to foster sector-coupling.

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Part I
The European Climate and Energy Policy Framework

EU Climate and Energy Policy Beyond 2020: Are Additional Targets and Instruments for Renewables Economically Reasonable?

Paul Lehmann, Erik Gawel, and Sebastian Strunz

Abstract The European Union has decided to increase its target for greenhouse gas emissions reductions to 40% by 2030, compared to 1990 emissions levels. In contrast, the target for the share of renewable energy sources in electricity consumption—even though increased to 27%—will not be binding anymore for Member States beyond 2020. This is in line with many existing assessments which demonstrate that additional RES policies impair the cost-effectiveness of addressing a single CO_2 externality, and should therefore be abolished. Our analysis explores to what extent this reasoning holds in a second-best setting with multiple externalities related to fossil and nuclear power generation and policy constraints. In this context, an additional RES policy may help to address externalities for which first-best policy responses are not available. In addition, we also argue that an unambiguous, "objective" economic assessment is impossible because (i) policies may have a multiplicity of impacts, (ii) the size of these impacts is subject to uncertainties and (iii) their valuation is contingent on individual preferences. Thus, the eventual decision on the optimal choice and design of climate and energy policies can only be taken politically.

1 Introduction

The European Union (EU) is pursuing a set of explicit climate and energy targets for the year 2030: greenhouse gas (GHG) emissions are to be cut by 40% compared to 1990 levels, energy efficiency is to be improved by 27%, and the share of renewable energy

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P. Lehmann (✉) · E. Gawel
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany
e-mail: paul.lehmann@ufz.de

S. Strunz
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

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sources (RES) in total energy consumption is to be increased to 27% (European Commission 2014b; European Council 2014). It should be noted, however, that the RES target is not binding. This is due, first, to the fact that no specific RES targets have been agreed on for individual member states—in contrast to the previous 2020 climate and energy targets (European Commission 2008). Consequently, no party can be held liable if the target is not met. Second, the proposed level of ambition would correspond to the RES share which is expected to be attained under the GHG target anyway (European Commission 2014a). Thus, the European Union has in fact agreed to abstain from a strong and credible RES target in the future. Our study aims to review this decision critically. Are there economic rationales for implementing a strong RES target in addition to the GHG target at the European level?

The discussion on the 2030 targets can benefit from a large strand of economic studies which analyse the welfare effects of the EU 2020 targets, using computational general equilibrium (CGE) models (Bernard and Vielle 2009; Boeters and Koornneef 2011; Böhringer et al. 2009a, b; Kretschmer et al. 2009), energy system optimization models (Aune et al. 2012; Capros et al. 2008, 2011) or partial equilibrium models (Böhringer and Rosendahl 2011).[1] These studies have been complemented by analyses of post-2020 targets, including the assessment mandated by the European Commission (2014a) as well as others employing energy system models (Flues et al. 2014; Jägemann et al. 2013; Knopf et al. 2015; Möst and Fichtner 2010; Unteutsch and Lindenberger 2014). These studies consistently find that an additional RES target leads to excess economic costs as it impairs cost-effective attainment of the GHG target—even though the actual excess cost may be relatively small. Certainly, there is also a small strand of literature using econometric models which shows that RES targets may also increase overall welfare (see Smith et al. 2019). More generally, the decisive question is: Which policy recommendations can be derived if RES policies are found to increase the costs of GHG mitigation? An unambiguous plea to abolish a RES target and corresponding instruments can only be made if (1) technology choice for electricity generation is only distorted by a GHG externality, (2) the GHG externality is perfectly addressed by the GHG targets and instruments chosen, and (3) there are no other policy objectives beyond efficient climate change mitigation. These restrictions are acknowledged by most of the studies. Böhringer and Rosendahl (2011, p. 471) point out, for example, that the excess costs of a RES target may be interpreted as the "price tag [. . .] for the composite of objectives different from emission reduction." This notwithstanding, these rationales are not further examined by the strand of literature mentioned above.

Our study aims to shed more light on the role of RES targets and instruments once the above assumptions are relaxed. In particular, we consider a setting with multiple market failures—including the GHG externality as well as technology market failures, other environmental externalities from using fossil and nuclear fuels (e.g., air pollution, land-use effects, nuclear hazards), and externalities related to fossil fuel imports—which for a variety of reasons cannot efficiently be addressed by first-best

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[1] For a review, see also Tol (2012).

policies. In addition, we also take into account policy objectives which are beyond allocative efficiency but which may nevertheless be relevant for practical policy-making, such as job creation or decentralized ("democratized") energy supply. In such a setting RES targets and instruments may be justified if (1) they actually help to address the market failure or policy objective, and (2) they are more cost-effective than other feasible policy approaches. Our assessment primarily builds on a literature review regarding possible benefits of using RES targets and instruments in addition to GHG policies.

The remainder of the article is organized as follows: Section 2 provides an overview of possible benefits of RES policies implemented in addition to a GHG policy. Section 3 reviews first-best rationales for RES policies. Section 4 points out rationales for RES policies in a second-best world. Section 5 discusses reasons for implementing RES policies that go beyond the criterion of allocative efficiency. Section 6 concludes.

2 Benefits of Additional RES Targets and Instruments: An Overview

For the purpose of our analysis, it is useful to distinguish three elements of policy design: objectives, targets and instruments (see Fig. 1). By *objectives* we refer to the rather general societal goals associated with sustainable climate and energy policy. These include most prominently climate change mitigation, environmental and resource conservation beyond climate change, technology development, the security of energy supply, the promotion of green growth and green jobs and the decentralization (or democratization) of energy supply (European Commission 2011). *Targets* are operationalized and usually also quantified values which shall be attained in a certain period of time and are expected to contribute to the overall objectives. In our analysis, we will focus on the RES target which coexists with a GHG target for the EU ETS sectors. Finally, *instruments* are those measures which are implemented in order to actually attain the targets—and thereby also the objectives. We will restrict our analysis to RES support schemes in the electricity sector which complement the EU ETS.

Existing assessments of RES targets and instruments relate additional costs primarily to benefits in terms of climate change mitigation (see above). These kinds of benefits are null in a first-best setting where a GHG externality is perfectly addressed by an ETS. However, there may be benefits if the assumptions of a single market failure and perfect policy responses as well as the focus on allocative efficiency are relaxed. Correspondingly, three lines of arguments can be differentiated (see also Fig. 1): (1) a first-best setting where the RES policy directly addresses market failures other than a GHG externality, (2) a second-best setting where there are multiple market failures for which first-best policy responses (targets and instruments) are either absent or insufficient for diverse institutional and political

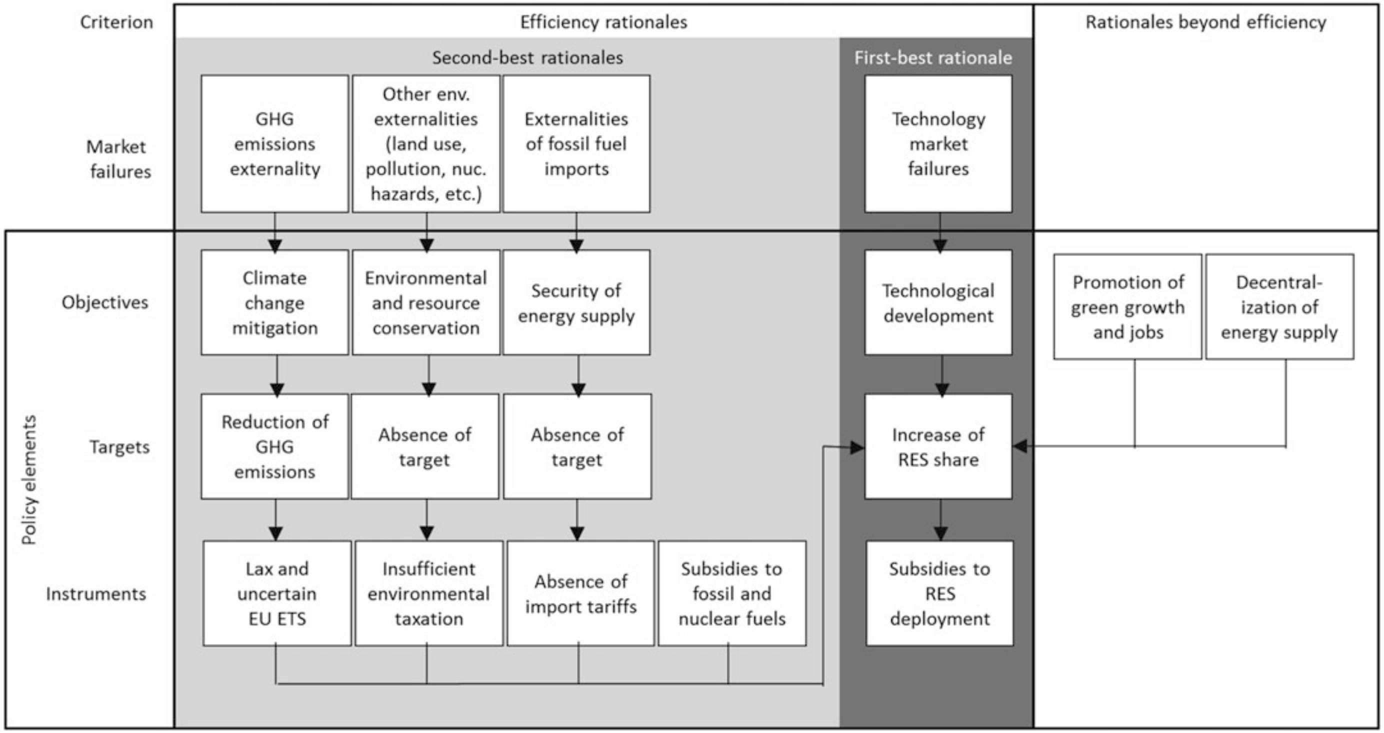

Fig. 1 Possible economic rationales for RES targets and instruments in the electricity sector. Source: Own illustration

constraints, and (3) a setting with policy objectives that go beyond mere allocative efficiency and which may reflect a broader definition of the social welfare function, including, e.g., distributional concerns. In the latter two settings, RES targets and instruments can be justified if they (1) actually generate benefits in terms of correcting market failures or attaining policy objectives, and (2) if they are more cost-effective than other institutionally and politically feasible policy options, including no (additional) policy intervention.

When assessing these potential benefits of a separate RES target and instrument, it is important to consider that the welfare losses from both market and policy failures mentioned above may be quite significant in the long run as suboptimal investments in the electricity sector are perpetuated over decades by strong socio-technical path dependencies (Kalkuhl et al. 2012; Lehmann et al. 2012; Lehmann and Gawel 2013; Neuhoff 2005; Unruh 2000).

The discussion in this chapter is not meant to assess whether or not an additional RES target and instrument is actually welfare-increasing—nor what the optimal level of such target would be. Instead, it aims to broaden the perspective on which costs and benefits should be taken into account when assessing RES policies.

It is usually assumed that the rationales for implementing a separate RES target and a separate RES instrument are basically the same. In addition, it has also been shown analytically that a mix of emission reduction and RES deployment targets can only be achieved simultaneously and cost-effectively by a mix of an emissions policy and a technology policy (Jensen and Skytte 2003; Pethig and Wittlich 2009).

3 First-Best Setting: Additional Technology Market Failures

In a first-best setting, the GHG emissions externality is assumed to be properly addressed by the ETS. In this case, an additional RES target may be justified in the presence of additional technology market failures, most notably positive externalities related to learning-by-doing with RES technology deployment. These externalities arise because firms learn to optimize products and production processes as their cumulative output increases, and this knowledge may at least partly spill over to other market competitors (for overviews, see Bennear and Stavins 2007; Fischer and Newell 2008; Gawel et al. 2017; Jaffe et al. 2005; Lehmann 2012, 2013; Lehmann and Gawel 2013). Quantitative evidence on the existence of such externalities for RES technologies is still scarce.[2] So far, Bollinger and Gillingham (2014) have been

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[2] There is increasing evidence of knowledge spillovers associated with research and development of renewable energy technologies (Bjørner and Mackenhauer 2013; Braun et al. 2010; Dechezleprêtre et al. 2013; Garrone et al. 2010; Noailly and Shestalova 2013; Popp and Newell 2012). However, such externalities cannot be properly addressed by general RES deployment targets, but rather by more specific RES-R&D targets and policies.

the only authors to provide empirical evidence—for significant learning spillovers related to solar photovoltaics deployment in California. In addition, anecdotal evidence for the RES sector (Hansen et al. 2003; IEA 2000; Junginger et al. 2005; Neij 1999) as well as experience with non-renewable energy technologies (Lester and McCabe 1993; Zimmerman 1982) and the manufacturing sector in general (Argote and Epple 1990; Irwin and Klenow 1994) seems to underpin that learning spillovers may characterize RES deployment also. The potential welfare effects from learning spillovers may be particularly high in the energy sector, as it is characterized by long-term investments with strong path dependencies and lock-in effects (Goldthau and Sovacool 2012; Kalkuhl et al. 2012). Thus, policy intervention would be more warranted in the energy sector than in other sectors where similar externalities tend to occur as well.

In the presence of positive externalities associated with learning-by-doing in RES technologies, targets and instruments to promote RES deployment are justified. Depending on how the learning process is modelled, a GHG policy has to be supplemented by a technology-specific subsidy to either (i) RES generation (Canton and Johannesson Lindén 2010; Fischer and Newell 2008; Kalkuhl et al. 2012; Lehmann 2013; Lehmann and Söderholm 2018), (ii) RES generation capacity installed (van Benthem et al. 2008), (iii) investments in RES generation capacity (Kverndokk and Rosendahl 2007), or (iv) output of manufacturers of RES installations (Bläsi and Requate 2010).

4 Second-Best Setting

In a second-best setting, rationales for RES policies may arise if first-best policies to address market failures are not available, or if there are pre-existing policy distortions which cannot be corrected.

4.1 Imperfect Internalization of the GHG Externality

It may be unclear whether the current GHG targets (20% reduction by 2020, 40% reduction by 2030) and even more ambitious long-term targets are efficient, given the large uncertainties surrounding the costs and benefits of GHG emission reductions (for a sceptical view, see, e.g., Tol 2012). However, the picture becomes clearer if an ambitious long-term target of 80% emissions reduction by 2050 is accepted as a reasonable target. A model comparison by Knopf et al. (2013) shows that in this case the 2020 GHG target is not ambitious enough, while the 2030 target seems to be in line with cost-effective pathways for achieving the 2050 target.

Even if the targets are set properly, the attainment of these targets will be questionable given the current design of climate policy instruments. Knopf et al. (2013) point out that the trajectory agreed upon for the reduction of the emissions cap under the EU ETS (1.74% annually) is clearly below the levels needed to actually achieve short- and long-term targets. This does not come as a surprise as the cap as well as other design features of the EU ETS have been the result of a political bargaining process—rather than some cost-benefit analysis (Anger et al. 2016; Markussen and Svendsen 2005; Rudolph 2009; Skodvin et al. 2010). In addition, the carbon price signal generated by the EU ETS exhibits major short- and long-term uncertainties. Against this background, the EU ETS fails to set sufficient incentives to switch to low-carbon technologies which are needed to attain the long-term targets cost-effectively (for overviews, see Lehmann and Gawel 2013; Matthes 2010). Under these conditions, an additional RES policy may serve as a second-best strategy to mitigate climate change cost-effectively in the long run (Bläsi and Requate 2007; Fischer 2008; Palmer and Burtraw 2005; Ulph and Ulph 2013).

Obviously, the first-best approach would always be to strengthen the EU ETS. This appears to be particularly warranted as RES deployment may bring about significantly higher societal costs than if the policy failures were addressed directly (Borenstein 2012; Kalkuhl et al. 2013). However, given past experience with politico-economic decision-making, it is unclear whether the EU ETS emissions cap will actually be reduced to the levels required to attain the targets. Moreover, Gawel et al. (2014) show that a separate RES policy may have another advantage in this respect. As RES targets are typically implemented by subsidies, they bring down abatement costs for participants under the EU ETS. These may therefore be willing to accept stronger emissions reductions. Thus, a separate RES target and instrument may also help to negotiate a tighter emissions cap.

4.2 Imperfect Internalization of Other Externalities

A separate RES target can also be understood as a second-best policy to address externalities beyond GHG emissions if these cannot be corrected directly by appropriate first-best approaches (Edenhofer et al. 2013b, c; Lehmann and Gawel 2013; McCollum et al. 2011; Lehmann et al. 2019). This type of rationale will be discussed in the following for the two most prominent examples: additional environmental externalities associated with the use of fossil and nuclear fuels and externalities arising from the import of fossil fuels.

Fossil and nuclear fuels also produce *environmental externalities other than climate change*. For fossil fuels, these may be related to damages from fuel extraction (e.g., ecological impacts of open cast coal mining and fracking), transportation (e.g., oil spills), and combustion (e.g., local air pollution) (e.g., Epstein et al. 2011). Similarly, there are hazards associated with the operation of nuclear power plants and the final storage of nuclear wastes (Heyes and Heyes 2000). These externalities are typically not addressed perfectly by Pigovian tax-like policies. If such externalities are produced by economic activities within the territory of the EU, the absence of direct policies for internalization may be explained by lacking political will (in order to reduce the burden for voters or interest groups). Yet, externalities reducing welfare within the EU may also be related to economic activities outside the EU. Examples include the inter-regional transportation of pollutants or radioactivity by air and ocean currents or the loss of biodiversity. In such cases, the lack of regulation is simply due to the fact that externalities arise beyond the legislative scope of the EU. In both cases, the promotion of RES deployment may help to substitute fossil and nuclear fuels for electricity generation and control externalities indirectly (IPCC 2011; McCollum et al. 2011; Siler-Evans et al. 2013). Certainly, the actual extent of benefits from RES deployment needs to be assessed with care. First of all, it depends on which types of non-renewable power plants are drawn out of the market and where (Borenstein 2012). Second, there may be interactions between RES and GHG policies. Under a fixed CO_2 cap, increasing the share of renewable energy sources may drive down the CO_2 price (for an overview, see Lehmann and Gawel 2013). As a consequence, coal-fired power generation may benefit at the expense of gas-fired power generation (Böhringer and Rosendahl 2010), with corresponding implications for the related externalities. Moreover, emitters outside the electricity sector may directly or indirectly benefit from the reduced CO_2 price, increase production and generate additional environmental externalities (Lehmann et al. 2019). Finally, RES may produce new types of environmental externalities, such as land- use conflicts associated with the installation of wind turbines and biomass production or negative impacts on aquatic ecosystems related to the use of hydropower (IPCC 2011; Kerr 2010; Zerrahn 2017).

Fossil fuels may also generate externalities in terms of *security of energy supply* if they are imported from politically unstable regions. Sudden supply interruptions may significantly impair importing economies (Borenstein 2012; Johansson et al. 2012). Estimating these external costs is certainly difficult (see, e.g., Bohi and Toman 1996; Gillingham and Sweeney 2010). In theory, such externalities could be corrected directly by tariffs on imported fuels. The ubiquitous lack of such policies may be attributed to the fact that they would oftentimes violate international trade law and may raise political fears of economic sanctions imposed by exporting countries. Against this background, promoting domestic RES to substitute imported fossil fuels may produce benefits in terms of safeguarding the security of supply (McCollum et al. 2011). For electricity generation in the EU, such benefits will primarily arise if natural gas imports from Russia or Northern Africa are substituted (Borenstein 2012; Edenhofer et al. 2013a). In a theoretical model, Böhringer and Rosendahl (2010, 2011) confirm that a RES policy in fact reduces the share of electricity generation from natural gas. Certainly, the use of RES may also produce new problems of security of supply due to their intermittency and the related system integration costs (Hirth et al. 2015). Moreover, the lower CO_2 prices following from RES subsidies may also stimulate natural gas consumption and imports by other industry sectors (Lehmann et al. 2019). Again, it thus needs to be assessed carefully whether and to what extent RES subsidies are a useful policy instrument for reaching the objective of security of supply.

4.3 Direct Subsidies to Fossil and Nuclear Fuels

The use of non-renewable energy technologies is also supported directly. This includes subsidies to fuel production and consumption as well as to technology research and development (Ellis 2010; IEA/OPEC/OECD/World Bank 2010; OECD 2011). These subsidies reduce the cost of non-renewable energy sources to inefficiently low levels. Obviously, the first-best solution would again be to abolish the subsidies. However, this may be difficult politically due to opposition from affected mining companies, plant manufacturers and energy utilities, as well as from consumers facing higher electricity prices. Against this background, a RES policy is again a means to establish a level playing field for technology decisions in the electricity sector.

5 Objectives Beyond Allocative Efficiency

In the political arena, RES targets are often associated with multiple objectives to be attained. Some of them—such as climate change mitigation, environmental and resource conservation and security of supply—may be justified on the basis of allocative efficiency in first-best or second-best settings, as outlined in the previous sections. However, there are also policy objectives associated with RES targets—such as green jobs and green growth or the decentralization of energy supply—which may be more difficult to relate to improvements in allocative efficiency or the correction of a market failure. Nevertheless, this finding does not imply that such objectives should be disregarded in economic analyses for at least two reasons: First, these objectives may be highly relevant for practical decision-making. For example, RES policies may only be politically feasible if they also address concerns of employment (Edenhofer et al. 2013b). Analyses neglecting these kinds of objectives risk following a nirvana approach (Demsetz 1969). Second, the existence of such objectives may also reflect societal preferences beyond allocative efficiency, such as justice, fairness or participation. These may be revealed in a political process of elections and influences from different interest groups (Oates and Portney 2003)—even though this process is certainly subject to manifold distortions (e.g., Olson 1965). In these cases, the primary question is not so much whether the objective makes sense economically but rather whether it can be attained cost-effectively by a RES policy.

The most prominent objective in this realm is the stimulation of green growth and green jobs. It will be a hard test to show that this objective can be justified on the basis of market failures, such as imbalances in the labour market (Gillingham and Sweeney 2010). This notwithstanding, RES policies have certainly promoted gross growth and employment in green industry sectors, such as RES manufacturing. O'Sullivan et al. (2016) estimate that Germany's RES policy has generated 330,000 jobs in RES industry sectors up to 2015. Certainly, this comes at the cost that economic development in other economic sectors may be impaired, such that net effects may be quite different. Borenstein (2012) points out that one has to distinguish between a short-term stimulus objective and a longer-term objective of job creation. Creutzig et al. (2014) argue that a European energy transition could have a positive stimulus effect, primarily because RES investments involve large upfront construction costs. In contrast, empirical evidence on net job effects of RES policies is very mixed involving negative as well as positive assessments (EWI et al. 2004; Hillebrand et al. 2006; Lehr et al. 2008; Rivers 2013; Wei et al. 2010, see also Smith et al. 2019). On the one hand, RES technologies are more labour-intensive for producing energy than the non-renewable technologies they substitute (Borenstein 2012). On the other hand, RES policies which are refunded by increases in electricity prices (or taxes) crowd out investments elsewhere in the economy (Frondel et al. 2008, 2010). Thus, using RES policies to promote green growth and employment may be quite costly, which also raises the question whether other available means—such as macroeconomic fiscal and monetary or wage policies—could be more cost-effective in attaining the target.

RES policies are also expected to contribute to a more distributed generation of electricity which is associated with a fairer distribution of, and participation in, the benefits of electricity generation (Alanne and Saari 2006; Pepermans et al. 2005). Empirical observations seem to confirm this expectation. In Germany, for example, almost half the RES-E capacity installed in 2012 was owned by private individuals, farmers and cooperatives (Trend Research/Leuphana 2013). Of course, the eventual magnitude of such benefits depends crucially on the specific design of the RES policy, particularly on how investment risks are mitigated (for a discussion, see Lehmann et al. 2012).

6 Conclusion

The European Union has opted to stick to a more ambitious GHG target but to scrap a binding RES target for the post-2020 period. This is in line with many existing assessments which demonstrate that additional RES policies impair the cost-effectiveness of climate policies, and should therefore be abolished. Our analysis shows that this reasoning may be flawed for a variety of reasons. Most economic studies so far rely on a problem framework tackling a single climate-related externality through a perfect ETS instrument, in which additional RES policies indeed create additional costs but no added value. If we relax the underlying assumptions in order to analyse energy policies in a more reality-oriented framework we have to take into account (1) additional, non-climate externalities of energy provision, (2) imperfections of instruments under real-life conditions and (3) policy objectives beyond allocative efficiency touching upon other politically relevant societal concerns. If multiple market failures have to be addressed using imperfect instruments, as it is the case in the real world, additional RES policies can create social benefits compared to a stand-alone ETS policy. These benefits are economically relevant from an efficiency perspective, whereas "political" benefits from different objectives (3) usually are considered irrelevant (political "co-benefits", see Edenhofer et al. (2013b)).

Moreover, it has become obvious that an objective assessment of all costs and benefits of an additional RES policy is nearly impossible. First, the assessment of costs and benefits is impaired by underlying uncertainties and complexities. Second, it eventually always hinges on the value judgments, risk preferences and ethical considerations of individuals or groups of individuals. In this respect, economic analyses of possible benefits and costs under certain assumptions can be used to inform political decision-makers. Yet, the final decision on whether or not a certain policy target makes sense—given possibly additional benefits but also possibly additional costs—can only be taken by the political decision-maker. This has been pointed out for the setting of GHG targets (IPCC 2014; Knopf and Geden 2014)—but it equally applies to the setting of (additional) RES targets (Lehmann et al. 2014).

Since social benefits of RES supporting policies are likely under real-world conditions, economic analysis should not only assess possible excess costs in fulfilling the single climate target. Rather, the analysis ought to compare the overall economic performance of energy policies under different scenarios with or without separate RES targets and instruments reflecting multiple externalities and imperfections of instruments in a second-best framework.

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EU Climate and Energy Policy Beyond 2020: Is a Single Target for GHG Reduction Sufficient?

Alistair Smith, Unnada Chewpreecha, Jean-Francois Mercure, and Hector Pollitt

Abstract The immediate and long-term requirements of energy policy in Germany and the wider EU are widespread. In addition to meeting decarbonisation targets to mitigate climate change, energy policy must be designed in such a way that is socio-economically advantageous, delivering multi-policy objectives of energy security, a stable environment for energy system operation, affordable energy prices for consumers and industry, and an environment conducive to economic growth.

There has been much debate about the merits and weaknesses of alternative policy frameworks to deliver on emissions targets. Introduced in 2005, the EU emissions trading system (ETS) was designed to monetise the externalities associated with GHG emissions, with many citing the carbon price as providing the most efficient and cost-effective means of achieving a certain emissions target. By contrast, subsidies for renewable electricity generation and energy efficiency measures, when implemented alongside an emissions trading scheme, are often criticized for increasing the costs of emissions abatement and producing no additional environmental benefits. This chapter re-assesses the merits and weaknesses of this policy mix and explores the socio-economic impacts of alternative policy scenarios that

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A. Smith · U. Chewpreecha
University of Cambridge, Cambridge, UK

Cambridge Econometrics, Cambridge, UK

J.-F. Mercure
University of Cambridge, Cambridge, UK

Cambridge Econometrics, Cambridge, UK

Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge, Cambridge, UK

Radboud University, Nijmegen, Netherlands

H. Pollitt (✉)
University of Cambridge, Cambridge, UK

Cambridge Econometrics, Cambridge, UK

Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge, Cambridge, UK
e-mail: hp@camecon.com

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achieve the same emissions target. We use E3ME, a global macro-econometric model, to show that environmental regulation and subsidies for energy efficiency and renewable investment at European level, when implemented alongside a carbon price, lead to improved long-term environmental and socio-economic outcomes compared to when a carbon price is the sole policy instrument.

1 Introduction

1.1 Theoretical Background

With the Paris Agreement (UNFCCC 2015) now ratified, the decision to limit global emissions to a level that is consistent with a 2°C target has been taken. Leaving aside the issue of the US's participation in the Paris Agreement, the main decision that remains at global level is how far to pursue the objective of limiting climate change to 1.5°C above pre-industrial levels.

At national level (and regional in the case of the EU), however, there are still important decisions to be made. In the medium term, there is the question of how the current Paris pledges, known as NDCs (Nationally Determined Contributions) can be scaled up in ambition to be consistent with the 2°C target. More immediately, policy makers must decide upon a policy mix that will help their territories comply with the pledges that they have made.

Economists have played an important role in advising policy makers. Much of the advice has been drawn from neoclassical economic theory, which underpins the current mainstream. The main modelling tools that have been used by economists, a combination of Computable General Equilibrium (CGE) (Dixon and Jorgensen 2012) and energy systems optimisation models (Loulou et al. 2005), are based on this strand of economic theory.

These models consistently suggest that the most efficient way of reducing greenhouse gas emissions in line with the specified targets is to apply either a tax on emissions at the rate required to meet the targets or an emission trading scheme in which the carbon price is determined by the market[1] (Böhringer and Rosendahl 2011; Fankenhauser et al. 2010; Meran and Wittmann 2012). This carbon price should be applied to all emitters equally with no exemptions. If it is not possible to price all greenhouse gas emissions, then at least energy CO_2 emissions should be covered. If there are any existing subsidies on fossil fuels, these should be removed immediately due to their market distorting effect.

However, this result comes directly from the assumptions that are used in the models. The models are optimisation tools; by placing a constraint directly on the output that is to be manipulated (i.e. greenhouse gas emissions), there is minimum disruption to the rest of the economy.

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[1] As the models typically do not cover uncertainty well, a carbon tax and emissions trading scheme may have the same properties in modelling terms.

This in itself is not problematic; all models are based on assumptions and almost by definition the results from the models must reflect the underlying assumptions. However, especially given the wide range of literature and policy analyses (see examples in Dixon and Jorgensen 2012) that has been developed from these models, it is important to dig further into the structure and assumptions of the models. The policy recommendations that arise from them can only be accepted if the assumptions are correct.

Perhaps the most important assumption is what economists refer to as ‘perfect knowledge’. In order to produce optimal decisions, agents must be fully aware of all their options, and the costs and benefits of each one. Further assumptions include fully optimising, ‘rational’ behaviour by individuals to maximise their welfare and firms to maximise profits, and the existence of markets that operate without constraint.

There are legitimate questions to be asked about how realistic any of these assumptions are, but arguably the most important relates to real-world limitations in the degree of knowledge that agents have when making economic decisions. Recently, some economists have developed new theories based on knowledge limitations (Goldberg and Frydman 2007) but the treatment of knowledge gaps has always been an important feature of the whole Keynesian school of economics. Even prior to the Great Depression and Keynes’ more famous works, *A Treatise on Probability* (Keynes 1921) laid out the foundations for his later theory. Keynes realised that fundamental uncertainty (now sometimes referred to as ‘unknown unknowns’) hindered economic decision making and led to individuals building up savings reserves to protect against future stocks. As the money that was saved rather than spent did not lead to demand for goods (and the labour associated with producing those goods), the economy tended to operate below capacity.

Several key economic properties follow from the relaxation of this single assumption of perfect knowledge. Most notably, the level of production is determined by the balance between expenditure and savings (i.e. aggregate demand) rather than purely supply-side constraints on the maximum that an economy can produce. Other important outcomes include:

- If the level of demand is not high enough, it will not be possible to provide jobs for all the available workers, leading to involuntary unemployment.
- ‘Perfect’ competition is unlikely; gaps in knowledge lead to branding and differentiated products that can charge a price premium.
- Income inequality is a likely outcome as firms and individuals can exploit knowledge gaps for their own benefit.
- Firms may underinvest, particularly in research and development, as they cannot be certain that they will be rewarded for their efforts.

There are many more, but these features are all prominent in the real world and present challenges to policy makers across a range of government departments. They are also recognised as important issues in the current post-Keynesian school of economics (King 2015; Lavoie 2015), which has developed the original ideas of Keynes further.

The modelling that we carry out later in this chapter uses an approach that has been developed from post-Keynesian economics. We test whether, with some of these key assumptions relaxed, it still holds that a single carbon pricing instrument is the optimal policy approach. Before that, however, we summarise the current EU policy.

1.2 EU Policy

There are numerous climate-related policies at European level and many more at national level. However, three main policies cut across most sectors in the European economy:

- An aggregate target for greenhouse gas (GHG) emission reduction, which is supported by the European Emission Trading System (ETS) in the power sector, heavy industry and intra-EU aviation.
- A target for the share of final energy consumption that should come from renewable sources.
- A target for improvements to energy efficiency (measured as reductions in energy consumption), relative to a baseline projection.

These three targets formed the '20-20-20' targets for 2020, meaning a 20% reduction in GHG emissions compared to 1990 levels, a 20% renewable energy share and a 20% improvement in energy efficiency. The targets that were set in 2014 for 2030 include a 40% reduction in emissions, a 27% renewable share and a 30% improvement to energy efficiency.

Even though carbon pricing plays a central role in EU policy, the approach of having three targets rather than a single GHG reduction target (backed by a price on emissions) has been criticised heavily by neoclassical economists, see e.g. Böhringer et al. (2009), for being inefficient. European policy makers justify the range of policies on several different factors, some of which are political but others relating to the real-world validity of the economic assumptions discussed above.

In the case of renewables, European policy has the aim of developing key technologies so that they can contribute to emissions reductions around the world, up to and beyond 2030. The current solar revolution is likely to be at least in part due to policies in certain European countries that increased adoption, leading to more efficient production and lower prices for everyone else. The recognised limitation is that, without specific support, 2030 targets could be met in Europe by, for example, switching from coal to natural gas in the power sector, but without the necessary technologies to make further emission reductions.

In the case of energy efficiency, it is widely recognised by the European Commission and others that households face non-price impediments.[2] A lack of direct

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[2] See e.g. European Commission web pages, https://ec.europa.eu/energy/en/topics/energy-efficiency

knowledge is a key issue (e.g. what to buy and how to install it) but access to credit and principal agent problems with landlords not wanting to make investments that benefit their tenants are also important. By setting targets for energy efficiency, the EU and national governments are setting ways to tackle these issues that cannot be addressed with carbon pricing alone. The IEA (IEA 2014) lays out clearly some of the potential benefits of improving energy efficiency.

Clearly there is strong interaction between these policies, which present additional challenges to policy makers. For example, it seems very likely that if the 2020 energy efficiency target is met then the GHG reduction target will be met easily. Alongside the recession in Europe, policy interaction has been cited as a reason for having very low ETS prices in Europe; if renewables and energy efficiency do all the work to reduce emissions then a carbon price is not so important. It is recognised, however, that a low carbon price does not provide non-power sector companies (where emission reduction measures are typically more expensive) the necessary incentives to invest in low-carbon future technologies.

Recent work has discussed the need for policy makers to consider a comprehensive policy mix to effectively manage and encourage sustainability transitions (Rogge and Reichardt 2016); and the advantages of complementing carbon pricing with additional targets (Lehmann and Gawel 2013; del Rio 2017; Lehmann et al. 2019). Grubb et al. (2014) provides a clear outline of how technologies require different types of policy support at the various stages of their development.

1.3 Structure of This Chapter

The modelling in this chapter builds on previous work by Sijm et al. (2014). It brings in more recent data to reflect changing economic fortunes in Europe and the recent falls in solar prices. The current version of the post-Keynesian macro-econometric E3ME model (see below), linked to a set of bottom-up energy technologies models (FTT), is used to assess scenarios in which the different targets are met. The modelling does not include assumptions about the optimality of different policies but instead simulates the policies one-by-one and assesses them on their own merits.

The complex and interdependent nature of the energy-economy interactions requires a whole-system modelling approach. Due to the inherent uncertainty about technology costs and future energy requirements, no method will yield a certain outcome, but there is scope to assess the potential environmental and economic impact for a given set of scenarios based on best estimates of future technology costs and characteristics.

The following section summarises the modelling approach that was used and the scenarios that were assessed. We then present the results before discussing in more detail in the last section the benefits of different policy combinations.

2 Quantitative Analysis

2.1 *Model Characteristics*

2.1.1 The E3ME Model

The E3ME model (Energy-Environment-Economy Macro-Econometric model) is a computer-based tool that has been constructed by international teams led by Cambridge Econometrics. The model is econometric in design and is capable of addressing issues that link developments and policies in the areas of energy, the environment and the economy. The essential purpose of the model is to provide a framework for policy evaluation, particularly policies aimed at achieving sustainable energy use over the long term. However, the econometric specification that the model uses also allows for an assessment of short-term transition effects. The current version of E3ME covers 59 world regions, although in this analysis we focus solely on the EU. The model integrates energy demand and emissions with the economy; fuel demand is determined by prices and economic activity, with feedback through the energy supply sectors. Energy combustion results in greenhouse gas emissions. An extensive description of the model is provided in Cambridge Econometrics (2014), with further information at the model website www.e3me.com.

In terms of basic accounting structure, purpose and sectoral and regional coverage, there are many similarities between E3ME and CGE models, such as GTAP (Hertel 1999) and GEM-E3 (E3MLab, National Technical University of Athens 2017). However, the modelling approaches differ substantially in their treatment of behavioural relationships and the structure of markets. As discussed above, CGE analyses pursue an optimisation approach and typically assume purely rational behaviour of agents with perfect knowledge. Price adjustments provide for equilibria in all markets, including the labour market. In contrast, E3ME is an econometric model which predicts agents' behaviour on the basis of historical data sets. Thus, E3ME does not assume optimal behaviour. Prices are set by a mark-up principle and wage rates are determined by the wage-bargaining process between employers and employees.

These differences have important implications for the possible model results. In CGE models, all resources are fully utilised, meaning the economy is always operating at full capacity. Therefore, it is not possible to raise output or employment by government interventions. In E3ME, there are existing market disequilibria and unused capital and labour resources, which may allow for regulation to increase investment, output and employment. Thus, if an economy is not operating at close to capacity, E3ME may provide a more realistic assessment of policy performance as it does not depend on the rigid assumptions of CGE models.

The major drawback of the E3ME approach is that it relies on the quality of time-series data sets (Jansen and Klaassen 2000; Bosetti et al. 2009; Cambridge Econometrics 2014). Moreover, this approach rests on the assumption that past behaviour can be employed to predict future trends, even under different policy regimes, i.e. the

Lucas Critique (Lucas 1976). Although it has now been recognised that all models are subject to the Lucas Critique (Haldane and Turrell 2017), uncertainty around the results from macro-econometric models must be considered especially carefully when making substantial policy changes.

2.1.2 The FTT Family of Models

The E3ME model is linked to three bottom-up technology models that form the FTT (Future Technology Transformations) family of tools. This level of technology detail is critical to understanding the processes that drive the development and adoption of new technologies, which is required to meet long-term carbon reduction targets.

FTT:Power is a simulation model of technology diffusion in the electricity sector globally and is explained in detail in Mercure (2012). As opposed to most other models (see, e.g., Messner and Strubegger (1995) for the MESSAGE model and Seebregts et al. (2001) for the MARKAL model), it does not solve a cost-optimisation problem in order to model investor decisions and the composition of the electricity sector. FTT:Power is composed of a decision-making model for electricity sector investors at the firm level, evaluating decisions made by a diverse distribution of investors influenced by cost and policy considerations. It uses pairwise comparisons of options at the investor level using a stochastic description of component costs, based on 24 technologies in 59 E3ME regions. It includes cost dynamics such as learning-by-doing and natural resource cost-supply curves (Mercure and Salas 2012), as well as a dynamic model of non-renewable energy commodity price dynamics (Mercure and Salas 2013).

FTT:Transport works on a similar basis but is applied to passenger cars. The model includes 25 different types of vehicle (cars and motorcycles) based on size class and power train. Individuals do not automatically purchase the lowest-cost vehicle but instead make decisions based on their individual characteristics and existing choice of vehicle. In the same way as in FTT:Power, it takes time for new technologies to diffuse, even if they become cost-effective for consumers. The FTT: Heat model also works on a similar basis and covers heating technologies within residential properties. New technologies (e.g. heat pumps) take time to diffuse due to household characteristics and limitations in expertise in installation.

The FTT models have been fully integrated to the E3ME model with two-way feedbacks between each of the E3 modules of E3ME (Cambridge Econometrics 2014). The results presented in the next section therefore show the interaction between the different models.

2.2 Scenarios

We apply the combined modelling framework to assess five scenarios (one baseline and four policy scenarios). The scenarios are chosen with reference to the EU climate and energy policy package for 2030. All meet an ambitious 49% cut in GHG emissions from 1990 levels:

- A baseline where the current trajectories for the EU ETS cap and current EU policy are maintained (*BASE*)
- A scenario where an economy-wide carbon tax achieves the 49% emissions reduction (*CP)*
- A scenario where the 27% renewables target is met, coupled with an economy-wide carbon tax, which together achieve the 49% emissions reduction (*RES)*
- A scenario where a 30% energy efficiency improvement target is met, coupled with an economy-wide carbon tax, which together achieve the 49% emissions reduction (*EE)*
- A scenario where the 27% renewables target and 30% energy efficiency improvement targets are met, coupled with an economy-wide carbon tax, which together achieve the 49% emissions reduction (*RES&EE)*

This section introduces the basic assumptions underlying all the scenarios and specifies the characteristics and rationales of the baseline and policy scenarios.

2.2.1 Baseline Scenario

The baseline scenario (*BASE*) represents the business-as-usual case in which existing 2020 GHG and RES-E policies, as well as other policies related to reducing energy consumption or improving energy efficiency, are maintained but not tightened. The EU region has been calibrated to the reference scenario of the 'PRIMES projections', published by DG Energy (European Commission 2016). The publication includes full details of the policies that are included in the projections.

All non-EU regions have been calibrated to the current policies scenario of the IEA in its World Energy Outlook report (IEA 2016). Effectively this means that the rest of the world does not advance climate policy and would not meet the NDC targets that were pledged as part of the Paris Agreement. Although there are some feedbacks from countries outside the EU in the scenario through trade competitiveness and technology spillovers, the choice of baseline for the rest of the world does not affect our conclusions.

2.2.2 Common Basic Scenario Assumptions and Input Variables

In each policy scenario, a carbon tax is applied without discrimination across all sectors of the economy. There is no differentiation between the carbon price for ETS and non-ETS sectors. Carbon price revenues from the electricity sector, and non-ETS sectors,[3] are recycled through lump-sum allocations to households, which are treated as increases in wealth.

In all scenarios, RES-E subsidies are in place (but with different subsidy levels). In the *BASE*, *CP*, & *EE* scenarios, the already existing RES-E subsidy levels are represented. Subsidies are technology-neutral, uniform across EU Member States, and paid in addition to the wholesale electricity price. Feed-in-Tariffs (FiTs) are defined as a percentage of the difference between the average levelised cost (LCOE) of RES-E generation and the current electricity price. Due to the model set-up with inertia related to technology adoption, the percentage is larger than the actual relative difference between the LCOE and the electricity price. Subsidies are funded through carbon price revenues.[4]

2.2.3 Policy Scenarios

In the *CP* scenario, a carbon price is applied across all sectors of the economy, and increased from *BASE* ETS prices, to achieve a more ambitious GHG target in 2030. A reduction of 49% of GHG emissions from 1990 levels has been chosen as an ambitious target for 2030, surpassing the EU's Paris Agreement commitment; this ambition reflects recent improvements in renewable power generation technology costs, and a revised interim target for a trajectory to 80–95% GHG reductions by 2050.

In the *RES* scenario, the revised Renewable Energy Directive target of 27% renewables in the final energy consumption in the EU by 2030 is met.[5] Policies are introduced in the three areas targeted by EC policy: power generation (RES-E), transport (RES-T), and heating & cooling (RES-H&C). In power generation, capital investment subsidies are increased by 50% and FiTs are increased by 10% of the difference to the electricity strike price. It is assumed that there is some development in a combination of demand side management, grid interconnectors and electricity storage to allow a larger share of intermittent renewables while retaining grid stability.

Investor discount rates for investment in solar and wind power are reduced to encourage investment, to capture effects of policy instruments like guarantees and subsidised capital. In transport, a fuel tax levy on fossil fuels (equivalent to the economy wide carbon tax) and purchase subsidies on electric vehicles (EVs) are introduced. EV subsidies start at €3000 in 2018 and increase linearly to €4000 in 2030 (2017 prices). In heating, coal technology in households is increasingly regulated from 2018, and capital subsidies of 50% are introduced for heat pump and solar thermal heating systems.

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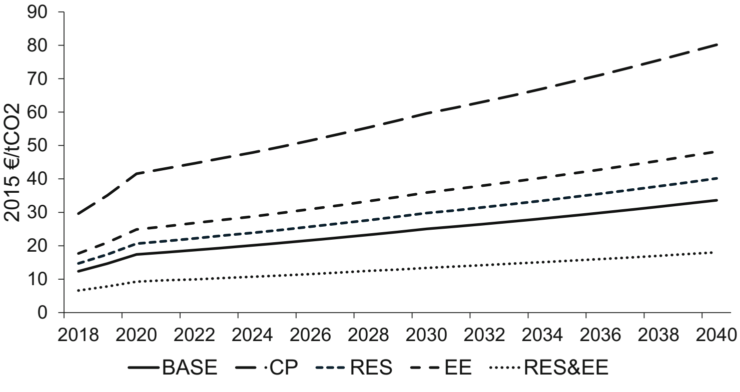
[3] Non power generation ETS sectors are allocated for free on a lump sum basis.

[4] Where subsidies are greater than carbon price revenues, the lump-sum payment to households becomes a lump-sum levy.

[5] The RES—T Share calculation following the ILUC amendment of the RES Directive is used.



Source: own illustration

Fig. 1 EU Carbon Price, 2018–2040

In the *EE* Scenario, the updated Energy Efficiency Directive target of 30% gains is met. The scenario uses detailed data from PRIMES scenarios to introduce exogenous changes in energy used by households and the tertiary sector.

In the final scenario, *RES&EE,* both the 27% renewables and 30% energy efficiency targets are met. Given the significant reduction of electricity consumption in the *EE* scenario, to achieve the 27% renewables target, we must assume that there are further developments in energy storage and demand side management to maintain grid stability.

The carbon price is adjusted in each policy scenario so that the 49% emissions reduction target is achieved. Figure 1 shows the carbon price trajectories under *BASE* and the four policy scenarios.

2.3 Model Results

2.3.1 Introduction

This section presents the key results from the chapter. We start by showing the two most important findings, that the single carbon price does not produce the best outcome either in terms of reducing long-term emissions or maximising levels of economic production. The following sections present some of the more detailed results from the modelling exercise.

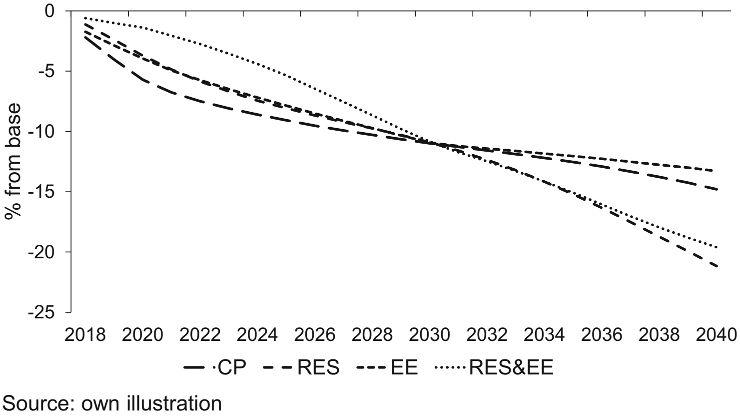


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Fig. 2 EU CO_2 Emission Levels, 2018–2040. Notes: Figure shows % reduction in emissions from baseline. In 2030 an 11% reduction compared to baseline is equal to a 49% reduction compared to 1990 levels

2.3.2 Results for CO_2 Emissions

Figure 2 shows the impacts of the policies on CO_2 emissions, compared to the baseline case. In all four policy scenarios the 2030 emissions targets are met (emissions 11% below baseline is equivalent to 49% below 1990 levels once non-CO_2 emissions are accounted for).

The different policies show different trajectories in reducing emissions up to 2030. The carbon price (CP) has the most immediate effect, mainly by incentivising a switch from coal to gas use in power generation. Renewables (RES) have a slower reduction in emissions because the technologies required to meet the renewables target continue to be developed throughout the projection period. In the energy efficiency scenario (EE), the rate of progress depends on how the energy efficiency programmes are implemented (here we have assumed a linear path). The slowest reduction in emissions is in the case with both energy efficiency and renewables policy (RES&EE). This may seem counter-intuitive but this scenario also has the lowest carbon price and, as noted above, the carbon price offers the quickest emissions reductions.

In general, however, these differences are relatively minor and could be smoothed out by advancing energy efficiency programmes earlier in the period. More important are the impacts after 2030, for which we can see that emissions continue to fall much faster in the scenarios with targets for renewables deployment (RES, RES&EE), even though the carbon price in these scenarios is less than half the rate in the CP scenario. The difference, around 6% of emissions by 2040 (and growing), is substantial.

The message from the modelling is quite clear, that long-term decarbonisation is dependent on the development and diffusion of low-carbon technologies. Policies

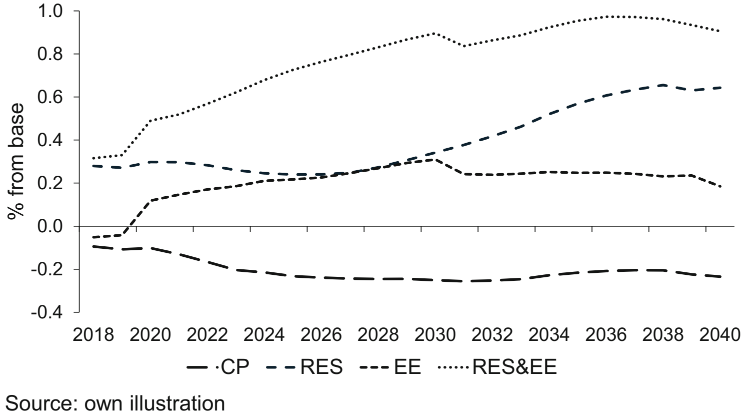

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Fig. 3 EU GDP Impacts, 2018–2040

that support these technologies will lead to much lower economic costs further down the line.

2.3.3 Results for GDP

Figure 3 presents the impacts on GDP in each scenario, as % difference from baseline. In these scenarios the GDP impacts result from two main factors:

- Changes to investment led by borrowing, which can provide a short-term stimulus to the economy.
- Changes in the trade balance, particularly the import bill for fossil fuels.

The scenarios with higher renewables and increased energy efficiency both include substantial short-term investment (the blip in the EE and RES&EE lines on the chart are when the energy efficiency investment ends in 2030). The carbon price in the CP scenario does not lead to a very large increase in investment on its own. Moreover, both renewables and energy efficiency investments lead to reduced imports of fuel to the EU, particularly for gas, whereas the carbon price on its own could lead to a higher import bill if the main effect is to replace coal with gas.

We therefore see in the results that the carbon price on its own (CP scenario) leads to the worst outcome for the European economy. The energy efficiency policy (EE scenario) leads to a small but stable increase in GDP while the renewables targets boost short-term activity, albeit while increasing debt levels in the economy (RES, RES&EE scenarios).

Table 1 Macroeconomic impacts, 2030, % from baseline

	CP	RES	EE	RES&EE
GDP	−0.3	0.3	0.3	0.9
Employment	−0.1	0.1	0.0	0.3
Consumption	−0.6	0.3	0.1	0.9
Investment	−0.1	0.4	0.3	1.0
Exports	−0.2	0.0	0.0	0.1
Imports	−0.5	−0.2	−0.5	−0.1
Prices	0.9	−0.1	−0.2	−1.1

Table 2 Sectoral impacts, 2030, % from baseline

	CP	RES	EE	RES&EE
Primary	−0.2	0.2	0.2	0.6
Manufacturing	−0.4	0.4	0.0	0.8
Utilities	−2.1	0.8	−3.5	−0.9
Construction	−0.2	0.3	0.6	1.1
Bus. Services	−0.4	0.4	0.2	1.0
Public Services	−0.2	0.1	0.1	0.3

The pattern of GDP results across EU Member States is very consistent, with the same characteristics found in nearly all countries. The only exceptions are in Latvia and Lithuania, where changes in trade of refined fuels between the countries impacts trade balances and GDP differently, but with little knock-on effect to employment.

2.3.4 Other Economic Impacts

Table 1 presents the impacts on the main macroeconomic indicators in 2030. The impacts on employment are modest overall and follow the pattern of results for GDP. Impacts on investment and trade follow the patterns described above. Although imports fall in all scenarios there is a difference in the composition of the change; in the CP scenario there is a general fall in imports due to lower domestic activity while in the other scenarios it is mainly lower fuel imports (with some other imports increasing). In the context of energy security, the RES and EE policies therefore produce a better outcome than the CP scenario.

One big difference between the scenarios is the impact on prices. The RES scenario shows a small fall in prices, which is partly due to renewables becoming more cost competitive by 2030 and partly due to continued government support which keep down renewable costs (financed by carbon tax revenues which impact on the amounts returned to households).

Table 2 presents a summary of the results at sectoral level. In most cases the results for sectoral production follow the patterns that we have seen in the GDP results.

The biggest differences between scenarios are in the construction and utilities sectors. The construction sector benefits substantially in the EE and RES&EE scenarios because of the large installation programmes required. Construction also makes a (smaller) contribution to installing renewables but sees little impact in the CP scenario.

The utilities sector can be summarised as gaining in the RES and RES&EE scenarios due to electrification (including in transport) but losing out in the CP and EE scenarios, where measures are put in place to reduce demand.

3 Discussion

The E3ME results differ to those from typical optimization modelling approaches, not only in the order of preference for the policies, but in finding potential positive economic impacts. To understand the outcomes better we must look deeper into the modelling approach.

First, there is the availability of spare capacity in the economy. Much of the economic benefit in the energy efficiency and renewables scenarios comes about from a redistribution of spending from imports of fuel to domestically produced goods. Such a shift in spending patterns can only lead to higher output if there is available capacity to produce more, otherwise we would expect prices to increase and crowding out of existing production.

Similarly, if higher investment levels boost the economy overall, there must be available capacity in the economy (particularly the construction sector) to produce the goods, otherwise there will again be crowding out of production. Fortunately, data from Eurostat on the manufacturing sector suggest that firms typically operate at around 80% capacity; quantitative information about the construction sector is more difficult to assess but surveys also suggest that most firms are not operating at capacity. However, it should be noted that if firms did reach capacity then it would be much more difficult to see positive results overall.

A closer look at the results for investment also highlights the importance of available capacity in financial markets, i.e. allowing for an endogenous stock of money in the economy. Or, to put another way, if firms are able to increase borrowing to fund investment in renewables, the net impact depends on whether this results automatically in lower investment in other sectors (or increased savings elsewhere). In standard optimization approaches, the stock of available money is fixed (a condition to solve the model) but E3ME allows for additional debt to be taken on and the supply of money to increase (Pollitt and Mercure 2017). This is more in tune with how central banks believe the system to operate in reality (McLeay et al. 2014).

The other key outcome in the results stems from the FTT submodels and, in particular, the path dependency of technological progress. In the real world, technologies take time to diffuse, for example due to gaps in knowledge or a lack of available infrastructure. The FTT modelling framework reflects the time it takes for technologies to become established in the marketplace. However, once established, technologies can continue to capture market share, even without further policy support. The current 'solar revolution' that was kick-started by policies in Germany and other European countries provides a good example of such a mechanism.

4 Conclusions

Current EU climate policy is based on three targets: one which sets the level of emissions reduction, one which sets a minimum share for renewable energy and one which sets a target for energy efficiency. This policy approach has met some resistance from mainstream economists who claim that the optimal way to reduce emissions is to have a single emissions reduction target and use market-based measures to get there.

There are two fundamental differences between the positions set out by European policy makers and mainstream economists. First, whether the world we live in is 'optimal' or 'first-best' in which all firms and individuals are aware of the technological options available to them and minimize their costs accordingly, and in which markets operate freely with prices adjusting to market clearing levels. Second, the nature of technological development itself, in particular whether the pace and direction of technology development is something that happens 'outside the system', or which can be influenced by policy decisions.

The aim of the modelling exercise presented in this chapter was to use a model that does not rely on optimizing assumptions to test whether the EU was right to set a combination of climate and energy targets for 2020 and 2030, rather than relying on a single emissions reduction target and price-based mechanisms. The E3ME model, a tool based on empirical estimates of human behavior was used to assess four scenarios with combinations of policies.

The model results show that a carbon price alone does not appear to be the best way to limit long-term emission reductions, because it does not lead to the rapid development and deployment of the necessary technologies. The results also show that a carbon tax alone would not lead to the best outcome for GDP in Europe. Other policies can assist in both influencing behavior and promoting technology development.

In summary, the modelling results give a clear message that we do not live in an optimal world and any policy recommendations based on the assumption of optimizing behavior should be taken with extreme caution. Current EU policy appears to be well targeted at addressing some of the most important issues around decarbonization and, at least for now, all three targets are needed.

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Assessment of Policy Pathways for Reaching the EU Target of (At Least) 27% Renewable Energies by 2030

Gustav Resch, Lukas Liebmann, Jasper Geipel, Luis Janeiro, Corinna Klessmann, Mario Ragwitz, Anne Held, and Pablo del Rio

Abstract As an important first step in defining the framework for renewable energies (RE) within the European Union post 2020, a binding EU-wide target to achieve a renewables share of at least 27% of gross final energy demand by 2030 was adopted by the European Council and Parliament in October 2014. On 30 November 2016, the next step was taken: The European Commission published a package of proposed legislative measures for the time horizon from 2020 to 2030 called "Clean Energy for all Europeans", commonly referred to as the "Winter Package". It is aimed at facilitating the clean energy transition while developing the internal market for electricity, thus fostering the Energy Union.

Within the scope of the Intelligent Energy Europe project "towards2030-dialogue" we have facilitated and guided the RE policy dialogue for the period up to 2030 over the past number of years. The dialogue process was coupled with in-depth and continuous analysis of relevant topics that included renewable energies in all energy sectors, but with more detailed analyses for renewable electricity. The analytical works included, for example, a first critical reflection on the Winter Package as well as a model-based analysis of distinct renewable electricity policy pathways up to 2030, including options for coordinating and aligning national support schemes as well as the clustering of regional support schemes.

This chapter describes the approach taken and presents some of our key results together with recommendations on the way forward.

G. Resch (✉) · L. Liebmann · J. Geipel
Technische Universität Wien (TU Wien), Energy Economics Group, Wien, Austria
e-mail: resch@eeg.tuwien.ac.at

L. Janeiro
Bonn, Germany

C. Klessmann
Ecofys, Köln, Germany

M. Ragwitz · A. Held
Fraunhofer ISI, Karlsruhe, Germany

P. del Rio
CSIC, Madrid, Spain

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1 Introduction

The first decade of the new millennium was characterised by the successful deployment of renewable energies (RE) across EU member states, leading to an increase in overall RE deployment of more than 40%. The impressive structural changes in Europe's energy supply are the result of a combination of strong national policies and the general focus on RE created by the EU Renewable Energy Directives in the electricity and transport sectors leading up to 2010 (2001/77/EC and 2003/30/EC).

The pathway for renewables for the period up to 2020 was set and accepted by the European Council, the European Commission (EC) and the European Parliament in April 2009. The related policy package, in particular the EU Directive on the support of energy from renewable sources (2009/28/EC), subsequently referred to as the RE Directive, comprises the establishment of binding RE targets for each member state. The calculation of the specific targets is based on an equal RE share increase modulated by the respective member state's GDP per capita. This provides a clear framework and vision for renewable technologies in the short to medium term.

Despite the successful development of the RE sector over the last decade, substantial challenges still lie ahead. The EU Energy Roadmap 2050 gave the first indications of potential renewable energy development pathways beyond the year 2020 and identified renewables as a "no-regrets" option. As an important first step in defining the framework for RE post 2020, a binding EU-wide RE target of at least 27% of gross final energy demand was adopted by the European Council and Parliament.

On 30 November 2016, the next step was taken: The European Commission published a package of proposed legislative measures for the time horizon from 2020 to 2030 called "Clean Energy for all Europeans", commonly referred to as the "Winter Package". It is aimed at facilitating the clean energy transition while developing the internal market for electricity, thus fostering the Energy Union. The package includes the EC's proposal for a recast of the existing Renewable Energy Directive 2009/208/EC. The recast aims to establish a stable framework for the promotion of energy from renewable sources and mainly includes an EU-wide binding target for a 27% minimum RE share of in gross final consumption by 2030. In contrast to the 2020 context, the recast does not include a breakdown of the EU-wide RE target into binding national targets. Instead, the new governance directive shall establish adequate measures for ensuring that the EU meets its overall target. Member states are supposed to commit themselves through free pledging concerning their contribution and by establishing dedicated support schemes as essential driver for the further RE expansion. These support schemes are now to be carried out in an "open, transparent, competitive, non-discriminatory and cost-effective" manner.

These proposals for a recast of existing and an introduction of new EU legislation as well as accompanying and alternative policy documents on RE need to be contextualized within the broader discussion on the degrees of harmonisation and the choice of instruments for the support of electricity from renewable sources.

According to Bergmann et al. (2008) harmonisation can be defined as the top-down implementation of common, binding provisions concerning the support of RE throughout the EU. In practice, it is however often simplified as a single RE support scheme being applied EU-wide. In parallel to the long-lasting political debate and possibly both influencing it and being influenced by it, the academic literature started drawing a more nuanced picture: different degrees of harmonisation have been identified (Guillou 2010; Bergmann et al. 2008), including coordination and convergence between RE support schemes (Resch et al. 2013; Gephart et al. 2012; Kitzing et al. 2012; del Río et al. 2017).

The objective of this chapter is to shed light on renewable electricity policy pathways suitable for the European Union within the forthcoming decade. Building on a detailed qualitative and quantitative analysis conducted in the Intelligent Energy Europe (IEE) project "towards2030-dialogue"[1] key policy pathways will be introduced and analysed with respect to their impacts on costs and expenditures. A solid basis for further elaboration of such pathways had been established by the IEE project "beyond2020" where policy pathways with different degrees of harmonisation of RES support in the post-2020 framework were analysed from a legal, economic, technical and political viewpoint (see del Río et al. 2017). In the "towards2030-dialogue" project we incorporated thanks to an intensified stakeholder dialogue potential new policy and market trends, including possible options for coordinating and aligning national support schemes as well as the clustering of regional support schemes.

This chapter presents some of our key results together with recommendations on the way forward. It is structured as follows: the next section (Sect. 2) provides information on the recent policy context, summarising the key elements and—from a renewables perspective—takeaways of the European Commission's "Clean Energy for All Europeans" package as published in November 2016 and currently debated in the European Council and Parliament. Section 3 introduces the approach taken in our accompanying analysis of renewable electricity policy pathways in line with the 2030 targets. Key results on feasible policy pathways for renewable electricity as well as on related future RE developments and corresponding costs and expenditures are then shown in Sect. 4. The chapter closes with conclusions and recommendations on the way forward in Sect. 5.

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[1] We gratefully acknowledge the intellectual and financial support provided by the Intelligent Energy Europe programme, operated by the European Commission, Executive Agency for Small and Medium Enterprises. For details on the project we refer to www.towards2030.eu, and specifically to Resch et al. (2017).

2 Policy Context: The European Commission's "Clean Energy for All Europeans" Package

On 30 November 2016, the next step was taken in defining the policy framework for the forthcoming decade: The European Commission published a package of proposed legislative measures for the time horizon from 2020 to 2030 called "Clean Energy for all Europeans" commonly referred to as the "Winter Package". It is aimed at facilitating the clean energy transition while developing the internal market for electricity, thus fostering the Energy Union.

Its legislative proposals have three explicitly stated main goals:

- Putting energy efficiency first
- Achieving global leadership in renewable energies
- Providing a fair deal for consumers

They cover the fields of:

- Energy efficiency by the revised Energy Efficiency Directive (COM(2016) 765 final)
- Renewable energy by the recast of the Renewable Energy Directive (COM(2016) 767 final/2)
- Design of electricity markets by the recast of the Internal Electricity Market Directive and the proposal for a recast of the Internal Electricity Market Regulation (COM(2016) 864 final/2, COM(2016) 861 final/2)
- Governance rules by the new Regulation on the Governance of the Energy Union (COM(2016) 861 final/2)
- Miscellaneous topics (eco design, strategies for connected and automated mobility, building renovation, innovation incubation, etc.)

Before being adopted, the Winter Package has to pass through the ordinary legislative procedure. The whole procedure is expected to last at least until April 2018 but must be completed before May 2019.

The legislative proposals formulate a holistic representation of the policy framework for the Energy Union during the 2020–2030 period. Below we summarise some key takeaways from a renewables perspective.

2.1 The EC's Proposal for a Framework for the Promotion of Renewable Energy Sources

The package includes the European Commission's proposal for a recast of the existing Renewable Energy Directive 2009/208/EC. The recast aims to establish a stable framework for the promotion of energy from renewable energy sources and mainly includes an EU-wide binding target for a 27% share of renewable energy in gross final consumption by 2030. Unlike for the 2020 energy and climate targets, the recast does not include a breakdown of the EU-wide target into binding national targets. This may hamper target achievement for the EU as a whole as member states cannot be held directly responsible for target achievement. Instead, the new governance directive shall provide adequate measures to ensure that the European bloc hits its targets. Member states are supposed to commit themselves through free pledging, stipulated in "integrated national energy and climate plans (INECPS)". While member states have considerable legislative scope in designing policies for achieving their national pledges, falling below the binding 2020 targets is directly sanctioned with penalty payments into a fund.

Member states continue to be entitled to set up dedicated support schemes as an essential driver for the further expansion of renewable energy sources (Art. 4). Increased requirements placed on support schemes in relation to cost-efficiency and market integration of renewable electricity (RE-E) are designed to prevent escalating costs and consequent challenges such as diminishing public support. However, the recommendations on detailed criteria for the design of support schemes remain vague. Support schemes are now to be carried out in an "open, transparent, competitive, non-discriminatory and cost-effective" manner. While this does not explicitly require member states to implement tender-based support schemes, it hints towards tendering as the preferred method of choice for dedicated RE support. Overall, the EC's proposal does not contain any detailed criteria or requirements for RE support mechanisms. For instance, there is no technology specificity mentioned or required for RE-E support. In order to foster regional cooperation, support mechanisms must be opened to investors from other member states for at least 10% of the newly supported capacity between 2021 and 2025, and 15% between 2026 and 2030 (Art. 5).

Moreover, the recast intends to improve RE deployment by diminishing investment uncertainty and administrative hurdles. This shall improve cost-effectiveness and the general policy framework for RE. Member states are obliged to publish their support allocation schemes at least 3 years in advance in order to improve predictability for investors and to design these schemes based on an ongoing assessment of their efficiency (Art. 15). Member states are to establish "single administrative contact points" to reduce the administrative hurdles for new RE projects. These one-stop shops will then handle all administrative procedures related to the construction, grid connection and operation of RE capacities. This is accompanied by the introduction of limitations on the maximum duration of the approval procedures (Art. 16). A stability clause shall prevent retroactive changes in the support schemes that negatively affect the supported projects (Art. 6). In addition, RE should be given easier and non-discriminatory access to all power markets in particular to balancing markets. In view of the high capital costs of RE projects the EC further supports ambitious member states through Union funds. However, the design of these financial instruments has yet to be determined and the criteria on who will receive support are not yet defined (Art. 3).

The article granting priority dispatch for renewable energy sources contained in the 2009 Renewable Energy Directive was removed from the recast. In general, rules related to dispatch, redispatch and curtailment are now set out in the regulation on the internal market for electricity.

The EC strengthens the right of individuals and communities to self-produce their electricity (Art. 21, 22). They are further entitled to sell their excess production without forfeiting their rights as consumers and may obtain remuneration reflecting the market value of the sold electricity. In particular, this should increase the deployment of rooftop solar installations in countries where grid-parity is reached and where self-generation was previously restricted. On the other side, the new directive could potentially prohibit constant feed-in tariffs for the sold excess electricity if self-generators only receive remuneration that reflects the market value. In consequence, the share of self-consumption becomes even more pivotal in the assessment of the economic viability of RE projects by self-consumers.

2.2 The EC's Proposal for a Regulation of the Governance of the Union

The European Commission's proposal on the Governance of the Union shall ensure that the European Union meets its climate and energy targets without imposing binding national RE targets (Art. 1). The proposal mainly implements a harmonised framework for planning and reporting obligations concerning the Energy Union. Member states are obliged to set up integrated national energy and climate plans (INECPs) covering 10-year periods in which they determine their national contributions (Art. 3). The plans take a holistic approach addressing all dimensions of the Energy Union and thus include the five pillars: security of supply, internal energy market, decarbonisation, energy efficiency, and research innovation and competitiveness. The EC will monitor member states' progress and their compliance with their national targets by means of a formally narrow planning and reporting concept. These plans shall further comprise an assessment of the interests of neighbouring states and thus foster regional cooperation on climate and environmental topics. Overall, the member states have considerable legislative flexibility. The Commission may only react and impose compensation measures at Union level in case of an ambition or delivery gap. As mechanisms to close a potential implementation gap, the regulation enables the EC to

- issue recommendations to member states
- implement measures at Union level in addition to recommendations (gap-fillers)
- urge member states to implement additional measures (e.g. quotas for heating & cooling, funds, etc.)

In order to identify such gaps, however, (internal) comparative benchmarks must be set for each member state. Up to now, the EC has mentioned the consideration of "early efforts" in relation to the proposed compensation measures without specifying a concrete calculation algorithm for a benchmark.

2.3 The EC's Proposal for a Regulation and Directive on the Internal Market for Electricity

The new regulation and directive have set out the rules for proper functioning of the internal electricity market. They are aimed, in particular, at enabling undistorted market signals to increase flexibility, decarbonisation, consumer participation and innovation.

To ensure that prices reflect the real value of electricity in time and location, price caps and floors on wholesale prices are ruled out. This is directly aimed at permitting scarcity prices to appear at wholesale markets and thus to stimulate investment towards solutions that increase the flexibility of the electricity system.

To incentivise flexibility on the demand side, consumers shall be entitled to have access to smart metering of their consumption and in turn to enter into dynamic pricing contracts and into agreements with demand response providers and aggregators. Aggregators were included for the first time into EU legislation and they are entitled to non-discriminatory access to all electricity markets.

Balancing markets for energy and capacity have to be open to all market participants (individually or by aggregation). Though all participants including RE-E generators (except for small capacities <500 kW (<250 kW from 2026 onwards) are being held responsible for imbalances they cause, thus reinforcing their accountability and promoting further market integration.

While the dispatch of electricity generation and demand response must be non-discriminatory and market-based, new RE-E generation capacities do not benefit from priority dispatch anymore (exceptions for smaller installations persist). Due to their low marginal cost, renewable energy sources such as photovoltaics and wind power are placed at the left side of the merit order curve and therefore will unlikely be heavily impacted by their loss of priority dispatch but rather by curtailment rules (see next paragraph). However, new biomass power plants with comparatively high marginal costs are strongly affected by the removal of priority dispatch.

The planned legislation on re-dispatching, curtailment and network congestion management, which shall be market-based, objective and non-discriminatory will further impact RE deployment: If no market-based re-dispatch alternatives are available, or if they cause "disproportionate costs" or if system stability is jeopardised, "non-market-based downward dispatching or curtailment" can be imposed on RE.

The European Commission introduced and set out the rules for capacity mechanisms**.** Before implementing such a mechanism, member states are obliged to demonstrate a minimum level of resource adequacy by means of a standardised "European resource adequacy assessment", whose methodology was determined by ENTSO-E.

The policy framework for a renewed internal market also envisages increased regional cooperation at the transmission and distribution grid level. Transmission system operators (TSO) are obliged to increase their cooperation with neighbouring TSOs through regional operational centres and to ensure transparent, non-discriminatory, market-based participation of all interested parties in the procurement of ancillary services. It also introduces a European entity for DSOs to promote the coordinated operation of distribution and transmission systems.

3 Method of Approach

This section provides a brief recap of the approach taken in our accompanying analysis of renewable electricity policy pathways in line with 2030 targets. First we describe the qualitative pre-assessment of policy pathways and then introduce the methodology used for the model-based quantitative part.

3.1 Identification and Qualitative Pre-Assessment of Pathways Towards Convergence of Member States' Renewable Electricity Policy Portfolios

The overall objective of this task within the "towards2030-dialogue" project was to identify, describe and qualitatively assess different possible pathways towards convergence of European RE policy in the post-2020 period. The task built on a previous analysis of harmonisation pathways undertaken as part of the IEE project "beyond2020".[2] Within that project, several convergence pathways with different degrees of harmonisation of RE support in the post-2020 framework were analysed from a legal, economic, technical and political viewpoint. This section focuses on the convergence pathways that seem to be more realistically in line with the recent RE policy debate.

We started our research by compiling a list of RE policy convergence pathways for analysis. This list was based on an extensive literature review (see e.g. del Rio et al. 2017)—including previous work in the beyond2020 project, recent official publications of the European Commission, and several other publications by research institutes, NGOs, industry organisations, etc. Inputs from a stakeholder consultation and from other members of the consortium are also taken into account to select suitable pathways for detailed analysis. The outcomes of this process are introduced and qualitatively analysed in Sect. 4.1 of this chapter.

After completing the identification of the convergence pathways we characterised and described them according to the following main questions:

- What is the scope and depth of convergence? What are the elements of RE policy that would converge under such a pathway?

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[2] For details on the project or the assessment of harmonisation pathways see Resch et al. (2014) or del Rio et al. (2017).

- What are the drivers and motivations for different stakeholders to follow that pathway?
- What are the potential technical, legal and political challenges for each pathway?

The characterisation of the convergence pathways was followed by a qualitative pre-assessment along policy assessment criteria, including effectiveness in achieving convergence, effectiveness in terms of RE deployment, efficiency, equity and political feasibility.

At a later stage of the project, as outlined in the subsequent section, the pathways selected were the subject of in-depth quantitative analysis using TU Wien's Green-X model. The consolidated outcomes of both the qualitative and the quantitative analyses served to draft final policy recommendations, cf. Sect. 5.

3.2 Model-Based Quantitative Analysis of RE Developments up to 2030

3.2.1 Applied Modelling System

The accompanying quantitative analysis builds on modelling works undertaken using TU Wien's Green-X model (see Huber et al. (2004) for a detailed description). Green-X is an energy system model that offers a detailed representation of RE potentials and related technologies in Europe and in neighbouring countries. The model was designed to indicate the consequences of RE policy choices in a real-world energy policy context. It simulates technology-specific RE deployment by country on a yearly basis, in the time span up to 2050, taking into account the impact of dedicated support schemes as well as economic and non-economic framework conditions (e.g. regulatory and societal constraints). Moreover, the model allows for an appropriate representation of financing conditions and of the related impact on investors' risk. This, in turn, allows for in-depth analyses of future RE deployment and corresponding costs, expenditures and benefits arising from the preconditioned policy choices on the country, sector and technology level.

For assessing the interplay between RE and future electricity market design that involves an analysis of the merit order effect and related market values of the produced electricity for variable and dispatchable renewables, Green-X was complemented by its power-system companion—i.e. the HiREPS model—to shed further light on the interplay between supply, demand and storage in the electricity sector thanks to a higher intertemporal resolution than in the RE investment model Green-X.

Figure 1 gives an overview on the interplay of both models. Green-X delivers a first picture of renewables deployment and related costs, expenditures and benefits by country on a yearly basis (2010–2030). The output of Green-X in terms of country- and technology-specific RE capacities and generation in the electricity sector for selected years (2020, 2030 (and 2050)) serves as input for the

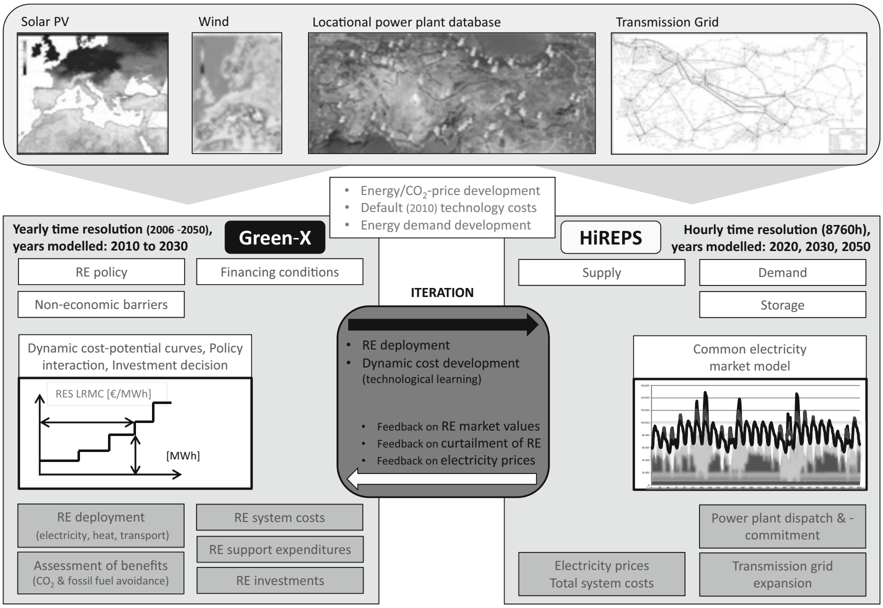

Fig. 1 Model coupling between Green-X (left) and HiREPS (right) for a detailed assessment of RE developments in the electricity sector

power-system analysis done with HiREPS. Subsequently, the HiREPS model analyses the interplay between supply, demand and storage in the electricity sector on an hourly basis for the given years. The output of HiREPS is then fed back into the RE investment model Green-X. In particular the feedback comprises the amount of RE that can be integrated into the grids, the electricity prices and corresponding market revenues (i.e. market values of the produced electricity of variable and dispatchable RE) of all assessed RE technologies for each assessed country.

3.2.2 Key Parameters

In order to ensure maximum consistency with existing EU scenarios and projections the key input parameters of the scenarios presented in this chapter are derived from PRIMES modelling and from the Green-X database with respect to the potentials and cost of RE technologies. Table 1 shows which parameters are based on PRIMES, on the Green-X database, and which have been defined for this study. The PRIMES scenarios used here are the latest publicly available reference scenario (European Commission 2016g) and the climate mitigation scenarios PRIMES euco27 and PRIMES euco30 that build on the targeted use of renewables (i.e. 27% RE by 2030) and an enhanced use of energy efficiency compared to reference conditions—i.e. 27% (euco27) or 30% energy efficiency (euco30) by 2030, respectively. Please note that all PRIMES scenarios are discussed in depth

Table 1 Main input sources for scenario parameters

Based on PRIMES	Based on Green-X database	Defined for this assessment
Primary energy prices	Renewable energy technology cost (investment, fuel, O&M)	Renewable energy policy framework
Conventional supply portfolio and conversion efficiencies	Renewable energy potentials	Reference electricity prices
CO_2 intensity of sectors	Biomass trade specification	
Energy demand by sector	Technology diffusion/Non-economic barriers	
	Learning rates	
	Market values for variable renewables	

in the EC's Winter Package, see also the impact assessment of the recast RED (SWD (2016) 410 final) (European Commission 2016f).

Although a target of 30% for energy efficiency has already been fixed for 2030, we show ranges with regard to the actual achievement of energy efficiency to cover both a higher and a substantially lower level of ambition in terms of energy efficiency policy: Under reference conditions an improvement in energy efficiency of 23.5% compared to the 2007 baseline of the PRIMES model is projected for 2030, whereas in the PRIMES euco30 scenario, assuming a strong ambition level for energy efficiency, an increase to 30% is assumed.

4 Results of the RE Policy Pathway Analysis

This section presents key results of our analysis on future policy pathways for renewable electricity in the EU up to 2030. First we introduce the pathways identified and summarise key findings from the corresponding qualitative analysis. Then we present selected results of the in-depth quantitative assessment.

4.1 Assessed Policy Pathways and Qualitative Pre-Assessment

4.1.1 Overview on Assessed Renewable Electricity Policy Pathways

A list of RE policy convergence pathways for further analysis has been identified as shown in Fig. 2. These have been classified into two main categories (for a conceptual discussion of convergence pathways, see chapter "Cross-Border Electricity Interconnectors in the EU: The Status Quo"):

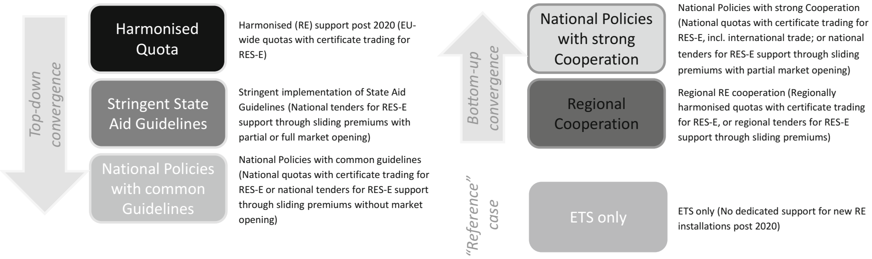

Fig. 2 Top-down and bottom-up RE policy convergence pathways

- *Top-down* convergence pathways, i.e. those forms of convergence in RE policy driven by EU institutions. We have identified three main top-down convergence pathways for further analysis: Firstly, the implementation of a harmonised EU-wide RE support scheme. Alternatively, specific types or designs of (market-based) instruments to be implemented by member states could be prescribed by the EU institutions. This could take a strict form as assumed in the case "Stringent State Aid Guidelines" where member states are enforced to apply the philosophy of market-based support to its full extent, as prescribed via stringent state aid guidelines for the period 2020–2030. A more moderate way of top-down convergence is presumed in the pathway named "National Policies with common Guidelines": here the EU would prescribe common guidelines that member states have to respect when implementing RE support post 2020. This would facilitate the convergence process and the implementation of best practices in policy design but would leave the choice of a support instrument in the hands of the member states.
- *Bottom-up* convergence pathways, i.e. those forms of convergence driven by member states cooperating with each other. Three main forms of bottom-up convergence have been identified within the qualitative assessment: increased coordination of national RE policies, the partial opening of national RE support schemes as well as other forms of RE cooperation, and the implementation of joint RE support schemes at the regional level. Whereas our fifth pathway is dedicated to the latter option (regional cooperation) under the fourth pathway named "National Policies with strong Cooperation" we focus on increased coordination and RE cooperation.

Finally, we discussed a 'reference' convergence pathway in which there is no dedicated RE support. In this case, the EU would rely on the ETS carbon price as the only incentive to achieve the 2030 RE target. Please note further that all policy pathways build on a strengthening of national policies already in the period before 2020, serving to meet the given 2020 RE targets and where a gradual mitigation of currently prevailing non-economic RE barriers is presumed.

4.1.2 Conclusions from the Qualitative Pre-Assessment

Different convergence processes may take place simultaneously and in parallel in the 2020–2030 period. For instance, the strengthening of state aid guidelines may be compatible with member states' increased coordination in RE support or the adoption of regional (joint) support schemes. The EU RE policy landscape for the 2020–2030 period consists, as laid down by the EC's Winter Package, of a mix of these convergence pathways. As to the top-down convergence pathways, no directly harmonised EU-wide RE schemes were implemented. Instead, guidelines for their implementation were specified: support schemes on the energy market are now to be carried out in an "open, transparent, competitive, non-discriminatory and cost-effective" manner. Nonetheless, the new legislation puts a stronger emphasis on bottom-up convergence pathways: support schemes must be partially open to investors from other member states. In order to further foster regional cooperation member states are obliged to consult neighbouring member states and even to take their energy-related interests into consideration when preparing their own integrated national energy and climate plans. At the level of the network operators, regional cooperation is to be strengthened through the introduction of regional operation centres consisting of TSOs introduction of a European entity for DSOs. Bottom-up processes tend to be slower but are likely to enjoy higher levels of public acceptance.

While the newly proposed policy framework certainly encourages European convergence on RE policy, it has been criticised for its missing concrete top-down framework for national RE support schemes. According to the former German Minister for Economics and Energy, the current patchwork carpet of national support schemes is unsuited for achieving global leadership in renewable energy (BMWI 2016).

4.2 Results from the Model-Based Assessment

4.2.1 Key Results on Future RE Deployment

We start with an analysis of RE deployment for all six policy pathways assessed. More precisely, Fig. 3 shows the development of the RE share in overall gross final energy demand at EU level in the period 2021–2030. The corresponding illustration for renewables in the electricity sector is provided by Fig. 4, indicating the renewable electricity share in gross electricity demand throughout the period 2021–2030 in the EU28. All the policy pathways with ongoing dedicated support (harmonised quota, stringent state aid guidelines, national policies with common guidelines, national policies with strong cooperation, regional cooperation) for RE deployment during the 2021–2030 period reach the EU RE target of 27% in 2030. In contrast to above, without dedicated support, i.e. in the case of the "ETS only" policy pathway, the RE and renewable electricity shares in 2030 do not comply with the official targets and only reach 22.2% and 42.6%, respectively, in the electricity sector. The higher

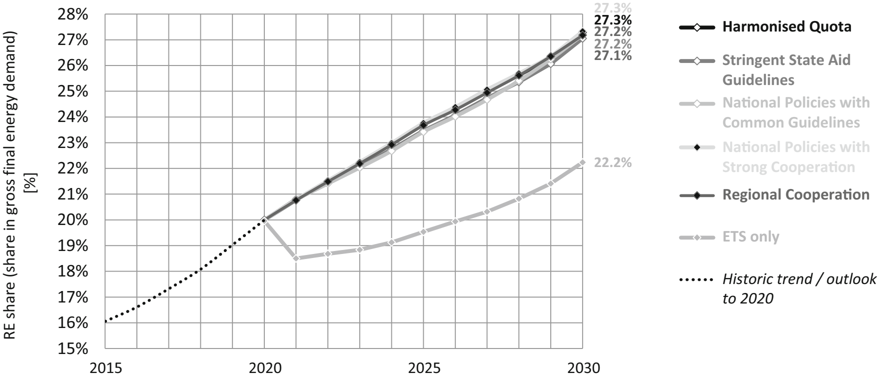

Fig. 3 Comparison of the resulting RE deployment in relative terms (i.e. as the share in gross final energy demand) over time in the EU28 for all assessed renewable electricity policy pathways

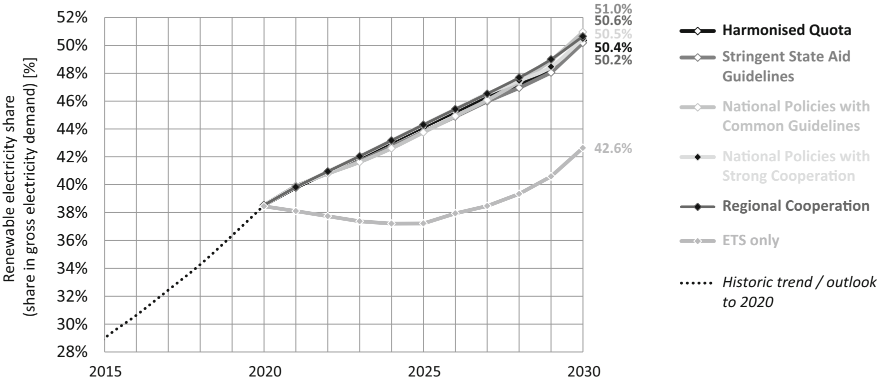

Fig. 4 Comparison of the resulting renewable electricity deployment in relative terms (i.e. as the share in gross electricity demand) over time in the EU28 for all assessed renewable electricity policy pathways

difference between pathways with and without dedicated support in the electricity sector (7%) compared to the overall RE share in the combined sectors transport, electricity and heating & cooling (5%) indicates that dedicated support for renewable energies is particularly needed in this sector. In the case of policy pathways including dedicated RE support, the RE as well as the renewable electricity shares show almost linear trajectories from 2020 towards 2030. Thus, differences in the trajectories between the different policy pathways including dedicated support are generally negligible whereas strong deviations to the "ETS only" pathway are applicable. In the electricity sector, an "ETS only" pathway leads to slightly decreasing shares up to 2024 and a moderate increase thereafter. As for the total RE share, between 2020 and 2021 it drops by 1.5%. This is mainly caused by the assumed omission of the blending obligations for biofuels, which entirely eliminates the RE share on final

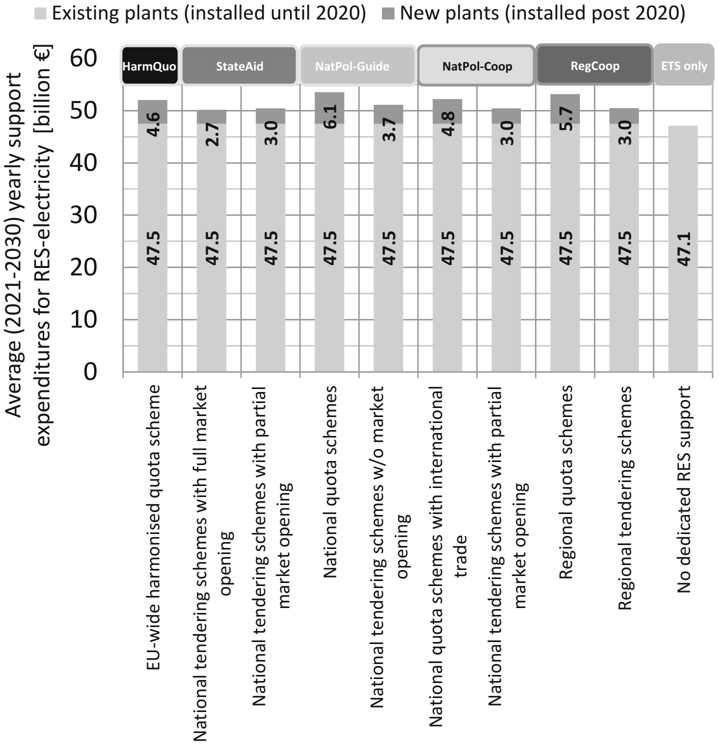

Fig. 5 Comparison of the required average (2021–2030) yearly support expenditures for renewable electricity in the EU28 for all assessed renewable electricity policy pathways

transport fuel demand. Yet from 2021 on the RE share increases continuously until 2030. This direct recovery of the RE share in the first half of the 2020s is mainly driven by energy efficiency improvements and higher competitiveness of RE technologies in the heating sector.

4.2.2 Indicators for RE Support Expenditures

Next we take a closer look at the financial impact of RE support in the electricity sector: Fig. 5 complements the above depictions of RE deployment, indicating the resulting support expenditures for renewable electricity. More precisely, this graph compares the required support expenditures (on average per year for the period 2021–2030) for all assessed renewable electricity policy pathways, including policy variants that have been defined for selected paths. Apparently, overall policy costs are of a comparatively similar magnitude for all cases. An exception to that general trend is the "ETS only" scenario where costs are lower in magnitude. Under this pathway, as applicable in Fig. 5, no dedicated support for new RE (installed post

2020) is prescribed, leading to a RE share of about 22.2% in 2030 instead of the targeted minimum share of 27%.

This graph clearly indicates that the bulk of support expenditures in the forthcoming decade is dedicated to RE installations erected in the years up to 2020: only 5–11% of total support for renewable electricity in the forthcoming decade will be for new installations built in the period 2021–2030.[3]

Below we provide a brief evaluation of the performance of assessed policy pathways and the underlying support schemes, respectively. We refer again to Fig. 5, which allows for a comparison of the performance of the different renewable electricity policy pathways and, more specifically, of the policy variants analysed under each pathway. In practical terms, we are now comparing the dark grey bars on top that represent the average (2021–2030) yearly support expenditures for new RE plants (installed post 2020) in the electricity sector.

Key results derived from this comparison are:

- Most importantly, our model-based analysis shows clear preferences for feed-in premium schemes where support levels are determined in a tendering procedure in comparison to quota schemes with certificate trading.
- The best-performing policy variants appear to be those where the allocation of RE investments is done at a multinational level rather than following a purely national strategy. This can be facilitated through partial or full market opening with tendering as well as through regional cooperation and specifically the establishment of regional tenders. Yearly support expenditures for new RE installations vary then between € 2.7 and 3.0 billion on average throughout the forthcoming decade.
- Pure national tenders without market opening leads to a different resource allocation that results in slightly higher policy costs: € 3.7 billion is the corresponding figure under this policy variant.
- The worst-performing of the assessed policy options are technology-neutral quota schemes with certificate trading, thanks to the uniform pricing concept under this approach: here support for all RE is determined by the marginal option needed for achieving the targeted RE volumes. Average (2021–2030) yearly support expenditures for new RE (installed post 2020) range here from € 4.6 to 6.1 billion. Again, the lower boundary reflects a European or multinational approach whereas at EU level higher costs occur under a purely national policy orientation.
- A complete phase-out of dedicated RE support as assumed in the "ETS only" pathway would lead to zero direct policy cost for new RE installations. It would however also result in a strong market crash in early years and only partial recovery in the years coming up to 2030. RE-related investments in the forthcoming decade decline here by about 50% compared to all other policy variants,

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[3] The expressed ranges indicate the variations observable among the different policy pathways. We have excluded from this comparison the "ETS only" pathway since here no dedicated support will be paid for new RE installations and also since the EU would fail to achieve the given 2030 RE target under this policy path.

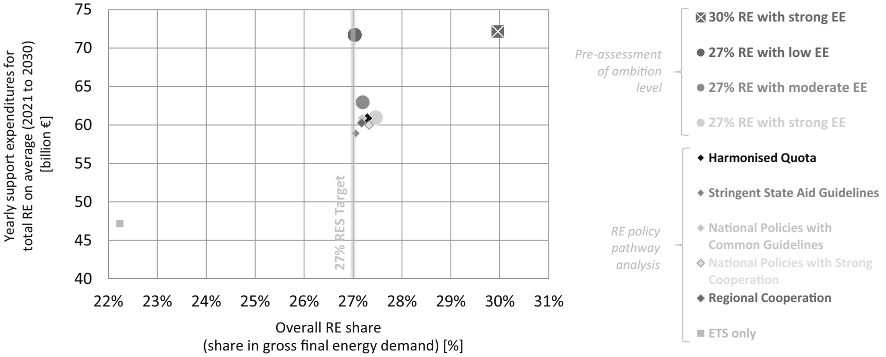

Fig. 6 Comparison of the resulting 2030 RE deployment and the corresponding (yearly average) support expenditures for total RE in the EU28 for all assessed renewable electricity policy pathways as well as other scenarios illustrating the ambition level of 2030 RE targets

and we see a decline of RE deployment of a similar magnitude. Additionally, an indirect cost-burden may arise for consumers thanks to the merit order effect that comes along with an enhanced renewable electricity deployment. The lack of renewable electricity generation needs to be compensated by a stronger use of conventional generation, and a higher fossil fuel use would, in turn, also lead to a stronger increase of wholesale electricity prices than applicable under the other policy pathways: on average throughout the focal years (2021–2030) wholesale prices increase by 1.0 €/MWh. This, in turn, results in higher costs for consumers amounting to € 3.5 billion on average per year at EU level. If we consider in addition the decline of support costs for existing RE (installed up to 2030), thanks to the higher wholesale prices in the "ETS only" path, we come up with € 3.2 billion as the net cost for electricity consumers under this pathway. This is in the same order of magnitude as the support expenditures required to refinance the stronger RE uptake that is projected in all other policy pathways.

Figure 6 complements the above depiction of RE support in the electricity sector by taking the comparison up to a higher level, indicating the resulting policy costs for total renewables—i.e. the required support expenditures for all RE (i.e. within the electricity sector, in heating & cooling and in transport)—in relation to RE deployment. More precisely, this graphs compares overall RE deployment by 2030 with the corresponding support expenditures (on average per year for the period 2021–2030) for a broad set of assessed RE scenarios by depicting the RE share in gross final energy demand on the horizontal axis, and the corresponding support expenditures on the vertical axis. The scenarios included in this comparison comprise the renewable electricity policy pathways discussed above as well as more generic cases where the overall 2030 RE ambition is analysed along with the interplay between RE and energy efficiency targets.

On the one hand, we can identify an almost linear relationship between RE deployment and corresponding support expenditures: an increase in RE deployment—if the same level of energy efficiency is followed—leads to a proportional rise of RE-related support expenditures. On the other hand, an increase of the ambitions related to energy efficiency would lower the efforts required for meeting a given RE target—compare, for example, the scenarios of striving for 27% RE by 2030 under moderate and strong energy efficiency. Note that RE-related expenditures would for example stay at the same level if a 27% RE target has to be reached under low energy efficiency ambition (23.5% EE) rather than under the combination of strong energy efficiency (30% EE) and strong RE deployment (30% RE).

5 Conclusions and Policy Recommendations

We conclude this chapter with a concise summary of conclusions and policy recommendations on the way forward.

RE ambition and the role of energy efficiency: to maintain the level of ambition for renewables, the newly established 30% energy efficiency target calls for an increase of the targeted renewables share.

Apparently, the need to deploy renewables declines with stronger energy efficiency ambitions. This and related financial impacts have been analysed as part of the model-based scenario assessment undertaken in the course of the “towards2030-dialogue” project (see Sect. 4). A closer look at the corresponding costs reveals that, on the one hand, we can identify an almost linear relationship between RE deployment and related support expenditures: an increase in RE deployment—if the same level of energy efficiency is presumed—leads to a proportional rise of RE-related support expenditures. On the other hand, increasing the energy efficiency ambition level would lower the effort required to meet a given RE target that is defined in percentage terms—compare, for example, the scenarios of striving for 27% RE by 2030 under moderate and strong energy efficiency. Note that a similar amount of renewables and RE capital and support expenditures is needed to achieve a 27% RE share by 2030 under low energy efficiency as compared to a 30% RE share in the case of strong energy efficiency. Thus, to maintain the level of ambition concerning renewables an increase of the targeted RE share to at least 30% RE by 2030 appears useful with the newly established 30% energy efficiency target.

The bulk of support expenditures in the forthcoming decade will be dedicated to RE installations erected in the years up to 2020

Our model-based quantitative assessments in relation to the given 2030 RE target provided clear insights and allowed us to draw straight-forward conclusions. Most importantly, the renewable electricity policy pathway analysis provides a clear indication that the bulk of support expenditures in the forthcoming decade will be dedicated to RE installations erected in the years up to 2020: only 13 to 18% of total RE support in the forthcoming decade will be for new installations built in the period from 2021 to 2030. A closer look at the electricity sector—where renewables will contribute to meeting half of the sectorial demand by 2030 and where more than 85% of all RE support in the period 2021–2030 will be directed—shows a similar range.

Here new RE plants installed post 2020 account for 5% to 11% of all renewable electricity-related support expenditures in the forthcoming decade. These results indicate that the costs of various renewable technologies are expected to decline (in line with technological progress) whereas prices of fossil energy carriers and of carbon are expected to rise in forthcoming years according to recent trend analysis. Thus, this significantly lowers the gap that has to be filled through dedicated financial support for new RE installations.

The harmonisation and/or convergence of European RE policies remain topics of key interest within the political debate. Guiding and framing this process will be a major task for the evolving Energy Union.

European RE policies are still diverse and inhomogeneous. In general, we have identified two groups of possible convergence pathways, that would either follow a top-down or a bottom-up approach:

Top-down convergence pathways (i.e. forms of convergence in RE policy driven by EU institutions):

- the implementation of a harmonised EU-wide RE support scheme, and
- the prescription of specific types of (market-based) instruments by the EU institutions to be implemented by member states (e.g. strengthening of current state aid guidelines in the period 2020–2030).

Bottom-up convergence pathways (i.e. those forms of convergence driven by member states cooperating with each other):

- increased coordination of national RE policies,
- the partial opening of national RE support schemes, and
- the implementation of joint or regional RE support schemes.

Different convergence processes may take place simultaneously and in parallel in the period post 2020. The EU RE policy landscape in 2030 will most probably be the result of a mix of these convergence pathways. Yet, according to the EC's proposal, it will focus largely on bottom-up convergence pathways, as a harmonised EU-wide RE-support scheme has not been proposed or implemented so far.

Concerning renewable electricity policy pathways for meeting the 2030 RE target, our model-based analysis shows clear preferences for feed-in premium schemes where support levels are determined in a tendering procedure in comparison to quota schemes with certificate trading. The allocation of RE investments at the multinational level also appears beneficial.

Our model-based analysis of renewable electricity policy pathways in line with meeting the given 2030 RE target shows clear preferences for feed-in premium schemes where support levels are determined in a tendering procedure in comparison to quota schemes with certificate trading. The best-performing policy variants appear to be those where the allocation of RE investments is done at the multinational level rather than following a purely nationally oriented strategy. This can be facilitated by partial or full market opening with tendering as well as through regional cooperation and, more specifically, the establishment of regional tenders.

In contrast to above, the worst-performing of the assessed policy options are technology-neutral quota schemes with certificate trading, thanks to the uniform pricing concept under this approach: here support for all renewables is determined by the marginal option needed for achieving the targeted RE volumes.

A complete phase-out of dedicated RE support as assumed in the "ETS only" pathway would lead to zero direct policy cost for new RE installations. It would however also result in a strong market crash in early years and only partial recovery in the years coming up to 2030. RE-related investments in the forthcoming decade decline here by about 50% compared to all other policy variants, and we see a decline of RE deployment of a similar magnitude. Additionally, an indirect cost-burden may arise for consumers thanks to the merit order effect that goes along with enhanced RE-electricity deployment: The lack of RE generation then needs to be compensated by a stronger use of conventional generation, and higher fossil fuel use would, in turn, also lead to a stronger increase of wholesale electricity prices than under the other policy pathways.

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The Influence of European State Aid Law on the Design of Support Schemes for Electricity from Renewable Energy Sources in Germany and Other Member States

Markus Kahles and Fabian Pause

Abstract Since 2014, the EU Commission's Guidelines on State aid for environmental protection and energy 2014–2020 (EEAG) have become the main driver for the progressing convergence of support schemes for electricity from renewable energy sources (RES) in different Member States. The key requirements for the design of RES electricity support schemes are, inter alia, the introduction of auctions to determine the amount of aid and its payment in form of a market premium. These State aid requirements have led to some major changes in the support schemes of different Member States and raised concerns whether the EU Commission is overstepping its competencies. This article summarizes this development with a special focus on the German support scheme (EEG 2014 and EEG 2017) and gives an outlook on the likely future situation for RES electricity support schemes under the currently discussed European legal framework for the years 2021–2030.

1 State Aid Character of RES Support Schemes: The Case of *Germany*

The case of the German RES support scheme can be seen as one of the main examples for the discussion on the State aid character of RES support schemes financed by electricity consumers. In fact, RES support schemes of other Member States have come under the legal scrutiny of the Court of Justice of the European Union as well (France: ECJ 2013, Austria: EGC 2014). But the German case stands out because of its far-reaching legal history beginning with the landmark decision on *Preussen Elektra* (ECJ 2001) in which the Court denied the State aid character of the German RES support scheme of that time (*Stromeinspeisungsgesetz—StrEG*) on the

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M. Kahles (✉) · F. Pause
Stiftung Umweltenergierecht (Foundation for Environmental Energy Law), Würzburg, Germany
e-mail: kahles@stiftung-umweltenergierecht.de

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grounds that no State resources were involved. Since then, the German RES support scheme has not been the focus of State aid control until the EU Commission initiated a State aid procedure against the Renewable Energies Act EEG 2012 (*Erneuerbare-Energien-Gesetz 2012*).

After Germany had filed an action for annulment of the decision of the EU Commission to classify the German Renewable Energies Act EEG 2012 as State aid (COM 2014a), the General Court of the European Union (EGC) followed in its first instance decision on 10 May 2016 the argumentation of the Commission and dismissed the action (EGC 2016). To prove that the scheme had State aid character, the Court argued, contrary to the German opinion, that State resources were used in the context of the EEG. Firstly, the funds generated via the EEG surcharge (*EEG-Umlage*) and managed jointly by the Transmission System Operators (TSOs) remained under the dominant influence of the public authorities (EGC 2016: para. 93). Secondly, the amounts generated via the EEG surcharge were funds involving State resources being therefore equivalent to a public levy (EGC 2016: para. 95). Thirdly, the competencies and responsibilities of the TSOs implied that they were neither acting independently nor on their own account, but administering public aid financed by State resources comparable to a concessionaire (EGC 2016: para. 105 et seq.). Ultimately, the EEG by that time was remarkably different from the previous German law (*Stromeinspeisungsgesetz*) underlying the *Preussen Elektra* decision (ECJ 2001). Contrary to the EEG, the compensation scheme within the former StrEG had not been considered as involving the State as the funds were at no time under State control. In addition, there has not been a mechanism comparable to the EEG establishing a guarantee by the State for private suppliers to fully cover their additional costs which has been introduced by the State to balance higher costs resulting from the purchase obligation (EGC 2016: para. 105).

By handing down this decision the EGC has supported the tendency to extend the notion of State aid (Soltész 2014) which can be observed in the Commission's practice for some time already. The reaction on the judgement in the literature is divided (dissenting: Schmidt-Preuß 2016: 251; Martinez 2016: 218; Stöbener de Mora 2016: 539; Overkamp 2016: 265; Frenz 2016: 848; Ehrmann 2016: 998; Kröger 2016b: 419; approving: Ludwigs 2016: 240; Schaefer 2016: 244; Müller-Terpitz/Ouertani 2016: 536; Rogala 2016: 290 et seq.; Michl 2016: 261). This contribution holds the view that the decision of the EGC went beyond the wording of Art. 107 para. 1 TFEU with its interpretation of State aid. According to the text of the treaty, only aid "granted by a Member State or through State resources" can be classified as State aid measures. Admittedly the EEG effects and is meant to effect the financial support of generators of electricity. However, it has to be recognized that under the compensation scheme of the EEG funds are at no time at the disposition of the State or under State control thus not fulfilling the State aid definition in Art. 107 para 1 TFEU (Schroeder 2015: 212; Schmidt-Preuß 2016: 419). The government of Germany filed a timely appeal on 19 July 2016. Nevertheless, the subsequent amendments to the EEG, namely the EEG 2014 and EEG 2017, were notified to the Commission for reasons of precaution and thus were designed according to the requirements of the EEAG, which will be presented in the following.

2 Requirements of the Commission's Guidelines on State Aid for Environmental Protection and Energy (EEAG)

2.1 Scope and Structure of the EEAG

In contrast to the previous guidelines, the provisions in the EEAG cover nearly all aid measures in the energy sector (inter alia, energy from renewable sources, energy efficiency measures, including cogeneration and district heating and cooling, reductions in funding support for electricity from renewable sources, energy infrastructure and generation adequacy measures). In assessing whether an aid measure is compatible with the internal market in the field of environmental protection or energy, the Commission's analysis follows a system of principles and compatibility criteria which depends in its degree of precision on the specific aid measure in question (Pause 2015: 219 et seq.). After all, under para. 26 EEAG, the positive impact of the aid towards an objective of common interest has to exceed its potential negative effects on trade and competition. Thus the aid has to fulfill several conditions in order to be considered compatible with the internal market. First, any measure considered as State aid has to contribute to a well-defined objective of common interest. In addition, the need for State aid as well as the appropriateness and proportionality of the measure have to be established to ensure that the aid is limited to the minimum required. Furthermore, the aid has to create an incentive effect for the behaviour of companies and undue negative effects on competition and trade between Member States have to be avoided. Finally, the transparency of the aid has to be guaranteed. These common principles, as provided for in Section 3.1 of the EEAG are further specified in Section 3.2 by establishing general compatibility criteria and finally clarified or modified by Chapter 3 (Pause 2015: 232 et seq.).

2.2 Provisions for Aid for the Generation of Electricity from Renewable Sources

For operating aid to promote electricity from renewable sources, Section 3.3.2 stipulates specific rules for the State aid compatibility assessment which have priority over the more general rules set out in Section 3.2. To be admissible, from 1 January 2016 onwards all new operating aid measures have to fulfill all of the following conditions.

2.2.1 Mandatory Implementation of a Market Premium and Other Regulatory Obligations Governing the Market

In accordance with para. 124 lit. (a) EEAG, an aid must be designed as market premium in addition to the market price at which generators sell electricity on the market (mandatory direct marketing). However the EEAG do not specify whether the market premium shall be flexible or fixed. Nevertheless the possibility to set a specific feed-in tariff is limited for installations below the threshold levels as provided by the EEAG (cf. below). Furthermore according to para. 124 lit. (b) EEAG the beneficiaries of aid are subject to standard balancing responsibilities, unless no liquid intra-day markets exist. The term "standard balancing responsibility" is defined in para. 19 no. 38 EEAG as "non-discriminatory balancing responsibilities across technologies which do not exempt any generator from those responsibilities."

Finally, para. 124 lit. (c) EEAG requires Member States to put in place measures to ensure that generators have no incentive to generate electricity under negative prices. Beyond para. 124 lit. (c) EEAG, the text of the EEAG provides no indications for the design of provisions preventing the generation of electricity from renewable sources under negative prices (Kahles/Müller 2015).

2.2.2 Derogations from the Market Premium and Other Regulatory Obligations Governing the Market

According to para. 125 EEAG the conditions established in para. 124 EEAG do not apply to installations with an installed electricity capacity of less than 500 kW or demonstration projects. Moreover a specific threshold value is set for electricity from wind energy where an installed electricity capacity of 3 MW or 3 generation units applies. Concerning these installations operating aid can still be granted in the form of a set feed-in tariff.

Uncertainties arise with regard to the interpretation of the threshold levels for installations with an installed electricity capacity of "3 MW or 3 generation units". The wording ("or") suggests, that each of the 3 generation units can exceed the 3 MW limit. In this case the 3 MW limit would turn out to be superfluous. It can be deducted from the interpretation of parallel provisions concerning exceptions to the principle of mandatory tendering according to para. (127) ("6 MW or 6 generation units"), that the Commission construes the derogation from a practical point of view with an average installation capacity of currently 2.5–3 MW (Vestager 2016). Accordingly, a wind farm with 3 generation units where an installed electricity capacity of 3 MW each applies could be exempted from the above-mentioned obligations. It remains open whether the capacity will be adjusted in accordance with technological developments.

2.2.3 Determination of the Level of Aid Via Technology-Neutral Bidding Processes

In compliance with para. 124 lit. (a) and 126 EEAG the market premium shall be determined and attributed from 1 January 2017 onwards following a competitive bidding process. If all generators producing electricity from renewable energy sources can participate in this procedure on a non-discriminatory basis, the Commission will assume that the aid is proportionate and does not distort competition. Competitive bidding procedures are therefore emerging as the core element in determining who shall receive how much funding in the future. Under para. 19 no. 43 EEAG, a competitive bidding process is defined as a "non-discriminatory bidding process that provides for the participation of a sufficient number of undertakings and where the aid is granted on the basis of either the initial bid submitted by the bidder or a clearing price. In addition, the budget or volume related to the bidding process is a binding constraint leading to a situation where not all bidders can receive aid". However, the EEAG do not give further indications as to how a bidding process should be designed. Consequently, Member States will have broad discretionary powers in shaping the bidding process, e.g. in determining substantive and financial pre-qualification conditions, the award procedure, realization periods, penalties etc.

2.2.4 Derogations from Mandatory Tendering and Technology-Specific Bidding Processes

For installations where an installed electricity capacity of less than 1 MW applies and for demonstration projects (except wind power systems, where a maximum installed electricity capacity of 6 MW or 6 generation units applies), the requirements of para. 124 lit. (a)–(c) EEAG continue to apply. Nevertheless, aid can be granted in this case without adhering to a competitive bidding process. Besides, according to the exhaustive list in para. 126 sentence 3, lit. (a)–(c) EEAG exceptions can be made if Member States demonstrate that only one or a very limited number of projects or sites are eligible, or that a competitive bidding process would lead to higher support levels or low project realization rates (avoid underbidding).

Finally, the competitive bidding process may only be limited to specific technologies by way of exception. In conformity with para. 126 sentence 5 lit. (a)–(e) EEAG this applies where a process open to all generators would lead to a suboptimal result which cannot be addressed in the process design. As potential reasons the EEAG enumerate in a non-exhaustive ("in particular") list the longer-term potential of a given new and innovative technology, the need to achieve diversification, network constraints and grid stability or system (integration) costs.

2.2.5 Determination of the Level of Aid Outside of Competitive Bidding Processes

In case no competitive bidding procedure needs to be carried out due to the above-mentioned exceptions, the operating aid measures have to comply with the conditions generally applicable for "aid for energy from renewable sources other than electricity", as the reference to para. 131 EEAG in para. 128 EEAG shows. The determination of the level of aid has to take into account particularly the levelized costs of producing energy (LCOE).

2.2.6 Maximum Funding Period

With regard to the maximum period of funding para. 129 EEAG stipulates that operating aid to promote electricity from renewable sources can only be granted until the plant has been fully depreciated according to normal accounting rules. However previously received investment aid must be deducted from the operating aid. An exception for existing biomass plants permits to grant operating aid after plant depreciation under specific conditions, para. 133 EEAG.

3 Influence on EEG 2014 and EEG 2017

Despite the ongoing dispute about the State aid character of the EEG, the German government notified the EEG 2014 for legal certainty (COM 2014b: para. 5) and the EEG 2014 in the following was declared to be compatible with the internal market by the EU Commission on 23 July 2014. Due to this State aid procedure the EEAG initially affected the design of the EEG. This impact was even strengthened in the course of the EEG 2017 State aid procedure (COM 2016). The EU Commission's Decision on the compatibility of the EEG 2017 with the internal market, published on 20 December 2016, is valid until 31 December 2020 and obliges Germany to submit an evaluation report by 30 June 2020 at the latest. As demonstrated in the following, the main impacts of these State aid procedures were the introduction of auctions to determine the level of the market premium, obligatory direct marketing, the rule that no market premium will be paid in times of negative prices and the partial opening of EEG support to foreign RES installations.

3.1 System Change to Auctions

The most obvious and highly disputed impact of the EEAG on the German support scheme was the introduction of auctions to determine the level of the market premium, which was generally classified to be a major change to the EEG system (Müller 2016: 45; Müller/Kahl/Sailer 2014: 141; Wustlich 2014: 1121; Assion 2015: 43; Kröger 2016a: 86). In an initial pilot phase auctions for ground-mounted PV installations were conducted by the German *Bundesnetzagentur* (BNetzA) based on the newly introduced regulation governing auctions for ground-mounted PV installations, the so called *Freiflächenausschreibungsverordnung* (FFAV). In parallel and according to § 2(5) EEG 2014 the already envisaged fundamental change to auctions was already announced by the year 2017 at the latest.

3.1.1 Technology-Specific Auctions

Despite the requirement contained in para. 126 EEAG that aid should be granted through a bidding process on the basis of, inter alia, non-discriminatory criteria, which is commonly understood to mean that technology-neutral auctions should be conducted as a rule and technology-specific auctions as an exception, Germany had already decided at an early stage to conduct separate auctions for onshore wind, PV and biomass installations after the pilot phase (BMWi 2015). Therefore the EU Commission's State aid decision on the EEG 2017 was highly anticipated, especially with regard to the remaining possibilities for Member States to conduct technology-specific auctions. Separate auctions for offshore wind were introduced as well. The relevant provisions governing the design of offshore wind auctions are laid down separately from the EEG 2017 in the *Windenergie-auf-See-Gesetz* and are thus not treated this article.

3.1.1.1 Biomass Installations

To justify the necessity for separate auctions for biomass installations, Germany referred to the exceptions set out under para. 126 subpara. 5 lit. (b) (need to achieve diversification) and lit. (c) (network constraints and grid stability) EEAG (COM 2016: para. 246–250). On the one hand Germany argued that biomass installations would not be able to submit winning bids if faced with wind installations and solar installations. On the other hand, however, biomass installations would still be needed because they contribute to grid stability through their ability to offer non-intermittent production and to provide flexible production, which is particularly important given the increase in intermittent electricity production from wind and PV installations. Furthermore, the EU Commission noted that even within separate auctions for biomass installations there would be enough potential to ensure a competitive bidding process, because biomass and biogas installations as well as new and existing installations will be included (COM 2016: para. 252).

3.1.1.2 Onshore Wind and Solar Installation

After excluding biomass installations the EU Commission further assessed whether separate or joint auctions have to be conducted for onshore wind and solar installations. The EU Commission concluded that separate auctions for onshore wind and PV installations are justified according to para. 126 EEAG given the existing network constraints and grid stability issues Germany is currently facing (COM 2016: para. 258–265). The EU Commission does not explicitly name the legal exception on which the justification was based. But given its reasoning, para. 126 subpara. 5 lit. (c) EEAG (network constraints and grid stability) in particular seems to have been relevant in this regard. The Commission agreed with Germany that the network constraints result from a combination of three factors: Firstly, a sharp increase in onshore wind installations in northern Germany in particular, while most consumption-intensive centres are located in the south; secondly, delays in grid expansion; and thirdly, the shutting down of nuclear power plants in the south of Germany (COM 2016: para. 260). Germany further demonstrated that, due to these network constraints, it needs to have balanced wind and solar electricity production at the national and regional level in order to transmit electricity from the areas where it is produced to the areas where it is consumed and that a joint auction design currently cannot address this issue (COM 2016: para. 261–264).

The EU Commission furthermore focused especially on the special reference mode (*Referenzertragsmodell*) which Germany applies in onshore wind auctions. Due to the use of this model participants in the auction do not submit bids based on their true costs but by reference to a modelled 100% onshore wind farm. Once their bids are ranked, selected operators obtain a premium based on a corrected reference value. However, as all bidders are subject to the same methodology, as the methodology is applied in advance with a detailed manual on how to determine the wind quality of a given site, and as the correction factor curve is also publicly available, the Commission considered that it can conclude a priori that the onshore wind auctions will constitute a competitive bidding process based on clear, transparent and non-discriminatory criteria (COM 2016: para. 268). But nevertheless the EU Commission obliged Germany to examine the impacts of the *Referenzertragsmodell* on the auctions in the evaluation plan.

3.1.2 Special Auction Rules for Citizens' Initiatives

According to § 36g EEG 2017 Germany foresees special auction rules for citizens' initiatives. The EU Commission nevertheless considers these privileges as exceptions from the rule of non-discriminatory auctions. But the EU Commission also notes that citizens' initiatives play a positive role, inter alia, by increasing acceptance of renewable energy policy, and emphasizes that there is currently little experience on how citizens' initiatives are best promoted. The effect of the special auction design and the exact extent of the advantage was, however, unknown at the time of the decision (COM 2016: para 271). Germany submitted studies indicating a limited number of citizens' initiatives in the near future. The studies led the EU Commission to believe that the special auction rules will above all enable citizens' initiatives projects to bid their real costs and that overall they will not distort the auction significantly given that citizens' initiatives are ranked according to their bid in the same way as the other participants. The EU Commission also considered that the concept of a citizen's initiative is still strictly defined and is limited to local projects led by citizens. The Commission therefore concluded that the special rules are in line with the EEAG but notes, in particular, that Germany has to evaluate the impacts of the provision and publish the results of the evaluation in 2018. Given the results of the first onshore wind auctions, which led to a high share of winning bids among citizens' initiatives (BNetzA 2017a: 4; BNetzA 2017b: 4), it is doubtful that the EU

Commission will uphold its initial assessment that the special rules for citizens' initiatives do not lead to a distortion of competition. Apart from this, the auction results prompted a discussion in Germany on whether the special auction rules for citizens' initiatives actually favour "real" citizens' initiatives or whether they unintentionally set the wrong incentives for established market players to use the legal structure of citizens' initiatives to increase their chances of winning auctions. For the moment, due to this discussion the auction rules have already been changed to the extent that citizens' initiatives are no longer allowed to take part in the auctions before they have received an emissions-control approval. A final regulation on this issue has to be found in the course of the next EEG amendment.

3.1.3 No Auctions for Certain Technologies

For installations producing electricity from landfill gas, sewage gas and geothermal energy as well as hydropower installations, Germany was able to justify an exemption from the obligation to carry out auctions according to para. 126 EEAG. For those installations the level of support will still be set by law according to §§ 40, 41 EEG 2017.

3.1.3.1 Hydropower Installations

Hydropower installations do not have to compete with other technologies or other hydropower installations for support. The Commission agreed that if put in competition with biomass, solar and onshore wind installations, new hydropower installations of between 750 kW and 2 MW as well as modernized installations of between 750 kW and 5 MW are likely not to be selected in the auction given that solar and wind installations have relatively high additional development potential and also lower costs compared to new hydropower installations of between 750 kW and 2 MW and modernized hydropower installations of between 750 kW and 5 MW (COM 2016: para. 211). This would put at risk the deployment of the remaining hydropower potential and its contribution to the diversification of the energy mix and grid stability according to para. 126 subpara. 5 lit. b) and c) EEAG. Besides, an auction putting hydropower installations with an installed capacity of 750 kW in competition with biomass installations with an installed capacity of 150 kW could lead to windfall profits for hydropower installations according to para. 126 subpara. 3 lit b) EEAG (COM 2016: para. 214). As to auctions for hydropower installations only, the EU Commission agreed that such auctions would be non-competitive and lead to higher support levels or lower realization rates and would from the start be or soon become uncompetitive. Therefore, and based on para. 126 subpara. 3 EEAG, the EU Commission found it justified that the support for hydropower installations is not granted based on a bidding process (COM 2016: para. 216–222).

3.1.3.2 Landfill Gas, Sewage Gas and Geothermal Energy Installations

As in the case of hydropower installations, the EEG 2017 does not foresee the granting of support to installations producing electricity from landfill gas, sewage gas and geothermal energy on the basis of auctions. With regard to landfill and sewage gas installations, Germany demonstrated that the potential is not sufficient and auctions would be uncompetitive given the very small number of projects that would be eligible. In addition, given the relatively low cost of those installations compared to PV, onshore and offshore wind or biomass installations, including them in a competition with other technologies would not put competitive pressure on the other technologies, but would risk leading to higher support levels for sewage gas installations. Therefore the EU Commission considered that the exemption from auctions for installations producing electricity from landfill gas and sewage gas is in line with para. 126 subpara. 3 lit. (a) and (b) EEAG (COM 2016: para. 204–207).

With regard to geothermal installations the EU Commission considered that putting this technology in competition with the other cheaper technologies could jeopardize the longer term potential of this technology according to para. 126 subpara. 5 lit. (a) EEAG. Furthermore, given the limited number of projects expected in the coming years an auction limited to geothermal installations would not be competitive and would lead to higher support levels according to para. 126 para 3 lit. (a) and (b) EEAG.

3.1.4 Pilot Auctions: Technology-Neutral Auctions for Wind and PV and Innovation Auctions

Despite the fact that Germany was to a great extent able to successfully rely on exemptions from the rule of technology-neutral auctions, it nevertheless committed to the EU Commission to undertake a study into possibilities to integrate congestion and system integration costs into the auction design and to undertake test auctions based on the results of the study (COM 2016: para. 264, 49–51). Furthermore, while auctioning does not seem adequate for hydropower installations in Germany, Germany has committed to launch a pilot innovation auction of 50 MW in which it would require participants to provide a specific stable or flexible quality of production (COM 2016: para. 221). According to this commitment within such auctions applicants could apply with joint projects, e.g. a renewable installation coupled with a storage facility or a combination of two renewable facilities having complementary qualities. This could on the one hand trigger innovative joint renewable projects and make it possible to test alternative auction designs open to several technologies, including hydropower. These obligations are implemented by § 39i and § 39j EEG 2017 according to which joint auctions for onshore wind and PV as well as innovative auctions will be carried out in the years 2018–2020. Based on the results of these auctions the German government will make a proposal whether and to what extent such auctions will be carried out as of the year 2021. On 10 August 2017, the German Government therefore already adopted a regulation implementing joint auctions for onshore wind and PV installations (*Verordnung zu den gemeinsamen Ausschreibungen—GemAV*). The joint auctions will take place in the years 2018 and 2019 with a total volume of 400 MW per year. The first joint auction round was conducted in April 2018 and led to the result, that only bids for PV installations were awarded (BNetzA 2018).

3.1.5 Opening of Auctions to Operators Located in Other Member States

The opening of auctions to installation operators located in other Member States constitutes another significant change to the EEG system and was introduced in § 2 para. 6 EEG 2014 (Kahles/Pause 2015) and is now laid down in § 5 para. 2–6 EEG 2017. The detailed auction rules are determined by the regulation for cross-border auctions (*Grenzüberschreitende-Erneuerbare-Energien-Verordnung—GEEV*). Although the integration of electricity produced in other EU Member States in the EEG system is not genuinely State aid related, it did play a central role especially in the EEG 2014 State aid procedure. In fact, the EU Commission states in para. 122 EEAG that national support schemes that are open to other EEA or Energy Community countries will be considered positively. But in the end, the EU Commission successfully argued that the EEG surcharge constitutes a discriminatory charge according to Art. 30 or Art. 110 TFEU (COM 2014b: para. 329–337). But in view of the opening of auctions to operators located in other Member States, the EU Commission considered that the EEG complies with Art. 30/110 TFEU.

The EU Commission accepted several conditions for the implementation of cross-border auctions in Germany (COM 2014b: para. 334–336; COM 2016: para. 292). Therefore cross-border auctions are subject to the conclusion of a cooperation agreement, the compliance with the principle of reciprocity and the physical import of the electricity or at least a comparable impact on the German electricity market. Furthermore, the total volume of cross-border auctions is limited to 5% of the yearly capacity to be installed. On the legal basis of the *GEEV* and a cooperation agreement with Denmark a first cross-border auction was carried out for ground-mounted PV installations in late 2016 (BNetzA 2016a; Danish Energy Agency 2016a), which was considered positively by the EU Commission in the course of the EEG 2017 State aid procedure (COM 2016: para. 292).

3.2 Direct Marketing, Market Premium and Standard Balancing Responsibilities

The introduction of market premiums as the main form of support and the obligation to sell the electricity directly in the market constitute another important impact of State aid law on the EEG. These changes were implemented gradually. At first, installations with an installed capacity of not more than 500 kW and which went into operation before 31 December 2015 were still entitled to receive a feed-in tariff (§ 37 para. 2 no. 1 EEG 2014). Installations that went into operation after 1 January 2016 are only entitled to receive a feed-in tariff if their installed capacity does not exceed 100 kW (§ 37 para. 2 no. 2 EEG 2014). Note that the threshold of 100 kW chosen in the EEG 2014 was considerably lower than the threshold of 500 kW laid down in para. 125 EEAG. Furthermore, every operator selling electricity directly in the market is subject to standard balancing responsibilities according to § 35 sentence 1 no. 3 EEG 2014. These principles were maintained in the EEG 2017. Overall, the EEG 2014 and EEG 2017 therefore comply with para. 124 lit. (a) and (b) EEAG (COM 2014b: para. 249, 251; COM 2016: para.192, 194).

3.3 No Incentive to Generate Electricity Under Negative Prices

According to § 51 para 1 EEG 2017 no market premium will be paid during hours where prices were negative for at least 6 hours in a row on the day-ahead market. This provision was first introduced by § 24 para. 1 EEG 2014. Furthermore, according to § 51 para 3 no. 1 the rule does not apply to installations of less than 500 kW for all technologies (except wind) and of less than 3 MW for wind installations. Germany has made a commitment to the EU Commission that in the case of wind installations account will be taken of other wind turbines belonging to the same owner and built in the vicinity of the first installation within a period of 12 months to verify whether the threshold of 3 MW is reached. The EU Commission therefore concluded that the condition of para. 124 lit. (c) EEAG is fulfilled (COM 2014b: para. 251–253; COM 2016: 195–199).

4 Influence on RES Support Schemes in Other Member States

The EEAG not only had a great impact on the German RES support scheme, but on several other Member States as well. So far, RES support schemes of 18 other Member States have been examined by the EU Commission under the EEAG (United Kingdom 2014; Luxembourg 2014, 2016; Denmark 2014, 2016; Estonia 2014; The Netherlands 2015; Romania 2015; Italy 2016; Portugal 2016; Bulgaria 2016; Czech Republic 2016; Malta 2016; Slovenia 2016; Greece 2016; Belgium 2016; France 2016, 2017; Hungary 2017; Spain 2017; Poland 2017). On the basis of these State aid decisions and despite the fact that the EEAG still provide for other forms of support for RES electricity, like investment aid or aid granted by way of certificates (e.g. Romania 2015; Belgium 2016), it can be observed that more and more Member States choose market premiums as their main RES support instrument. If this development continues, market premiums may soon replace feed-in tariffs as the main support instrument for RES in the EU (for an overview of the support instruments deployed in the different Member States see CEER 2017: 10). In addition, several Member States began to implement technology-neutral or technology-specific auctions to determine the level of the market premium at least for certain technologies (United Kingdom 2014; Denmark 2014; Luxembourg 2014, 2016; Estonia 2014; Greece 2016; Italy 2016; Malta 2016; Portugal 2016; Slovenia 2016; France 2016, 2017; Hungary 2017; Spain 2017; Poland 2017). Other Member States already had an auction system in place (The Netherlands 2015). Another impact of the EEAG is the increasing implementation of rules prohibiting the payment of support for RES electricity in times of negative prices (United Kingdom 2014; Denmark 2014; Luxembourg 2014, 2016; Estonia 2014; Greece 2016; Italy 2016; Portugal 2016; Slovenia 2016; Czech Republic 2016; France 2016, 2017). Finally, more and more Member States also made a commitment to the EU Commission to at least partially open up their RES support schemes under certain conditions (Luxembourg 2014, 2016; Estonia 2014; Romania 2015; Greece 2016; Italy 2016; Portugal 2016; Belgium 2016; Hungary 2017). Denmark initially committed to partly open up its support scheme (Denmark 2014) and even conducted the first cross-border auctions of its kind with Germany (BNetzA 2016b, Danish Energy Agency 2016b). But due to a change of the financing method the EU Commission concluded that the Danish support scheme is compliant with Art. 30/110 TFEU even without an opening obligation (Denmark 2016).

5 Conclusion and Outlook

The EEAG, as applied by the EU Commission in several State aid decisions, have a great impact on the design of RES support schemes across the EU. As shown, this impact is especially evident from the example of the German EEG 2014 and EEG 2017 but holds true for a growing number of other Member States as well. Despite the fact that the EEAG still provide for other forms of support for RES electricity, it can be observed that the EEAG have led and are still leading to convergence of certain support instrument features in different Member States, like the implementation of market premiums, auctions, the prohibition of support in times of negative prices or the opening up of support schemes, although differences in detail remain. This very confident application of the EEAG by the EU Commission has raised legal concerns that the Commission is overstepping its competencies by pursuing a certain energy policy "*through the back door*". Indeed, it can be argued that the decision on provisions, which affect the right of the Member States to choose between their energy sources, such as the principle of technology neutral auctions, should remain within the competence of the Member States or at least the EU legislator according to Art. 194 TFEU. This concern should be addressed during the planned revision of the EEAG in 2018/2019 and the ongoing legislative procedure regarding the new

Renewable Energies Directive for the period from 2021 to 2030 as part of the so-called Clean Energy Package.

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A Step Further Towards a European Energy Transition: The “Clean Energy Package” from a Legal Point of View

Grit Ludwig

Abstract With its “clean energy package”, the European Commission intends to shape the legal framework for a European Energy Union for the period between 2020 and 2030. The package is based on the new EU competences in energy policy which the Lisbon Treaty established in 2009. Besides a Regulation on the Governance of the Energy Union, the package comprises seven proposals for revisions and amendments of existing directives and regulations in the energy sector. These are supposed to build a new legal framework for renewable energies, energy efficiency, energy efficiency in buildings, as well as for the electricity market. This contribution gives an overview of the new regulations and a tentative assessment of the package from a legal point of view.

1 Introduction

With the entry into force of the Lisbon Treaty in 2009, Article 194(1) of the Treaty on the Functioning of the European Union (TFEU) endows the EU with a special competence in the energy sector (for details cf. Bovet 2018; Callies and Hey 2013). The legal framework shaping the energy transition on EU level at present is still based on the competences for the environment, on the authority over internal market harmonization, and the authority over trans-European electricity grids. Under reference to these, the EU had adopted the Renewable Energy Directive (RED I, 2009/28/EC), the Directive on Energy Efficiency (EED, 2012/27/EU) and the Directive on the energy performance of buildings 2010 (EPBD, 2010/31/EU). These legal acts provide the EU with a predominantly indirect, yet powerful impact on the national energy mix of the member states (Callies and Hey 2013).

With the proposal of the so-called “winter package”, based on the new competence in the energy sector, the European Commission (hereinafter Commission)

G. Ludwig (✉)
Department of Environmental and Planning Law, Helmholtz Centre for Environmental Research, Leipzig, Germany
e-mail: grit.ludwig@ufz.de

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opened up a new chapter in EU energy policy. The Commission pursues three main goals: putting energy efficiency first, achieving global leadership in renewable energies and providing a fair deal for consumers. The EU shall "lead the clean energy transition and not only adapt to it" (European Commission 2016a). The Commission supposes an EU Energy Union to contribute—along with other flagship initiatives of the EU such as the Digital Single Market, the Capital Markets Union and the Investment Plan for Europe—to modernize the EU's economy in order to deliver on jobs, growth and investments for Europe (European Commission 2016b). In its framework strategy for an Energy Union (European Commission 2015), the Commission had pointed out that the Energy Union should be based on five mutually supportive and interlinked dimensions: energy security, solidarity and trust; a fully integrated energy market; energy efficiency contributing to moderation of demand; decarbonisation of the economy; as well as research, innovation and competitiveness. As two thirds of greenhouse gas emissions in the EU result from energy production and use, the implementation of the EU's ambitious Paris climate change commitments depends to a large extent on the successful transition to a clean energy system (European Commission 2016b). In this context, the winter package aims at implementing the cut of CO_2 emissions by at least 40% by 2030; an objective the EU had committed to in 2014 (Council of the European Union 2014). This contribution summarizes the main content of the clean energy package (2) and assesses the proposals tentatively (3).Finally, a light will be cast on the impacts on the German legal framework for the energy transition (4).

2 Content of the Package

The winter package comprises revisions of the legal framework in the energy sector in terms of renewable energy (Sect. 2.1), energy efficiency (Sect. 2.2), energy efficiency in buildings (Sect. 2.3), as well as the electricity market (Sect. 2.4). It also includes a new regulation on the governance of the emerging energy union (Sect. 2.5).

2.1 Renewable Energy

With the recast of the Directive on the promotion of the use of energy from renewable sources (RED II, COM(2016) 767, COD 2016/0375), the EU Commission aims at guaranteeing investment security and equal basic conditions for all technologies, without prejudice to the climate protection and renewable energy targets. Nevertheless, unlike its predecessor the RED II proposal contains very few mandatory requirements. Article 3 of the compromise text of 21 June 2018 foresees a new EU-wide target of 32% (RED I: 20%) for the share of renewable energies in the EU (as opposed to individual national targets in the RED I) for 2030, with an upward revision clause for the year 2023. In the legislative process the Parliament had voted for a 35% RES target by 2030 and a separate 12% share of energy from renewable sources in transport in January 2018, whereas the Council had backed the Commission's 27% target for RES (Council of the European Union 2017b). According to a request of the European Council made in 2014, the 32% target shall only be achieved with complete respect of the freedom of the member states to determine their energy mix (Council of the European Union 2014). The EU-wide target will be fulfilled by individual member states' contributions guided by the need to deliver collectively for the EU. In every case, the share of energy from renewable sources in each member state's gross final consumption of energy shall not be lower than the 20% goal stipulated in the RED I, Article 3(3). As there are no binding national targets, the new governance regulation is supposed to provide a hinge for the achievement of the binding EU target (cf. Sect. 2.5 below).

RED II is founded on a market-based approach composed of a variety of singular measures. One of the rules which had been proposed as binding for the member states within the Commission's proposal was the mandatory opening of national support schemes to generators based in other member states according to article 5. In the informal trialogue this obligation was transformed into a voluntary support of renewables produced in a neighbouring state. As indicative shares were stipulated at least 5% every year between 2023 and 2026 and 10% between 2027 and 2030. To decide on the mechanics of opening its schemes up to cross-border participation is up to the individual member states, Article 5(3).

For the calculation of the EU-wide gross final consumption of energy from renewable resources in each member state, Article 7(1) distinguishes between electricity, heating/cooling, and transport. Article 2(i) RED II provides for a legal definition of "support scheme"; Article 4 establishes requirements which support schemes need to fulfil. According to Article 4(2), for instance, support for electricity from renewable sources shall be designed so as to maximise the integration of electricity from renewable sources in the electricity market. An earlier version of the proposal for RED II had incorporated more specific requirements for the promotion of renewable electricity. It had counted on tenders as the main instrument. Another provision was that in case of direct support, a supplement on the price achievable on the market should be paid. The earlier version also had contained the obligation to opt for technology neutral tenders, if possible (Schulz and Losch 2017: 110).

Heating and cooling represents around half of the final energy consumption of the Union and therefore was identified as a key sector in accelerating the decarbonisation of the energy system as well as a strategic sector in terms of energy security by the Commission (Recital 56 RED II). Member states shall aim at an annual increase of 1.3% points of the share of renewables, or 1.1% points if waste heat is not taken into account (Article 23 RED II). For the transport sector, RED II states a duty for the member states to oblige fuel suppliers that the share of renewable energy supplied for final consumption in the transport sector is at least 14% by 2030 (Article 25). Conventional biofuels will be capped EU-wide at a maximum of 7%. The counting of biofuels with a high risk of indirect land use change (ILUC) will be freezed at 2019 levels and gradually phased out from 2023 towards 2030. Within this total share, the contribution of advanced biofuels and biogas shall be at least 0.2% of the transport fuels supplied for consumption or use on the market in 2022, increasing up to at least 3.5% by 2030. Advanced biofuels are made of non-food biomass listed in Annex IX Part A, for instance algae or straw (cf. also Article 2(ee)). member stateEnergy from biofuels, bioliquids and biomass fuels shall be taken into account contributing towards the Union target and member states renewable energy share if it fulfills the reworked sustainability and the greenhouse gas emissions saving criteria for biofuels (Article 26). New in Article 21 RED II is a special protection clause for "self-consumption" of RES. Installations of up to 30 kW will be exempted from certain grid obligations. This regulation recognises the rights of energy communities and citizens to participate in Europe's energy transition.

2.2 *Energy Efficiency*

The EED 2012 established a framework of measures for the promotion of energy efficiency in order to ensure the achievement of the EU's 2020 20% headline target on energy efficiency (Article 1 EED 2012). The 20% target is non-binding, but Article 3 obliges the member states to set binding national energy efficiency targets and notify them to the Commission. The most important provision of the directive, Article 7, requires member states to implement Energy Efficiency Obligations and/or alternative policy instruments in order to reach a reduction in final energy use of 1.5% per year. With the launch of the Energy Union Communication in February 2015 (European Commission 2015) the EU adopted the principle of "Efficiency First". Put simply, the principle prioritizes investments in customer-side efficiency resources (including end-use energy efficiency and demand response) whenever they would cost less, or deliver more value, than investing in energy infrastructure, fuels, and supply alone (Rosenow et al. 2017). Regarding the headline target of energy savings by 2030, the Commission's proposal had stated a 30% goal (COM(2016) 761; COD 2016/0375) which represents a drop in final energy consumption of 17% compared to 2005 (explanatory memorandum in the proposal). After the Parliament had entered the informal trialogue with a 35% target, negotiators met halfway on 32.5%. Differently to its predecessor, the target is binding, but solely on EU level. According to Article 3(4), member states are required to set indicative national energy efficiency contributions towards the Union's 2030 target and include these in the NECPs (cf. Sect. 2.5 below). Besides the headline target, Article 7 is the key element under revision in the EED. The new Article 7 extends the scope of application for the efficiency requirements and optimizes existing rules (Scholtka and Martin 2017a). However, whereas the obligation to save end-use energy in the EED 2012 had been 1.5% per year, now it was set to only 0.8% per year until 2030.

2.3 *Energy Efficiency in Buildings*

The EPBD 2010 requires concrete actions to achieve energy savings in buildings and reduce the differences among member states in this sector. Besides of other measures, the Directive sets minimum energy performance requirements for new buildings (Article 4), for major renovations (Article 7) and for the installation, replacement or retrofit of technical building systems (Article 8) (Rosenow et al. 2017). The recast EPBD (2018/844/EU) pursues the objective of 85–90% reduction of THG emissions of the building stock in the EU by 2050 in comparison to 1990. Regarding long-term national building renovation strategies, a new obligation for the member states was introduced to set out a roadmap with clear milestones and measures to deliver on the long-term 2050 goal to decarbonize their national building stock, with specific milestones for 2030, Article 2a(2). Moreover, there is a focus on "smart buildings": Article 8 establishes an obligation for the equipment of specific non-residential buildings with a recharging point for e-mobility. Article 8 (6) foresees a smartness indicator for buildings which shall be provided as additional information to prospective new tenants or buyers. Here, delegated acts are necessary. Article 14 reinforces the use of building electronic monitoring, automation and control in order to streamline inspections. In respect to the energy efficiency in buildings, not only the rules of the EPBD, but also Articles 23 and 24 RED II (cf. Sect. 2.1) are relevant.

2.4 *Electricity Market*

Whereas the other legislative acts bundled in the winter package had passed the informal trialogue until June 2018, the proposals on the electricity market are expected to be stipulated until the end of 2018. The EU has been striving for an internal EU market in the energy sector since the mid-nineties. An internal electricity market represents one of the five dimensions of the Energy Union (cf. Sect. 1). It is regarded as a prerequisite for the achievement of the triad of objectives in the European energy policy: affordable prices for consumers, security of supply and ecologically sustainable production. In respect to the electricity market, four legislative proposals are bundled up in the winter package: a directive on common rules for the internal market in electricity (COM(2016) 864); a new regulation on the internal electricity market (COM(2016) 861); a new regulation on risk-preparedness in the electricity sector which repeals Directive 2005/89 (COM(2016) 862); and a revised regulation establishing a European Union Agency for the Cooperation of Energy Regulators—ACER (COM(2016) 863). Since 1996, the EU has adopted three Energy Market Liberalisation Packages, the last in 2009. The new proposals aim at reshaping once more the design of the electricity market. Besides other objectives, the suggested revisions aim at a better integration of RES in the electricity market (Scholtka and Martin 2017b). Increased reliance on renewable energy sources not only poses major technical as well as economic challenges; but a decentralised market has also more players and creates new roles such as aggregators and 'prosumers' (Hancher and Winters 2017: 4). These challenges need to be responded to by an adequate legal framework. In this context, Germany had revised its electricity market design already in 2016 with the Electricity Market Act (Gesetz zur Weiterentwicklung des Strommarktes, of 26 July 2016). Key elements of this regulation, like the transition to a more flexible electricity market, the strengthening of price signals, or the promotion of balancing responsibility, are also part of the winter package (Scholtka and Martin 2017b).

More detailed: The proposal for a new E-Directive revises the common rules for the internal market in electricity and recasts Directive 2009/72 concerning common rules for the internal market in electricity. The new E-Directive is supposed to bring forward common rules for a competitive, consumer-centered, flexible and non-discriminatory electricity market (Article 1 and 3). For the realization of this aim, the directive banks, for instance, on consumer empowerment and protection (Articles 10–29). According to Article 11, e.g., member states shall ensure that every final customer is entitled, on request, to a dynamic electricity price contract by his supplier. Article 15 obliges member states to ensure that "active consumers" (definition in Article 2 no. 6) are entitled to generate, store, consume and sell self-generated electricity in all organized markets either individually or through aggregators (definition in Article 2 no. 14) without being subject to disproportionately burdensome procedures and charges that are not cost reflective. Article 19 emphasizes the need for the development and introduction of smart metering systems (detailed Scholtka and Martin 2017b: 241 f.).

The Council agrees to the Commission's proposal of the E-Directive under the condition that price regulation will remain possible under certain conditions. Furthermore, the Council voted for the inclusion of coal-fired power plants in capacity mechanisms and hence opened a door to subsidy of high-polluting fossil fuels. According to the Council, existing power plants should receive payments until 2030; the payments need to decrease after 2025. A limit in CO_2 emissions the Council only stipulated for new installations after 2025 (550 gr CO_2/kWh or below 700 kg CO_2 on average per year per installed kW) (Council of the European Union 2017a). As the CO_2 emissions of all coal-fired power plants exceed this threshold, the Council's position is that subsidies for coal-fired power plants shall be possible for the whole period in which the winter package will have effect. By contrast, the intention of the Commission is to prevent the inclusion of these carbon intensive installations from the payments.

The main objective of the proposal for a Regulation on the internal Electricity Market (E-Regulation) is to enable market signals to be delivered for increased flexibility, decarbonisation and innovation, Article 1(a). It also underlines the importance of market-based remuneration of electricity generated from renewable sources. Cross-border exchanges of electricity shall be facilitated, Article 1(d). An important provision is Article 4(1) obliging all market participants to strive for system balance. Market participants shall be financially responsible for imbalances they cause in the system. Article 5 establishes the rule that all market participants shall have access to the balancing market, be it individually or through aggregation. The Commission considers RES as market ready; according to Article 11, the priority dispatch for the grid access will be abolished. Exemptions are foreseen only for very small generating installations or generating installations using emerging technologies. In the case of congestion of networks, a non-market based redispatching and curtailment order is defined by Article 12(5). Generating installations using renewable energy sources or high-efficiency cogeneration shall be the last to be switched off. The owner of the curtailed or redispatched generation or demand facility shall be financially compensated by the system operator requesting the curtailment or redispatching, Article 12(6).

Article 14 sets criteria for the introduction and design of national capacity mechanisms. "Capacity mechanisms" means an administrative measure to ensure the achievement of the desired level of security of supply by remunerating resources for their availability, Article 2(2)(u). Under Article 23(4) of the Commission's proposal, new installations shall only be eligible to participate in a capacity mechanism if its emissions are below 550 gr CO_2/kWh. After 5 years after the entry into force of the E-Regulation, generation capacity emitting 550 gr CO_2/kWh or more shall not be committed in capacity mechanisms. With the new ACER-Regulation, this agency shall be reformed and strengthened. The proposal for a regulation on risk-preparedness in the electricity sector recommends preventive instruments such as risk-preparedness plans (Articles 10–12).

2.5 Governance of the Energy Union

The governance regulation (COM(2016) 759; COD 2016/0375) comprises a mechanism which aims at closing the void between the binding EU-RES-target and the individual contributions of the member states. The Commission counts on detailed reporting on national efforts. An integrated reporting obligation on all energy and climate aspects set out in Article 3 brings together more than 50 existing planning, reporting and monitoring obligations from the main pieces of EU legislation, across energy climate and other related policy areas (Hancher and Winters 2017: 7). Member states are obliged to notify national integrated energy and climate plans (NECPs) to the Commission for the period 2021–2030 by 31 Dezember 2019, and for subsequent 10 year periods. In the NECPs, member states shall set out their individual contribution to the 32% RES target, stipulated in RED II, with a linear indicative trajectory for that contribution from 2022 onwards, Article 4(a) no. 2(i) of the compromise version of 28 June 2018. The NECPs also have an integrative function across borders (Schulz and Losch 2017: 109): According to Article 11(2), member states shall identify opportunities for regional cooperation and consult neighboring member states. The member states are supposed to submit draft national plans for the first period (2021–2030) by 31 Dezember 2018, (Article 9(1)). The Commission assesses draft NECPs and may issue recommendations that member states must take into due account, cf. Article 9(3). If a member state does not address a recommendation or a substantial part thereof, it shall provide reasoning and make it public. Member states shall update the NECP's or justify to the Commission that the plan remains valid according to Article 13.

Article 15 obliges the member states to report to the Commission every 2 years on the status of implementation of the NECPs, covering the five dimensions of the Energy Union. The first report is due on March 15th 2023. The progress of each individual member state will be assessed by the Commission on the bases of Articles 25–28. Regarding the impact of recommendations of the Commission, Article 28 (2a) requires that member states take them into due account. The wording in the Commission's proposal had been "utmost account". If the Member State concerned decides not to address a recommendation or a substantial part thereof, it shall provide reasoning, Article 28(2b). After having assessed all the NECPs, the Commission concludes if the Union trajectory is met collectively and if national baselines are respected. If not, Article 27(4) for the RES target and (5) for the efficiency target shall apply. Article 27(4), in particular, sets out options for member states to increase their contributions to the RES target, e.g. by adjusting the share of renewable energy in the heating and cooling sector or by making a voluntary financial contribution to a financing platform to be set up at Union level to contribute to renewable energy projects, managed directly or indirectly by the Commission. Another key instrument beyond the NECPs is an obligation for the member states to develop long-term strategies with a 30 years time horizon at least and to deliver these by 1 January 2020, Article 14. In order to ensure comparability of the plans of the different member states, Annex I comprises a general framework for integrated national energy and climate action plans; Annex IIa for long-term strategies.

The Council had stated a diverging opinion in particular in respect to the governance of the energy union.

3 Tentative Assessment of the Package

The Commission proposed the clean energy package in a difficult political environment. It tries to find a modus for the transition of the European energy system(s) to more sustainability, although not all member states are convinced about its necessity (for details cf. Ringel and Knodt 2018). With the winter package, based on the previously announced political will to create an Energy Union, the Commission pursues objectives which partially contradict each other and, beyond that, which are differently understood in Western Europe compared to some Eastern European member states (Fischer 2015). So, several "policy cleavages", for instance Europeanization versus maintaining member states sovereignty in the energy sector or pitching security and affordability against sustainability in the notion of 'rehabilitating' fossil fuels versus enhancing renewable deployment (Szulecki et al. 2016), need to be overcome.

The main sticking points from a legal point of view is how the 32%-target can be reached without binding targets for the member states. Here, a mechanism with sanctions in the case of nonfulfillment seems necessary. However, the best legal framework doesn't help if the intention to achieve the overarching political goal dwindles over time. An example is the EU Emissions Trading Scheme with an existing instrument not delivering the expected results, a major reason for that being deficits in the EU climate policy (Gawel 2016). Another point is, that legal bindingness is a double-edged sword if it leads states not to participate or to make less ambitious commitments (Bodansky 2016 for the Paris Agreement). As the EU is constituted of national member states, the European policy-makers need the political consent of different electorates, but the intended switch to renewables does not find approval in all European societies. Nevertheless, although legal bindingness was not stipulated on the national level, it was defined for the EU target. The main instrument enabling the Commission to guarantee the achievement of the binding EU target is the monitoring of the NECPs. Here, the Commission's involvement in the preparation of the NECPs can strengthen the European perspective at an early stage, but the Commission's ability to challenge pledged contributions is weak. The proposal for a Governance Regulation only contains qualitative criteria to guide member state's contributions. Recommendations are not legally binding (Art. 288(5) TFEU) and only need to be taken into "due" account, so member states will have many ways to avoid strong commitments (for another interpretation see Ringel and Knodt 2018 who expect stronger effects from the Commission's recommendations). Therefore, the regulation should include quantified reference values on what constitutes a fair national contribution to the EU targets or establish an individual duty for member states to support the EU target on RES and energy efficiency in an adequate, proportionate and/or fair manner (Duwe et al. 2017). Beyond that, it is to criticise that the proposal for a Governance Regulation only counts on bilateral negotiations between Commission and the respective member state on NECPs. Discussions on NECPs should rather take place with all member states and also include the European Parliament (Duwe et al. 2017). However, as a positive step in this context is to be mentioned that the NECPs as well as the recommendations of the Commission need to be publicly available (articles 3(3b) and 28(1)) of the compromise version as of 28 June 2018.

However, a bit "harder" tool in the part of the Commission's proposal is an authorization to go directly for additional legislation at European level in the field of energy efficiency in the event of insufficient ambition on the part of member states (Article 27(5) Governance Regulation). (Ringel and Knodt 2018).

Regarding energy efficiency in buildings, the revisions for the EPBD imply more a streamlining of existing provisions and ensuring consistency with other policies, in particular the EED, rather than introducing new requirements. The package doesn't recognize sufficiently the role of buildings in the transition to a sustainable and secure energy system (Rosenow et al. 2017). Hence, there is still potential for strengthening the EU rules on energy efficiency in buildings. The leaked earlier version of the winter package had comprised more specific requirements for the promotion of renewable energies in the heating and cooling sector (cf. Buchan and Keay 2016).

The suggested new legal framework for the electricity market strengthens the position of consumers, which will be vested with more individual responsibility, for instance in respect to the consumer generation of renewable electricity, rules for Sustainable Energy Communities and the possibility to influence the individual provider of district heating or cooling (Schulz and Losch 2017). On the other hand, decentralization in energy provision comes along with a shift of competences in direction of the EU (Scholtka and Martin 2017b). The Commission's proposals on the internal electricity market and on the enlargement of the competences of the ACER has been challenged by Germany with a subsidiarity complaint (Deutscher Bundestag 2017). In consideration of the political objective of decarbonisation of the economy harshly to be criticised is the Council's position to include coal-fired power plants in capacity mechanisms in the Electricity Market Directive. Another brick to the EU governance framework of the energy system are the Guidelines on State aid for environmental protection and energy, which for the years beyond 2020 not have been determined yet. In sum, although the clean energy package has a wide scope, it is rather evolutionary than revolutionary (Fischer 2017). Although the winter package can be qualified as a step forward in terms of climate protection and a switch to renewables in the energy system of the EU, stronger commitments are crucial for the achievement of the objectives of the Paris Agreement.

4 Outlook for the German Legal Framework

Generally speaking, the German transition towards a renewable-energy-based electricity system is being facilitated by a supporting EU policy framework, especially regarding binding RES targets (Fischer and Geden 2014; Gawel et al. 2014) and infrastructure development (Callies and Hey 2013). In respect to the latter some concluded, that an electricity market design for the energy transition will only be successful, if it is a European electricity market design (Scholtka and Martin 2017b). Considering this background, the winter package is a step in the right direction, also for the German energy transition. Regarding the future obligations for the adoption of the legal rules in Germany, the winter package includes essential elements which are already part of the German legal framework for the energy sector, especially in the electricity market design. Generally speaking, as the energy sector is already in transition in Germany and as most of the provisions leave leeway for discretion in implementation, it should not raise too many difficulties to adopt the envisaged EU rules. Nonetheless, there will always be aspects which require the adaptation of German legislation, for instance regarding details in the priority dispatch of renewables (Kahles et al. 2017). A comprehensive analysis on that is necessary after the final versions of all legal acts bundled in the winter package will have been presented.

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Part II

Unilateralism or Cooperation and Convergence?

Electricity Market Integration and the Impact of Unilateral Policy Reforms

Luigi Grossi, Sven Heim, Kai Hüschelrath, and Michael Waterson

> *Our vision is of an integrated continent-wide energy system where energy flows freely across borders, based on competition and the best possible use of resources, and with effective regulation of energy markets at EU level where necessary.*
> European Commission (2015), A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, Brussels (Communication from the European Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of Regions and the European Investment Bank. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM (2015) 80 final, February 2015, p. 2.).

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L. Grossi
University of Verona, Verona, Italy

S. Heim (✉)
Mines ParisTech, Paris, France

ZEW Centre for European Economic Research, Mannheim, Germany
e-mail: sven.heim@mines-paristech.fr

K. Hüschelrath
ZEW Centre for European Economic Research, Mannheim, Germany

Schmalkalden University of Applied Science, Schmalkalden, Germany

M. Waterson
ZEW Centre for European Economic Research, Mannheim, Germany

University of Warwick, Coventry, UK

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Abstract We investigate the impact that two German energy reforms—phase-out of nuclear power plants after the Fukushima incident and expansion of renewables due to fixed feed-in tariffs—had on neighbouring countries' consumers. The unilateral German reforms generated substantial negative and positive impacts, respectively, in neighbouring countries with the highest overall effect of German policy found in France, not Germany; an annual negative impact on consumers of 3.15 billion €. We also find significant differences in market integration between neighbouring countries by calculating ratios between the estimated policy decisions' impacts before and after controlling for interconnector congestion.

1 Introduction

Cross-border trade in electricity is growing rapidly, albeit from a low base compared with other energy sources (Oseni and Pollitt 2014). The Western European interconnector system is a leading example, benefiting from a strong push provided by the three Energy Directives, plus Swiss cooperation. International trade of electricity in OECD Europe reached around 10% of gross production in 2011 (Baritaud and Volk 2014, Fig. 42). As with other forms of trade, there are clear benefits in aggregate; Booz & Company et al. (2013) estimate the gross welfare benefits from cross-border trade in Europe will eventually amount to an average of 6.7 €/MWh. At the same time, trade in electricity leads to tensions between national energy policies and wider European effects.

In this context, our paper examines the monetary impact on its neighbours of two recent reforms in the German market, Europe's biggest power market and one with significant imports and exports of electrical power. These are the nuclear shutdown response to the Fukushima earthquake and the contemporaneous expansion of renewables. We find that both unilateral reforms had substantial—opposing—impacts on market prices in neighbouring countries. While the nuclear phase-out triggered price increases of up to 25%, the price reductions caused by Germany's renewable energy support schemes were up to 0.16% for each percentage point of additional generation from German renewables.

Furthermore, we construct a counterfactual that enables causal inference of the degree of market integration by capturing the impact of cross-border congestion. Germany's neighbouring countries exhibit large differences in this respect. Our empirical findings emphasize the need for increased efforts to harmonize national energy policies—especially against the background of renewable energy and climate targets in general—with relevance beyond the European Union.

The paper is structured as follows. Section 2 briefly reviews the benefits and current extent of electricity market integration in the European Union. Section 3 then characterizes the interplay between market integration processes and unilateral policy reforms and covers the German unilateral policy decisions. Section 4 presents our empirical analysis, subdivided into the description of the data set, the development of our empirical approach as well as detailed discussion of our estimation results. Section 5 concludes the paper with a summary of the main insights and a discussion of policy conclusions.

2 The Benefits of Electricity Market Integration in the European Union

European energy policy is undergoing a lengthy (and ongoing) integration process. Initially, national electricity markets were heavily regulated, state-supported monopolies that first needed to be liberalized and harmonized before a serious integration process could commence (see generally Serralles 2006).

A key driver is the European Union's expectation of clearly positive welfare effects associated with development of the respective market integration processes. As Antweiler (2016) explains, although electricity is in one sense homogeneous, given differing demand patterns and generation techniques, cross-border trade should be manifest in bi-directional flows which take advantage of arbitrage opportunities. Following, e.g., Domanico (2007) or Serralles (2006), this is believed have four potential impacts.

First, it should increase competition, thereby pushing the respective providers towards cost reductions and/or productivity increases through innovation. More efficient utilization of existing generation and network capacities should lower electricity prices for customers. Second, a given security of supply level can be guaranteed with reduced spare capacities,—essentially because an interconnected internal market makes it easier to balance fluctuations in demand in a particular country. Third, this balancing effect is becoming increasingly important with the increasing desire for environmental protection exhibited through expansion of intermittent wind and solar energy. Fourth, these (interrelated) beneficial effects of an internal electricity market arguably enhance the overall competitiveness of the European Union's energy intensive industries by contributing affordable, secure and sustainable energy supply.

The benefits of electricity market integration—alongside assessments of its current degree—have been the focus of several prior studies. In a detailed survey of integration benefits, Booz & Company et al. (2013) subdivide the existing literature into studies estimating the benefits of (1) full market integration, (2) market coupling,[1] and (3) market liberalization.[2] In the first category, Neuhoff et al. (2013) quantify the effect of further integration of mainland-European electricity markets and the benefits from the utilization of additional wind capacity.[3] In the second, Newbery et al. (2015) estimate the potential EU benefit of coupling interconnectors

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[1] See, e.g., De Jong et al. (2007) and Kristiansen (2007a, b).

[2] See, e.g., Pollitt (2009a, b, 2012).

[3] Other contributions include Leuthold et al. (2005), Green (2007) and Pellini (2014).

to increase efficiency of trans-border trading. In the (more specific) literature aimed at identifying the degree of market integration, several studies apply pairwise price tests such as price ratios, correlations and cointegration analysis and typically find an increase in integration over time. Examples include Mjelde and Bessler (2009), Zachmann (2008), Robinson (2007) and Nitsche et al. (2010).

De Menezes and Houllier (2015) analyse whether price volatility and market integration has changed across EU electricity markets after the German nuclear phase-out through correlation and co-integration analyses. Böckers and Heimeshoff (2014) study the convergence process of European wholesale electricity markets using national bank holidays as exogenous demand shocks across their two subsamples 2004–2008 and 2008–2014. They estimate a reduced form and consider demand dynamics indirectly through calendar dummies. However, they do not identify the actual degree of integration, nor do they make comparison with a full integration counterfactual. In this paper, we apply a novel approach to estimate such counterfactual prices, which enables us to compute a measure for the degree of market integration.

3 Market Integration and Unilateral Policy Reforms

Although there is no doubt that measures increasing integration of European electricity markets are likely to create substantial societal benefits, they also increase the potential impact of unilateral policy reforms on neighbouring countries; spot prices for electricity in one country become increasingly dependent on other single Member States' actions. These can result in negative impacts, which might raise policy discussions or even storms of protest (in the worst case damaging the idea of Europe).

Furthermore, such negative impacts are likely to go beyond short-term price increases to impacts on medium- and long-term investment decisions, even resulting in failures of national energy policies. For example, German government subsidies for renewable energies together with the improved interconnection of the German-Austrian and French markets may have a knock-on effect on, for example, the profitability of a proposed French investment in construction of a thermal power plant. Indeed, there are already discussions on mechanisms to reduce interconnection aiming at protecting national electricity markets from externalities through unilateral neighbours' policies, i.e. "grid-locks" between Germany and Poland (see Puka and Szulecki 2014).

In this context, we analyse empirically the impacts of two distinct unilateral German policy reforms: the phase-out of nuclear power plants after the Fukushima incident in March 2011 and promotion of renewables that started in 2000 and since reformed several times. Clearly, there are differences. First, while the nuclear phase-out was a single, sudden, unilateral decision with no comparators in other European countries, most European countries promote renewables and many have revised their policies over time.

Second, we expect opposing impacts of the two policy reforms. Whilst removing a substantial fraction of nuclear power is likely to increase spot prices (provided that cross-border capacities are available and sufficiently large), promoting renewable energy production is likely to create a downward trend on price, since renewable generation at zero marginal costs reduces the residual demand on conventional generation (the so called "merit-order effect"). We investigate not only whether the two unilateral reforms caused the expected effects, but also quantify them in terms of percentage price changes in neighbouring countries arising from Germany's unilateral policy reforms.

3.1 Nuclear Phase-Out in Germany

The events of Fukushima in March 2011 marked a complete switch in Germany from a 2010 policy favourable to nuclear power to a sudden decision to shut-off all the six active nuclear power plants opened before 1981. This was an event of some significance: 6.3 GW of capacity, around 7% of installed conventional capacity and 12% of average German load, was permanently removed from the system, with significant impacts on nuclear plant output, as indicated in Fig. 1.

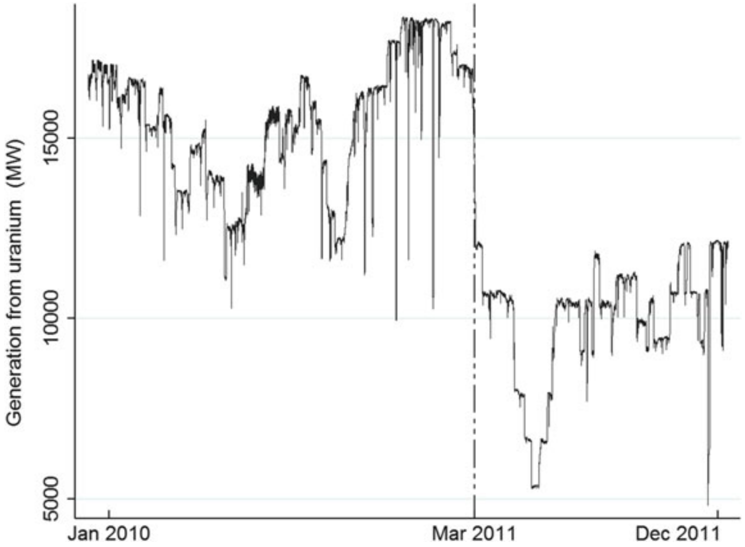

Fig. 1 Generation from German nuclear power plants before and after the nuclear phase-out. Note: The dashed vertical reference line indicates the time of permanent closure of the 6.3 GW taken offline in March 2011 directly after the Fukushima Daiichi nuclear incident. An additional temporary drop in generation capacity from nuclear sources—to a minimum marginally above 5 GW—in May and June 2011 was caused by obligatory security checks of the remaining nuclear plants. Source: Grossi et al. (2017)

Naturally, the removal of a significant fraction of generation capacity is expected to cause price increases on the spot and future markets. In particular, nuclear capacity provides a base-load power source, consistently generating, at low marginal costs to satisfy minimum demand. Removing a significant fraction of this capacity forces a switch to more expensive (lignite, hard coal or gas-fired) power plants—located nearer to the right-hand side of the supply-cost curve (merit order)—in order to meet demand (e.g. Knopf et al. 2014). The existing literature on the (price) effects of nuclear power plant closures confirms the general argument.[4]

3.2 Promotion of Renewables in Germany and Neighbouring Countries

Germany had actively promoted the growth of renewable energy production long before Fukushima by implementing three basic principles: (1) investment protection through guaranteed feed-in tariffs for 20 years, with unlimited priority feed-in to the grid and connection requirement imposed on the system operator, (2) subsidies paid not by taxes but by domestic consumers as an Erneuerbaren Energien Gesetz (EEG) surcharge included in the electricity bill[5] and (3) feed-in tariffs for new renewable plants, decreasing at regular intervals to create cost pressures (and innovation incentives) on renewable energy companies.

Although the EEG was successful in making Germany a world pioneer in renewable energy from wind and especially solar sources[6] (Borenstein 2012; Joskow 2011), renewable capacity—as noted by Grossi et al. (2017)—is utilizable nowhere near as intensively as conventional sources, and due to its stochastic nature is not ‘biddable’ according to electricity demand in the same way as coal, gas and pumped hydro plants are (Joskow 2011). While an average thermal plant in practice provides

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[4] Using a dummy variable approach, Grossi et al. (2017) investigate the impact of the phase-out on the German market itself. They find prices in Germany have increased—most significantly in hours of low demand (caused by a shift in the merit order), with only a small price increase in hours of high demand, (caused by increased market power). Davis and Hausman (2016), a related exercise with some parallels, finds comparable price effects of an unexpected nuclear power plant closure in California. Using a semi-parametric regression approach to identify the marginal generation unit each time-period before and after the event, they find the closure created binding transmission constraints, causing short-run inefficiencies and potentially making it more profitable for certain plants to act non-competitively.

[5] In 2014, the EEG surcharge was 6.24 ct/kWh. However, energy intensive industries are widely exempted from paying the surcharge.

[6] Capacity in these areas has been growing rapidly, boosted by EEG support. According to the German Ministry for Economic Affairs and Energy (2014), in late 2011, wind capacity reached almost 30 GW with photovoltaic power capacity at about 25 GW (out of a total system listed capacity of 175 GW). In sum, in the year 2011, more capacity had been added through renewables (wind: 1.9 GW; solar: 7.5 GW) than had been removed by the nuclear phase-out.

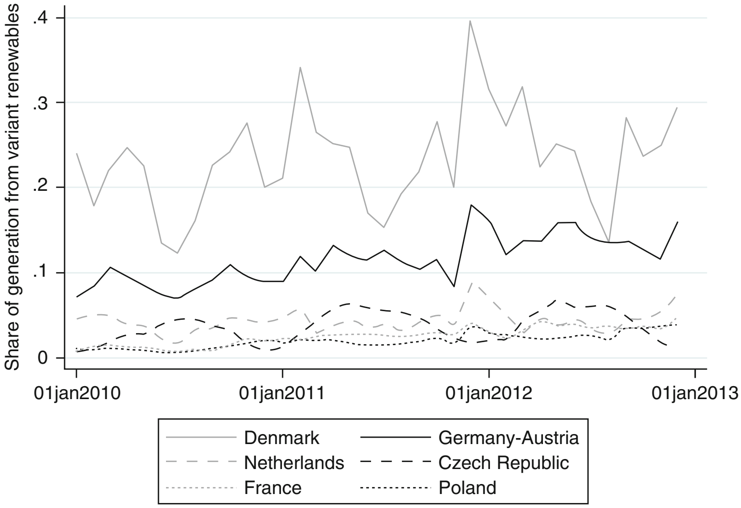

Fig. 2 Share of intermittent renewable energy in total electricity generation (monthly). Note: Legend is ordered from highest to lowest shares of renewable energy generation in total energy generation. Renewables include wind and solar. Switzerland excluded due to negligibly small intermittent renewables

around 50% of its total theoretical capacity over a year, wind hovers around 20% and photovoltaic only around 11%.

We should highlight the difference between the nuclear phase-out and the expansion of generation from renewable sources. Whilst the nuclear phase out is a single natural experiment in that it was un-planned, the increase of renewable generation capacity is a multi-year programme benefiting owners of renewable plants with priority feed-in to the grid and fixed feed-in-tariffs for a period of 20 years, hence rendering renewable generation exogenous. Generation from renewables creates permanent supply shocks for conventional power plant owners. Importantly—by contrast with the nuclear phase-out—promotion of renewable energy production was also introduced (and incrementally extended) in Germany's neighbouring countries.[7] Figure 2 plots the respective country shares of intermittent renewable energy in gross final energy consumption between 2010 and 2012. Denmark and Germany-Austria are the 'intermittent variable renewable leaders' with shares reaching (on average) 25% and 15%, respectively, in 2012. France, the Netherlands, the Czech Republic and Poland lag far behind with shares around 5%. The intermittent nature of generation from wind and solar is evident in the figure (see also Grossi et al. 2017) and means that controls for these effects are necessary in isolating the impact of the German reforms on the respective spot prices.

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[7] It should be noted that we control for the simultaneous generation from renewables in the neighbouring countries in all regressions and thus capture parallel developments therein.

The impact of German unilateral energy policy reforms on market prices also allows a trade theory interpretation[8] in terms of studying the welfare effects of policy measures such as tariffs/taxes or subsidies on consumers and producers in the trading partners' countries as well as the originator. For example, a tariff or subsidy can improve the terms of trade of the (large) originating country while imposing a negative impact on social welfare on the trading partners (see, e.g., Krugman et al. 2014).

Here, an application of basic trade theory would suggest that Germany—if it reduces the price of its imports by expanding renewables—could improve its welfare (with the overall net effect on welfare being dependent on the size of the "renewables subsidy"). Yet, assuming the loss of nuclear capacity raises the relative price of imports from neighbouring countries, a countervailing decrease in its welfare would result. For the trading partners, Germany's renewable subsidy is expected to increase net welfare due to lower import prices whilst the nuclear reduction likely has the opposite effect.[9]

However, it is important to recall a distinctive feature: Germany as the originating state was not aiming at increasing short-run welfare at the expense of the trading partners through an application of standard "beggar-thy-neighbour" policies known from strategic trade theory (see, e.g., Brander and Spencer 1985), but had in mind longer-run environmental goals. While different in motivation, the effects on the trading partners can be quite similar (i.e., they either profit or suffer from the unilateral German decisions). We study the existence and size of the effects on market prices empirically below.

4 Empirical Analysis

How significantly are neighbouring countries affected by Germany's unilateral policy decisions? In a highly integrated market, both actions—the sudden nuclear phase-out and the expansion of renewables through support schemes—may be expected to cause substantial knock-on effects, while if the country is not integrated at all with Germany, we would expect zero impact. By combining this with information on import and export cross-border congestion the degree of market integration can be measured. More significantly, however, the degree of interdependence raises the question of whether the project of integrating European energy markets is in danger if unilateral decisions of certain Member States have substantial effects on medium- and long-term investment decisions in neighbouring countries as well as on short-term prices.

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[8] We are grateful to an anonymous reviewer for suggesting a discussion in light of (strategic) trade theory.

[9] Specifically, while producers in the trading partners' countries are expected to increase profits due to less cheap nuclear plants in Germany, the respective consumers are likely to face reductions in consumer surplus due to higher market prices.

We provide an empirical assessment of the impacts of the two unilateral energy policy reforms in Germany on wholesale electricity prices in its directly connected neighbours: the Netherlands, France, Poland, the Czech Republic, Switzerland and Denmark (West and East). Spain is used in a placebo test since, being unconnected directly or indirectly with Germany, it would not be expected to be affected by either change.[10] Section 4.1 describes the construction of the data set and presents descriptive statistics, Sect. 4.2 describes our modelling approach. The estimation results are in Sect. 4.3.

4.1 Data Set and Descriptive Statistics

We collected and merged data from several sources over the calendar years 2010–2012 to create the rich, unique data set used for our empirical analysis. Our dependent variables are country-specific wholesale (spot) day-ahead prices obtained from the respective power exchanges: EPEX Spot for Germany-Austria, France and Switzerland, Elspot for the two Danish zones (West and East), PXE for the Czech Republic, PPX for Poland and APX for the Netherlands. All price series are collected on an hourly basis, but transformed into daily averages, in order to maintain analytical tractability.

Our independent variables are of two broad types. Starting with the individual variables, hourly data on observed load in each country was obtained from the European Network of Transmission System Operators for Electricity (ENTSO-E), while information on hourly forecasted generation from the intermittent renewables wind and solar (for each country) comes from the commercial data provider Eurowind GmbH. To control for cross-border congestion, we have collected hourly data on the import and export interconnectors available for trade (Available Transfer Capacities, ATC). This comes partly from the respective transmission system operators (TSOs) TransnetBW, 50 Hertz, Amprion (all three Germany), TenneT (Germany and the Netherlands), RTE (France), Energienet.dk (Denmark), CEPS (Czech Republic), PSE (Poland) and SwissGrid (Switzerland) and partly—due to changes in the responsibility for the allocation of interconnector capacity—from the Auction Offices CAO (for the Central Western Europe (CWE) area) and CASC (for the Central Eastern Europe (CEE) area). We use this to calculate daily import and export congestion indices, defined as the percentage of hours of a day over which the respective interconnectors were congested. Congestion prevents further trans-border trade that would otherwise continue until prices equalize and arbitrage possibilities

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[10] German and Austrian markets are fully integrated and therefore considered as a single market. Although Germany and Belgium are neighbouring countries, they currently are connected only through loop flows. However, according to Jauréguy-Naudin (2012), the TSOs of the two countries were considering the construction of an HVDC line with a capacity of 1000 MW. Furthermore, the existing (small) interconnector between Germany and Sweden is excluded due to data unavailability. Spain's interconnector with France is very limited.

vanish. As common variables, we include monthly European hard coal and natural gas price indices (base year 2005)—obtained from the Federal Statistical Office of Germany—and an EU ETS carbon emission price index (which was downloaded from Thomson Reuters Datastream).

Since load is likely endogenous, we instrument for it in our econometric analysis below. Our instruments for load are the current level of area-specific air temperatures in each country and their squares. Data on daily air temperatures in many cities in Germany and its neighbouring countries have been downloaded from Mathematica 9 (WeatherData and CityData). This data constitutes the basis for the calculation of population-weighted temperature indices.[11] The descriptive statistics for the resulting data set are reported in Table 1 and subsequently discussed selectively.

Table 1 shows some variation in the spot prices for electricity (expressed in Euro per MWh) between Germany and its neighbouring countries. As electricity is a homogeneous good, not trivial price differences indicate imperfectly integrated markets. In fact, spot prices are found in a range from Denmark (West) with an average price of 43.59 € up to Switzerland showing an average price of 52.27 €, i.e., an about 19.9%higher price.[12] A summary on average absolute price differences between the German-Austrian market and its neighbours is presented in Table 2, showing that the price difference is highest with Poland and lowest with the Netherlands and Czech Republic.

Information on renewables in the form of electricity production through either wind or solar is limited to countries with an appreciable share of renewables.[13] In particular solar is largely confined to a subset. Germany-Austria has by far the largest amount in both categories (4.97 GWh and 2.20 GWh), but small compared to total load.

Germany has by far the largest import and export capacities available for trade (ATC) in both categories. However, surprisingly because Germany is a net exporter, interconnector capacities for export are roughly half the size of import capacities. This is mainly because interconnector capacity from Switzerland to Germany is around five times higher than in the opposite direction. The derived import and export congestion indices—defined as the proportion of hours of the day at which the respective interconnectors were congested (thereby hindering further trans-border trade)—reveal that, in terms of imports, congestion appears to be a minor issue for the Netherlands (10%) while the opposite is true for Poland (48%). For exports, the spectrum includes 13% in the case of Denmark (West) and 62% for Switzerland.[14]

The congestion variables for Germany incorporate all congestions and cross-border capacities Germany shares with its interconnected neighbouring countries,

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[11] To avoid problems of quadratic transformation, the temperature indices are converted into degrees Fahrenheit, which always take positive values within our data. *Source*: Authors' calculations.

[12] Dickey-Fuller and Phillips-Perron tests clearly reject the null hypothesis of a unit root in the underlying price and load series; test statistics reported in Table A.2 in the online Appendix.

[13] Unfortunately, we do not observe Scandinavian reservoir levels which would also be relevant, in particular we would expect them to have an effect on electricity prices in Denmark. Nordpool publishes such data but only since 2015.

[14] We define congestion as the existence of a price difference between Germany and a certain neighbour in a certain hour.

Table 1 Descriptive statistics

	DE-AT	FR	NL	CH	DKE	DKW	PL	CZ	ES
Dependent variable									
Price (Euro/MWh)	46.09	47.81	48.49	52.27	47.97	43.59	45.87	45.58	44.76
	(16.00)	(25.46)	(13.75)	(17.34)	(35.23)	(15.03)	(9.93)	(15.91)	(15.53)
Individual variables									
Load (GWh)	62.31	56.21	12.51	5.66	1.55	2.30	16.49	7.20	29.20
	(11.43)	(12.92)	(2.39)	(1.10)	(0.35)	(0.52)	(2.79)	(1.25)	(3.13)
Wind (GWh)	4.97	1.10	0.53	–	0.89	0.89	0.31	0.03	4.25
	(4.12)	(0.95)	(0.47)	–	(0.78)	(0.78)	(0.30)	(0.03)	(2.37)
Solar (GWh)	2.20	0.27	–	–	–	–	–	0.23	0.77
	(3.61)	(0.45)	–	–	–	–	–	(0.40)	(0.28)
Import ATC (GW)	12.10	2.19	2.51	4.34	0.52	0.90	0.53	1.11	–
	(1.03)	(0.58)	(0.38)	(0.24)	(0.16)	(0.44)	(0.29)	(0.53)	
Export ATC (GW)	6.75	2.61	2.12	0.69	0.50	0.81	0.24	2.21	–
	(0.90)	(0.60)	(0.39)	(0.23)	(0.20)	(0.28)	(0.24)	(0.46)	
Import Congestion Index (0–1)	0.22	0.18	0.10	0.23	0.29	0.32	0.48	0.42	–
	(0.25)	(0.38)	(0.31)	(0.42)	(0.45)	(0.47)	(0.50)	(0.49)	
Export Congestion Index (0–1)	0.31	0.28	0.30	0.62	0.23	0.13	0.43	0.38	–
	(0.29)	(0.45)	(0.46)	(0.48)	(0.42)	(0.34)	(0.50)	(0.49)	
Common variables									
Gas Price Index	164.85	164.85	164.85	164.85	164.85	164.85	164.85	164.85	164.85
	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)
Coal Price Index	174.66	174.66	174.66	174.66	174.66	174.66	174.66	174.66	174.66
	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)

(continued)

Table 1 (continued)

	DE-AT	FR	NL	CH	DKE	DKW	PL	CZ	ES
Carbon Price Index	8.40	8.40	8.40	8.40	8.40	8.40	8.40	8.40	8.40
	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)
Instrument for load									
Temperature (°C)	9.83	12.71	10.30	10.30	8.32	8.59	8.83	9.41	17.16
	(8.00)	(6.61)	(6.26)	(7.61)	(7.03)	(7.20)	(8.99)	(8.62)	(6.40)

Notes: Descriptive statistics show means and standard deviations (in parentheses) of the utilized data; “Import” and “Export” variables always represent flow direction from the German perspective. For countries with missing values for solar and/or wind generation, the respective values were too low to be measured. For countries outside the European Currency Union daily exchange rates from Thomson Reuters are used for the transformation. Though Spain has no interconnection with Germany we include it for the application of a placebo test. *Source*: Authors’ calculations

Table 2 Average price differences between the German-Austrian market and its interconnected neighbours

Germany-Austria and	FR	NL	CH	DKE	DKW	PL	CZ
Average price difference in Euro/MWh	4.9	3.3	8.2	8.3	5.2	9.5	4.2
Standard deviation of price differences	20.4	8.2	10.4	31.4	8.6	10.7	5.5

Source: Authors' calculations

while for Germany's neighbours only their interconnection with Germany is relevant. They are constructed as follows: first, we interact the hourly congestion dummies in each country with the transfer capacity available for trade in the respective hour (ATC) and build the hourly sum over all countries. Second, we divide the hourly sum by the sum of ATC's in all countries in the respective hours (also including all ATC from uncongested), formally

$$Cong_t^{imp(exp)} = \frac{\sum_{i,t}^{K} DC_{i,t}^{imp(exp)} \times ATC_{i,t}^{imp(exp)}}{\sum_{i,t}^{K} ATC_{i,t}^{imp(exp)}}$$

with $Cong_t^{imp(exp)}$ representing the congestion variable for Germany for imports and exports, respectively. $DC_{i,t}^{imp(exp)}$ is a dummy indicating the existence of import (export) congestions in country *i* and hour *t* while $ATC_{i,t}^{imp(exp)}$ describes the respective import (export) *ATC*s between neighbour *i* and Germany in hour *t*. Finally, we compute daily averages from the hourly import and export congestion indices.

However, our congestion index variables cannot be interpreted as direct measures for the degrees of integration. For example, price differences can occur even if interconnector capacity is not fully utilized (depending on the allocation mode of interconnector capacity). Particularly in explicit auctions—as used between Germany and Switzerland, Poland and the Czech Republic—expectation errors of electricity traders can cause such price differences (despite some interconnector capacity being available).[15] Furthermore, congestion price differences can differ significantly between countries. For instance, when congested, the price difference between Germany and the Czech Republic is, on average, 5.13 €/MWh, while it is, on average, 15.96 €/MWh when the interconnector between Denmark East and Germany is congested because Danish electricity generation (and thus its price) is much more intermittent due to their high wind share of generation reflected in Fig. 2. Also, as was shown above in Table 2, while the interconnectors between Germany and the Czech Republic are congested in 42% (imports) and 38% (exports) of the time, the average absolute price difference between Czech and German-Austrian prices is only 4.2 €/MWh) while it is on average 4.9 €/MWh between France and Germany where interconnectors suffer less frequent congestion (18% import and

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[15] In our empirical analysis below, we exclude such cases by assuming a state of congestion only as soon as the price difference exceeds 1 €/MWh. Our results are found to be also robust to price differences of 1%, 5% and 10% or 0 €/MWh.

28% export congestions). The same is observed when price correlations are considered. For instance, French prices are less correlated with German-Austrian prices than Czech prices despite the fact that Czech interconnectors with Germany are more frequently congested than French interconnectors with Germany.[16] Thus, average of price differences and the frequency of congestions are not necessarily related.

We further assume interconnector capacities are exogenous in the short run and unaffected by the nuclear outage. Interconnector capacity expansion is a long-term matter and variation in the transfer capacity is based on technical calculations according to the ENTSO-E method, reflecting the physical realities of the grid adjusted (varying) security margin. We also assume national fuel-fired generation capacities are exogenous and unaffected in the short-term and generation from renewables is particularly exogenous due to fixed feed-in tariffs and quota obligations provided through national renewable support schemes.[17] Nevertheless, we instrument for the congestion variables later due to simultaneity with prices.

4.2 Empirical Approach

Our empirical approach is subdivided into two parts. First, we estimate the impact of unilateral German policy decisions—the nuclear phase-out and the recent expansion of renewables resulting from national support schemes—on prices in its (interconnected) neighbouring countries and the German-Austrian market itself. As both the nuclear phase-out and generation from renewables are exogenous, our study has a quasi-experimental character. Second, we additionally control for the (price-increasing or price-decreasing) impact of congested interconnectors through the inclusion of import and export congestion variables, respectively, to estimate the impact the nuclear phase-out and renewable generation would have had on the neighbouring markets absent cross-border congestions. The degree of market integration is then calculated as the ratio between the estimated policy decisions' impacts before and after controlling for congestion. For instance, if we find that Germany's nuclear phase-out has caused a 10% price increase in one country before controlling for congestion and 20% afterwards, we measure the degree of integration between these two markets as 50%.

Technically, we estimate the following two equations (with all non-indicator variables in logs)

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[16] See Table A.1 in the online Appendix.

[17] While most countries use some form of feed-in tariff, some decided to introduce quota obligations, tenders, exemption from energy taxes or instruments as part of which a fraction of the revenue of general energy taxes finance renewable energy sources. See Ragwitz et al. (2012) for a detailed comparison of European renewable support schemes.

$$P_{i,t} = \alpha_1 + \beta_{1i} L_{i,t} + \delta_{1i} NPO_{i,t} + \vartheta_{1i} RE_{i,t} + \boldsymbol{\varphi}_{1i} \boldsymbol{X}_{i,t} + \boldsymbol{\sigma}_{1i} \boldsymbol{Cal}_{i,t} + \varepsilon_{1\ i,t} \tag{1}$$

and

$$P_{i,t} = \alpha_2 + \beta_{2i} L_{i,t} + \delta_{2i} NPO_{i,t} + \vartheta_{2i} RE_{i,t} + \boldsymbol{\varphi}_{2i} \boldsymbol{X}_{i,t} + \boldsymbol{\sigma}_{2i} \boldsymbol{Cal}_{i,t} + \boldsymbol{\theta}_i \boldsymbol{Cong}_{i,t} + \varepsilon_{2\ i,t} \tag{2}$$

where $\varepsilon_{1\ i,t} \sim N\left(0, \sigma^2_{\varepsilon_1}\right)$, $\varepsilon_{2\ i,t} \sim N\left(0, \sigma^2_{\varepsilon_2}\right)$, with $P_{i,t}$ denoting average wholesale prices in country i at day t, $L_{i,t}$ representing load and $\boldsymbol{X}_{i,t}$ being a vector of covariates including input price indices for hard coal and natural gas, carbon emission prices at time t and forecasted generation from wind and solar in country i at time t. $\boldsymbol{Cal}$ is a vector of calendar variables including weekday and month dummies. *NPO* and *RE* are our variables of interest representing, respectively, the supply-side shock dummy variable resulting from the German nuclear phase-out (*NPO*) in March 2011 and the electricity generation from intermittent renewables (*RE*) wind and solar promoted by national support schemes. Equation (2) only differs from equation (1) by including the additional ***Cong*** vector containing the variables indicating the daily percentage of hourly import and export congestions. From the parameters estimated in (1) and (2) the degree of integration (*DoI*) can be formalized as $DoI^{NPO}_{i \neq DE\_AT} = \frac{\delta_{1i}}{\delta_{2i}}$ and $DoI^{RE}_{i \neq DE\_AT} = \frac{\vartheta_{1i}}{\vartheta_{2i}}$, respectively, for Germany's neighbours and $DoI^{NPO}_{DE\_AT} = \frac{\delta_{2i}}{\delta_{1i}}$ and $DoI^{RE}_{i = DE\_AT} = \frac{\vartheta_{2i}}{\vartheta_{1i}}$, respectively, for the German-Austrian market.

Given this basic set-up, correct identification of the impact of Germany's energy policy reforms on neighbouring countries crucially depends on an appropriate modelling of the supply curve. Generally, endogeneity is likely to play a role due to the joint causality between electricity demand and supply.[18] We therefore use instrumental variables (IV) and employ national temperatures and their squares as excluded instruments.[19] Hence, we have the following first stage regressions:

$$L_{i,t} = \alpha_3 + \boldsymbol{\beta}_{3i} \boldsymbol{Instr}_{i,t} + \delta_{2i} NPO_{i,t} + \vartheta_{2i} RE_{i,t} + \boldsymbol{\varphi}_{2i} \boldsymbol{X}_{i,t} + \boldsymbol{\sigma}_{2i} \boldsymbol{Cal}_{i,t} + v_{i,t} \tag{3}$$

The Kleibergen-Paap Wald F-statistic always exceeds the weak identification critical values from Stock-Yogo (see Table A.4–Table A.11 in the Supplementary Material) which suggests that load is identified by the instruments. In the estimations which control for cross-border congestions we also instrument for the congestion

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[18] Although demand is often considered as perfectly inelastic, recent demand-side management activities aim at reacting to price signals and therefore question the assumption of perfectly inelastic demand. The Durbin-Wu-Hausman test for endogeneity will support this view later.

[19] Temperature can be thought as an instrument because hotter temperatures increase electricity demand through the need for cooling, while colder temperatures require more electricity for heating purposes. The squared term captures a possible nonlinear relation.

variables due to simultaneity with price. We use heteroscedasticity based instruments as suggested by Lewbel (2012).

We believe that endogeneity is not a major issue for the remaining variables since coal, gas and emission certificates are traded supra-nationally and Germany only accounts for a fraction of the trade.

As the shape of the supply curve is unknown and likely non-linear, we model it as flexibly as possible by estimating a semiparametric partially linear regression model with Robinson's (1988) double residual method. Consider a partially linear regression model of the type

$$P_i = \theta_0 + \boldsymbol{Z}_i\boldsymbol{\theta} + m(L_i) + \eta_i \quad \textit{with} \quad i = 1, \ldots, N \tag{4}$$

where P_{i} represents spot prices in country *i*, $\boldsymbol{Z}_i$ is the row vector of control variables, and θ_0 is the intercept term. Variable L_i represents load and enters in a non-linear way according to a non-binding function *m*. η_i is the disturbance, assumed to have $E(\eta | L) = 0$, an assumption which we will later relax. The double residual methodology applies conditional expectation on both sides leading to

$$E(P_i|L_i) = \theta_0 + E(\boldsymbol{Z}_i|L_i)\boldsymbol{\theta} + m(L_i) \quad \textit{with} \quad i = 1, \ldots, N \tag{5}$$

and through subtracting equation (5) from equation (4), we get

$$P_i - E(P_i|L_i) = (\boldsymbol{Z}_i - E(\boldsymbol{Z}_i|L_i))\boldsymbol{\theta} + \eta_i \quad \textit{with} \quad i = 1, \ldots, N \tag{6}$$

where $P_i - E(P_i | L_i) = \eta_{1i}$ and $Z_{ki} - E(Z_{ki} | L_i) = \eta_{2ki}$ reflect the residuals with $k = 1, \ldots, K$ indexing the control variables entering the model parametrically. In a two-step procedure we first obtain estimates of the conditional expectations $E_n(P_i | L_i)$ and $E_n(\boldsymbol{Z}_i | L_i)$ from some non-parametric (kernel) estimations of the form $P_i = m_P(L_i) + \eta_{1i}$ and $Z_{ki} = m_{Z_k}(L_i) + \eta_{2k}$. After inserting the estimated conditional expectations in equation (6), we estimate the parameter vector $\boldsymbol{\theta}$ consistently without explicitly modelling $m(L_{\mathrm{i}})$ by a standard non-intercept ordinary least square (OLS) regression and we obtain $\hat{\theta} = \left(\hat{\eta}_2' \hat{\eta}_2\right)^{-1}\left(\hat{\eta}_2' \hat{\eta}_1\right)$. Finally, $m(L)$ is estimated by regressing $\left(P - \boldsymbol{Z}\hat{\boldsymbol{\theta}}\right)$ on L non-parametrically.

The endogenous nature of the non-parametrically modelled variable L, however, yields $E(\eta | L) \neq 0$. As standard IV-techniques such as two-stage least squares (2SLS) and general method of moments (GMM) are not feasible in the context of endogenous variables that are non-linear in parameters, we apply a two-step residual inclusion control function and add the residuals ν fitted in the linear prediction of L in equation (3) as control function to the semi-parametric regression model stated in equation (6) (see Blundell and Powell 2004; Imbens and Wooldridge 2009).

We next apply Hardle and Mammen's (1993) specification test to assess whether the nonparametric fit can be approximated by a parametric polynomial alternative. The specification test is based on squared deviations between parametric and non-parametric regressions. Critical values are obtained, simulating by wild bootstrap. The test results justify a polynomial adjustment for load of order 2 for all countries (see Table A.2 in the Supplementary Materials). This information on the supply curve enables us, in a second step, to correctly model the shape of the supply curve parametrically through the inclusion of squared load as a second endogenous variable and, in addition, to consider correlation between the disturbances across countries through the estimation of system-wide two-step GMM. We instrument for the square of load with $\hat{L}^2$, the square of the first stage prediction of load from equation (3). When the congestion variables are included we use Lewbel's (2012) heteroscedasticity based instruments for them.

4.3 Estimation Results

Table 3 presents our main estimation results. Columns (1) and (2) report the results of the semiparametric estimation by Robinson's (1988) method—excluding or including congestions—and columns (3) and (4) report the results of the parametric estimation by two-step IV GMM (see Table A.4–Table A.11 in the Suppementary Materials for the respective first-stage test statistics). Note that—in columns (1) and (2)—the reported coefficients stem from 16 separate regressions (which we do not report for the sake of clarity and brevity[20]).

Comparing regression results between the Robinson estimator and two-step system IV GMM, Table 3 shows very similar results in terms of both direction and size of the coefficients across the two estimation approaches.[21] We therefore concentrate our further discussion on the results from the system GMM model shown in columns (3) and (4) which, for the reasons given above, arguably generates more efficient estimates.

Comparing the estimation results excluding congestion controls, the expected positive impact of the nuclear phase-out on spot price is confirmed for all neighbouring countries except Poland, while the promotion of renewables in Germany pushed prices down. The nuclear phase-out caused large price increases in Germany-Austria itself (16%), but also in its neighbouring countries France (18%), DK East (25%) and the Czech Republic (20%). The promotion of renewables, however, led to price decreases particularly in Germany-Austria (0.21% for a 1% increase in generation from renewables), Denmark West (0.15%) and the Czech Republic (0.16%).

Turning to the results of our estimations including congestion controls, a comparison of the respective values in columns (3) and (4) shows diverging results for coefficient magnitudes while their direction and general significance remain unaffected (again excepting Poland). In particular, we find (absolute) size reductions for both unilateral decisions—nuclear phase-out and promotion of renewables—for

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[20] The full set of regression tables is available in Tables A.4–A.11 of the Supplementary Materials.

[21] The only, minor, exception is Poland.

Table 3 Estimation results

	(1)		(2)		(3)		(4)	
	Semiparametric IV		Semiparametric IV		System IV GMM		System IV GMM	
Congestion Control	NO		YES		NO		YES	
DE-AT								
Phase-out	0.152^{***}	(0.031)	0.123^{***}	(0.038)	0.158^{***}	(0.032)	0.110^{***}	(0.003)
Renewables	-0.185^{***}	(0.014)	-0.164^{***}	(0.026)	-0.206^{***}	(0.020)	-0.199^{***}	(0.001)
FR								
Phase-out	0.125^{***}	(0.046)	0.177^{***}	(0.042)	0.179^{***}	(0.039)	0.232^{***}	(0.003)
Renewables	-0.083^{***}	(0.014)	-0.136^{***}	(0.021)	-0.072^{***}	(0.014)	-0.117^{***}	(0.002)
NL								
Phase-out	0.084^{**}	(0.034)	0.084^{**}	(0.038)	0.075^{**}	(0.035)	0.092^{**}	(0.002)
Renewables	-0.061^{***}	(0.013)	-0.076^{***}	(0.014)	-0.067^{***}	(0.016)	-0.085^{***}	(0.001)
CH								
Phase-out	0.092^{**}	(0.035)	0.096^{**}	(0.036)	0.080^{**}	(0.035)	0.131^{***}	(0.003)
Renewables	-0.096^{***}	(0.021)	-0.116^{***}	(0.028)	-0.088^{***}	(0.016)	-0.132^{***}	(0.001)
DK East								
Phase-out	0.235^{***}	(0.052)	0.291^{***}	(0.052)	0.248^{***}	(0.051)	0.276^{***}	(0.004)
Renewables	-0.101^{***}	(0.032)	-0.134^{***}	(0.024)	-0.090^{***}	(0.027)	-0.123^{***}	(0.002)
DK West								
Phase-out	0.110^{**}	(0.049)	0.153^{**}	(0.059)	0.089^{**}	(0.048)	0.102^{***}	(0.004)
Renewables	-0.157^{***}	(0.033)	-0.174^{***}	(0.026)	-0.150^{***}	(0.021)	-0.160^{***}	(0.002)
PL								
Phase-out	-0.007	(0.037)	0.067^{**}	(0.036)	-0.001	(0.034)	0.066^{***}	(0.002)
Renewables	-0.013	(0.009)	-0.068^{***}	(0.014)	-0.022^{**}	(0.010)	-0.068^{***}	(0.001)

CZ								
Phase-out	0.186^{***}	(0.040)	0.176^{***}	(0.041)	0.198^{***}	(0.034)	0.180^{***}	(0.003)
Renewables	-0.161^{***}	(0.037)	-0.196^{***}	(0.048)	-0.159^{***}	(0.023)	-0.179^{***}	(0.002)
#Obs.	1095		1095		1095		1095	

Note: The table reports the main results from 16 separate semiparametric regressions in columns (1) and (2) and two regressions using system wide IV-GMM in columns (3) and (4). Parameters of phase-out are transformed through (exp(β[Phase-Out] $-$ 1) to render them interpretable as percentage impact on prices. Standard errors in parentheses; block bootstrap S.E. on weekly blocks for models (1) and (2), Newey-West HAC S.E. for models (3) and (4); the semiparametric models (1) and (2) are estimated by the Robinson (1988) double residual estimator with load modelled non-parametrically; models (3) and (4) estimated through two-step GMM with correlated disturbances; in models (1) and (2) we control for endogeneity of load through the inclusion of the first stage residual as control function; instruments for the first stage regressions in all equations are temperatures in the respective countries and their squares; in models (3) and (4) squares of the first stage predictions of load are included as additional instruments to approximate the nonparametric fit through a quadratic function of load; in columns (2) and (4) we control for congestions and instrument for the congestion variables using heteroscedasticity based instruments as suggested by Lewbel (2012); all covariates from equations (1) and (2) are included in the estimated models though not reported for the sake of clarity and brevity; the full set of regression tables is available in the online Appendix (Tables A.4–A.11); significance levels: * $0.05 \leq p < 0.1$, ** $0.01 \leq p < 0.05$, *** $p < 0.01$. *Source*: Authors' calculations

Table 4 Degree of market integration

	DE-AT (%)	FR (%)	NL (%)	CH (%)	DKE (%)	DKW (%)	PL (%)	CZ (%)
Phase-out Index	70	77	82	61	90	87	0	100
Renewable Index	97	62	79	67	73	94	32	89
Mean	83	69	80	64	82	91	16	94

Note: Degree of market integration is the ratio of the coefficients from the GMM estimates in Table 3 (capped at 100%). In the case of Germany, the coefficient of phase-out and renewables, respectively from column (4) is divided by the respective coefficient from column (3). For all neighbouring countries, the index is computed as the ratio of (3) to (4). Mean refers to the mean value of both market integration indices. Coefficients insignificant at 10% are considered as zero. *Source*: Authors' calculations

Germany-Austria indicating that a higher degree of market integration would have reduced the impact of German reforms on the German-Austrian market itself. Most expected neighbouring countries exhibit larger (absolute) coefficients when controlling for congestions—the impact of Germany's reforms would have been higher if the markets were fully integrated.

Although the discussion of the empirical results of the two separate stages—excluding and including congestion controls—has provided valuable insights on the price effects of the two unilateral energy policy decisions of Germany, we ultimately want to use these results to derive a measure of the degree of market integration. In Table 4, we present calculations of the ratio of the estimated policy decisions' impacts before and after controlling for congestions.[22]

As Table 4 shows, the degree of market integration is mostly similar regardless of whether we measure it for the nuclear phase-out or renewable generation—the cross-country correlation[23] between both types of measures is around +0.81. We would expect it to be less than 100%, because the impact is felt differently across countries due to their different circumstances.

Based on the mean of both measures, the Czech market (94%) is almost fully integrated with the German-Austrian market with the Netherlands and Denmark somewhat less so. By contrast, the lowest degree of market integration is found for Poland (16%).[24] The mean value of 83% for the German-Austrian market can be interpreted as the average degree of integration of all neighbouring markets with the German-Austrian market.

In order to provide confidence that the effects we uncover are indeed associated with interconnection, we employed the same estimation strategy for the Spanish electricity market as a placebo test. Spain was chosen because it is not directly

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[22] The computed integration indices are surprisingly similar to the price correlations reported in Table A.1 in the online Appendix.

[23] The coefficient measures the correlation between values in the first and the second row of Table 4.

[24] The huge difference in terms of market integration across countries—for instance between Poland and the Czech Republic—might be surprising against the background of similar mean prices for Poland and the Czech Republic. However, the mean price similarity is rather coincidental as can be seen in Figure A.1 in the online Appendix.

connected with Germany but is similar in generation patterns. The indirect connection via France is also relatively low. Thus, we assume that the impact of the German policy reforms on the Spanish market should be negligible and finding significant effects of the German policies on the Spanish market would suggest either that the Spanish market is more strongly connected with the German-Austrian market or—which would be worse—that our estimates of the policy effects reflect coincidental developments rather than the policy effects. However, the GMM estimates show both German policy measures had insignificant impacts on Spanish electricity prices. Details are given in Table A.12 (in the Supplementary Material).

We close the section by providing some ballpark figures on the monetary effects of the two German unilateral policy reforms on its neighbours. Table 5 quantifies the yearly windfall negative and positive impacts on consumers as well as the respective (country-specific) net effects of the two unilateral reforms.[25]

Based on the estimated coefficients from column 3 in Table 3 and mean values of the control variables we compute hypothetical counterfactual spot prices for each country. Define the (k by c) matrix $\bar{\mathbf{X}}_1$ where the column vectors are the mean values for all k variables for country $i, \quad i = 1,\ldots, c$ and the (k x c) matrix $\hat{\mathbf{B}}$ as the matrix of coefficients on each of these variables country by country. Then $\bar{\mathbf{p}}_1 = diag\left(\hat{\mathbf{B}}'\bar{\mathbf{X}}_1\right)$ is the (c x 1) vector of estimated mean prices for each country. Further define $\bar{\mathbf{X}}_0$ as the version of $\bar{\mathbf{X}}_1$ where, counterfactually, the German renewables increases had not happened, and $\hat{\mathbf{B}}_0$ as the version of $\hat{\mathbf{B}}$ if the German nuclear outage had not happened.[26] Then calculate $\bar{\mathbf{p}}_A = diag\left(\hat{\mathbf{B}}_0{}'\bar{\mathbf{X}}_1\right), \bar{\mathbf{p}}_B = diag\left(\hat{\mathbf{B}}_1{}'\bar{\mathbf{X}}_0\right)$ and $\bar{\mathbf{p}}_C = diag\left(\hat{\mathbf{B}}_0{}'\bar{\mathbf{X}}_0\right)$. Define $\mathbf{q}$ as the (c by 1) vector of annual loads for each country. The (transposed) values $\left(\bar{\mathbf{p}}_A - \bar{\mathbf{p}}_C\right)'\mathbf{q}$, $\left(\bar{\mathbf{p}}_B - \bar{\mathbf{p}}_C\right)'\mathbf{q}$ and $\left(\bar{\mathbf{p}}_A - \bar{\mathbf{p}}_B\right)'\mathbf{q}$ are listed in Table 5. The output reveals substantial resulting monetary effects. Concentrating on the respective net impact figures, only Polish consumers—i.e., from the least integrated country included into our study—realize a small net annual gain of about 0.05 billion € in the period analysed. Furthermore, we find that while the smaller (rather well integrated) countries in our data set face small (in absolute terms) net impacts,

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[25] In discussing the results, where we write of "consumers" we mean both domestic and industrial consumers, unless we qualify the word. Of note, the costs for German consumers are even higher than computed in Table 5 as German consumers also have to pay a so called "Renewable Energy Surcharge" (in German: EEG-Umlage).

[26] The slight differences in the estimates for Germany found here compared to those reported in Grossi et al. (2017)—focusing on Germany only—result from several differences in the data set and the estimation method. First, data availability issues constrain us here to the observation period from 2010 to 2012, while Grossi et al. (2017) include the year 2009 in their analysis. Second, our estimations here are run on daily data while Grossi et al. (2017) go down to hourly level. Third, we were unable to include river-related control variables here as they were not consistently available for all countries. Fourth, we instrument for cross-border congestion while Grossi et al. (2017) argue it is exogenous in the case of Germany. Last, the estimation approach followed here is system-wide GMM including all neighbouring countries while Grossi et al. (2017) estimate the effects for Germany in isolation.

Table 5 Yearly windfall impacts on consumers from unilateral German energy policies

in € billion/year	DE	AT	FR	NL	CH	DKE	DKW	PL	CZ
Higher costs from the phase-out	−3.23	−0.44	−3.73	−0.38	−0.19	−0.14	−0.07	0.00	−0.51
Lower costs from increased German renewables	1.60	0.22	0.58	0.13	0.08	0.02	0.05	0.06	0.16
Net impact of unilateral policies on consumers as a whole	−1.63	−0.22	−3.15	−0.25	−0.11	−0.12	−0.02	0.06	−0.35

Source: Authors' calculations

consumers in the two large countries France and Germany experienced substantial negative net impacts, notably of 3.15 billion € for France.[27] One explanation for this is that French domestic consumers use electricity for heating purposes in winter when it benefits less from Germany's renewable expansion due to lower solar generation.[28] For instance in 2012 hourly solar generation in summer was on average 4.96 GWh compared to 0.89 GWh in winter. In sum, the nuclear phase-out generated extra costs of about 8.7 billion € per year for consumers in Germany and its neighbours, while the promotion of renewables caused windfall savings of about 2.9 billion € yearly in the analysed post-phase-out period.[29]

With respect to the impact of the policy reforms on electricity producers in neighbouring countries the opposite is true: the German nuclear phase-out increased electricity prices and thus producer rents in neighbouring countries whilst the increase of German renewables reduced foreign prices and thus rents for neighbouring producers. As electricity demand is rather inelastic—and deadweight losses thus rather small—these policy reforms present potentially similarly sized windfall costs and savings between foreign consumers and producers. However, it should be noted that—beyond these eventually mostly distributional impacts—unilateral policies are also likely to have an impact on the investment risks for foreign electricity producers, if they are unexpected.

In sum, the main result of our empirical analysis is that because most central continental European countries are already highly integrated, unilateral policy

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[27] We treat Germany and Austria as separate markets here (with an average actual hourly load of 54.85 GWh for Germany and 7.46 GWh for Austria in our observation period).

[28] Figure A.2 in the online Appendix illustrates the different load patterns for Germany/Austria and France.

[29] Technically, we measure industry benefits from renewables in Germany here because German customers have to pay the costs resulting from the difference between the fixed feed-in tariffs for renewables and the wholesale price, the so-called EEG surcharge, as a part of their electricity bills. Industry, by contrast, is mainly exempted from paying the EEG surcharge.

reforms have significant impacts on consumers in neighbouring countries.[30] By demonstrating the substantial impact unilateral policy reforms—particularly in large countries—can have on neighbouring countries in an internal market for electricity, our results raise the question of policy implications.

5 Conclusions and Policy Implications

Harmonization and integration of separate national energy markets to an interconnected internal European market is a top priority for the European Commission; something we do not question here. However, as energy policy largely remains subject to national sovereignty, greater integration means unilateral national policies can impact interconnected markets. We investigated the impact of two distinct national energy reforms in Germany—the phase-out of nuclear power plants after the Fukushima incident and the expansion of renewables promoted by fixed feed-in tariffs and unlimited priority feed-in—on neighbouring countries. The phase-out triggered price increases of up to 25%in neighbouring countries whilst the renewable energy support schemes caused a price decrease of up to 0.16% for each percent of additional generation from German renewables. Also, in most cases the impact of both policy reforms would have been little higher in the absence of cross-border congestion. The range of the identified market integration spans from 16 to 94%. However, the 16% for Poland is an outlier since the second lowest value in terms of market integration is 64% (Switzerland). Hence, the goal of a single internal electricity market with all the benefits such as an increased (and cheaper) security of supply or a power smoothing and the resulting smoothing in prices is not far away.

From a policy perspective, the externalities of unilateral decision in one Member State imposed on the others demonstrates the importance of a coordinated approach of European energy policy in a largely well-integrated European electricity market. This does not necessarily suggest that all strategic decisions are made on the European level. However, it requires significant monitoring in order that their costs and implications are discussed.

Considering the cost implications in more depth, separation into economy-specific, industry-specific and market-specific perspectives appears feasible. First, from an economy-specific (macroeconomic) perspective, increasing electricity prices act like a VAT increase on the one hand and decrease available income for consumers on the other, thereby having direct impacts on real purchasing power, hence, on industry production and economic growth in both the originating and the neighbouring countries (see also, e.g., Hamilton 1983; Mork 1989; Kilian 2008; Berk and Yetkiner 2014; or Cox et al. 2014).

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[30] Analogously, unilateral policy reforms made in a small country likely will have no impact, even in the implementing country.

Second, from an industry-specific perspective, intensive energy-using firms face substantial absolute increases in costs causing a competitive disadvantage with respect to foreign competitors (either less integrated—and therefore less affected by the policy reform—or located outside Europe). If the respective price increases are permanent and substantial, unilateral policy reforms in one country may cause firm closures—and even changes in industry structures—in neighbouring countries, triggering potentially substantial knock-on effects from social and labour market perspectives for example.

Third, from a market-specific perspective, unilateral policy reforms have a direct impact on investment decisions in neighbouring countries. For example, the NPV calculation of an investor considering construction of a French power plant will depend on expectations regarding neighbours' unilateral policy reforms, creating uncertainty in addition to positive or negative price effects. Anticipated lower prices—caused by the promotion of renewables—will reduce the incentives to invest into construction of a new plant. In any case, unilateral policy reforms will therefore impact upon the future structure of the European electricity industry. Potentially, the induced insecurity with respect to expected return on investments can cause under-investment and thereby negative externalities on supply security.

Against this background, it appears to be important to design new rules—or alternatively enforce existing rules—on what types of decisions need debate or even decision at the Community level before they are actually implemented. Although in this article, we only provide evidence on the importance of this issue for the case of (parts of) the European electricity market, the main allocative and distributive impacts of unilateral national decisions are likely to apply to other policy areas in the European Union as well—thus suggesting the development and implementation of a comprehensive general approach that reflects the strategic importance of the issue for the future development of the European Union.

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Supplementary Material

Supplementary material is available online at the OUP website. This comprises an online Appendix and the data replication files. The data used in the paper are bought from commercial providers and are not publicly available. Independent researchers, however, can be given access to the data required to run the do-file at ZEW subject to the signing of a data usage contract. The usage contract allows independent researchers to access the data, but not to take the data set away from ZEW.

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Creating Convergence of National Energy Policies by Increased Cooperation: EU Energy Governance and Its Impact on the German Energy Transition

Michèle Knodt and Marc Ringel

Abstract Our contribution reviews the impact of the European energy governance regulation on the German energy transition (*Energiewende*). The German energy transition has largely been conceived as a national project of system transformation. Based on a close policy fit, the national strategy is aligned to European targets and policies, but still has only taken account of the European dimension of this transformation when this was beneficial for the implementation of national policies. The European governance regulation included in the European Commission's 'winter package' in turn introduces a new type of stronger interaction and coordination which we define as a 'horizontal joint decision-making+' type governance. This governance relies on a densely meshed reporting structure leading to a structured dialogue between several groups of stakeholders within a member state, among member states and finally between each member state and the European Commission. The primary effects of this new governance type can be judged to be closely aligned to national German policy-setting, which explains the strong German support for the new governance proposal. However, the secondary effects of horizontal governance legislation and sectoral policies might lead to a stronger influence on German energy policies by both neighbouring EU member states and the European Commission.

1 Introduction

The German *Energiewende* has largely been conceived as a national project of system transformation (International Energy Agency 2013; Hake et al. 2015). It can be argued that the European dimension of this transformation has only been

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M. Knodt (✉)
TU Darmstadt, Darmstadt, Germany
e-mail: Knodt@pg.tu-darmstadt.de

M. Ringel
Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen, Geislingen, Germany

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taken into account in instances where this dimension was beneficial for the implementation of national policies, notably in the domains of climate, renewable energy and—at a later point in time—energy efficiency objectives. Contrary to this, the governance of the Energy Union (EU) seeks to align national policies and foster closer co-operation between EU member states in order to create convergence between them. The type of governance the EU proposes in its latest legislative proposal is that of horizontal joint decision-making+, which we class as a type between horizontal joint decision-making and more joint decision-making types with more coercive character. It combines the allocation of authority at the national level in horizontal coordination with limited authority from a higher level and represents a new type of joint decision-making which is perceived in a positive way by German authorities.

This raises the question of the impact of EU energy governance on the policy coordination and policy formulation within Germany. We will show that policy formulation and coordination so far has largely taken place within the country and mostly reached out to the European level for reporting and implementation of the European Directives and Regulations. The primary effects of the EU governance regulation can be expected to have only minor effects on the German energy transition. However, if they are working jointly with sectoral policies, the influence of the European level and indeed of neighbouring member states on energy policy formulation and implementation in Germany might increase considerably.

The contribution starts with the development of the horizontal joint decision-making+ type of governance in comparison with other types of multi-level governance. Different types of decision-making within EUs energy governance is shortly presented in Sect. 2. Section 3 describes in detail the horizontal joint decision-making+ type of governance in European energy governance with special reference to the newest legislation act, the “Clean and Secure Energy for All Europeans” of November 2016. The impact this type of governance has on Germany’s energy governance is analyzed in detail in Sect. 4. Section 5 sums up our analysis and discusses policy implications for the further development of the German energy transition.

2 Multi-level Coordination in European Energy Governance

The scope of energy governance in the European multi-level system encompasses the European right through to the local level in the different member states and is linked to different governing strategies. Governance can be described as comprising interactive arrangements which rest on different “forms of interaction between actors who have conflicting objectives, but who are sufficiently independent of each other so that neither can impose a solution on the other” (Schmitter 2002). In those governance arrangements different kinds of actors, non-state actors and state actors, from different levels cooperate. These forms of liberal governance arrangements aim at “solving societal problems or creating societal opportunities” (Kooiman 2002; Müller et al. 2015). Thus, the term governance refers to how people make decisions, share power and competences, organize responsibility and assure accountability within a given structure of formal and informal institutions (Kemmerzell and Knodt 2017).

The range of governance modes spans from supranational hierarchical governance, as witnessed in ordinary legislation which allows for the adoption of legally binding decisions, up to forms of soft governance which attempt to steer without legally binding acts. The mode of governance is very much determined by the distribution of competences within a given policy field or subfield.

Within multi-level governance systems the literature distinguishes mainly three types of governance (cf. Stephenson 2013) from centralized to decentralized governance. Between the extremities of centralized governance in the sense of a concentrated power and authority at the higher level on the one side and regulatory autonomy at the decentralized levels on the other, authors have distinguished several forms of joint decision-making. According to Scharpf, in the system of joint decision-making or ‘*Politikverflechtung*’, different levels are working together in an institutionalized negotiation system in which both parts jointly take decisions. Both parts are forced to work together and negotiate successfully to achieve their common objectives and aims. Thus, the high costs of centralized governance with regard to information, learning capacities of political systems as well as incongruence of level-encompassing problems and level-specific decision-making structures might be overcome. In those systems, coercion may occur through constitutional law or de facto necessities, which do not allow unilateral decisions or might bring negative consequences. Scharpf differentiates three forms of joint decision-making according to the origin of the actors and the distribution of decision-making power: hierarchical joint decision-making, the ‘*Verbundsystem*’ as a joint decision-making system, as well as horizontal joint decision making. We will add a fourth type of joint decision-making—the horizontal joint decision-making+ type—which is placed between the ‘*Verbundsystem*’ and the horizontal joint decision-making type as shown in Table 1 and explained in the following.

Scharpf provided only a rudimentary elaboration of hierarchical joint decision-making as a category. Within this category, the upper level, in Scharpf’s work Federal Government, is endowed with competence to decide but consults the states for information in order to achieve its aims. The ‘*Verbundsystem*’ (joint system) represents the well-known type of coordination in Scharpf’s theory. Coordination takes place by negotiation and consent where co-decision between two levels of authority is required. Horizontal joint decision-making aims at a coordination mechanism where only decentralized authorities work together without the Federal Government to come to joint decisions. Also bi-lateral or multilateral forms of cooperation on a horizontal level are possible (Scharpf et al. 1976; Scharpf 2006). This category fails to capture possibilities of horizontal joint decision-making where the higher level tries to steer the horizontal coordination of the lower levels through more or less authority. This is why we introduce a fourth type of joint decision-making. The horizontal joint decision-making+ type, which combines the allocation

Table 1 Types of governance in multi-level systems

	Centralized governance/ hierarchy	Joint decision-making				Decentralized governance
		Hierarchical joint decision-making	‘*Verbund-system*’	Horizontal joint decision-making+	Horizontal joint decision-making	
Levels involved	European	European and national	European and national	European and national	European and national	National
Distribution of authority	European	European (unilateral)	European and national	National with very limited European authority	National	National

Source: Based on Scharpf et al. (1976), Scharpf (2006), extended, own illustration of authority at the national level in horizontal coordination with limited authority from a higher level. This could be described as soft governance with clear elements of hierarchical steering by an actor to which this kind of authority is not legally attributed. Table 1 shows all types of governance in a multi-level system. It may be applied to the EU energy policy case by defining the levels involved in the governance system as European and national.

The literature on Europeanization provides us with insights into how European policy impacts on national policies from a top-down perspective. In order to explain Europeanization a whole variety of explanation is given. Besides factors such veto points within a country’s institutional structure as well as opportunity structures or norm entrepreneurs (Börzel and Risse 2003) there is one classical factor to explain Europeanization processes. The ‘goodness-of-fit’ hypothesis (Cowles et al. 2001) argues that it makes a difference whether the national policy resembles the European policy specifications or whether it does not fit at all. It is assumed that the poorer the fit in the sense of compatibility between European and domestic processes, policies, and institutions, the higher the adaptational pressure and thus the impact (Börzel and Risse 2003). In situations with a very good fit, Europe is absorbed with no need to change. An extreme misfit on the other side will lead to inertia. Based cost-benefit calculation the member state will not initiate changes. Everything between these extremes will activate change. The misfit argument was criticized for overlooking national factors such as elections and interests as well as European actors like the Commission and the fact that misfit is socially constructed. Nevertheless, the case of Germany shows that institutional fit, and in many cases also policy fit, leads to a moderate impact of European policies, as can be observed in energy policy, too.

For most of the period of European integration, the European Community and later the European Union carried out energy measures through secondary legislation without regulating energy policy in the primary law. Only since the entry into force of the Lisbon Treaty in 2009 is energy policy included in the treaties as a policy area in its own right. However, this step was not accompanied by any substantial transfer of competences to the supranational level. The treaty, for the first time, delivered a contractual basis for energy policy within the European treaties. Article 194 TFEU defines common objectives and an energy policy at the EU level addressing, among others, the internal energy market as well as energy efficiency as areas of EU competence. Article 194 (2) states that decisions concerning the energy mix of the member states are not affected. Thus, member states continue to determine the conditions for exploiting their energy resources, their choice of energy sources and the general structure of their energy supply (Knodt 2018). In addition, a distinctive feature of energy policy is its ‘nexus quality’: Energy as a policy field is an almost classical cross-cutting issue, standing in close connection especially to climate policies, but also to development cooperation, research and innovation policies, trade policies, and foreign and security policies (Müller et al. 2015). Thus, governance of energy policy can also be carried out e.g. referring to the competences of the EU in the policy field of climate change (referring to Articles 191 and 192 TFEU).

A limited transfer of competences, the lack of competences in respect to policy mix as well as its cross-cutting nature allow the EU to apply different modes of governance in energy policy. In the field of climate change we can find issues predominantly organized in a centralized and hierarchical way, as in the case of the Emissions Trading Scheme (ETS), which only partly provides for national exemptions. In the same field we can observe heterogeneous instruments in non-ETS sectors as well as parallel autonomous decentral national climate change policies. The same picture can be found in the case of the internal market for energy and transnational transmission grids. In the latter case, the requirements for the unbundling of transmission grids are binding and central hierarchical governance is used, whereas national transmission grid planning is mostly decentralized (Gawel et al. 2014). The issue of security of energy supply also is organized in a mainly decentralized way, apart from the obligation to maintain minimum stocks of crude oil and/or petroleum products already imposed on member states since the 1960s (Knodt 2018), which is decided in a hierarchical way. Issues such as the promotion of renewable energy sources and energy efficiency are partly hierarchically steered through hierarchical joint decision-making, in the sense of a common EU goal (in some cases with fixed national contributions), and national requirements and partly left to horizontal decentral joint coordination in the form of soft governance mechanisms.

The impact on national as well as subnational energy policy varies according to the types of joint decision-making in multilevel governance. Depending on the issue, the impact within EU policies should harmonize or converge national policy on a given policy issue. Whereas hierarchical governance has a strong and direct impact on national/subnational energy policy in member states, the impact through the type of '*Verbundsystem*' as well as horizontal joint decision-making is less clear. Especially the latter is discussed in the literature on integration as a mode of soft governance. The most prominent example of such a soft mode of governance is the Open Method of Coordination (OMC) which was introduced as a new mode of governance in 2000 within the Lisbon Strategy (European Council 2000). It rests on the principles of voluntarism, participation and convergence and works with the mechanisms of iteration, setting of standards and learning processes. It uses instruments such as benchmarking, peer-review and best practice. Thus, the OMC rests on a system of coordination through central goal setting and decentral implementation responsibilities (Schmid and Kull 2005). It has to be seen as the horizontal joint decision-making type of multi-level governance. The OMC varies from harder (e.g. Stability and Growth Pact) to softer (e.g. education policy) open modes of coordination (Linsenmann and Meyer 2002). The OMC was criticized for not provoking profound learning, for its convergence and integration effects (Hartlapp 2009), and for encouraging limited and selected learning instead (Linsenmann and Meyer 2002). Mostly, the setting up of national plans as well as their implementation follow national paths (Knodt and Stoiber 2010). It seems that this kind of soft governance which is not set up in the shadow of hierarchy and lacks the potential to impose sanctions does not function well. Without the potential to impose sanctions EU recommendations are apparently not perceived as orders to act accordingly by member states (Linsenmann and Meyer 2002; Knodt and Ringel 2017).

Nevertheless, EU energy governance in the areas of renewable energies and energy efficiency is not easily classified as horizontal joint decision-making. This labelling would neglect the role of the European Commission, which has to be seen as less than that of a hierarchical authority but more than one of pure horizontal decentral coordination. At the same time, it is not a '*Verbundsystem*' type because it lacks the necessary degree of coercion. The following chapter will show that it has to be characterized as a 'horizontal joint decision-making+' type.

3 'Horizontal Joint Decision-Making+' in European Energy Governance

The first regulation to draw on OMC in sustainable energy policies was the Energy Service Directive of 2006 (European Commission 2006). The Directive asks member states to deliver a dedicated amount of energy savings by introducing or up-grading energy efficiency policy measures. Both the measures and their impact need to be documented in tri-annual reports, so-called National Energy Efficiency Action Plans (NEEAPs). The member states have to submit their NEEAPs to the Commission Services by 20 June 2011, 2014, 2017 and 2020. In turn, the Commission will get back to the member states with suggestions on how to improve their policies (Coalition for Energy Savings 2013). Whereas the NEEAPs were originally conceived as reporting documents, it became soon obvious that they could be used for a structured dialogue on energy efficiency policies between the EC and the member states. Recognizing this fact, the Commission subsequently asked the member states to consider the NEEAPs as "policy tools" (Suomi 2015). This philosophy was subsequently adopted by the Energy Efficiency Directive (EED), presently under revision (Sajn 2017). In the framework of the EED, a template for the NEEAPs has been established. This allows a structured dialogue on the various provisions between the Commission and the member states. Adding to the formal coordination structures in the energy efficiency field, informal coordination was added through the means of the Concerted Actions on the EED and the Buildings Directive (Energy Performance of Buildings Directive, EPBD) which enable biannual informal meetings between member states and the Commission Services to discuss implementation issues on the Directives and enable peer learning (CA EED 2013; CA EPBD 2012). The Directive on Renewable Energy Sources (RES) largely adopted the same policy instruments (here named NREAPs—National Renewable Energy Action Plans, and "progress reports" thereof) and processes (a Concerted Action on RES) (see Barreto-Gómez et al. 2016; Karlsson-Vinkhuyzen et al. 2012; Knodt and Ringel 2017: 4f).

With the emergence of the Energy Union, it became clear that the originally political coordination of energy and climate change policies in the realm of the European Semester would need to be followed up by a legal proposal to codify the coordination structures in a post-2020 perspective in line with the newly proposed climate and energy objectives for 2030 (Meyer-Ohlendorf 2015; Nesbit 2014; Turner et al. 2015; Turner 2015). This new coordination structure is also supposed to mend a number of weaknesses which the EC addressed in its impact assessment (European Commission 2016c). The assessment mentions that member states often fail to consider the cross-national dimensions of their energy policies and EU-wide targets when planning national measures. It also finds that reporting obligations are often not coordinated under the existing energy and climate acquis. Similar considerations apply to Commission monitoring obligations, whose frequency varies greatly. The European Union follows this approach and enriches it with its newest legislation act, the "Clean and Secure Energy for All Europeans" or so-called "winter package" of November 2016 (European Commission 2016a). With its winter package the EU is attempting to overcome the dilemma that the European Council could only agree on EU-wide policy targets in the areas of renewable energies and energy efficiency which are not accompanied by binding national targets, thus leaving the EC without the power to control the process. Included in the proposals is a "Regulation for the Governance of the Energy Union" in which the EC details governance structures and processes for the years post-2020 (European Commission 2016b). The Governance Regulation aligns the post-2020 energy and climate change reporting. The proposed Energy Union governance can be divided into (a) strategic and long-term energy and climate planning and (b) short-term reporting (Ringel and Knodt 2018).

Ad a) *Long-term energy and climate planning* comprises two strategic elements and processes: The *integrated National Energy and Climate Plan* (iNECP) with a 10-year perspective on the one hand and the long-term *Low Emissions Strategies* with a 50-year perspective on the other.

The iNECPs cover a 10-year period from 2021 until 2030 and subsequent 10-year periods. The standardized reporting in its main part comprises the following sections (Governance Regulation, articles 3-13): (1) An overview of the process to establish the iNECP, including a mandatory consultation of national stakeholders and potentially other member states in terms of regional energy and climate cooperation; (2) a description of national objectives, targets and contributions in each of the five dimensions of the Energy Union; (3) a section for including and identifying possibilities for regional cooperation across member states; (4) an account of national policies and measures foreseen to meet these objectives; (5) an analysis of the status quo on the five dimensions of the Energy Union in the given member state, including projections as to whether the existing policies and measures are likely to achieve the national objectives and (6) an assessment of the impacts of planned polices and their impact on meeting the objectives (Sajn 2017).

The second pillar of strategic climate policy planning is the *Low Emission Strategies (LES)* covering a 50-year horizon and integrating the EU's and member states' commitments towards achieving the greenhouse gas reductions of 80%–95% by 2050 in accordance with the objectives of the Paris Agreement. In parallel, climate action is seen as key to contributing to green growth of the EU and its member states (Ringel et al. 2016) in terms of economic transformation, jobs and growth. Along this integrated line of thought, the LES cover: (1) Total greenhouse gas emissions reductions including removals by sinks; (2) emissions reductions per sector (electricity, industry, transport, buildings) as well as agriculture including land-use, land-use change and forestry (LULUCF); (3) expected progress towards a low greenhouse gas emissions economy (green economy), including strategies for related research, development and innovation; (4) links to other national long-term planning or strategies (Knodt and Ringel 2017).

Ad b) *Short-term reporting* on the part of the member states and the EC complements the long-term strategic planning. Reporting is foreseen in two forms: (i) biennial progress reports and (ii) annual reporting. Both reporting strands are organized as structured dialogue, like in the case of the strategy documents. After member states have handed in their reports, the Commission Services will issue recommendations on the reports which in turn need to be taken into account by the member states when issuing an update of the respective report. Annual reporting further substantiates the governance cycle. Largely, the annual reports are to provide information to comply with the international commitments of the EU and its member states. The information to be provided in the reports mainly relates to greenhouse gas and LULUCF inventories as stipulated by the UNFCCC reporting (article 23). Following the planning and reporting obligations of the member states, the governance regulation lays out the details for tracking progress with the Energy Union by the EC. As described above, the role of the European level is twofold: (a) to assess the progress member states have made in terms of reaching the energy and climate objectives and policies; (b) to provide feedback and take corrective action in case of insufficient ambition (Knodt and Ringel 2017: 7f).

In order to assess the member states' efforts, the Governance Regulation empowers the EC to take corrective action first in case of inconsistencies, insufficient progress towards the overarching Energy Union objectives and insufficient ambition of the iNECPs—this refers to *ambition gaps* within the national planning. As there are no binding national targets formulated to achieve the European targets, the reference framework of the Commission to evaluate the ambition for each member state remains unclear in the regulation proposal. Second, the Commission should assess the implementation of the national policies and measures according to national objectives laid down in the national plans—this refers to *implementation or delivery gaps*. Both gaps will be answered by the Commission in the form of recommendations to the member states. The recommendations were introduced with a binding character, as in case of a recommendation by the Commission to the respective member state, the latter "*shall* take the *utmost* account of any recommendations from the Commission when finalising their integrated national energy and climate plan" (Article 28; European Commission 2016b, italics by the authors). As a consequence of the recommendation, a member state is obliged to set out within 1 year how the recommendation is taken into account or provide justifications in case it deviates from the recommendation. Member states are attributed with the burden of proof. In case of non-compliance with the recommendation, an automatic gap-filling mechanism would be triggered; adjusting inter alia the share of renewable energies in both the heating and cooling sectors as well as in the transport sector and/or contributing financially towards developing renewable energy projects

(Wilson 2017). Member states in this case can contribute to an EU financing instrument for renewables. Likewise, the short-fall of ambition would directly empower the EC to take corrective action by means of revising the Energy Efficiency Directive, the EPBD, the product efficiency regulations (eco-design) or energy efficiency measures in the transport sector (see Article 27 Governance Regulation) by delegated acts/tertiary law (Ringel and Knodt 2018).

To sum up the description of the main governance type in the renewable energy and energy efficiency field, there are the following characteristics which would be important to justify its characterization as a fourth type of joint decision-making—a 'horizontal joint decision-making+' type:

- Assessment of the national aims, strategies and measures according to their ambition by the Commission—referring to 'ambition gaps';
- Assessment of the national measures according to their goal achievement/delivery by the Commission—referring to 'implementation/delivery gaps';
- Recommendations regarding the gaps for each member state has to be of utmost concern
- Burden of proof on member state's side;
- Potential corrective actions—delegated acts/financial contributions to a fund to be set up;
- Introducing bilateral horizontal coordination parallel to the joint horizontal coordination;
- Linking European and national efforts to an international agreement such as the Paris agreement to put pressure on and legitimize climate goals by internationally agreed norms.

The question is: What kind of impact will this type of governance have on the national energy transition by trying to create convergence at the European level between the national energy policies of the member states? This question will be analyzed below with reference to energy governance in Germany, a federation with its own multi-level system.

4 Impact of European Energy Governance on the German *Energiewende*

4.1 The German Energy Concept and Monitoring

The German energy transition has been widely discussed in literature (see for example: Hake et al. 2015; Lehr and Lutz 2016; Schmid et al. 2016). Its main pillars are the deployment of renewable energies throughout all uses (electricity, heating and cooling, transportation), the increase of energy efficiency (both in terms of enhanced efficiency on the supply side and a reduction of consumption in all uses, notably buildings and transport) (Federal Ministry of Economic Affairs and Energy

Table 2 Target framework of the German energy transition strategy

	2015	2020	2030	2040	2050
Greenhouse gas emissions (relative to 1990)	−27.2%	At least −40%[a]	At least −55%	At least −70%	−80% to −95%[a]
Renewable energy shares					
Of gross final energy consumption	14.9%	18%[a]	30%[a]	45%	60%
Of gross final energy consumption	13.2%	14%			
Of heat consumption	13.2%	14%			
In the transport sector	5.2%	10%[a]			
Energy consumption reduction (compared to 2008)					
Primary energy consumption	−7.6%	−20%[a]			−50%[a]
Gross electricity consumption	−4.0%	−10%			−25%
Heat consumption in buildings	−11.1%				−80%
Final energy consumption in transport (relative to 2005)	1.3%	−10%			−40%

Source: Authors' own compilation; based on the Federal Ministry of Economic Affairs and Energy 2015, own illustration

[a] Target values which are coordinated with or derived from European legislation

2010a, b). Table 2 presents an overview of the overall target framework put forward by the German government (Federal Ministry of Economic Affairs and Energy 2015). Lastly, sector coupling, market integration and network development are needed to ensure that the new energy system meets the overall energy policy goals (supply security, competitive energy prices and sustainable energy provision and use) as well as the ambitious 2050 decarbonization targets. As can be seen from the comparison with the European energy and climate targets, the national targets and indicators largely fit with the European level and thus exert only low adaptational pressure. Overall, the *Energiewende* target framework coincides with the European targets and spells out additional national targets, as is the case with the sectorial targets for renewable energy and energy efficiency.

The federal government has underpinned the individual policies with some 70 indicators in total. These are used to track the progress in the individual fields of the energy transition. A scientific monitoring through energy experts and statisticians is performed annually and leads to analytical "Monitoring Reports". Every second year, the monitoring is stepped up by projections and analyses of future trends (Federal Ministry of Economic Affairs and Energy 2015).

Until recently, Germany, like almost all EU member states, has relied on national support policies for both renewable energies and energy efficiency in the framework of the respective EU directives and regulations. The German government has been keen to differentiate between the task of reporting under EU legislation and its national monitoring and policy programmes. To give an example: In the field of energy efficiency this has led to the establishment of a National Action Plan on Energy Efficiency (NAPE) with dedicated analysis and policy measures, whereas the European format of National Energy Efficiency Action Plans (NEEAPs) established by the Energy Efficiency Directive for 2014, 2017 and 2020 are seen as pure reporting tools (Ringel et al. 2016).

Within the federal structures of Germany, all levels of government (federal government, regional federal states and the local level) have law-making or regulatory competences in the various fields of energy policy (International Energy Agency 2013). Partly these are shared competences and partly they are exclusive. The latter is the case where laws or regulations only relate to the federal state territory. It emerges that regional governments can and do add regulations on top of federal government energy policy. By now, the energy system transformation strategy (*Energiewende*) as presented in the federal government's energy concept (Federal Ministry of Economic Affairs and Energy 2010a, b) is supplemented by state-level energy strategies and laws. These define supplementary targets and strategies at the regional level.

Germany's energy policy coordination mechanisms are regularly assessed in the country reviews of the International Energy Agency. The latest review for Germany took place in 2013 (International Energy Agency 2013). In addition, several EU projects (Schlomann et al. 2014; Ringel 2016) track the country's energy policy development. However, in most cases these international and European reviews limit themselves to taking stock of the formal vertical coordination existing in Germany.

Formal vertical coordination is performed largely in the legislative context set up by the shared competences for energy policy of the federal level and the federal states. Most laws on energy policy action require the approval of the *Bundesrat*, the second chamber of parliament, where the federal states are represented. In the process towards adoption of legislation the respective committee on 'economy and energy' or 'environment and climate change' will ensure that the 16 federal state ministries in charge of energy issues provide the federal government with their comments and amendments for the given legislation and finally cast a vote on the legal proposal from the federal government. In this process the federal states will assure that the monetary and human resources needed to transpose a federal law will be granted to them by the federal level or will negotiate compensations in case the transposition is to be financed by their own resources.

In case local governments are impacted by this legislation, the federal state ministries will in turn ensure coordination with the respective associations of local level representatives (e.g. the German Association of Towns and Cities—*Deutscher Städtetag*). As this process of law-making is common to most fields of policy, it is an established procedure. It proves to be relatively slow in comparison to centralized states but highly effective in terms of coordination and consultation (Ifo-Institut 2013; Rave 2012; Ringel 2016).

The national, regional and local levels interact to a certain extent within horizontal coordination. Formal horizontal coordination of energy policies is assured both on the national and on the federal state level. The coordination mechanism works along the same principle for both levels of government. Once the lead ministry drafts a legislation (including legislation to set up a financial support programme), it is obliged to install an inter-ministerial working group (*Interministerielle Arbeitsgruppe*, IMA) with all ministries concerned to ensure policy coherence.

Within each federal state's administration, this horizontal coordination process is used as well. The lead ministry for energy efficiency will inform all concerned ministries on planned legislative legal proposals and consolidate a common position for the government of the state (*Ministerium für Inneres und Kommunales des Landes Nordrhein-Westphalens* 2014). In addition, the federal states interact in thematic working groups, the so-called "inter-ministerials". Typically, settings like the meeting of the "ministers of economics" or the "ministers of the environment" would assemble the 16 responsible regional ministers. At the local level a direct horizontal coordination is organized only in an indirect manner. Here, the coordination and dissemination of information is usually done by the associations representing cities and communities. Systematic direct contacts between mayors or local actors via dedicated instruments such as an information sharing platform do not exist at present.

In order to estimate the impact of the newest initiatives at the European level on German energy policy, we will take a look at the German perception of the proposed new governance structure and processes in comparison with selected other member states' views.

4.2 German Perception of the Proposed New Governance Structure and Processes in Comparison

In designing the Governance Regulation proposal, the Commission carried out an internal and an external review of existing governance frameworks within the individual policy action fields. Internally the review was conducted by means of a so-called "fitness check" exercise in the framework of the Commission's Better Regulation Initiative (REFIT; European Commission 2016d). Externally, a stakeholder consultation was undertaken, assembling 103 submissions including 15 member states. The information obtained was then overhauled in an impact assessment of the 2020 governance structures for climate and energy policies (European Commission 2016c). Of the 15 member state submissions, 11 made their submissions publicly available, with some member states not answering some of the questions posed. The Commission notes that "old" and "new" member states (meaning those that joined with the 2004 enlargement) differ in their way of answering. With many planning and reporting obligations in place in the "old" member states, "new" member states have additional costs of compliance in this respect (European Commission 2016c).

Along with some of the "older" member state representatives, Germany's response to the stakeholder consultation is clearly very much in favor of the new legislation. Asked how the stakeholder would rate the following aspects of reporting obligations in EU legislation, the "old" member states all find it very important to have the possibility to monitor performance and trends (and put in place corrective measures if the results are lagging behind) (see Figs. 1 and 2).

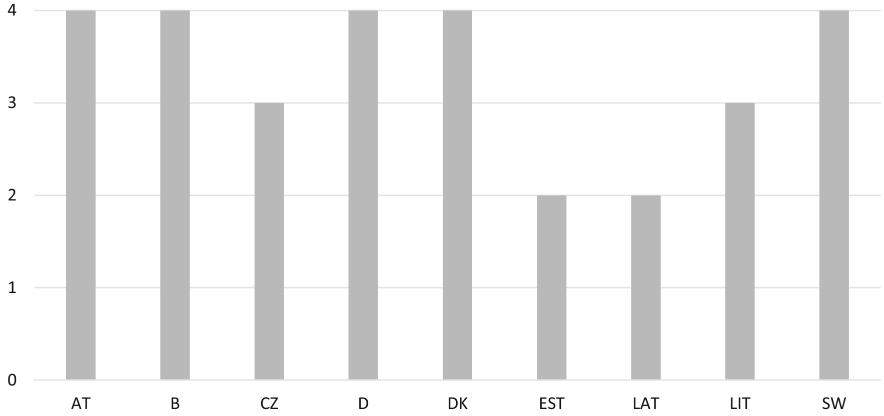

Fig. 1 Perception of the possibility to monitor with corrective measures (rating: 4 = very important to 1 = not important). Source: data made available by the European Commission (2016c), own illustration

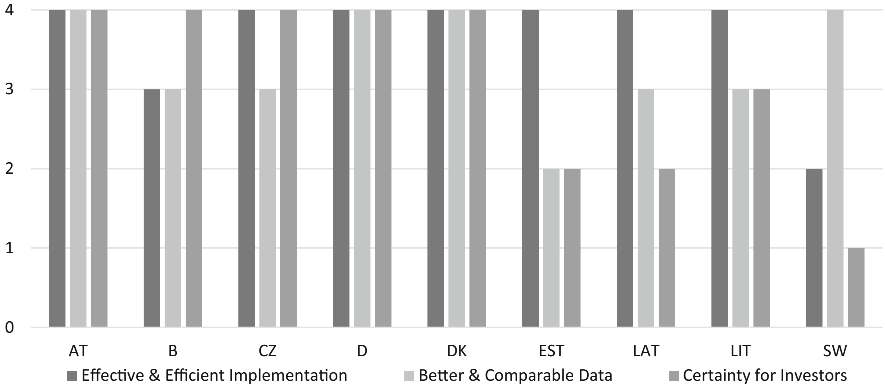

Fig. 2 Perception of the advantages of the New Governance Structure. Source: data made available by the European Commission (2016c), own illustration

There are three arguments put forward referring to advantages of the new governance structure in the stakeholder consultation. Firstly, that the new governance structure and processes will help to implement the EU legislation in the energy and climate field more effectively and efficiently. In this respect we see a very equal assessment of the new system making energy and climate policy more effective and efficient. Especially the efficiency argument seems to be shared by all stakeholders in the sample with the exception of Sweden (and to a certain extent Belgium), being more sceptical of the importance of the changes for better implementation. The impact assessment analysis of the EC (European Commission 2016c) presents a comparison of administrative costs for both the present reporting structure and the revised governance proposals. According to this analysis, the present reporting and monitoring exercises are likely to lead to cumulative costs for the member states of €222.7 million for the years 2021–2030 (Ringel and Knodt 2018).

When it comes to the possibility of delegated legislation, the German government is critical of the Commission's suggestion. State Secretary Baake of the Federal Ministry of Economic Affairs and Energy stressed after the Energy Ministers' Council meeting March 2017 how important it is to include European citizens in decision-making processes and therefore to leave all important decisions to the Council and the Parliament.[1]

Secondly, the stakeholders were asked to rate the possibility of getting better comparability of data from different member states to enable a better informed evaluation. The "old" member states, with the exception of Belgium, perceive the idea of getting better comparability of data as very important. Whereas the "new" member states are not as convinced and only rate the possibility of getting better data as important. Estonia even rates this point as less important.

Thirdly, the argument was put forward that the new governance structure would increase certainty for investors across all EU member states, stimulating economic growth, research, innovation, and competitiveness. The "old" member states, with the exception of Sweden, perceives this argument as very important. This argument is put forward by the German government in its assessment of the Governance Regulation proposal. "In the view of the German Government, such a governance system is necessary in order for the common goals to be achieved in practice. It is similar to the system of long-term planning and monitoring that is employed in Germany, and creates more investment and planning reliability for companies and other market players".[2]

All in all, the stakeholders were confronted explicitly with the comparison between setting up a new legislative act or following a non-binding approach. In detail, stakeholders were asked if a new legislative act covering planning & reporting on the 2030 Energy and Climate framework can ensure consistency and reduce administrative burden, and if a non-legislative approach can assure the streamlining of planning & reporting and provide the necessary certainty for investors (see Table 3).

Interestingly, scepticism about a new legislative act can also be found in the "new" member states, in the Czech Republic and Latvia, but also in Austria. Asked if the necessary streamlining of the procedures should be done in the current system, with a new legislative act or a non-legislative approach, Austria, the Czech Republic and Cyprus even voted for the current system, while Latvia again preferred a non-legislative approach. All the other stakeholders seem to be convinced that overall a new legislative act is the best way to implement the aims and goals of the Energy Union.

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[1] http://www.bmwi-energiewende.de/EWD/Redaktion/EN/Newsletter/2017/04/Meldung/topthema.html (Accessed 20.9.2017).

[2] http://www.bmwi-energiewende.de/EWD/Redaktion/EN/Newsletter/2017/04/Meldung/topthema.html (Accessed 20.9.2017).

Table 3 Country stakeholder feedback on type of legislative proposal

	New Legislative Act		Non-Legislative Approach	
	Yes	No	Yes	No
AT		■		■
BE	■			■
CZ		■	■	
DE	■			■
DK	■			■
EST	■			■
LAT		■	■	
LIT	■			■
SW	■			■

Source: Data made available by the European Commission (2016c), own illustration

4.3 Impact of European Governance Regulations on National Policies

With the provisions foreseen in the (draft) governance regulation, a direct influence on the governance of the energy transition does not seem likely. Rather at a first glance, the monitoring structure and horizontal joint decision-making set up in the regulation complements the German governance structure and offers the possibility of aligning the energy policies vertically from local to European level. For this alignment, the reporting cycle of national reports would need to be rearranged to match the European monitoring system. A strong argument for this would be cost-effectiveness and developing synergies between both reporting systems.

On closer examination, however, taking into account the horizontal joint decision-making+ detected within the governance regulation proposal—in combination with sectoral legislation in the field of electricity markets, renewable energies and energy efficiency—might turn out to influence national policy making to a greater extent. Given the strong linking of the individual proposals, the technically complex nature of the individual regulations and lastly the amendments presently discussed in the Council and the European Parliament, it remains hard to judge the precise future impact on German sustainable energy policies at this point in time. Table 4 sums up the impacts of the main winter package legislations on key fields of the German energy transition identified so far.

Besides the obvious primary impacts of EU legislation on national sectoral policies—as for example in the case of renewable energies support, the secondary impacts of governance provisions combined with (minor) primary legislative provisions or the combined functioning of two primary legislative acts can prove to be challenging for the national energy policy field:

As one aspect, as laid down above, the (draft) regulation asks that member states "*shall*" take the feedback of the European Commission into account. Such a reaction to Commission feedback has lately had a demonstrably material effect in the field of renewable energies where the German support system based on feed-in tariffs has

Table 4 Key legislative components of the winter package and their impact on the German energy transition strategy

Regulation	Aim	Key content of the proposal	Tentative impact on the German energy transition
Governance regulation (COM/2016/0759 final/2)	Coordinate member states' climate and energy policies	• Integrated National Energy and Climate Plans (iNECPs) • Low Emission Strategies (LES) • Iterative consultation and coordination process, including citizen dialogue and coordination with neighbouring member states	• Strengthening of participatory processes and citizens initiatives (e.g. renewable energy cooperatives, *Mieterstrom* contracting models) • Stronger influence of Commission on national planning • Stronger influence of neighbouring countries on energy policies through peer review mechanism of iNECPs)
Revised Renewable Energy Directive (RED II; COM/2016/0767 final/2)	• EU target of minimum 27% RES share by 2030 • Global leadership as RES producer	• No national targets; review in 2023 • Consecutive opening of national support schemes for European producers and across borders (10%–15%) • Limit of priority dispatch of RES to small installations; cut-off of RES as last resort • Gradual reduction of first-generation biofuel cap • Enhanced sustainability standards for solid biomass • Set-up of EU fund for supporting RES deployment	• Change in support scheme methodology (already adopted with switch to defining feed-in tariffs through auctioning system). • Limit of priority dispatch might hurt big RES installations, especially off-shore wind • Use of solid biomass will need to comply with EU standards
Revised Energy Efficiency Directive (EED; COM/2016/0761 final)	Binding EU energy efficiency target of 30% by 2030	• Energy efficiency first principle: Energy savings need to be implemented before increasing generation capacity • Prolongation of supplier obligation or alternative schemes to deliver 1.5% final energy savings per annum to 2030	• Support for national 'energy efficiency first' logic • Potential pressure on government to switch to supplier obligations over time

(continued)

Table 4 (continued)

Regulation	Aim	Key content of the proposal	Tentative impact on the German energy transition
Revised Energy Performance of Buildings Directive (EPBD; COM/2016/0765 final)	Full decarbonization of EU building stock by 2050	• Tightened rules for building refurbishment; in parts simplification of existing regulation • Push for building automatization • Obligation to install charging stations for electric vehicles with major renovations or new built non-residential buildings	• Regulations overall in line with energy transition strategy of the German government • E-charging stations' obligation might foster further integration of transport and building strategies
Internal Electricity Market Directive & subsequent Regulations (COM/2016/0864 final/2; COM/2016/0861 final/2; COM/2016/0863 final/2)	By 2030 electricity market design should be fit to work on ~50% RES	• New wholesale market design: shorter lifetime of products; abolition of price caps • Empowerment of consumers (abolition of price regulations; possibility of demand side management; easier and quicker switching of supplier; new energy models)	• Further empowerment of consumer might lead to yet stronger push for decentralization • Support for energy cooperatives; support for enhanced energy cooperation between citizens (barter trade of electricity in enhanced prosumer models)
Regulation on risk-preparedness in the electricity sector (COM/2016/0862 final)	Stronger flexibilization and integration of national power markets	• Cut-off of RES limited to 5% maximum • Limit of carbon emissions (550 g CO_2/KWh) of power plants set aside for capacity mechanisms • Enhanced regulation of system adequacy on regional level (harmonized method for measuring supply security) • Re-design of price zones for areas with structural capacity problems • Enhanced cooperation of regulators within ACER and on regional level (ROCs)	• Stronger coordination with neighbouring member states/regions needed • Installation of regional trans-border cooperations and integration into national coordination. • Role of coal-fired power plants in the capacity mechanisms to be revisited

Source: Authors' own compilation based on: Becker Büttner Held (2017), Buck (2016), Umpfenbach (2017), European Parliament (2017), own illustration now shifted to a tendering system which foresees a minimum share of capacities in cross-border auctions following European legislation.

Likewise, it can be expected that EU commenting on insufficient transposition of legislation can serve as a trigger to stepped-up national policies. By and large this has been the case with the implementation of the Energy Efficiency Directive, where Commission feedback incited the German government to step up efforts for the set-up of alternative measures to implement Article 7 (energy efficiency obligations or alternative measures) of the directive (European Commission 2016e; Crisp 2015; Dehmer 2014). It has also acted as a trigger to renounce on the originally strong separation between energy efficiency monitoring for EU purposes (in the triannual National Energy Efficiency Action Plans stipulated by the EED, the plans due in 2014, 2017, 2020) and the set-up of national programmes and measures in the 2015 National Action Plan on Energy Efficiency (NAPE) (Ringel et al. 2016).

Lastly, the potentially strongest influence of the combination of the EU governance regulation and sectoral legislation can be expected in electricity market regulation. The governance regulation explicitly asks in Article 11 that plans and measures are regionally coordinated and peer-reviewed by other member states. Given that the Commission did not further spell out the content and realm of this coordination and peer-review it remains too early to judge the impact this might have on German energy policies.

However, this provision might strongly urge German energy policy makers to take neighbouring energy policy considerations and worries into account when formulating and designing their national policies. Such considerations would most likely be complaints of renewable energy ring flows out of Germany into the Netherlands, Poland or the Czech Republic; it might be considerations from Austria on the de-coupling of the presently integrated Germany/Austria/Luxemburg electricity market; and it might be formally established comments from Poland and some Baltic states on the German project to expand the NordStream gas pipeline. As the governance mechanism asks for a formal participation in the peer-review, the European Commission would be quasi-obliged to take these views and comments into account when formulating its recommendations, triggering respective comments from the European side as well. And these recommendations would have a quasi-binding nature, with the governance regulation stipulating that they “shall” be taken into account, equalling a “must” condition in European legal terms.

5 Conclusion

Summing up the above discussion, we could show that the European Commission is enhancing its present policy coordination with the governance mechanisms foreseen in the winter package. It introduces a new type of stronger interaction and coordination which we defined as a ‘horizontal joint decision-making+’ type governance. This governance relies on a densely meshed reporting structure leading to a structured dialogue between several groups of stakeholders within a member state, among member states and finally between the member state and the European Commission.

For the time being the present governance and target framework does not pose strong impediments to the development of the German energy transition. This can be largely attributed to the close policy fit of national and European policies and a more refined target infrastructure on national level. Still, the German government took great care to separate national policy making from European reporting which in some instances led to bemusing results such as the National Energy Efficiency Action Plan (NEEAP, designed for European reporting) and the National Action Plan on Energy Efficiency (NAPE, designed for national policy making).

At first glance, the monitoring structure and horizontal decision-making+ structures set up in the regulation complement the German governance structure and offer the possibility of aligning the energy policies vertically from the local to the European level. This also explains the positive stance of the German authorities towards the regulation. At second glance, however, the picture might be more ambivalent when secondary effects of the governance scheme are taken into account. This relates largely to two effects: (1) The foreseen peer review of the iNECPs by other Member States might lead to a stronger influence of neighbouring countries on the German policies of RES deployment (especially the issue of ring flows by exceeding RES production not processed via the national grid) or market design (price zones). (2) The peer review process will empower the European Commission to comment on the national policy design. With the obligation to take into account these comments ("shall"), this would increase the influence of the European level on German policy making. Whereas this has not been an issue in the past due to a close policy fit, this might change with growing integration of European energy markets.

With the governance regulation presently being negotiated between the Council and the European Parliament, it remains too early to draw final conclusions on the impact of the EU regulation on the German energy transition. However, national policy makers should pay close attention to the textual changes in the negotiations, as the secondary effects of the combined governance regulation and sectorial directives especially might lead to a stronger framing of the national policy options.

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Policy Convergence as a Multi-faceted Concept: The Case of Renewable Energy Policies in the EU

Sebastian Strunz, Erik Gawel, Paul Lehmann, and Patrik Söderholm

Abstract The literature on policy convergence has identified numerous facets and causal drivers of convergence. Distinguishing four dimensions of convergence (object, benchmark, drivers, and directed process) helps to clarify why and in what form policy convergence may occur (or not). Thus, depending on, e.g., the object of analysis (policy outcome or instruments used), the same empirical case may give rise to opposing assessments. Furthermore, both economic and political drivers are necessary to account for successful policy convergence: economic convergence partly explains why countries may face similar problems and political mechanisms explain why they might choose similar policies to solve a given problem. The paper illustrates the multi-faceted character of convergence for the dynamic field of renewable energy policies in the EU. The empirical results indicate temporary convergence in the case of policy support instrument choices and conditional convergence in terms of renewables shares. However, the results suggest divergence of public R&D subsidies targeting renewables.

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S. Strunz (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: sebastian.strunz@ufz.de

E. Gawel · P. Lehmann
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

P. Söderholm
Economics Unit, Luleå University of Technology, Luleå, Sweden

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1 Introduction

"[A]dvanced industrial states are facing similar problems and are tending to solve them in similar ways" (Bennett 1991: 218). This, in a nutshell, is policy convergence. Alas, we need not go far to see this simple rationale shattered—to some, for instance, the European Union (EU) appears as a system of differentiated integration (cf. Leruth and Lord 2015); others ask, more sharply, "how much distrustful divergence the European Union can contain without degenerating into ineffectiveness and fragmentation" (Hayward and Wurzel 2012: 1). Against this backdrop, we analyse how the concept of policy convergence, understood here as an increase in policy similarity over time (cf. Kerr 1983; Drezner 2001; Holzinger et al. 2008b), can be framed and productively employed within a contested empirical context: policies supporting electricity from renewable energy sources (RES)[1] in the EU.

Surprisingly, the convergence literature is rather dispersed: there is a long trail of political science literature, including empirical studies on convergence of environmental policies (e.g., Fernández 1994; Howlett 2000; Holzinger et al. 2008a) as well as specific case studies on RES policy convergence (e.g., Jacobs 2012; Kitzing et al. 2012). Rather independently, economists have thoroughly investigated (both theoretically and empirically) the general mechanisms of economic (growth) convergence (for overviews see Rodriguez and Rodrik 2001; Islam 2003), and its relationship with environmental pollution convergence (e.g., Brock and Taylor 2010). Moreover, a handful of econometric studies assess international convergence along various environmental indicators (e.g., Camarero et al. 2013; Pettersson et al. 2014). Still, as Plümper and Schneider (2009) observe, there exists a gap between theoretical and empirical work on convergence because compared to the many theoretically proposed drivers of convergence, the empirical evidence is rather weak. This implies a problem for the conceptual research on convergence in that it does not sufficiently explain under what conditions and to what extent convergence processes actually unfold.

The paper contributes to closing this gap by extending previous conceptualizations (e.g. Bennett 1991; Holzinger and Knill 2005; Holzinger et al. 2008b) through a systematic differentiation that includes both economic and political science reasoning on convergence issues. Specifically, the paper distinguishes four dimensions (object, benchmark, drivers and directed process) of policy convergence, which help to clarify why and in what form convergence might occur (or not). First, acknowledging that the *object* of convergence may refer to, amongst others, policy instruments or policy outcomes leads to the insight that convergence of the former not necessarily implies convergence of the latter. Second, the *benchmark* of convergence measurement may either be absolute or conditional on some other characteristic (e.g., with respect to geographical variables) so as to take overall heterogeneity between countries into account. Third, the *drivers* of policy convergence include

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[1] Throughout the paper "RES" stands for electricity from renewable energy sources.

both economic and political processes and these complement each other: economic convergence explains why states are facing the same problems while political drivers account for why states actually may employ the same (or closely related) solutions to address these problems. On their own, however, neither economic nor political drivers can sufficiently explain policy convergence. Fourth, convergence should be understood as a *directed process* that not necessarily leads towards a single final state. In contrast, convergence processes may lead to different final states.

Thus, the main contribution of this paper consists in conceptual consolidation, thereby also setting the stage for more accurate future empirical research: the framework should prevent researchers from confusing evidence for convergence with respect to a specific dimension over a certain period with sustained convergence over all dimensions. In order to illustrate the conceptual propositions, we turn to the empirical case of RES in the EU, a very dynamic field with rapid technological development and continuous policy evolution over almost three decades now.

The average share of electricity consumption in the EU met by RES has almost doubled from 14% in 2004 to 27% in 2014.[2] Worldwide, in 2014 RES experienced their fastest expansion rate, accounting for almost half of overall additions in electricity generation capacity (IEA 2015a). In other words, RES are leaving their former status as niche technologies, thereby fundamentally transforming electricity systems (e.g. Edenhofer et al. 2013). With increasing RES penetration, the main impetus of RES policies shifts from rapid capacity addition to market and system integration as well as to the cost-effectiveness of RES deployment (e.g., Miller et al. 2013). In consequence, national RES policies are regularly updated, often on yearly basis.

At the same time, RES policies in the EU have been scolded as too fragmented and in need of "Europeanization" (e.g., Tagliapietra 2014). Critics advocate coordinated RES support on EU-level as a means for a more efficient geographical allocation of RES installations (e.g., Teyssen 2013; Unteutsch and Lindenberger 2014). However, these calls for Europeanization of RES policies neglect both normative trade-offs and politico-economic restrictions. From a normative economic perspective, centralization also has its downsides: in particular, the "laboratory federalism" argument (Oates 1972, 1999) points to the advantages of decentralized experimentation (see also Tews 2015; Gawel et al. 2014). Moreover, Member States do not only dismiss any suggestion to concede sovereignty over energy and climate policy but they are also hesitant to coordinate their RES support schemes (Klinge Jacobsen et al. 2014).[3] Specifically, RES are often used as a vehicle for regional development and job creation and/or as a way to reduce regional and local environmental impacts, outcomes which could not be guaranteed in case of an integrated

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[2] http://ec.europa.eu/eurostat/documents/38154/4956088/The_average_share_of_electricity_from_RES-2004-2014.pdf/df494f3c-6bea-4dab-b767-5d8f9ad2b007

[3] Moreover, Member States sometimes employ separate policy instruments in addition to what has been agreed on the EU level, as, for instance, the UK's carbon floor price as add-on to the EU emissions trading scheme demonstrates.

EU-approach. Thus, bottom-up processes may better conform to both politico-economic restrictions and normative trade-offs than coercive top-down harmonization (Strunz et al. 2014, 2015).

In consequence, the development of RES in the EU provides a particularly relevant empirical case for policy convergence research. Indeed, it illustrates the main challenge posed by the multi-faceted character of convergence: depending on the specific object of analysis and the benchmark used, the analysis does or does not find convergence. The paper provides some evidence for a temporary convergence around feed-in tariffs as support instrument (i.e., RES producers receive a fixed remuneration for each kilowatt hour (kWh) of electricity), conditional convergence of RES shares and divergence of public R&D subsidies for RES at the national level.

The rest of this paper is organized as follows: in the next Section, we explicate four dimensions of policy convergence. Subsequently, we illustrate the conceptual framework via empirical evidence for economic convergence and RES policy convergence in the EU. Finally, we discuss and summarize our findings.

2 What Is Policy Convergence? An Interdisciplinary Recapitulation in Four Dimensions

Most commonly, policy convergence is understood as the “increase of policy similarity over time” (Holzinger et al. 2008b: 24), although a variety of alternative (albeit similar) definitions could be brought forward. In the following, we systemize the multi-faceted concept of policy convergence via differentiating four dimensions. Within this framework, we draw on both economic and political theories of convergence. In order to contextualize an otherwise abstract discussion, we revert to the case of RES policies for empirical examples.

2.1 The Object of Policy Convergence

The objects of policy convergence may be distinguished along the specific stages of the policy process. Figure 1 provides a stylized overview of the development and implementation of public policies. Needless to say, it is not meant to be a comprehensive and an entirely realistic representation of politics.[4]

Compared to rather general notions of convergence such as “the tendency of policies to grow more alike, in the form of increasing similarity in structures, processes, and performances” (Kerr 1983: 3, cited in Drezner 2001: 53), we obtain more specific concepts of policy convergence objects when focusing on particular

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[4] For instance, Fig. 1 does not elaborate on the role of stakeholder involvement in policy formulation.

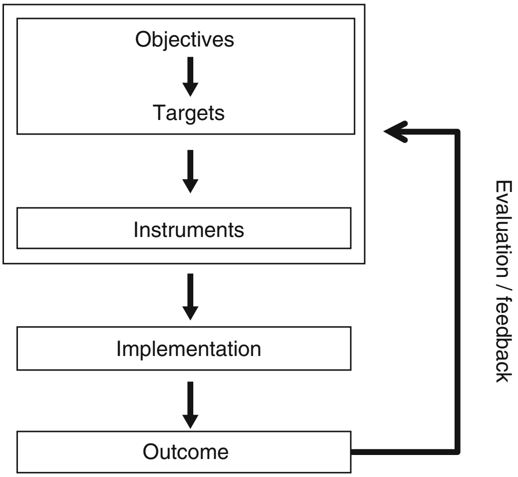

Fig. 1 Stylized overview of the different stages of the policy process

stages of the above scheme. Similarly, Bennett (1991) argues that policy convergence may relate to the dimensions of *objectives, content, instruments, outcomes* and *style* of policies. The following discussion demonstrates that the question on which dimension to focus on is closely related to normative questions on why convergence might be desirable in the first place.

First, objectives guide the long-term trajectory of policies. For instance, one might explore whether all EU Member States adhere to the main objective of the EU Roadmap 2050 towards a decarbonization of European energy provision. Alternatively, one might investigate policy targets, which typically represent quantified values that shall be attained in a certain period of time, in order to acknowledge distributional aspects (i.e., fair burden sharing).

Second, convergence of policy instruments is of particular interest from the normative perspective of (narrow) economic efficiency. Subsidizing RES deployment in the EU will be least costly—in terms of minimizing RES generation costs only—if the geographical allocation of RES facilities closely follows natural conditions. Such a deployment pattern, in turn, could be achieved via a harmonized scheme of RES support instruments in the EU (Unteutsch and Lindenberger 2014). Thus, a range of benefits, including economies of scale in RES production, might be realized. However, instrument alignment *per se* is not sufficient for cost-effectiveness, it also requires convergence of *support levels*. Certainly, accounting for country-specific benefits of RES, questions the economic desirability of converging instruments/support levels in the first place (cf. Söderholm 2008a).

Third, policy convergence may refer to outcomes. Yet, the policy outcomes may be more due to other factors rather than being intended policy effects. For instance, RES shares (e.g., out of total electricity consumption) are affected by the cost of these technologies relative to the price of conventional energy sources. The latter, in turn, is influenced by a number of exogenous variables, such as the world market prices for coal and natural gas. Thus, outcome convergence appears as a weak proxy for policy convergence, as it may be primarily driven by strong global factors. Then again, one interesting question is whether policy manages to "even out" differences in natural conditions so that convergence in observed outcomes obtains despite structural differences (cf. Overbye 1994).

In conclusion, it is important to acknowledge that policy convergence of a particular object (cf. Fig. 1: objectives-targets-instruments-outcomes) may not align with convergence in terms of another object—in fact, convergence of policy instruments may actually be directly responsible for *diverging* outcomes. To see this, consider the case of Sweden and Norway who merged their quota schemes (i.e., utilities are required to certify a certain amount of RES via tradable certificates), by establishing a common market for RES certificates in 2012. The aim of such a common market is not to achieve identical RES shares. In fact, the scheme should "promote increased wind power in Norway rather than Sweden" due to Norwegian comparative advantages (Söderholm 2008b: 2061). In the same vein, the calls for a uniform quota scheme in the EU actually tend to promote diverging RES shares across the EU following optimal geographical allocation of RES installations: wind farms along North European shores, photovoltaic energy in Southern Europe and, conversely, less RES production in Central Europe's centers of population and industrial production.

In sum, the first conceptual specification concerns the *object* of policy convergence (cf. Bennett 1991). In particular, one might refer to:

- policy objectives/targets (e.g., RES-objectives/targets),
- policy instruments (e.g., RES-policies),
- policy outcomes (e.g., RES-shares).

The following proposition captures the relevance of choosing the object of convergence in a nutshell: *Convergence of policy instruments does not necessarily imply convergence of outcomes (and vice versa).*

2.2 The Benchmark of Policy Convergence

The second conceptual specification concerns the benchmark of policy convergence (cf. Baumol 1986; Holzinger et al. 2008b), and here it is useful to distinguish between:

- *absolute convergence* implicitly assumes that all countries attain the same outcomes, e.g. in terms of the steady-state level of RES generation shares; and
- *conditional convergence* acknowledges key differences among countries, e.g., regarding economic wealth and geographical potential, in turn implying that countries may converge but towards different steady-state levels.

The notion of conditional convergence may be particularly helpful to improve the concept of outcome convergence. As noted above, a sole focus on observed outcomes may not relate much to policy convergence. But correcting for, for instance,

Table 1 Specifying "convergence" for the case of RES policies in Europe

Stage of political process	Convergence benchmark	
	Absolute	Conditional
Policy targets	Identical RES targets	Identical target ratios, with respect to (w.r.t.) correction factors, e.g.: – RES target/GDP/capita – PV target/solar radiation – Wind target/wind speed
Instruments/ support level	Identical instruments	Identical policy ratios, w.r.t. correction factors, e.g.: Feed-in-tariff/per capita GDP
Outcomes	Identical RES shares; identical RES mixes; identical deployment rates (convergence of target fulfillment speed)	Identical RES ratios/mixes/deployment rates, w.r.t. correction factors, e.g.: – RES share/per capita GDP – PV share/solar radiation – Wind share/wind speed

Member States' GDP could take exogenous economic factors sufficiently into account. Furthermore, correcting for Member States' RES potential would enable relating conditional outcome convergence to the normative rationale of minimizing RES generation costs. Thus, introducing conditional convergence measures might, in principle, solve some of the problems related to outcome convergence.

The crucial difference, then, lies in *when* we can argue to have convergence. We might say that conditional convergence is some weak version of policy convergence. For instance, in the case of RES policy instrument convergence in terms of support levels, absolute convergence is only achieved when support levels are equalized. In contrast, conditional convergence may describe a situation where countries are moving in the same direction (e.g., where not some countries are decreasing the support while others are increasing it), and there exist systematic and legitimate reasons for why we may never see completely equalized support levels. In short, the conceptual proposition regarding the benchmark of convergence reads: *Not only absolute but also conditional convergence may serve as a benchmark of convergence analysis.* Table 1 provides an overview of the specifications introduced so far.

2.3 The Drivers of Policy Convergence

A third conceptual issue relates to the *drivers* of policy convergence, which in turn can be distinguished into economic and political drivers. In Fig. 2, the economic drivers roughly correspond to the box at the top while the political drivers correspond to the large box which includes both bottom-up and top-down mechanisms. In the following, we first address the complementarity of economic and political drivers, before sketching possible sub-differentiations among the political drivers.

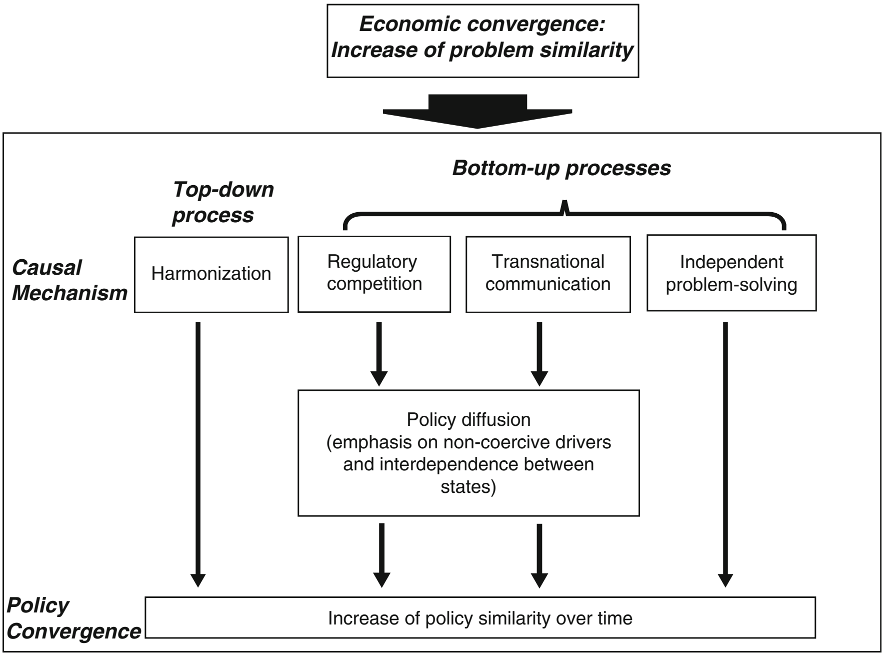

Fig. 2 Causal mechanisms of convergence. Based on and adapted from Holzinger et al. (2008b: 24)

Let us start with the *economic drivers of convergence*. The introductory quote of Bennett (1991) points at an important precondition for policy convergence—namely that *states are facing similar problems*. In principle, such an alignment of issues-to-be-addressed by policy intervention can come about through different channels, such as economic contexts, natural conditions, common institutional frameworks and ideological backgrounds. Nevertheless, the sobering experience of Europe's "monetary disunion" (Streeck and Elsässer 2016) hints to a particularly strong link between economic and policy convergence. While a common monetary policy binds the Euro group together, the lack of i) a sufficiently homogeneous area in terms of economic fundamentals and of ii) a fiscal stabilization mechanism has almost teared the Euro apart (thereby also supporting the theory of optimum currency areas, see Mundell 1961; Fingleton et al. 2015). In other words, policy convergence without economic convergence may often not be sustainable. What, then, is the rationale for expecting different countries to converge economically?

The modern economic theory of growth dates back to Solow (1956). It conceptualizes growth as extension of capital stocks (where capital includes all forms of productive assets, from machinery to know-how). If countries exhibit similar characteristics, such as the level of technological progress, the Solow-model predicts convergence of capital stocks (per capita) among these countries. In case the fundamental economic characteristics differ, convergence is not absolute but conditional, reflecting these differences. Yet, declining marginal productivity of capital may erode differences over time: poor economies should grow faster than rich economies because investments in the former yield higher *marginal* returns. Eventually, all countries would converge to the same steady-state level of capital (Baumol 1986). This is the so-called "catching-up" hypothesis—traditionally supposed to hold within an interdependent world of trade (Ohlin 1933; Samuelson 1948). Furthermore, a globalization-driven competitive pressure on economies may induce convergence of regulatory approaches. While Hall and Soskice (2001) pointed to persistent "Varieties of Capitalism", coordinated market economies have in recent years implemented more extensive deregulation than liberal market economics (Ther 2014; Pierre 2015)—possibly pointing towards a convergence of approaches.

Yet there is also a longstanding controversy over the "catching-up" hypothesis, in particular as regards the influence of international trade: for instance, it has been shown that opening up poorer countries to trade may stop growth convergence processes and even cause divergence (Bajona and Kehoe 2010). In addition, the catching-up hypothesis is empirically disputed (see Rodriguez and Rodrik 2001 as well as Islam 2003 for extensive overviews) and even staunch supporters of globalization concede that "catch-up will be a long, difficult grind" (The Economist 2014).

The economic literature on growth and convergence has been connected to environmental policies via the concept of the so-called Environmental Kuznets Curve (EKC, cf. Grossman and Krueger 1995). The EKC suggests an inverted U-shape relationship between gross domestic product (GDP) and environmental pollution: with raising wealth, pollution at first increases but then decreases. Brock and Taylor (2010) argue that the EKC is a necessary "byproduct" of economic convergence within the Solow model. Yet as to the specific mechanisms that might give rise to such patterns, a range of candidates has been discussed. One prominent mechanism relates to the increasing demand for high environmental quality with rising income levels. Thus, economic convergence would directly translate into convergence of demand for generally stricter environmental policies. For instance, demand for clean energy provision increases as poorer countries catch up economically; due to higher marginal productivity of capital, poorer countries can raise their RES shares (e.g., in terms of photovoltaics (PV), wind power) faster than early adopters, with all countries eventually converging. Conversely, without economic convergence, there *could* be little reason to expect countries to align their energy and environmental policies and to attain similar outcomes in terms of, for instance, RES shares.

Let us now turn to the *political drivers of policy convergence.* Theories of economic convergence are "apolitical" in the sense that they build on economic variables (e.g., technological progress, capital accumulation etc.) that may explain demand for specific polices; yet they are silent on the workings of the "political market" where policy supply needs to meet this demand (cf. Keohane et al. 1998). Policy convergence implies that demand is met in similar ways. In other words, problem convergence is a necessary but not a sufficient condition for policy convergence[5]: in principle, countries might promote rather different solutions to essentially identical problems. Thus, a comprehensive framework of convergence needs to identify the specific mechanisms that lead states to adopt similar policy solutions.

These political drivers may be differentiated into top-down and bottom-up drivers. Within the latter, one may further distinguish policy diffusion (in the narrower sense[6]), relying on interaction between countries, and independent policy formulation without interaction. As Fig. 2 demonstrates, the literature on policy convergence mostly highlights different forms of interdependence between states, possibly combined with elements of top-down steering. Bennett (1991) proposed four different drivers of convergence: emulation, elite networking, penetration by external actors and harmonization. Subsequently, the literature focused on specific variations of Bennett's first two mechanisms under the label "policy diffusion" (e.g., Busch and Jörgens 2005; Tews 2005; Maggetti and Gilardi 2016). In particular, the non-hierarchical character of diffusion has been emphasized: "Diffusion is the spreading of innovations due to communication instead of hierarchy or collective decision making within international institutions" (Tews 2005: 65).

Thus, diffusion should be differentiated from coercive imposition and harmonization as other possible mechanisms that may establish homogeneous policies. Diffusion proceeds horizontally rather than vertically and is "driven by information flows" (Busch and Jörgens 2005: 865) within processes of emulation and learning. Coming back to Fig. 2, policy diffusion marks the result of interdependent problem-solving: neither are policies implemented due to pressure from above, nor are they conceived by solitary policy-makers. Empirically, diffusion has been identified as a crucial driver of economic policy reform (Pitlik 2007). The bottom-up drivers of policy convergence were further investigated by Holzinger and Knill (2005), and Holzinger et al. (2008b) who focused on three bottom-up mechanisms of convergence—transnational communication, regulatory competition and independent problem-solving.

In the case of European RES policies, such bottom-up processes may be especially relevant. The main reason here is the relative weakness of supranational EU institutions with regards to energy policy. While the Lisbon treaty for the first time stipulates an active role for the EU in conducting energy policy, Member States have retained their sovereignty over the general course of their energy policies (Article 194(2) of the Treaty on the Functioning of the European Union, see EU 2012). The EU commission, on the other hand, tries to shape Member States' policies even if its *direct* regulatory power is limited. The common EU climate and energy target architecture for 2020 and 2030 constitutes an *indirect* way of top-down

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[5] Certainly, there may be cases where policy convergence is viable without economic convergence—namely if policies are of a mostly symbolic nature and without major economic implications.

[6] There are also wider notions of diffusion to be found in the literature that allow for top-down mechanisms, but we focus on a narrower concept of diffusion as bottom-up process to make the matter not overly complex.

influence—a common framework that creates a similar problem context (i.e., "how to increase the share of RES?") for all Member States without prescribing the use of specific instruments. Also, the Commission is increasingly active in using the internal market directives and the guidelines for environmental state aid to steer Member States energy policies in the preferred direction (e.g., in the form of tender schemes that use competitive bidding procedures to determine the level of RES support, or fixed premium schemes that offer RES-producers a mark-up on top of the spot-market price). Eventually, the "EU impact on the national energy mix is predominantly indirect, yet powerful" (Callies and Hey 2013: 88).

Furthermore, the EU's multi-level system with its complex architecture of partly differentiated, partly overlapping and often contested allocation of responsibilities allows for hybrid processes. For example, the so-called Open Method of Coordination (OMC), whereby the EU Commission influences national policies by agenda setting and framing inter-Member State discussions (cf. Ania and Wagener 2014; Borrás and Jacobsson 2004), represents one potentially important driver of convergence. So while national decisions may formally be taken voluntary, they may respond to pressures arising from, for instance, EU-guidelines and intergovernmental discussions. Thus, Member States may cooperate, compete, communicate, emulate one another or combine all of these activities.

In conclusion, theories of economic and political convergence processes complement each other: the former helps explain why states are facing similar problems, the latter provide rationales for why states choose or should choose the same policies to solve a given problem. We may summarize this argument in the following conceptual proposition: *On their own, neither economic nor political drivers can sufficiently account for policy convergence*.

2.4 The Directed Process of Policy Convergence

Finally, a fourth conceptual dimension of convergence results from its conjunction of both *process* and *final state.* Specific definitions may accentuate these characteristics to different degrees. Consider, for instance, the following hypothetical situation: some EU Member States move from wide diversity towards more similarity, albeit still far from homogeneity. If we emphasize proximity to *final states*, we would rather not refer to this situation as convergence. However, if we focus on the *process* of increasing similarity, we would speak of a case of convergence—even if the process is far from finished. In a similar vein, Plümper and Schneider (2009) introduce a distinction between complete and incomplete convergence.

Against this background, the process-dimension is a crucial conceptual element of convergence, not least because it directly opens the analytical framework for investigating the mechanisms that may lead to convergence. Furthermore, as Bennett (1991: 230) remarked: "Policy convergence should also be conceptualized in dynamic terms. The relevant theoretical dimension is time rather than space. Otherwise the concept becomes a synonym for similarity". At the same time, final states are important as a benchmark against which to measure the progress of increasing similarity. In the particular context of RES policies, the final states are moving targets (e.g., support level or RES share/per capita GDP) that evolve with technological and political development: unless we refer to the EU's long-term aim of full decarbonisation, essentially implying 100% RES, it does not seem sensible to consider specific support levels or RES shares as "final" in any literal way. In brief, we suggest the following conceptual proposition: *Convergence processes may notwithstanding lead to different final states*.

3 Methods and Data

The general point of this paper that convergence is multi-faceted has to be translated into a structured conceptual framework that can inform empirical research. To this end, the preceding section differentiated four dimensions of policy convergence (object, benchmark, driver and directed process) and condensed the discussion into one proposition for each dimension:

1. Object: Convergence of policy instruments does not necessarily imply convergence of outcomes (and vice versa).
2. Benchmark: Not only absolute but also conditional convergence may serve as a benchmark of convergence analysis.
3. Drivers: On their own, neither economic nor political drivers can sufficiently account for policy convergence.
4. Process: Convergence processes may notwithstanding lead to different final states.

Note that the paper's main objective is of conceptual nature and, therefore, it empirically illustrates the relevance of the conceptual propositions; it does not aim at full-fledged, comprehensive statistical analyses itself. Rather, the propositions provide building blocks for future more in-depth empirical assessments.

Methodologically, the multiple dimensions of convergence imply that there exists no uniform measure that fits for all dimensions. More specifically, under some circumstances it may be useful to conceive of convergence as a negative relationship between some initial level and the growth rate—suggesting that countries with lower initial levels catch up with the forerunners. For instance, this notion (often referred to as β-convergence, see Heichel et al. 2005) seems appropriate when policies/outcomes (e.g., emission levels) can be expressed as a continuous quantifiable variable. In contrast, the choice between policy instruments is a discrete choice, which implies that instrument convergence may not be representable in statistical terms. Then again, statistical measures such as absolute and conditional convergence may be relevant for specific policy design issues, such as tax levels, public expenses, etc. All this leads to our main argument that, depending on the specific object of analysis and the benchmark used, the same empirical area may give rise to opposing assessments. As a case in point, we now refer to some empirical evidence for RES policy convergence in the EU—temporary convergence around feed-in tariffs as support instrument, conditional convergence of RES shares, but divergence of public R&D subsidies for RES at the national level.

Specifically, we rely on three different sets of data: First, we present data on the use of support instruments for RES. Information on the type of support instruments that are currently employed is available from www.res-legal.eu, a database initiated by the European Commission. Moreover, information on support instruments that were employed in the past was gathered from Kitzing et al. (2012). Second, we present data on current RES shares and RES growth rates within the EU Member States. This assessment is based on the notion of convergence as catching-up and relates the initial level of RES shares to the respective growth rates. The data are available from Eurostat, the statistical office of the European Union (http://ec.europa.eu/eurostat). Third, we present empirical evidence on policy convergence in terms of public subsidies to R&D in the RES field. The data used are derived from the International Energy Agency's (2015b) *Energy Technology RD&D Statistics* database. Unfortunately, this data set is limited to 14 different EU countries. The empirical assessment builds on the calculation of so-called R&D-based knowledge stocks. Specifically, we start from the premise that previous public R&D expenditures in a country add to an R&D-based knowledge stock, i.e., comprising the cumulative expenditures (e.g., Ek and Söderholm 2010; Grafström et al. 2017). We assume that the R&D expenditures only add to this stock after some years have lapsed, since it takes time for investments in R&D to generate new useful knowledge. Moreover, it is also assumed that the stock depreciates in that the effects of previous public R&D expenses gradually become outdated (e.g., Griliches 1995). We here assume a time lag of two years, and a depreciation rate of 10 percent. The latter choice suggests a fairly high rate of depreciation of R&D-based knowledge, but this is reflected in the relatively rapid development of renewable energy technology during the last decades (see Edenhofer et al. 2013; Johnstone et al. 2010; IEA 2015b). The above permits a test of the convergence hypothesis that countries with low initial R&D-based knowledge states will experience higher growth rates in this stock over time (and vice versa).

In the following, we empirically corroborate the four conceptual propositions, addressing each in turn.

4 Assessing the Case for RES Policy Convergence in the EU

4.1 Convergence of Policy Instruments Does Not Necessarily Imply Convergence of Outcomes (and Vice Versa)

The early history of RES support instruments, from 1970 to 2000, is summarized by Knill et al. (2008: 115ff.) as the "emergence of two dominant approaches", first "subsidies or tax reductions" and second "legal obligations for energy users to

Table 2 Number of EU member states that have implemented major RES support instruments, 2000–2015

	2000	2005	2010	2015
Feed-in tariff (guaranteed remuneration for each kWh of electricity from RES)	7	16	23	19
Feed-in premium (mark-up on the electricity price)	–	4	7	8
Tender (RES remuneration is determined in a competitive bidding procedure)	2	2	6	8
Quota scheme (tradable RES certificates)	1	6	6	5

Source: Kitzing et al. (2012) for years 2000–2010, database www.RES-legal.eu for 2015 (From 2005 on, the number of support schemes exceeds the number of EU Member States because many of the latter are combining elements of different support schemes. Hence, one could conclude that a "meta-trend" consists in increasing complexity of individual support schemes. This trend also implies ambiguity in counting: to see this, consider the number of tenders for 2015. We arrive at eight Member States that employ tenders but considerably lower counts might be equally justified. One crucial question is whether to include schemes, which use auctions within more complex mechanisms (such as Denmark of the Netherlands) or whether to focus on tenders as main instrument. As more and more countries are experimenting with tenders, and as the Commission's guidelines intend to foster this development, we maintain a rather inclusive perspective)

purchase a certain amount of renewable energy". Yet, in hindsight, the latter cannot be reasonably called a dominant approach. Although quota schemes have been a long-time favorite of the EU Commission, there is no long-term trend towards a more widespread implementation of such schemes. In fact, in 2000, out of the 9 RES-obligation schemes cited by Knill et al. (2008: 118), only one involved tradable certificates; and while the number rose to 6 in 2005, it has been stagnating or even declining since then (cf. Table 2).

Major support instruments for RES have been available in all EU Member States since 2007. In particular, feed-in tariffs have emerged as the most popular support instrument, (see Kitzing et al. 2012 for more details on the period 2000–2010). Yet, Table 2 also shows that pure feed-in tariffs might have passed a peak around 2010 and that they are increasingly complemented or replaced by feed-in premiums and tenders. Given that often feed-in tariffs enabled the rapid increases of RES deployment in the first place, should we not expect first convergence towards this instrument and then towards specific regulatory details? Why would regulators shift away from a successful policy instrument?

The short answer is that feed-in tariffs have been falling victim to their own success. Feed-in tariffs foster niche technologies and with RES growing out of their niche, policy priorities change too. Specifically, feed-in tariffs have been empirically shown to facilitate technological innovation for solar energy but they are less effective for more mature technologies such as wind that are close to compete with fossil energies (e.g., Johnstone et al. 2010). Furthermore, the crucial success factor of feed-in tariffs, the mitigation of income risk for potential investors, also drives up the overall costs of RES deployment. With technologies maturing and concerns of cost-effectiveness increasing, RES support is entering a "critical policy transition period" so as to integrate RES into electricity markets (Miller et al. 2013).

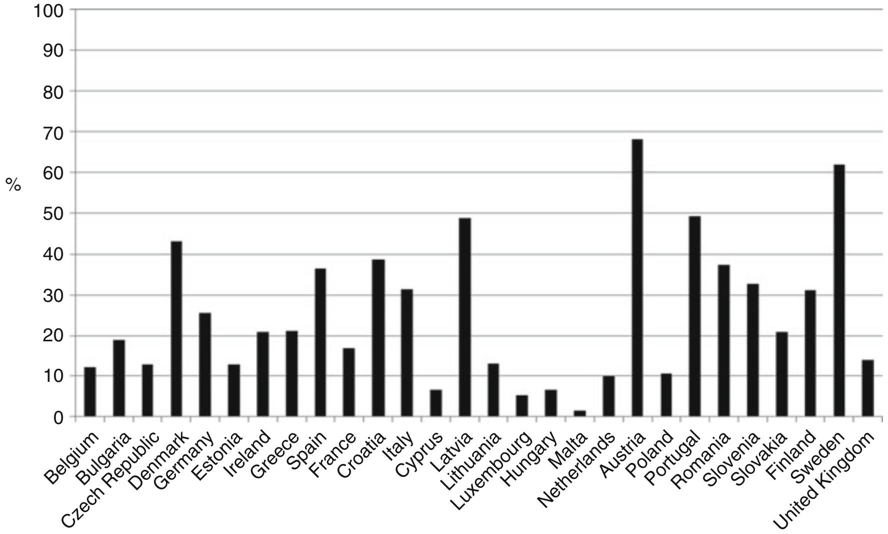

Fig. 3 Shares of electricity generated from RES in gross electricity consumption for EU-27 member states in 2013

In addition, EU energy policy puts partly explicit, partly implicit pressure on Member States to move away from feed-in tariffs. The Commission's argument here reads: once common rules for the generation, transmission and distribution of electricity are implemented all over the EU, substantial cross-border interactions will be prevalent, rendering country-specific support schemes incompatible. In order to minimize market distortions and inefficiencies, country-specific RES support should oblige RES producers to directly sell electricity in the market, promoting the overall market-integration of RES and increasing cross-border electricity trading. Recent developments indicate that the Commission successfully frames national discussions on RES policies along these lines (cf. Tews 2015). In consequence, one might say that during the first stage of RES support, policy instruments converged around feed-in tariffs but that the market integration of RES calls for different approaches.

In comparison to the (temporary) convergence of RES instruments, the diversity of RES shares at electricity consumption in the EU is striking (Fig. 3). One possible explanation for this diversity refers to heterogeneity in ideological orientation. Member States' ambitions to decarbonize their energy systems are diverse and RES still inhabit a technological niche in some markets. More importantly, though, geographical conditions seem to determine the sizes of the RES shares. Consider Austria and Sweden, which exhibit the highest shares of RES in gross electricity consumption in the EU: both rely heavily on hydropower—traditionally so, rather than triggered by recent and current RES deployment policies. By comparison, the Netherlands, with an even slightly higher level of GDP per capita, only covers a fraction of its electricity consumption with RES. Also, the EU's aim of finalizing the internal energy market with fully harmonized RES policies, not necessarily implies convergence of RES shares. As outlined above, policy instrument convergence may lead to diverging RES shares with geographically predisposed countries exhibiting higher shares than the rest (e.g., solar in Southern Europe, wind at the shores).

Hence, although RES support instruments (temporarily) converged around feed-in tariffs, this did not result in absolute convergence of outcomes and there is no reason to expect the latter any time soon. In the following, it will also become clear that—even when restricting the analysis to the object "RES policies"—both divergence and convergence may obtain, because different sets of policies need not align.

4.2 Not Only Absolute But Also Conditional Convergence May Serve as a Benchmark of Convergence Analysis

The diversity in RES shares notwithstanding, there might be conditional convergence. In order to account for the country-specific history of geography-induced renewables deployment, a look at the growth rates of RES shares seems useful. As Fig. 4a shows, the growth rates of RES shares in gross electricity are generally significantly higher for the Member States with low initial levels than for the ones with high initial levels (a very similar pattern emerges in the case of RES shares at overall energy consumption, including heat and transport). This empirical pattern therefore seems to support the catching-up hypothesis.

However, Fig. 4b provides a corresponding test of policy convergence in the case of public subsidies (i.e., government expenditures) for renewable energy R&D, here operationalized in terms of an R&D-based knowledge stock with time lags and a depreciation rate attached to the stock. These results show little direct support for the catching-up hypotheses since there is no clear negative correlation between the initial (beginning-of-period) knowledge stock and the growth rate in the knowledge stock over the time period. However, although there are few indications of absolute convergence there may be convergence after having controlled for other factors, such as GDP per capita, energy import dependence etc. In an empirical paper focusing solely on the drivers behind public R&D support in the EU (Grafström et al. 2017), we employ more elaborate econometric analyses over a more extended time period (1990–2013).[7] The results provide robust evidence for the presence of public R&D expenditures *divergence* across EU countries. In other words, countries with initially low R&D-based knowledge stocks have experienced lower growth

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[7] This companion paper has a much narrower scope than the present one. Specifically, it provides a panel-data based econometric analysis of the growth of the R&D-based knowledge stock for RES in the EU. The analysis indicates, for instance, how the changes in this stock have been influenced by energy import dependence, electricity regulation, GDP growth etc., and it permits a test of whether there is evidence of convergence (or divergence) in terms of public R&D support across EU Member States. The paper and the detailed results are available directly from the authors on request.

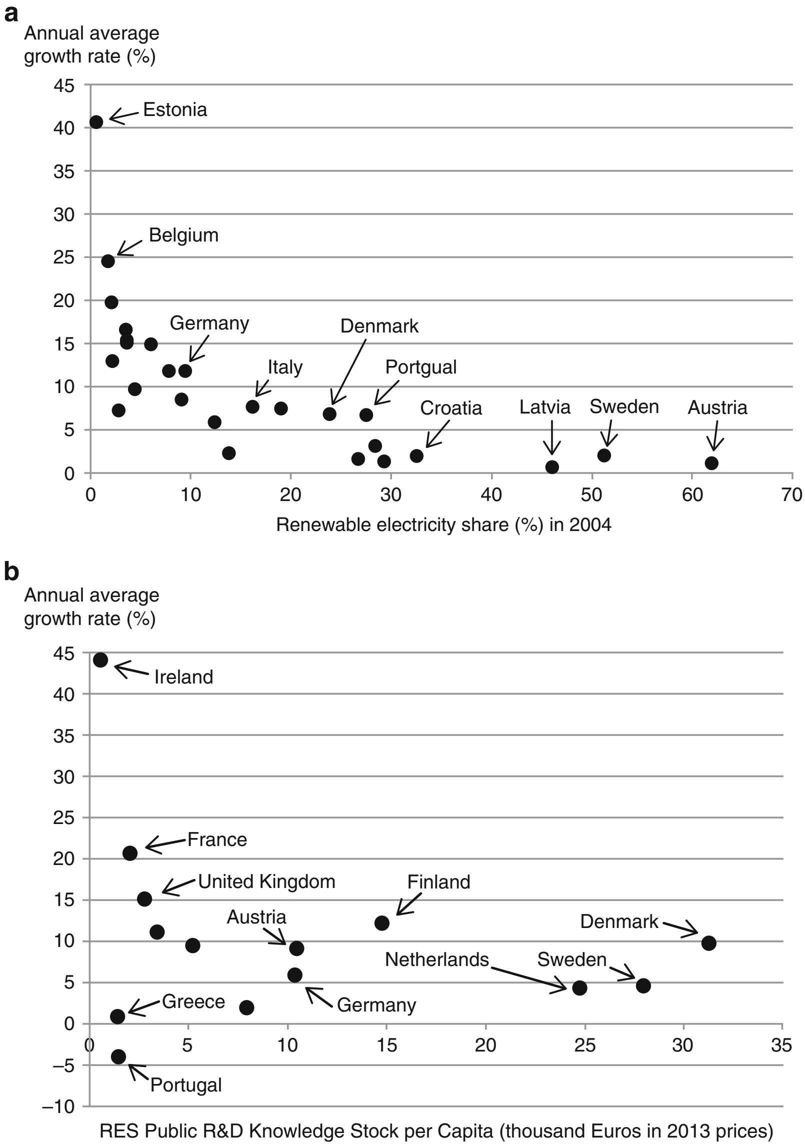

Fig. 4 (**a**) Shares of electricity generated from RES in gross electricity consumption (EU-27, excluding Cyprus) over the time period 2004–2013: annual average growth rates versus the initial level in 2004. (**b**) Per capita knowledge stock based on public subsidies for renewable energy R&D: annual average growth rates in 14 EU countries over the period 2004–2013 versus the initial level in 2004

rates in these stocks compared to countries that have already accumulated a lot of R&D-based knowledge in the RES field.

What might bring these different patterns between RES shares and public R&D RES support about? In contrast to the case of RES shares there are no mandatory targets regarding R&D expenses for the EU Member States, and divergence may be related to the public good characteristics of public R&D. Some countries could thus be free-riding on the others' development efforts through knowledge spillovers. This is not possible to the same extent in the case of RES-shares because of the presence of mandatory country-specific targets. Moreover, the countries' that choose to invest in R&D may experience increasing returns on their R&D investment, and investments may also be further spurred by vested interests and industrial policy motives.[8]

In conclusion, the ambiguous empirical results attest to the complexity of the policy convergence issue.

4.3 On Their Own, Neither Economic Nor Political Drivers Can Sufficiently Account for Policy Convergence

To start with, what is the empirical evidence for economic convergence (measured in real per capita income) in the EU? In short, there is meager evidence for overall convergence but there is evidence of convergence within several subgroups—that is, clusters of Member States growing at the same rate (Borsi and Metiu 2015). A clear separation between old EU-Member States and new Member States in Eastern Europe appears: although the latter have exhibited higher growth rates, catching-up has not yet been sufficient in order to smooth out differences across Member States (Borsi and Metiu 2015). This can also be seen from recent GDP per capita statistics for the EU-28: at the upper end (omitting Luxembourg), the Netherlands stay at 31% above the EU-28 average (year 2013, Eurostat[9]). On the lower end, Bulgaria is listed with a GDP per capita of 55% below the average. In sum, one might speak of clustered, slow and non-monotonic processes of economic convergence in the EU.

It can be noted that the Member States' catching-up in terms of RES shares (Fig. 4a) appears similar to this economic catching-up: both catching-up processes occur slowly and have reduced but not yet eliminated substantial differences between the Member States. In other words, both processes display conditional

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[8] This is not meant to imply, however, that the free-riding countries see no reasons to invest in own public R&D support to RES. For instance, there is often a need to adapt the new technology to local conditions (e.g., research on the icing of wind turbines in northern Europe). Moreover, in order to benefit from previous R&D efforts societies must also invest in own R&D since it contributes absorptive capacity, i.e., the ability to recognize and make use of the information generated through others' development activities.

[9] http://ec.europa.eu/eurostat/statistics-explained/index.php/GDP_per_capita,_consumption_per_capita_and_price_level_indices.

convergence. As laid out above, economic theory could explain this congruency via, for instance, a causal relation from economic growth over changes in peoples' preferences towards more environmental friendly electricity provision. Yet this tells us little about why similar policies should be used to address this demand.

We, therefore, turn to the political explanations for the spread of specific policy instruments to increase RES deployment within the EU. The literature here puts a clear emphasis on policy diffusion: "The international spread of feed-in tariffs and quotas was driven neither by mechanisms of harmonization nor imposition. Rather, the analysis [...] points to an important role of diffusion mechanisms during the instruments' spread" (Busch and Jörgens 2005: 876). As outlined above, at the end of the 2000s support schemes for RES in the EU converged towards feed-in-tariffs. To better understand the specific mechanisms behind this convergence/diffusion process, the detailed case study of RES policy convergence in Spain, France and Germany, as performed by Jacobs (2012) is helpful. Building on Holzinger et al.'s (2008b) framework, Jacobs identifies the three mechanisms of transnational communication, regulatory competition and independent problem solving as main political drivers of convergence towards feed-in tariffs (and their regulatory details).

First, transnational communication aligned approaches towards RES deployment in Spain, France and Germany; in particular, it was "decisive for the spread of certain feed-in tariff design options" (Jacobs 2012: 134). Second, regulatory competition arises from Member States' objective to stay competitive in terms of attracting investment. Here, Jacobs (2012) finds some evidence for convergence of photovoltaic feed-in tariffs due to competition between EU Member States. Interestingly, this contradicts the main results of Holzinger et al.'s (2008a) empirical analysis that regulatory competition has only had negligible explanatory power for environmental policy convergence in the EU. Third, common problem solving pressure may lead states to independently adopt very similar solutions. For instance, rapidly cumulating remunerations for photovoltaic installations was a problem both in Germany and Spain during the late 2000s. As a solution, "flexible tariff degression was developed independently in Germany and Spain" (Jacobs 2012: 227). A related case study suggests that these different convergence mechanisms possibly follow a chronological pattern: Carley et al. (2016) evaluate the diffusion of renewable portfolio standards in the US, demonstrating that processes of inter-state emulation explain the states' decisions on policy adoption and design while internal influences determine subsequent changes to these policies.

Against this background, does not a purely political account sufficiently explain RES policy convergence in the EU? The problem with such an approach is its blindness to economic factors that may disrupt convergence processes. From Jacobs's study one might get the impression that full alignment of feed-in tariffs was imminent—not only was there a general tendency towards feed-in tariffs at the end of the 2000s, but also did very specific regulatory details converge. But then the financial and economic crisis squeezed Member States' budgets and lowered priority of RES support on the overall policy agendas. In Spain, this pressure resulted in a drastic dismantling of the RES support scheme in 2013. In Germany, the economic repercussions of the financial crisis were not as severe. Thus, the policy agendas in both countries diverged and the RES policy convergence process tended to halt.

Meanwhile, as outlined above, Germany and other countries are beginning to switch away from pure feed-in tariffs. This development is in line with the EU Commission's push towards cost-effective RES support, and, more generally, stems from the growing economic impact of RES. In sum, therefore, a narrow look at the mechanisms of policy diffusion at work in the 2000s would give rise to a completely misleading picture of the way RES policies would be taking in the 2010s—the main reason being the importance of economic drivers in establishing problem-similarity as condition for sustained convergence of policies.

4.4 Convergence Processes May Notwithstanding Lead to Different Final States

Somewhat paradoxically, the very reason the EU Commission pushes for tender schemes, the market integration of RES, also raises doubts as to whether *any* RES instrument will serve as a convergence line. In short, the best way to integrate RES into energy markets remains unclear, as well as the final state of RES support in a world with very high RES shares (e.g., Kopp et al. 2012): will there be no more support at all? Alternatively, will "energy-only" markets transform to remunerate production capacities rather than the electricity, thereby fusing RES support with technology-neutral capacity payments?

Eventually, different forms of market integration might be observed, depending on geographical and other country-specific conditions. The heterogeneity of Member States in terms of both RES potential and preferences for sustainable energy provision may imply that, after all, there will not be only one but several final states: for example, we might see several subsets of Member States with similar policies transforming their energy systems at similar speed, corresponding to their respective regulatory models (cf. Ćetković and Buzogány 2016). Furthermore, there may be historic, institutional and cultural path dependencies that make *absolute* convergence of RES support polices highly unlikely. The framework of institutional economics (North 1990) may be particularly helpful to carve out the institutional inertia that may inhibit policy convergence. This concerns environmental policy in general (Fernández 1994), and energy transition pathways more specifically (Kern 2011; Laird and Stefes 2009). Such institutional path dependencies also challenge the quest for adaptive efficiency through RES policy reform efforts (Gawel et al. 2017).

The gist of the preceding discussion is that convergence processes notwithstanding, final states may not be identical. RES policies may converge towards different final states; or they may converge as regards their basic structure but still diverge in content (Vasseur 2014). That is, on the surface we might perceive similarity, where substantial divergence prevails. So even if all Member States pursue roughly similar energy transition pathways and even if there is broader economic convergence, this may not bring about absolute convergence of RES instruments and RES shares.

5 Conclusion

Policy convergence is a multi-faceted concept. The main argument of this paper is that distinguishing four dimensions of convergence helps to clarify why and in what form policy convergence might occur. In doing so, the paper aims to guide prospective empirical research. First, convergence analyses may refer to different objects and there may well be convergence for one particular object but not for another. Most notably, convergence of policy instruments does not necessarily imply convergence of outcomes. Second, the benchmark of convergence analysis may be absolute or conditional on some other characteristics to account for heterogeneity: differences in, e.g., economic performance or geographical conditions, can then be framed as conditional convergence. Third, a comprehensive explanation of successful policy convergence needs to account for both economic and political drivers. Economic convergence may explain similarity of problems rather than similarity of policy solutions. Converging policies, in turn, do not solve the same problems if there is no economic convergence. In other words, economic and political drivers of convergence complement each other. Fourth, convergence processes may notwithstanding lead to different final states. That is, convergence should be understood as an inherently dynamic concept, not to be confused with static similarity—due to heterogeneities and institutional path dependencies, there may exist more than one final state.

The case of RES support policies in the EU illustrates these conceptual propositions very well. First, while there is evidence for (temporary) convergence of RES instruments, RES shares exhibit no absolute convergence—in fact, calls for harmonization of RES support in the EU (arguably the most ‘convergence’ there might be), have the explicit objective of generating *diverging* outcomes (i.e., RES shares) so as to optimize allocation of production capacities following heterogeneous RES potential. Second, there is conditional convergence of RES shares, possibly reflecting this heterogeneity in RES potential. Interestingly, however, there is no evidence for convergence of public R&D expenses, but rather divergence. Hence, in short, whether an analysis of RES policies in the EU finds convergence heavily depends on the object and the benchmark of analysis. Third, the importance of considering both economic and political drivers of convergence becomes apparent from the evolution of RES policies in the EU: Around 2010, absolute convergence towards feed-in tariffs seemed all but imminent when analytically focusing on political processes of diffusion and emulation. Since then, however, feed-in tariffs have begun to decline from their pinnacle, which can be attributed to changing economic drivers. Finally, RES policies may well converge towards different rather than a single final state.

In conclusion, this paper hopes to inspire further empirical research efforts. Acknowledging the multiple dimensions of convergence and particularly the economic conditions of policy convergence, may help to further close the gap between theoretical and empirical literature with many proposed drivers of convergence but less actual empirical evidence (cf. Plümper and Schneider 2009). While a number of empirical case studies link *divergence* to institutional factors (e.g. Kern 2011; Laird and Stefes 2009), the importance of economic factors in explaining disruption of convergence processes and diverging pathways seems to deserve far more attention than it has hitherto attracted. As regards our example of RES policies, their prospective evolution in the post-niche era seems predestined for further convergence/divergence research.

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International Coordination on the Provision of Power Generation Capacity: An Institutional Economic Assessment of Decision-Making Competences in a Union of States

Albert Hoffrichter and Thorsten Beckers

Abstract Transnational cooperation on the provision of power generation capacity can be of great benefit to EU member states. Whether this potential can be realised depends essentially on the allocation of decision-making competences between the EU and its member states, which remains a matter of controversial debate. This chapter is dedicated to studying different options for the allocation of responsibilities in a union of states from an institutional economic point of view. Based on a qualitative examination of different simplified governance models we identify general advantages and disadvantages of national and supranational competences related to the provision of power generation capacity. We find that in some areas such as resource adequacy planning, comprehensive action at the supranational level seems desirable, so as to make full use of cooperation potentials. In other areas, the requirements imposed upon member states can be considered as an ill-conceived use of central decision-making power; this includes, for instance, designing national RES-E instruments and capacity remuneration mechanisms or the use and extension of interconnection capacities. In such cases restrictive binding standards on a supranational level are likely to neglect national preferences and will often turn out to be detrimental to achieving common policy goals. A presumably favourable role of a supranational regulator could be to provide a framework for international coordination and support cooperation initiatives that are implemented on a bilateral or regional level.

A. Hoffrichter (✉) · T. Beckers
Fachgebiet Wirtschafts- und Infrastrukturpolitik, Technische Universität Berlin, Berlin, Germany
e-mail: ah@wip.tu-berlin.de

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1 Introduction

The European Union (EU) represents a supranational association of currently 28 European countries with the purpose of promoting the prosperity level in its member states by means of economic and political cooperation.[1] The creation of an internal market is an essential means of achieving this aim. Reducing trade barriers, the internal market is supposed to help reap the benefits from international division of labour. Against this background, the member states have transferred certain decision-making competences to the EU and its institutions, implying restrictions of the national sovereignties in the corresponding policy areas. "Completing" the internal market remains one of the European Commission's (EC) primary objectives. In many policy areas this means a further convergence of national regulations, which is pushed forward by more extensive standardisation requirements if necessary. At the same time, the question of which concrete competences should be assigned to the supranational level has not substantially lost importance since the signing of the Treaty of Rome in 1957 establishing the European Economic Community (the EU's predecessor organisation). Recent developments and events, the most striking one being "Brexit", clearly demonstrate the crucial importance of the allocation of decision-making powers for the continued success of the EU. Acknowledging that the heated debate on the issue indicates potential shortcomings, the EC itself officially placed this topic high on the agenda by publishing its "White Paper on the Future of Europe" in March 2017. The White Paper presents several scenarios for the EU's future organisation and orientation, whose differences are largely related to variations regarding the allocation of competences between the member states and the EU. Although the EC's initiative aims first and foremost at the union's overall governance structure and policy focus, it can be argued that the allocation of responsibilities for individual sectors and specific detailed questions is ultimately not less important. This certainly applies to the electricity sector, which is a key industry for modern economies like the EU.

In this chapter we compare different alternatives for the allocation of decision-making competences in an interconnected power system of a union of states (like the European Union). We focus on the provision of generation capacity, which represents a crucial matter due to its large share in the overall costs of electricity

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[1] This chapter represents a condensed version of Hoffrichter and Beckers (2018a), which furthermore assesses the current situation in the EU in light of the findings presented in this chapter; besides, it discusses selected market design topics in more detail. The Working Paper Hoffrichter and Beckers (2018a) was prepared as part of TU Berlin—WIP's research activities in the project "Kopernikus 'ENavi', a navigation system for the energy transition" (funded by the German Federal Ministry of Education and Research, BMBF). The analysis incorporates previous work by TU Berlin—WIP carried out within the framework of the project "Effiziente Koordination in einem auf Erneuerbaren Energien basierenden europäischen Elektrizitätsversorgungssystem (EK-E4S)", which was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi); apart from the authors of this chapter, Daniel Weber and Alexander Weber delivered substantial contributions in this context.

supply. The aim of our analysis is to identify governance structures that allow countries to reap the benefits of international coordination without neglecting national preferences or leading to undesirable distributional effects. In particular, we examine the following questions: What are the potential benefits of a coordinated provision of generation capacity in an interconnected power system? How can these benefits be achieved? What are the general advantages and disadvantages of centralised and decentralised decision-making? With these questions in mind, we start off by drawing conclusions from observations made in a simplified industry model environment. The simplification includes that for most parts of the analysis we deal with a very basic set of actors between which responsibilities are distributed, namely: (1) the supranational level (the union of states), (2) the national level (member states) and sometimes (3) the level of market actors (mostly generators). Such an approach certainly does not deliver a suitable basis for immediate assessments of currently applied policies on a very detailed level and, as indicated before, the aim of this analysis is rather to attain a better understanding of the big picture. The findings of our analysis are supposed to help structure the debate on the complex examined topic and can be used as a baseline for assessing governance models applied in practice [as done, for instance, in Hoffrichter and Beckers (2018a)].

The analysis presented in this chapter is based on qualitative economic considerations. We apply insights from a broad range of economic fields, including (New) Institutional Economics (NIE), industrial economics, welfare economics, finance theory, game theory, public choice and fiscal federalism; different new institutional economic theories form the centrepiece of our approach's theoretical foundation. When comparing different governance solutions we mainly focus on their impact on costs. Apart from costs that are directly related to the use of resources in the electricity supply process, we also take transaction costs into account. While overall welfare effects generally play a prominent role in this context, in view of the research subject, the analysis furthermore has a special focus on the distribution of rents, mostly among states, but also between generators and consumers. Besides the cost efficiency objective, we assess how variations in governance models may affect environmental objectives and security of supply. These objectives, on the one hand, can be interpreted as necessary conditions, which must be achieved at least cost. On the other hand, it seems reasonable to acknowledge the obvious trade-offs between the objectives.[2]

In Sect. 2, we present a selection of general economic considerations concerning the topic of this chapter, which serve as a basis for our assessments throughout the subsequent steps of the analysis. This includes, firstly, a discussion of the fundamental mechanisms of international cooperation on power supply and the importance of the prevailing framework conditions. Secondly, we provide an overview of selected market design topics to which we refer later on. Section 3 contains a

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[2] Due to the inherent conflict of objectives, the problems discussed ultimately rather resemble a multi-objective optimisation than a constrained cost optimisation.

conceptual discussion of governance models for the provision of power plants in a union of states. Analysing models with extreme solutions for the distribution of competences as a first step, our major aim in this section is to identify suitable components of a governance model with a well-differentiated allocation of powers and tasks. In Sect. 3.2.2 we conclude with a summary of the main insights from our analysis.

2 Basic Considerations

2.1 Framework Conditions for International Cooperations on the Provision of Power Generation Capacity

International cooperation is an important issue in interconnected power systems like the European one. First of all, a coordinated approach to the provision and operation of power plants offers large cost-saving potential compared to stand-alone actions by each country. Secondly, investment and operational decisions made in one country possibly affect the situation in connected countries (directly or indirectly). In the case of commercially linked power markets, this includes effects on domestic electricity production, market prices and rent distribution, which might not always be desirable from the perspectives of each country involved. Since technical interdependencies exist regardless of trade agreements, decisions in neighbouring countries might have significant implications for a power system, even if there is no commercial connection. As the occurrence and size of (positive or negative) effects highly depends on the initial situations in the countries involved, it is important to take the prevailing conditions for cooperation into account when assessing the favourability of coordinated solutions. It seems logical that, in principle, all these aspects should be considered when pursuing a goal like the “completion” of the internal energy market. In the following subsections, we elaborate on some general potential benefits and drawbacks of cooperation on the provision of generation capacity in the European power sector, which will be essential for the subsequent steps of the analysis.

2.1.1 Potential Benefits of a Coordinated Provision

The magnitude of benefits that international cooperation offers depends on the initial situation in the electricity sectors of the countries concerned, including their respective national power systems, institutional frameworks and policy agendas. It could be argued that the potential benefits of coordination are, in general, even more obvious in the power sector than in some other areas, which can be explained by the following aspects:

- **Security of supply (provision of highly reliable plants):** Electricity is a good with peculiar characteristics, one of the most striking ones being that demand must always be matched by a simultaneous production of the required power volumes (including the infeed from electricity storage systems and taking account of possible adjustments on the demand side).[3] A system's guaranteed capacity, therefore, has to be sufficiently high to cover peak demand. As the load varies considerably over time and very high volumes are reached only rarely, some plants (usually the ones with high variable costs) typically function as reserve plants with a low utilisation rate. Given the fact that both changes in demand and the availability of power plants are not perfectly correlated across countries, a coordinated provision of plants promises significant cost savings; especially since fewer reserve plants are needed (which go along with particularly capital-intensive investments).[4] Although, for reasons of simplicity, we exclusively discuss resource adequacy issues in the following, it is important to point out that security of supply has several further dimensions, which partly also require coordinated action in an interconnected system (e.g., related to the task of frequency control during operation).[5]
- **RES-E expansion (provision of RES-E plants):** The cost and value of intermittent RES-E (electricity from renewable energy sources) production highly depends on the plants' location. Concerning the deployment of RES-E plants at a large scale, joint action of countries—especially in an interconnected system—is of great importance. Besides the fact that climate protection requires cooperation on an international (and ultimately global) level, a wider distribution of intermittent RES-E plants across a large system leads to more stable generation, since local infeed patterns vary. This is likely to increase production values and reduce the need for reserve plants. Furthermore (and somewhat opposed to the aspect addressed before[6]) cooperating countries may decide to use the best locations for RES-E plants, irrespective of national borders.

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[3] At this point in time, existing storage systems in Europe can only cover a small share of the aggregate load. Even though storing electricity might play an important role in replacing conventional plants in the future, in the following we do not explicitly distinguish between electricity generation in power plants and infeed from storage as it would increase the complexity without substantially affecting our main lines of argument and thus the findings. Furthermore, it is worth mentioning that, in principle, electricity demand can also be adjusted to a certain degree. Although in many power systems around the world the possibilities to make adjustments on the demand side have been improved over recent years—mostly due to increased regulatory efforts—short-term flexibility is generally still subject to significant limitations.

[4] The particularly high capital intensity of reserve plants is mostly due to their lower utilisation rates which go along with lower fuel costs. The same applies to intermittent renewables, whose production does not involve any fuel costs. Cf. for instance Neuhoff et al. (2015).

[5] Cf. for instance Joskow (2006).

[6] Installing RES-E plants at the most suitable locations with respect to production costs might lead to a higher spatial concentration, which is detrimental to the stability of the aggregate RES-E infeed.

- **Operation (plant dispatch):** The fact that electricity, unlike most other goods, can be transported promptly over long distances helps in meeting the challenge of accurately synchronising production with demand. Whenever power plants on the other side of a national border can contribute to satisfying demand at a lower cost than available domestic plants, interconnection and cross-border trade offer the potential to increase resource efficiency. For this, power systems have to be not only physically, but also commercially linked, which means that use is made of existing cross-border capacities to trade electricity volumes between national markets. In this context, the merit-order curves, which rank available plants according to their marginal costs of production, are combined across power systems as far as transmission capacities allow for this.[7]

In the following subsections, we discuss, among other things, obstacles to the realisation of benefits from cooperation in interconnected power systems.

2.1.2 Relevance of the Initial Situation and Heterogeneity Between Cooperating Countries

Among the important factors for an assessment of concrete cooperation opportunities, the grid capacity situation is particularly relevant, since it is responsible for the extent of interdependencies between power systems; this applies both to benefits and to undesired effects. While interconnector lines between the countries play the most obvious role in this context, it is also important to take potential hinterland transport bottlenecks into account. Furthermore, the grid situation determines the suitability of congestion management methods and, related to this, the necessity for active regulatory involvement in the process of selecting sites for new generation projects. Similarly, the suitable design of a country's institutional mechanisms for the provision of power plants depends on the existing domestic power plant fleet (in Sect. 2.2 we will take a brief look at some basic mechanisms for the provision of power plants and for congestion management). Different national power plant fleets might sometimes complement each other in some ways and thus be a source of cooperation benefits. On the other hand, a highly advantageous compatibility of generation fleets might not be given in each case. Indeed, the effects resulting from connecting power systems or intensifying existing linkages might sometimes be considered undesirable, which can impede collaborative action (we outline a few possible undesired effects in Sect. 2.1.3).

Apart from the technical system aspects mentioned, national regulations (in particular the electricity sector design) might affect the practicability of

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[7] In practice, the merit-order curve is based on the information transmitted to the system operator; usually by means of bids from the generators. In case of strategic bidding behaviour (which, for instance, often appears when generators have market power) the generators' bids might contain mark-ups and, therefore, the merit-order curve might not accurately reflect the plants' marginal costs.

cooperations. Sometimes national mechanisms for the provision of generation capacity diverge substantially and have a low degree of compatibility. The same applies to the procedures of system operation; e.g., grid-related differences, such as diverging methods of congestion management, might play a role in this context. The ownership situation of domestic power plants, which we touch upon in the following subsection, is yet another factor that can potentially affect the evaluation of cooperations.

2.1.3 Distributional Effects and Externalities

Externalities, which sometimes involve distributional effects, occur in interconnected power systems in many forms and for many reasons. As mentioned above, such effects are related to both physical and commercial links.[8] If national markets are linked, generation investment and decommissioning decisions can potentially affect the utilisation rate of plants as well as wholesale market prices across national borders. If the remuneration of generators relies on market revenues, such effects are potentially essential from an investor's point of view. Market price changes also matter to the demand side if they directly or indirectly affect the level of consumer payments; as mentioned above, the ownership situation might play a role in this context. In some countries the generation assets are majority-owned by the state, whereas in other countries private ownership prevails. If entering into cooperation leads to, for instance, higher domestic market prices—such effects are discussed in more detail in the following section—the assessment from a consumers' perspective might be rather positive in cases in which the plants are public property (because higher consumer payments are, in principle, offset by higher public revenues). An example of cross-border effects that also occur in the absence of market connections is the occurrence of voluminous loop-flows, as was the case with the large-scale development of wind farms in nothern Germany whose production—due to inner-German grid restrictions—interfered with the country's eastern neighbours' grids.[9] Instruments to counter undesired cross-border effects (i.e. negative externalities) include institutional and technical grid congestion management measures, which we will address in Sect. 2.2.2.

2.1.4 General Advantages and Disadvantages of Centralising Decision-Making Powers: A Differentiated View on the EU's Aim of Completing the Internal Energy Market

Enshrined in the EU primary law, the full functioning of the internal market represents one of the Union's overarching goals. Steadily developing the Europeanisation of power markets by enforcing the convergence of national regulations goes along

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[8] For an exemplary discussion and model-based illustration of distributional effects related to cross-border network extensions cf. Gerbaulet and Weber (2018).

[9] Cf. Kunz (2018).

with a high degree of centralisation in decision-making. On the one hand, the member states are substantially involved in European legislative procedures. On the other hand, the countries did forgo certain decision-making powers by transferring them to European institutions. In consequence, decisions made on the supranational level might not always be in line with individual interests. Since the relevance of this aspect depends on the very topic of centralised decisions, we take a brief look at potentially important factors in the following.

As pointed out above, cooperation offers great benefits in certain areas of electricity supply; in some cases an advanced internal market might be a suitable framework for reaping those benefits. Concerning the operation of generation units, for instance, a high degree of centralisation seems to be beneficial overall (a transnational approach to the dispatch of plants improves the possibilities for using the most cost-efficient production factors available to cover demand; see Sect. 2.1.1). Regarding operation, it seems appropriate to rely on market-based organisation as a convenient way to gather distributed information on current availabilities and costs of the plants. In a market system with multiple supply and demand side actors—which we assume throughout our analysis—the spot market, among the different segments of the wholesale market, is ultimately responsible for dispatch decisions (future and forward markets, by contrast, mainly serve to hedge the positions of supply and demand side actors over the medium and longer term). Ideally, the spot market's marginal cost-oriented selection and pricing mechanisms ensure a dispatch that, in the short run, leads to the lowest possible resource use. A high degree of centralisation might prove helpful in this context, since largely harmonised operational rules throughout the countries are a precondition for an optimisation across borders. Although the described synergy effects rely on the linkage of markets, this does not—for the reasons mentioned in the previous sections—imply that an increase in interconnector capacities, let alone a situation of no bottlenecks at the borders, is desirable.

As mentioned above, there is also a significant potential for synergies in the provision of generation capacity, concerning both intermittent RES-E as well as highly reliable plants that ensure security of supply. In Sect. 2.1.1 we suggested that possible advantages in this area, especially synergies resulting from portfolio effects with respect to the usage of generation capacity and infeed of RES-E plants, partly originate from differences between states. Heterogeneity among countries, however, might also lead to barriers to cooperation and to problems of centralised decision-making. Uniform rules, firstly, might neglect diverging preferences and, secondly, cannot always adequately take different local circumstances into account. If, for instance, the attitudes towards the usage of certain generation technologies diverge substantially between countries, there are good reasons for leaving decisions relating to the generation mix up to each state (as it is generally the case in the EU). Consequently, further central requirements placed on countries in a union of states should not dramatically affect their technological choices. By contrast, it might be very reasonable in some cases to seek consensual agreements on individual contributions to the achievement of common goals; this is especially likely with respect to objectives that necessarily require joint action, such as climate protection.

When assessing institutional solutions, it is important to also take transaction costs into consideration, because they might partly offset or even exceed the achievable benefits of cooperation. Transaction costs go along with, for instance, designing, implementing, monitoring and adapting (new or existing) governance models.[10] Costs of capital, which are associated with financing investments and risk bearing in this context, can also be regarded as transaction costs (in this chapter we do not consistently distinguish between cost categories such as production costs and transaction costs, because a clear classification is not always possible). Furthermore, transaction costs related to the political process of a reform can also be regarded as a relevant aspect for the practicability of measures. To give an example, considerable resistance from national states or from influential lobby groups against centralised decisions might not only reduce the achievable net gains of a measure; sometimes it might go along with alternations of the original concept and thus different effects of the measure than initially intended. Moreover, distributional effects implicated by centralised measures might give rise to laborious negotiations if the countries are involved in the legislative process (or if they can, at least, influence it—if not, undesirable distributional effects might cause further problems, as outlined above). If the countries are involved in decision-making, the amount of transaction costs of reforms is interrelated with the level of heterogeneity in the countries' preferences and objectives. Usually it will be easier to impose new rules when the supranational regulation promotes goals which are shared by all states. In cases in which central measures that promote coordination do not conflict with individual objectives, there is a very clear case for their implementation.[11]

Up to this point, for simplicity, our discussion on centralised and decentralised decision-making has focussed on the two extreme opposite solutions of (1) uniform rules for all member states established on the supranational level and (2) stand-alone actions by each country. Between those two options there is a continuum of conceivable solutions which all involve some form of coordination of national actions. In such differentiated governance models the standardisation of regulations, for instance, might be limited, leaving a certain part of decision-making powers to the national states. Moreover, centralised measures do not necessarily need to apply to each state, but only to a group of countries. Although at certain points of the following sections we refer to the extreme solutions again (especially in Sect. 3.2), the analysis is ultimately targeted at an assessment of differentiated governance models.

2.2 *Overview of Selected Market Design Topics*

As mentioned above, centralised decisions on the supranational level might affect market design choices on the national level; moreover, a great heterogeneity in national market designs might impede international collaboration. In this context,

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[10] Cf. Ostrom (1990), who distinguishes between so-called “transformation costs” and “monitoring and enforcement costs”.

[11] For a detailed discussion of the content, cf. Hoffrichter and Beckers (2018b).

both the institutional framework for the provision of power plants and the approach to managing grid congestions play important roles. This section summarises the results of more detailed analyses on these topics presented in Hoffrichter and Beckers (2018a) and Hoffrichter et al. (2018).

2.2.1 Institutional Framework for the Provision of Power Plants

Institutional frameworks for the provision of generation capacity always consist of complex structures of rules, which are often embedded in several different legislations. Designing the institutional framework involves a very large range of interdependent decisions and is therefore a complicated issue. Although seemingly minor design elements may sometimes strongly influence the practical overall functioning of a mechanism, some essential conclusions can usually also be drawn from comparing rough overall concepts. Two opposite approaches to the provision of generation capacity are often considered to be the basic alternatives for the organisational model's framework; namely: the so-called "energy-only market" (EOM), and capacity remuneration mechanisms (CRM).

The core idea of the pure EOM approach is that the provision of generation capacity is based on the interaction of supply and demand side actors on liberal wholesale and retail markets. This means that investment decisions and, virtually, the responsibility for resource adequacy are decentralised and put into the hands of (typically private) market actors. Revenues for generators to recover their investments predominantly arise from sales of energy volumes.[12]

In the literature and in the debates on electricity sector design, the term "capacity remuneration mechanism" and similar terms (such as "capacity market" or "capacity instruments") are not used consistently; they often refer to specific institutional mechanisms related to power plant investment and operation, substantially differing from case to case. In this chapter, when using the term "CRM", we refer to a broad category of organisational models for the provision of generation capacity which all have certain core characteristics in common: The regulator makes a (more or less detailed) decision on which plants or types of plants should be provided. This decision is implemented by (usually private) generators, who build and operate the plants according to the corresponding specifications provided by the regulator (which can be regarded as part of the CRM design); in this context the generators (explicitly or implicitly) enter into contracts with the regulator. The successful execution of the tasks is remunerated according to the rules laid down in the regulatory contracts. At least an essential share of the remuneration payments consists of relatively certain revenues that are not subject to great market risks. Using this definition, we consider all targeted regulatory instruments for the provision of certain plants (e.g., RES-E support instruments) as applications of the CRM approach.

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[12] Besides, further streams of income, such as revenues from contracts on the supply of ancillary services (e.g., control reserve) might be available to generators; with respect to the overall findings presented in this section, they do not play a very important role.

In principle, the EOM approach seems to fit naturally into the idea of an internal electricity market. However, in combination with liberal wholesale and retail markets, it is a very unusual concept for the provision of durable, capital-intensive specific investments, exhibiting some structural drawbacks that, among other problems, lead to a high cost of capital. A properly designed CRM scheme (including properly designed RES-E support instruments) allows for generation investment at considerably lower costs. To which extent potential benefits can be realised highly depends on the knowledge of the regulator who is planning and administrating the set of instruments.[13]

2.2.2 Approaches to Internal and Cross-Border Grid Congestion Management

A second element of the institutional framework that we will refer to during the subsequent analysis of governance models is the approach to managing grid congestions. This topic has numerous facets and there are plenty of conceivable solutions; in the following, we focus upon a few selected issues and instruments.

Grid congestion is a common phenomenon in many power systems and most regulators do not, in principle, aim to completely eliminate it. Existing congestions imply that it is sometimes necessary to depart from the rule of dispatching plants strictly in order of their marginal costs. How exactly this is done in practice depends on the applied procedure. Two typical methods of handling congestion issues are redispatch and the implementation of different price zones within a power system.[14] While redispatch is usually not supposed to influence the choices of market actors, price zones may affect locational decisions of plant investors; however, in an EOM environment the effectiveness of steering signals is unclear due to the high uncertainty regarding future developments.

When discussing the topic of congestion management, interconnectors between countries are particularly relevant, which, inter alia, has to do with distributional effects (see Sect. 2.1.3) as well as the impact of interconnections on a country's sovereignty over its national generation mix (we go into this issue in more detail in Sect. 3.2.1.2.3). Furthermore, in case of relevant grid bottlenecks within the power system of a country, problems associated with transport restrictions might be exacerbated by cross-border electricity exchange. If any undesirable effects appear, countries might consider a limitation of the transmission capacity. Although there

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[13] Cf. Hoffrichter and Beckers (2018a) and Hoffrichter et al. (2018).

[14] Redispatch means that in a first step, market interactions between supply and demand side actors happen without taking account of transport restrictions. Whenever the market results are not compatible with the grid's transport capability, the production of some plants, in a second step, is replaced by the production of other plants (with higher marginal costs) on the other side of the transport bottleneck. This centralised process is usually managed—more or less manually—by the system operator (on behalf of the regulator) and carried out in a way that affects market actions as little as possible.

are possible reasons against taking this step, it might sometimes represent a practicable solution to complex problems.[15]

3 Discussion of Conceivable Governance Models for the Provision of Generation Capacity in a Union of States

3.1 Overview of the Simplified Analysis Framework and Corner Solutions of Governance Models

Our goal in this section is to identify general findings regarding the suitability of governance models for the provision of generation capacity in an interconnected power system. As mentioned in the introduction, we do not refer to the current situation in any real power system. Instead, we detect and discuss interdependencies in a simplified model environment that play a role for determining which decision-making competences should be assigned to the supranational level, the national level or to the decentralised coordination of market actors. Our qualitative model framework features a union of states with (at least partly) interconnected national power systems. While we openly discuss different approaches for the provision of generation capacity—which vary with respect to their compliance with the EC's internal market ideas—we assume throughout the analysis that dispatch decisions are primarily based on the coordination of market actors (which does not preclude any necessary central redispatch measures). In order to systematise governance models for the provision of generation capacity, we start by using two dimensions:

- Centralised vs. decentralised market design; i.e., a uniform market design for all states established on the supranational level vs. decentralised competences to create national market designs
- Planning vs. competition: With these (intentionally simplistic) keywords, we refer to concepts for the provision of power plants that are either based on the EOM or on the CRM approach (as described in Sect. 2.2.1) and thus they are characterised by a different distribution of decision-making powers between the (national or supranational) regulators on the one hand and market actors on the other hand

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[15] Recalling the example of excessive loop-flows in the power systems of Germany's eastern neighbours (see Sect. 2.1.3), one solution that was discussed extensively was to split the uniform price zone of Austria and Germany into (at least) two parts to better align decentralised trade decisions with the reality of the grid. However, the acute problems were tackled in the end by installing phase shifters at the national borders to physically prevent the unwanted electricity flows. On a side note: It is, in principle, conceivable that the measures taken were partly or even predominantly based on motives other than the loop-flow problem (such as protecting domestic power instustries from competition); in this chapter, we do not discuss this issue in more detail.

In a first step, we interpret these dimensions as binary variables, which leads us to four options for governance models for the provision of generation capacity (which are referred to as "corner solutions" hereinafter):

- "Transnational EOM": International regulations, such as the competitive framework, are designed on the supranational level; investment decisions are made by individual investors based on market interactions
- "National EOMs": National regulators design their own institutions (such as organised markets), which might consequently vary from state to state; investment decisions are made by individual investors based on market interactions
- "Supranational CRM": Central planning on the supranational level
- "National CRMs": Decentralised planning at member state level, including a possible coordination of individual actions by means of international contracts

In the subsequent section, we start our analysis by taking a look at these extreme corner solutions to carve out the most striking differences. Building on this, we adapt the restrictive assumptions and discuss more differentiated (and thus arguably more realistic) models.

3.2 Advantages and Disadvantages of Centralised and Decentralised Governance Models

3.2.1 Assessment of Corner Solution Models

In the following Sect. 3.2.1.1 we take a look at the two corner solutions with a centralised market design approach. Afterwards, Sect. 3.2.1.2 deals with the decentralised models. Apart from the two basic decentralised alternatives mentioned before, we discuss several variations of the corner solutions, because there are various conceivable cases which differ considerably with respect to the expected performance of the model.

3.2.1.1 Centralised Market Design Decisions

3.2.1.1.1 Centrally Designed Competition: "Transnational EOM"

Model Description

In the "Transnational EOM" model all relevant decision-making powers related to the provision of generation capacity as well as to grid investment and cross-border power exchange are centralised. However, as far as the provision of generation capacity is concerned, the central planner only uses its authority to establish a competitive framework. The final investment decisions are decentralised and left to the market actors; i.e., generators invest in power plants based on their individual expectations on attainable contribution margins from future sales of electricity volumes.

When examining models based on the EOM approach, it is important to discuss the exact role of the regulator. In the following, we start by assuming a very pure application of the EOM ideas. This means that the regulator's only concern is to ensure effective competition, while regulatory specifications regarding the market actors' tasks are confined to a minimum.[16]

Model Assessment

The desired main advantage of the EOM approach is to make full use of all dispersed knowledge and thus render superfluous any extensive regulatory involvement. The idea is that market prices guide generators to reasonable investment decisions with respect to the technologies and locations of power plants. In combination with cross-border trade between the national wholesale markets, which is facilitated by standardised operational procedures, investor decisions should ideally lead to a realisation of large portfolio effects regarding security of supply and RES-E production values. However, the importance of dispersed knowledge depends on the specific decision and situation. Sometimes a great share of the relevant knowledge is only available at a central level, thus there is no case for assigning the respective decisions to market actors in the first place. Generators typically have advantages with respect to knowledge of details on project development and implementation. As far as general questions (regarding, for instance, the provided aggregate generation capacity, the technology mix or the regional distribution of power plants) are concerned, central decision-making often seems more appropriate. But even in cases where decentralised decision-making is potentially conducive to efficiency, it does not always lead to desirable results: Firstly, it is questionable whether EOM market signals comprise all information that is relevant with respect to costs and benefits from an overall system perspective. Secondly, in the light of an uncertain environment, market signals might not be powerful enough to influence investment decisions. And finally, effective coordination between large numbers of decentralised decision-makers in electricity markets is often hampered by transaction costs. This can lead to problems in the following areas (hereafter, the main aspects are presented in a condensed form; see Hoffrichter and Beckers (2018a) as well as Hoffrichter et al. (2018) for more detailed descriptions of the underlying interdependencies):

- **Security of supply:** When applying an EOM approach, the provision of sufficient generation capacity might be endangered by the fact that virtually no actor or group of actors is directly responsible for resource adequacy.[17] The high revenue uncertainty discourages investments in general. Even if generators are, in principle, willing to undertake investments under such circumstances, it will be even

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[16] In the course of the assessment, we consider additional regulatory measures to take account of emerging issues, which lead to more moderate applications of the EOM concept that feature an advanced scope of centralised regulatory action.

[17] As stated in Sect. 2.1.1, in this chapter we focus on resource adequacy when discussing security of supply issues.

harder in a “Transnational EOM” than in a single-country setting to make credible regulatory commitments not to interfere in situations of increasing scarcity and thus allow for high market prices and contribution margins. This would require that neither the supranational regulator nor individual states intervene when security of supply is at stake. In a union of states it is a common phenomenon that countries effectively opt out from mutual agreements as soon as they consider national interests—such as a certain security of supply level—threatened. Since national measures are likely to affect the functioning of the EOM’s mechanisms across borders, it is particularly difficult for investors to trust in the credibility of commitments made on a supranational level. Consequently, the incentives to provide generation capacity further decrease. Centrally applied instruments like the regulatory procurement of reserve capacity (often referred to as “strategic reserve”) could, in principle, serve to effectively tackle acute generation capacity shortages. However, they do not solve the general problems mentioned above. Moreover, the compatibility with the EOM approach is questionable.

- **Technology mix:** In a centrally designed and administrated EOM scheme, individual member states have little influence on which plants are used to serve the load. The disregard of national preferences might lead to certain problems, which we further elaborate on when discussing the “Supranational CRM” model, for which this aspect is particularly important. Apart from this, individual investment decisions in an EOM can generally not be expected to lead to a power plant fleet that serves the load at least cost, due to problems of coordination between decentralised market actors. In particular, this hampers the expansion of new technologies. In case of ambitious climate or other environmental targets in the union of states, somewhat EOM-compatible instruments such as cap and trade mechanisms might at first sight appear to be a suitable means for promoting a shift towards a low carbon generation system. However, the perceived advantage of fully incorporating all decentralised knowledge might not compensate for the drawbacks of the approach.[18] The decision whether certain abatement options should be employed over the following years must be made based on the information available at that respective point in time. It can be assumed that market actors will rarely exclusively possess the bulk of knowledge needed for ranking alternative abatement options. Usually regulators will not be any less capable of assessing whether certain measures form an integral part of the solution. If, for instance, a large-scale development of RES-E plants is considered reasonable, there is no point in exposing RES-E investors to high risks, as is typically the case when the choice of instrument is focussed on EOM compatibility. The implementation of targeted instruments that create appropriate investment conditions for RES-E technologies seems highly preferable.
- **Spatial distribution of plants:** The spatial distribution of plants matters for the cost of electricity supply and system stability. The EOM mechanism itself does not convey any locational signals to generators. Against this background, in a

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[18] Cf. Hoffrichter et al. (2018) and Hoffrichter and Beckers (2018a).

large interconnected system there are, in general, particularly good reasons for an implementation of different price zones, which reflect network constraints. However, zonal prices are likely to be inadequate to induce decentralised investment decisions that substantially improve efficiency in the long-run; besides, the smaller the market areas are, the higher the danger of market power, which might lead to undesirable distributional effects. Ideally, zonal price differentials accurately reveal short-term grid constraints. This information, however, is usually insufficient for forecasting long-term price gaps, let alone the optimal distribution of plants across the system. In some cases decentralised investment choices might, in principle, create a need for a more direct regulatory influence on the spatial distribution of plants; on the other hand, such measures tend to contradict the core ideas of the EOM concept.

- **Distribution of rents between generators and consumers:** Rent distribution is a general issue in EOMs, since the market mechanisms by no means consistently lead to risk-adequate investment returns. Furthermore, the cases in which an EOM may function over a longer period usually involve sustained market power on the supply side, which implicates the typical drawbacks from the consumers' perspective. In a large interconnected system, there might also be a number of powerful suppliers (especially if there are different market areas with persistent transport bottlenecks in between). Since such a market environment is very convenient for powerful suppliers, they might aim at influencing the regulator to maintain the current framework. In a "Transnational EOM" with several local incumbents, it would make sense from a supplier's point of view to join forces and (also) represent the common interests collectively. It is not hard to imagine that under such circumstances it might be more difficult for the regulator to implement reforms that are reasonable from the consumers' perspective if they undermine the position of incumbent suppliers.
- **Distribution of rents between member states:** In the "Transnational EOM" model the rents of consumers and producers in individual countries largely depend on investor decisions. They result, for instance, from decisions on the location or on the technology of plants, both of which can not be influenced by member states. Undesired market outcomes might lead to a low acceptance of the applied approach by individual countries. Compensatory measures could generally be a way to resolve conflicts, provided that apparent disadvantages for certain countries are acknowledged by the regulator or by the other member states. However, as we go on to discuss in the following section, meeting this condition is not easy in all cases.

To sum up, in a "Transnational EOM" the achievement of the underlying objectives is endangered by a range of significant potential problems. While some effective countermeasures are fairly compatible with the EOM approach, in other cases the basic principles of the model—especially the key role of independent investor decisions—are violated. Designing market structures or complementary instruments in order to guide investor decisions towards desirable outcomes could possibly be regarded as a somewhat hybrid solution. On the other hand, it often requires a deep centralised knowledge of the power system, market situations and institutional mechanisms. Under such circumstances more direct centralised planning usually seems preferable.

3.2.1.1.2 Centralised Planning: "Supranational CRM"

Model Description

Just like in the model discussed before, the relevant decision-making competences are centralised in the "Supranational CRM" model. In this case, however, the supranational regulator uses its authority to make a large share of substantial planning decisions on the development of the power system by itself. Generation assets are provided by investors who receive remuneration payments according to the centrally established requirements, which are generally identical across national borders. In this context, it is usually conducive to efficiency to allocate certain selected risks to generators, but overall, the volume of remuneration payments is less uncertain than in the EOM model.

The reasonable level of detail in the centralised system planning depends on the distribution of knowledge between the actors involved and thus varies from case to case.[19] This means that central decisions regarding, for instance, the usage of certain generation technologies or the spatial distribution of plants might sometimes be rather general (which leaves the implementing actors with more flexibility) and in other cases more specific (which means a limited scope of action for generators).

Model Assessment

The possibility of performing an integrated system optimisation is a major advantage of centralised system planning. The central regulator can compare the costs of multiple generation and grid scenarios and identify the best solution without having to regard national borders as binding constraints. In this way, it is possible to directly include and realise portfolio effects related to the spatial distribution of power plants across the system. This applies both to security of supply issues and to RES-E infeed (see Sect. 2.1.1). A further advantage with respect to security of supply is that free riding—unlike in decentralised models as we discuss below—is usually not a problem in a centralised CRM.[20]

A potential disadvantage of the "Supranational CRM" model is that a centralised optimisation might not take national differences adequately into account. For one thing, this applies to the design of the CRM's instruments (e.g., RES-E support schemes). The initial situations might differ significantly between the countries and one overarching instrument design might not be suitable in each case. Secondly, central decisions might not be able to meet diverging national preferences, e.g. with

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[19] Cf. Hoffrichter et al. (2018).

[20] Security of supply generally shows essential characteristics of a public good. In this context, individual states in an interconnected power system might be incentivised to minimise their own efforts in providing guaranteed generation capacity, if they can rely on other states to carry this burden.

respect to the use of certain generation technologies or the desired security of supply levels. Furthermore, decisions on the supranational level often imply a certain distribution of costs and benefits between the countries, which can be the subject of criticism from the member states (see the discussion of the "Transnational EOM" model above). While in an EOM setting, member states might attribute undesired effects to the mechanisms of the chosen model and thus be rather willing to tolerate them up to an extent, adverse effects resulting from decisions by the supranational regulator may be more likely to arouse great resistance from the countries. Although it is generally possible to address such problems with corresponding centralised measures, an exhaustive compensation of all distributional effects within a large system is usually not feasible, because it goes along with significant transaction costs.[21] But also a lack of compensation measures might induce substantial transaction costs if it leads to substantial resistance on the member state level against the supranational regulator's decisions.[22]

A crucial factor for the successful application of a "Supranational CRM" model is the knowledge of the central regulator. The more know-how and information the regulator has, the better he can make reasonable decisions with respect to system optimisation, instrument design and taking account of national specifics. Since usually part of the relevant information originally represents decentralised knowledge, the costs of centralising this knowledge can be decisive. In some cases the incorporation and operationalisation of decentralised knowledge will be a major barrier for the successful implementation of a "Supranational CRM" model.

3.2.1.1.3 Cross-Cutting Aspects and Summary

There is a vast range of design options regarding the institutional framework for the provision of generation capacity. The suitability of certain institutional solutions is often not completely obvious beforehand, but partly revealed during practical application. The parallel application of several different approaches might therefore improve the knowledge on mechanisms and interdependencies. Since centralised governance models establish one specific standard, learning effects will typically be rather small and there is little room for institutional innovations. Especially in case of a high uncertainty with respect to the suitable institutional framework, "competition" between regional authorities might lead to lower costs than a repeated process of evaluating and adapting one common design.[23]

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[21] For a discussion of how external effects (or "spill-overs") can be taken into account using the fiscal federalism approach, cf. Oates (1999).

[22] Member states might, among other options, use their remaining national competences to impede the implementation of centralised decisions. In order to prevent, for instance, the development of new plant projects in its territory, a country could theoretically use (local) spatial planning or environmental instruments. Effective resistance, however, does not necessarily require the existence of national competences. Cf. in this context Hirschman (1970), who describes how the compulsory character of a collective is determined by the amount of existing "voice and exit options".

[23] Cf. the considerations on "laboratory federalism" in Oates (1999).

The analysis of the "Transnational EOM" model demonstrated various severe problems, which seem to outweigh the potential advantages over the "Supranational CRM" model. As a consequence of this, we do not further consider the "Transnational EOM" model in the remainder of this analysis. The "Supranational CRM" model has several potential advantages. But, firstly, they are subject to meeting certain preconditions and, secondly, there are also some clear disadvantages. Centralised decision-making on a supranational level generally allows for integrated system planning and thus the realisation of optimisation potential in an interconnected power system. Sufficient centralised knowledge is necessarily required for making reasonable planning decisions. The incorporation of dispersed knowledge by designing the right framework for actors who carry out decentralised tasks may be regarded as the key challenge. One potentially important problem in the "Supranational CRM" model is that it might fail in adequately taking account of national differences and distributional effects between the countries.

3.2.1.2 Decentralised Market Design Decisions

3.2.1.2.1 Outline of the Array of Decentralised Corner Solutions

In the following, we discuss decentralised corner solution models, which are all based on the common principle that basically no decision-making powers are transferred to the supranational level. For simplicity, we examine a model environment with only two neighbouring countries whose power systems are physically connected. The national regulators have all relevant competences and may, regarding the national market design, each decide between a national system planning (national CRM) or a national EOM; if an EOM is applied, there are no additional instruments for the provision of capacity in that country. This leads to three possible settings:

(A) Both countries apply a CRM
(B) One country applies a CRM; the other one applies an EOM
(C) Both countries apply an EOM

Besides, we differentiate between settings in which the two countries actively cooperate with respect to electricity supply related decisions and settings with no such cooperation. In the following we assume that cooperating countries enter into more or less formalised interstate agreements for this purpose; especially in cases of good international relations, a coordination of actions sometimes works without explicit contracts. The alternative to active cooperation is that each country basically acts on its own without bilateral consultations. Since cooperation requires a consensus of both countries, there are only two alternative cases:

0. No cooperation
1. Cooperation

The combination of market design and coordination options results in six variations. In the subsequent sections we discuss the first model variations in more detail than the latter ones, because many interdependencies appear similarly across several model configurations.

3.2.1.2.2 Cross-Cutting Aspects

Before we take a closer look at the six individual cases, we outline two effects which are possible key reasons to engage in cooperations in the first place. These effects are related to the potential benefits of cooperation, as described in Sect. 2.1.1, and play a certain role in all model variations:

- **Free rider problems:** The less transmission capacity between the two countries is restricted, the more features of a public good (with regard to the overall interconnected system) security of supply exhibits. The possibility to rely on capacity abroad in scarcity situations might compromise the willingness to make own investments in order to guarantee resource adequacy.
- **Realisation of cooperation benefits:** If free rider problems are ruled out but there is no cross-border coordination, both countries would independently build up electricity systems that allow for self-sufficient supply. Aligning national actions in consideration of the opportunities and plans in the respective neighbouring country, by contrast, offers cost-savings with respect to security of supply; the same applies to RES-E production (see Sect. 2.1.1). Bilateral coordination theoretically allows for a system optimisation across national borders. However, as we show in the following sections, problems regarding the distribution of costs and benefits might sometimes limit the amount of achievable gains from decentralised cooperation.

3.2.1.2.3 Examination of Variations of Decentralised Corner Solutions

Model Variation (A.0): Uncoordinated CRMs

In the case of two independently applied CRMs, the free rider problem described above might appear; i.e., one country might decide to save costs by relying on imports instead of providing sufficient capacity to cover its own load. Such behaviour can be prevented if the other country is able to unilaterally reduce cross-border transmission capacities and thus impede exports. Undesired effects might not only result from deliberate strategic behaviour, but also from a neglect of externalities caused in the neighbouring country. Individual countries might, for instance, not adequately consider loop-flows or—to give a more drastic example—potential damages in case of nuclear accidents, because they first and foremost consider effects on their own national goals (such as effects on national welfare or on internal rent distribution); it is possible in some, but not all, cases to inhibit such effects by taking unilateral actions. Similarly, potential positive cross-border effects (such as contributions to security of supply in the neighbouring country) are typically not fully taken into account if there is no active cooperation.

If the existing interconnection capacity is used for electricity exchange, the countries partly forfeit their sovereignties over the national generation mixes, which are used to serve the load. Since the national merit-order curves are merged to a certain extent, investment and operational decisions in the respective neighbouring state influence how often certain plants are dispatched (see Sect. 2.1.1). However, the possibility to decide upon the volume of cross-border flows enables the countries to prevent undesired external effects; this means they have the option to ensure that their national preferences are met. Considering the lack of active cooperation, it will be possible to realise portfolio effects (related to security of supply and RES-E infeed) only to a small degree in model variation (A.0). If one of the countries or both decide to restrict the use of existing cross-border capacities, the benefits from system interconnection will further decline.

Model Variation (A.1): Coordinated CRMs

Active cooperation of the two countries in order to realise cooperation benefits might include joint planning regarding electricity supply and possibly an alignment of national CRM reglementations. In particular, the cooperation might comprise the following aspects:

- **Requirements on the provision of generation capacity in both states.**
- **Rules for cost and benefits sharing:** In some cases, the implementation of rules for cost and benefits sharing could be considered reasonable. This is particularly likely if generation capacity is distributed disproportionally between the countries (which might, for instance, be the result of cost-driven optimisation decisions). Furthermore, the countries might have an interest in arranging for the compensation of distributional effects that arise from the cooperation. However, the accurate detection and quantification of such effects will often be complicated and thus—especially when taking the corresponding transaction costs into account—not always feasible.[24] The same applies to further effects such as negative externalities related to the construction of power plants or positive externalities related to employment effects.
- **Agreements on the use of certain generation technologies.**
- **Implementation of a common CRM:** The countries could possibly also aim at implementing and operating a common CRM scheme, instead of applying two national mechanisms in parallel. In this case, there are numerous decisions to make and issues to solve, which we do not discuss in detail in this chapter.

The listed aspects show that an ambitious coordination of national CRMs might go along with considerable transaction costs. Especially if cooperation entails complex effects and a fair distribution of costs and benefits is considered indispensable, the transaction costs might sometimes be prohibitive. Under such circumstances cooperation with respect to only certain aspects, which are not subject to major problems, seems quite feasible, although the amount of achievable cooperation gains decreases

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[24] In a multi-country setting the complexity will be substantially higher.

accordingly. In other cases the transaction costs might be only moderate. If the cooperating parties are generally on the same side concerning the most important topics of the cooperation initiative, reaching an agreement will usually be significantly easier (see Sect. 2.1.4). Apart from this, mutual trust between the countries is very conducive to cooperation, as it might render unnecessary the inclusion of several aspects into the contract. Similarly, the countries could refrain from aiming at a very detailed and accurate distribution of costs and benefits if they are involved in numerous other economic or political cooperation projects which are based on the common understanding of a long-term welfare increase in both countries.

Model Variation (B.0): One CRM and One EOM, No Cooperation

If only one country applies a CRM while the other one is using an EOM scheme (without additional instruments that ensure domestic resource adequacy) and there is no active coordination, the appearance of free riding issues is particularly likely. When the typical EOM problems regarding security of supply materialise, they lead to a shortage in national power supply in the EOM country.[25] These deficits also affect the neighbouring CRM country, since the national electricity systems and power markets are interlinked. If the CRM country does not want to restrict the cross-border transmission capacity, it has to consider the additional demand from the EOM country when dimensioning its own provision targets. It is theoretically conceivable that these interdependencies could be exploited by the EOM country in order to avoid costs of providing generation capacity domestically. Regarding any further aspects, the mechanisms are similar to model variation (A.0).

Model Variation (B.1): Active Cooperation in a Setting with One CRM and One EOM

International agreements on the provision of generation capacity are hardly conceivable in model variation (B.1). Such commitments are incompatible with a pure EOM scheme and will usually contradict the intentions of the EOM country. One way to realise cooperation benefits could be to open the CRM to plants situated in the EOM country. This could be especially reasonable if production conditions in the EOM country are favourable and allow plants to be built and operated at lower cost. When considering such a decision, it is important to be aware of the current and future cross-border capacity situation (as well as the situation regarding relevant hinterland transmission capacities). In case of restrictions to the capacities and availabilities of interconnectors (and hinterland capacities), plants abroad might not deliver the same contributions to achieving national goals as plants located on domestic territory.[26] Apart from cost advantages with respect to the provision of power plants, positive cooperation effects could arise from an increased level of competition in generation.

Financing power plants abroad (instead of on domestic territory) has some implications for the distribution of rents; from the perspective of the CRM country,

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[25] Cf. Hoffrichter and Beckers (2018a) and Hoffrichter et al. (2018) for a detailed discussion of potential problems regarding security of supply when an EOM scheme is applied.

[26] Cf. Hoffrichter and Beckers (2018b).

these effects might be positive in some cases and negative in others (see Sect. 2.1.3). Furthermore, this setting leaves room for opportunistic behaviour of the host country; it could, for instance, impose a new tax on the plant's revenues during the operation period to appropriate a larger share of the rents.[27] If such behaviour cannot be ruled out in advance, the CRM country could be interested in impeding it by requesting an explicit cooperation contract which features corresponding rules. However, firstly, real-world contracts are practically always incomplete and, secondly, enforcing interstate agreements might sometimes turn out to be complicated.[28] If the achievable cooperation gains are high, such solutions might be worthwhile. In cases with only moderate efficiency gains from cooperation, by contrast, the proportionality of transaction costs that go along with such arrangements might be questionable.

Model Variations (C.0) and (C.1): Two EOMs

If both countries apply an EOM design, the possible advantages and disadvantages are very similar to the ones in the "Supranational EOM" model. In particular, this also applies to the potential appearance of problems with respect to security of supply, shortfalls concerning national preferences (since decisions are largely left to market actors) and especially cost efficiency; the decentralised EOM model, therefore, seems not considerably more suitable with respect to the underlying objectives than its centralised counterpart. However, the decentralisation of competences at least enables the countries to control the utilisation of cross-border transmission capacities and thus prevent problems in the neighbouring country from immediately spreading over to the domestic power system. In some cases it might also be reasonable to restrict the available cross-border exchange volume in order to avoid an aggravation of the situation if limited intra-country transport capacities constitute a problem.[29] In other cases, cross-border exchange might alleviate the problems and capacity restrictions would be counterproductive.

3.2.2 Summary

Both the centralised and the decentralised corner solution models show some obvious disadvantages, which can also be regarded as potential advantages of the respective opposite model. A major disadvantage of the centralised solution is the possible

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[27] To give another example of opportunistic actions, the host country could (unilaterally) limit the available interconnection capacity between the two countries to an extent that restricts the plants' possible contributions to electricity supply in the funding country. Economic theory also refers to such opportunistic actions as "creeping expropriation"; cf. for instance Sawant (2010) and Steffen (2018), who both address this topic when discussing the role of project finance in international infrastructure projects. For concrete examples of retroactive changes to RES-E schemes in EU countries, which might be assessed as opportunistic regulatory actions against foreign investors, cf. Fouquet and Nysten (2015).

[28] Cf. for in-depth analyses on the implications of incomplete contracts Williamson (1985), Alchian and Woodward (1988) and Tirole (1999) as well as Hoffrichter and Beckers (2018b) for a more detailed presentation of the specific context addressed here.

[29] Cf. Hoffrichter and Beckers (2018a).

neglect of national preferences and circumstances. If decision-making powers are decentralised, the countries can design the institutional framework according to their own targets and local conditions. However, decisions in the neighbouring country do affect the domestic power system, unless countries are willing to completely prevent cross-border exchange and thus also forfeit a large share of the potential benefits of system interconnection. In the decentralised corner solution models, transaction costs of bilateral or multilateral coordination are an important issue, because their existence might prevent the countries from reaping potential gains of cooperation. Tackling the inherent free rider problem and appropriately considering cross-border effects represent further challenges. If there is a conducive transaction atmosphere between the countries, it might be comparatively easy to reach agreements; especially if the benefits of cooperation are large. In other cases, supranational measures might, in principle, be very conducive to increasing welfare across countries.

3.3 Determination of Potentially Suitable Elements of a Differentiated Governance Model

3.3.1 Using the Advantages and Avoiding or Mitigating the Disadvantages of the Corner Solutions

In Sect. 3.2 we investigated corner solutions of governance models in an interconnected power system in order to make effects that arise from centralising or decentralising competences appear as clearly as possible. The obvious disadvantages in both cases strongly indicate that such corner solutions are basically unsuitable for practical application. This assessment very much corresponds to the fundamental rationales for applying federalist governance models in general and suggests that it is necessary to further differentiate when discussing the distribution of decision-making powers in a multi-level governance system. Thus the question to be examined is: Which specific competences should be centralised and which decisions should remain responsibilities of the national states in order to benefit from the respective advantages and to avoid or mitigate the respective disadvantages of centralisation and decentralisation?

Against this background, as a next step of our analysis, we derive a differentiated governance model with a targeted distribution of responsibilities between the supranational level and the national level. When conceptualising the model, we placed a special focus on consistency regarding the division of responsibilities across the relevant decision areas; the underlying considerations in this context are often not explicitly explained during the following discussion.[30] Nevertheless, the outlined

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[30] The omission of the derivation of certain decisions is partly due to the fact that some selection decisions during the model conceptualisation process were not entirely based on insights from economic theory. Some selection decisions were majorly influenced by the authors' experience as well as input from other experts on the subject.

governance model certainly does not represent the only solution, which, in comparison to a given benchmark, might promise improvements regarding the achievement of our assumed objectives (cost, security of supply and environmental objectives; see Sect. 1). As a matter of fact, there are numerous conceivable combinations regarding the allocation of responsibilities and each solution might be more or less suitable, depending on the specific circumstances. With this in mind, our proposal for a differentiated governance model should be regarded as a basis for further discussions on the topic.

3.3.2 Transition of the Corner Solutions Towards a Governance Model with a Differentiated Allocation of Decision-Making Powers

Based on the examination of the corner solution models, we derive potentially suitable elements of a differentiated governance model. Our aim is to create a model which combines the advantages of the corner solutions, while avoiding or at least mitigating the disadvantages. As an intermediate step we consider certain modifications of the centralised and decentralised corner solution models which might alleviate the detected problems by adding certain decentralised and centralised elements, respectively. As stated during the course of our analysis in Sect. 3.2.1, due to the inherent flaws of the EOM approach we limit the discussion to a CRM framework.

3.3.2.1 Modifications in Order to Reduce the Disadvantages of Centralised Corner Solutions

The examination of the centralised CRM model revealed the following critical aspects (which are partly interdependent or overlapping):

- Centralised solutions might neglect national preferences
- Standardised regulations might not adequately fit to the prevailing circumstances in each country
- Mechanisms established on the supranational level might go along with substantial distributional effects; redistributing rents between the countries—provided that it is desired—might entail high transaction costs
- The lack of direct involvement of the countries in decision-making might cause the need for an active centralisation of any essential dispersed knowledge, which results in additional transaction costs
- The establishment of one specific institutional standard is counterproductive with regard to the development of institutional innovations and determining the most suitable framework design

In order to take account of diverging local preferences and conditions, a differentiation of the rules and requirements could generally be reasonable. This assumes for one thing that the costs of acquiring the necessary information do not exceed the achievable benefits. Furthermore, the differentiation of rules may not undermine the idea of a system-wide optimisation, which limits the extent to which the framework can be tailored to national circumstances. Similarly, an exhaustive compensation of distributional effects is likely to, firstly, go along with heavy transaction costs and, secondly, somewhat contradict the basic concept of the centralised approach. By contrast, compensating only very obvious and large effects to a certain extent seems fairly consistent with the approach and might in some cases be sufficient to significantly increase acceptance among the countries concerned.

More drastically modifying the centralised CRM model, the incorporation of decentralised knowledge could be institutionalised by transferring some competences regarding the provision of generation capacity to the member states. This means, although overarching and binding requirements concerning the CRM design would be made on the supranational level, the countries' regulators would have a certain scope for individual adaptions of the instruments and regulations. In such a governance model, the national regulators can be regarded as executive bodies that support the achievement of centrally established goals, while ensuring the adequate consideration of diverging local conditions. The suitable share and selection of decentralised decisions depends on many factors, not least the severity of problems in a setting with completely centralised competences.

3.3.2.2 Modifications in Order to Reduce the Disadvantages of Decentralised Corner Solutions

In Sect. 3.2.1.2, we identified the following aspects as main problems of the decentralised corner solution models without cooperation:

- Large shares of the potential benefits from system interconnection, which often result from portfolio effects, are not utilised
- Since ensuring security of supply in an interconnected power system exhibits features of a public good, there are certain incentives for individual countries to pursue free riding strategies; preventing such strategies by inhibiting cross-border exchange comes at the expense of system interconnection benefits
- Individual countries tend to not fully take negative or positive cross-border effects into account on their own initiative

In some cases, a decentralised coordination of the countries involved might solve problems. Often, however, reaching interstate agreements does not come without substantial transaction costs; sometimes they might largely outweigh or even overcompensate the achievable gains. Whereas above we examined a setting with only two countries, complexity and transaction costs of decentralised coordination can be expected to considerably increase when a larger number of states are involved.

The (voluntarily) realisation of cooperation initiatives could be promoted by a set of overarching rules established on the supranational level. Such an approach could make it possible to reap a large share of the benefits from system interconnection without imposing obligations on the member states that might conflict with national conditions, goals and preferences. The supranational regulator could, for instance, design a framework for decentralised coordination which offers standard procedures for the determination and sharing of costs and benefits that result from joint initiatives. This would narrow down the scope for manoeuvre countries have in bilateral or multilateral negotiations and thus possibly reduce complexity, which potentially decreases transaction costs and, at best, makes the achievement of agreements more likely.[31] The establishment of binding standards for costs and benefits sharing should, however, be carefully considered, as such specifications might exclude possibly reasonable solutions which lie beyond the limits imposed by the central regulator. Moreover, distributional effects that result from cooperation are often generally difficult to measure and, therefore, designing an appropriate framework might not be a trivial task.[32] Apart from establishing a framework for decentralised coordination—and possibly in addition to this—the supranational regulator (or other supranational institutions) could function as an arbitrator, helping to avoid and resolve disputes between cooperating countries. The existence of such a neutral institution might especially encourage the realisation in cases with significant uncertainties regarding the behaviour of the opposite contracting party.

Externalities could be dealt with very similarly to the described way of handling distributional issues. This means for instance, that standards for the determination and evaluation of effects could be established on a central level. In some cases, it might be worthwhile to address the problems more directly by imposing regulations that decrease the generation of negative externalities or promote the generation of positive ones. However, measuring and attributing externalities to a specific originator is sometimes very challenging in principle; in such cases decentralised coordination might be indispensable.

In order to avoid inefficient redundancies and prevent free riding, increasing the degree of centralisation with respect to decisions on the provision of guaranteed capacity in each country could also be considered. This means that the supranational regulator would set and control individual capacity targets to ensure security of supply as well as adequate contributions of each country; in some cases, transferability of the obligations between the countries might allow for cost reductions. In contrast to a centralised CRM, designing the national institutional frameworks for the provision of power plants, on the basis of which the individual targets are pursued, would remain the countries' responsibility, leaving room for adapting the instruments to the respective local circumstances.

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[31] Cf. Hoffrichter and Beckers (2018b).

[32] Konstantelos et al. (2017) for instance, suggest applying the so-called "positive net benefit differential" (PNBD) method for the distribution of costs and benefits of collaborative initiatives. For further considerations regarding methods for the identification and sharing of costs and benefits from collaborations on electricity supply (although primarily with respect to grid investment), cf. Busch (2017) and Flament et al. (2015).

3.3.3 General Considerations Concerning the Creation of Regions as an Intermediate Level

Many of the described problems regarding centralised (supranational) decision-making as well as decentralised coordination between individual sates increase when a higher number of countries are involved. Against this background, establishing an intermediate regional level for decision-making could be helpful for handling some of the issues. This means that the coordination of certain essential matters would be assigned to regional groups of countries with a limited number of members. This might, on the one hand, allow a large share of the potential gains from cooperation to be realised while, on the other hand, significantly decreasing the complexity of coordination compared to a union-wide system optimisation. Successfully reducing problems of coordination, and thus transaction costs, requires a suitable partitioning of regions based on the problems' causes. Since, for instance, diverging national preferences may be a barrier to cooperation, more or less homogeneous goals among the countries (e.g., with respect to the use of certain generation technologies or the aspired security of supply level) within one regional cluster might be conducive to success. Besides, similar national circumstances make it easier to find adequate reglementations which suit the initial situations in all countries sufficiently well. Furthermore, the transaction atmosphere between the countries should be taken into account when defining regional clusters, because it plays an important role with respect to the difficulty of negotiations (see Sects. 2.1.4 and 3.2.1.2.3).

In cases of substantial problems of coordination between different regions, there might be reasons to limit external electricity exchange capacities in order to avoid complex interdependencies. Whereas a complete separation of electricity networks will hardly ever be a worthwhile option, a targeted manipulation of cross-border flows might sometimes represent a pragmatic solution.[33]

The introduction of regional clusters is possible in an originally rather decentralised governance model (i.e. bottom-up) as well as in cases in which decision-making powers are largely centralised (i.e. top-down). Consistently pooling competences on a regional level requires commitments by the countries involved to comply with the common cooperation framework and contribute to the achievement of the underlying common goals on a long-term basis. This implies that national states partly waive their sovereignty regarding future decisions.

Regional cooperations can benefit from support from the supranational level, which could, for instance, aggregate and provide knowledge or promote and coordinate interregional collaboration.

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[33] Cf. Hoffrichter and Beckers (2018a).

3.3.4 Compilation of Potentially Reasonable Building Blocks for a Well-Differentiated Governance Model

Based on the considerations heretofore, in this section we present a selection of building blocks for a differentiated governance model (regarding the distribution of competences) in an interconnected power system that might be suitable with respect to the underlying objectives.

Regarding the achievement of environmental and RES-E targets, the institutional framework could feature the following elements:

- If countries in a union of states agree on certain environmental goals, the introduction of binding national targets could be reasonable in order to establish firm commitments and avoid free riding behaviour.
- To increase allocative efficiency through cooperation, it might be worthwhile to allow countries to have their national obligations partly fulfilled by other countries (which consequently would have to overachieve their own targets).
- In order to take account of diverging national circumstances and preferences, it could be advisable to generally leave the selection of abatement options to the countries. Centralised cross-sectoral mechanisms, such as typical cap and trade schemes, seem compatible with this criterion, since participants usually largely maintain flexibility. However, they are inadequate as a framework for generation investments.[34]
- Extending RES-E capacities can be regarded as a key measure in achieving environmental policy goals in the electricity sector. National regulators are usually well able to assess which contributions RES-E extension measures, among their portfolio of domestic actions, can add to the achievement of national targets (in the majority of developed countries these contributions are assessed to be fairly high). Against this background, it could be reasonable to also specifically agree on binding national RES-E targets (instead of, for instance, only CO_2 abatement targets).
- The national regulators should be free to individually apply targeted instruments which create an adequate environment for RES-E investment.
- If national RES-E instruments are used in parallel to a cap and trade mechanism, it seems important to rule out any negative repercussions enhanced RES-E expansion might have on the CO_2 abatement efforts in other sectors by eliminating any such interdependencies.

Regulations with respect to arrangements for achieving security of supply and certain generation mixes could be based on the following considerations:

- Centralised generation capacity planning or joint planning accompanied by centralised measures, featuring a transnational adequacy assessment, is likely to be beneficial with respect to the underlying objectives. Firstly, a coordinated

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[34] Cf. Hoffrichter et al. (2018) and Hoffrichter and Beckers (2018a).

approach to the provision of plants prevents strategic behaviour and ensures appropriate contributions by each country. Secondly, the costs of attaining the security of supply objective probably decrease due to portfolio effects.

- The idea of coordinated planning could be implemented in a way that countries individually commit to providing a certain amount of generation capacity within their power system, which (on aggregate) meets certain quantitative and qualitative requirements regarding reliability and flexibility. Similar to the case of RES-E plants, a transferability of these obligations could possibly enhance allocative efficiency while achieving a fair cost distribution.
- If regulators know sufficiently well how measures to steer the generation mix contribute to emissions abatement, it could make sense to also address the non-renewable part of plants separately (instead of only including it in a cross-sectoral mechanism, leaving final decisions up to investors).
- There are good reasons to make the design of the institutional frameworks for the provision of plants which guarantee security of supply a national responsibility. However, certain restrictions on the countries' decision-making scope could be reasonable in order to prevent actions that endanger or contradict common goals. In this way, dispersed knowledge would be directly incorporated into the decision-making process and national states could make sure that their preferences are met; yet another advantage is that applying several differently designed mechanisms in parallel allows a more exhaustive realisation of learning effects.
- In cases in which national preferences—for instance with respect to the desired security of supply level or the use of generation technologies—diverge substantially, it seems necessary to limit cross-border power exchange, because otherwise interdependencies are unavoidable.

When considering measures for the promotion of international cooperation, the following aspects should be taken into account:

- Supranational institutions can play a useful role by offering a general framework for cooperation between countries as well as specific support of voluntary cross-border cooperations in the electricity sector. Possible measures include, among others, the centralisation and provision of knowledge which is relevant for the implementation of cooperative initiatives or the development of standard procedures for determining and sharing the costs and benefits arising from cooperations between the countries involved.
- Especially in case of large international unions, forcing cooperations might be rather more detrimental than conducive to the achievement of the underlying objectives. Since the initial situations in individual countries often diverge, cooperations are not reasonable in all cases.
- Similarly, compulsory requirements to enhance cross-border exchange of electricity (by extending interconnection capacities or increasing their utilisation) seem questionable for several reasons. They undermine, for instance, the countries' sovereignty regarding the use of certain generation technologies and tend to increase the size of possible undesirable distributional effects and externalities.

- If enhancing the trade of electricity between countries is considered highly desirable, it generally makes sense to take measures on a supranational level in order to prevent distortions. When implementing such measures, it is important to always take all further aspects (apart from the functioning of international trade) that are relevant to the underlying objectives adequately into account.
- In order to facilitate the realisation of cooperative initiatives within a large international union, creating regional clusters for the coordination of countries might sometimes be a helpful step; ideally, decisions on an intermediate level combine the advantages of centralised and decentralised decisions.
- Another potentially reasonable measure could be to provide centralised funds, which are used to promote the realisation of cooperative projects which lead to an improvement regarding the underlying objectives.

Comparison of the Findings to the EU Status Quo

In Hoffrichter and Beckers (2018a), we assess the governance model currently applied in the EU based on the considerations presented in this chapter. Our findings can be summarised as follows:

In the EU, member states have transferred certain decision-making powers concerning the provision of generation capacity to the supranational level. Such a step might, in general, be very reasonable, since supranational institutions can play an important role in harnessing the potential of international cooperation, possibly leading to lower costs of achieving security of supply and environmental objectives; however, an ill-conceived use of centralised decision-making powers might have the opposite effect. The EU electricity sector policy has been characterised by a strong focus on developing the internal market. Although there are certainly convincing arguments in favour of the internal market idea itself, "completing" the internal electricity market conflicts with the established principle of national sovereignty over the generation mix. The overarching EU Emissions Trading System (ETS) alone clearly does not provide an adequate framework for generation investment. There is a need for targeted instruments for the provision of both RES-E plants and highly reliable generation units that conform with the environmental ambitions in Europe. National mechanisms could generally make sure that the individual goals and preferences of member states are met; however, the EC, as a result of the preference for seemingly "market-based" mechanisms, intervenes against more targeted and differentiated—and thus, if applied in the right situation and manner, potentially more cost-efficient—national instruments. Similarly, the forced opening of national mechanisms to generators abroad as well as centralised instructions for the management of interconnection capacities is not likely to be conducive to the underlying objectives. One reasonable supranational policy measure to support the achievement of common goals could be to promote an agreement of member states on binding

(continued)

individual RES-E targets. The expansion of RES-E plants should directly reduce the amount of ETS certificates in order to prevent negative repercussions. The same applies to measures that aim at phasing out conventional power plants; the possibility to voluntarily withdraw emission allowances in such cases, as proposed in the Winter Package, can be regarded as a step in the right direction.

Summing up, the strong focus of the EU's electricity sector policy on internal market aspects has led to some questionable developments. Our findings suggest that supranational action should be based on a more differentiated set of goals and have a focus on supporting voluntary cooperations in cases with large expected net benefits.

4 Summary and Conclusion

This chapter dealt with the allocation of decision-making powers in a union of states for the provision of electricity generation capacity. The aim of the institutional economic analysis presented in this chapter was to determine and investigate aspects that are relevant to finding adequate solutions concerning the distribution of competences between the supranational and the national level. With this goal in mind, we started by qualitatively comparing simplified extreme versions of governance models in order to determine general advantages and disadvantages of centralising and decentralising decision-making powers. Based on this, we derived potentially reasonable components of governance models with a more differentiated approach to allocating competences. Our findings suggest that, in a union of states, a well-balanced mix of centralised and decentralised competences is most likely to achieve security of supply, environmental and cost objectives. A certain degree of centralisation might, for instance, be beneficial for determining national contributions to maintaining security of supply; the same applies to environmental targets in general and RES-E expansion targets in particular. On the other hand, it is important in this context to avoid situations in which mandatory requirements majorly interfere with critical national preferences. In particular, member states should have a broad scope of action regarding the design of national RES-E instruments and other remuneration schemes as well as with respect to the use and extension of interconnection capacities. Similarly, the promotion of voluntary international cooperation initiatives should be a key task of the supranational regulator; forcing member states into collaborative projects seems to be rarely a strategy worth pursuing.

The growing debate on fundamental reforms within the EU, which to a large extent is driven by a widespread dissatisfaction with the allocation of decision-making powers between the EU and its member states, should also include electricity supply related topics. The considerations presented in this chapter can contribute to assessing the current governance model in the EU and potentially point to reforms which lead to advances in both the efficiency of electricity supply and the adequate consideration of national preferences.

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From National to Cross-Border Support of Renewable Electricity in the European Union

Sebastian Busch and André Ortner

Abstract The ability to cooperate in the expansion of renewable energies has long been recognized as welfare improving. However, the existing cooperation mechanisms introduced in the European Union appear to be insufficient to facilitate an efficient level of trade across borders. In this chapter we focus on the electricity sector and identify several characteristics of the market for renewable electricity support that contribute to this failure. We then propose a novel mechanism for cross-border support of renewable electricity capacity that addresses these failures in two steps: First, a cross-border impact factor is derived that provides an approximate indication of the spillover of benefits induced from renewable electricity capacity across the member states of the European Union. Second, a cross-border auction in which member states and generators of renewable electricity bid to either buy or supply additional renewable electricity capacity. The auctioneer uses the cross-border impact factor to determine the aggregate cross-border willingness to pay for additional renewable electricity capacity in each member state and selects the set of bids, which maximizes the EU-wide surplus. Inevitably, the design of the mechanism uses a simplified representation of the underlying system 'reality' in order to achieve the complexity reduction needed to create a 'level playing field', but in our view it would still represent cross-border impacts accurately enough to spur efficiency improvements in the right direction. Moreover, the fact that it could be integrated into the emerging market and regulatory framework in the European Union fairly easily is appealing.

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S. Busch (✉)
International Institute for Applied Systems Analysis, Laxenburg, Austria

Knowledge for the Energy Union Unit, European Commission, Joint Research Centre,
Petten, The Netherlands
e-mail: busch@iiasa.ac.at

A. Ortner
Technische Universität Wien, Wien, Austria

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1 Introduction

The debate on efficient support schemes for renewable energy sources (RES) in the European Union (EU) has often taken place along a fault line between the merits of national (bottom-up) versus European (top-down) support instruments. In general, the efficient provision of renewable energy requires the simultaneous consideration of costs and benefits. Precisely because the latter have usually not been considered in the design of top-down approaches, these approaches have often been perceived as unfair, since cooperation could create winners and losers. In this chapter we sketch out how national policy instruments can be further developed into a hybrid (bottom-up—top-down) approach that is capable of addressing both of these dimensions of economic efficiency. The ability to exchange electricity from renewable energy sources (RES-E) between EU member states (MSs) improves the welfare of all MSs since potentials and demands for renewable electricity generation vary across the EU. This notion is reflected in the promotion of so-called cooperation mechanisms in the renewable energy directive currently in force, Directive 2009/28/EC (European Parliament and Council 2009). So far very little use has been made of the existing mechanisms. Sweden and Norway have set up a joint support scheme. Germany and Denmark have organized a cross-border auction and Lithuania and Luxembourg have signed an agreement on a statistical transfer of renewable energy.

Additional advocacy for using the cooperation mechanisms comes from the state aid guidelines for environmental protection and energy that call on the MSs to make better use of these cooperation mechanisms. Article 122 states that support schemes, in principle, should be open to other MSs and that the European Commission (EC) will consider positively schemes that are open to other MSs in notifications of new regulations (European Commission 2014). This principle has also been adopted in the Commission's proposal for a revised RES directive (European Commission 2016) for the post-2020 period, which is currently being prepared, where Article 5 establishes a gradual and partial opening of support schemes for cross-border participation in the electricity sector. However, given a variety of barriers and the absence of a scalable framework, only a small quantity of energy can be expected to be subject to cooperation mechanisms under the current directive. The role of the cooperation mechanisms under the new renewable energy directive (RED II) is not clear yet, in parts, since the EU target of at least 32% for the share of renewable energy consumed in the EU in 2030 will no longer be translated into national targets. Nonetheless the EC has already emphasized that regional cooperation is meant to play a more prominent role in the future (European Commission 2015, p. 7): "A more coordinated regional approach to renewable energy—including support schemes—could deliver considerable gains, among others by promoting cost-efficient development of renewable generation in optimal geographic locations. This would enlarge the market for renewable energies, facilitate their integration and promote their most efficient use. While Member States are becoming increasingly open to enhanced regional cooperation, practical difficulties remain. A concrete framework for cross—border participation in support schemes could address these practical difficulties." The contributions in this chapter are intended to inform this ongoing discussion, by introducing a new perspective on conceptualizing cooperation in renewable energy expansion in the electricity sector guided by the following research question: How can a mechanism be designed that provides for a scalable framework capable of overcoming the barriers to the use of the cooperation mechanisms under the current EU renewables directive in order to enable a more widespread application of cross-border support for renewable electricity in the post-2020 period?

This chapter proceeds as follows: In Sect. 2 we provide the economic rationale for cooperation in RES-E capacity expansion. The two main rationales we provide are different sources of cost synergies and multilateral externalities. In Sect. 3 we discuss the barriers that have hampered the formation of a market for joint RES-E capacity provision thus far. Subsequently, in Sect. 4 we outline the basic structure of a new mechanism that in our view would be capable of addressing some of the key barriers. The two subsequent sections are intended to inform readers interested in more technical implementation issues and can be skipped without missing out information on the overall concept. In Sect. 5 we discuss how the proposed mechanism relates to some concepts from economic theory and we point out conditions that should be fulfilled in order to provide for economic efficiency. On this basis Sect. 6 elaborates on the concept of the mechanism in more detail. In Sect. 7 we discuss how the mechanism can be implemented within the currently emerging institutional and market frameworks in the EU. Section 8 concludes.

2 Economic Rationales for Cooperation

In this section we investigate under which conditions cooperation in RES-E capacity expansion can create value or is otherwise warranted for achieving efficient outcomes. The scope of this analysis is limited to effects that can be related to some sort of economic reasoning and usually can be identified with costs and benefits, though not necessarily exactly. Thus, we do not attempt to address notions of cooperation rooted in other research fields such as political science, ethics, fairness or philosophy. From an economic perspective the potential for cooperation by a group of MSs is given, if cooperation leads to an allocation of both RES-E capacity and corresponding costs or benefits, such that the net benefit an individual MS or group of MSs experiences from RES-E capacity is increased compared to the allocation of RES-E capacity that would be achieved under non-cooperative behavior.

In the following we discuss the two main arguments—cost synergies and the existence of multilateral externalities in the power system—which in our view provide the foremost economic rationales for cooperation.

2.1 Cost Synergies

2.1.1 Comparative Cost Advantages (Resource Endowment)

There are two dimensions of relevance for resource endowment: (i) one concerns all resources that have an impact on the direct cost of electricity generation, such as the level of solar radiation; (ii) the other regards all resources that have an indirect impact on the costs of electricity generation, such as the flexibility of the power system and its capability to accommodate (variable) RES-E generation. The former type of synergy is the one most often referred to in the literature in the context of RES-E cooperation (European Commission 2013; Klessmann et al. 2010; Klinge Jacobsen et al. 2014; Unteutsch 2014), since it is the most intuitive one and moreover offers the largest potential for cost savings. The latter one has not been mentioned so often yet in the context of RES-E cooperation, partly because the potential cost-savings are probably much smaller and partly because the benefits are less intuitive; the discussion at EU level is however evolving. Taken together, both dimensions constitute a marginal (integration) cost curve for RES-E. In the non-cooperative case each MS achieves a targeted level of RES-E expansion by accessing resources based on its own territory only. In the cooperative case the whole pool of resources would be accessible to all MSs. Cooperation would lead to value since each MS could partly also make use of the potentials based in the comparatively low-cost MS so that the joint expansion target could be achieved at an overall lower cost than the sum of the individual targets.

2.1.2 Economies of Scope

Economies of scope derive from the sharing of assets in the production of multiple products, resulting in lower joint costs of production per unit of output (Bailey and Friedlaender 1982; Helfat and Eisenhardt 2003). With regards to RES-E immediate economies of scope can arise for instance from MSs jointly organizing processes, such as the agency conducting the RES-E auction or joint cost-benefit analyses. Moreover, economies of scope arise from synergies in space, where the need for a back-up system decreases if output from variable RES-E generation at different sites is considered jointly (Hirth et al. 2015; Neuhoff et al. 2013; Newbery et al. 2013; Nicolosi 2012). One further reason for economies of scope could be that investors might perceive the financing risk to be lower under a cooperatively organized EU instrument compared to a national auction, due to a possibly higher credibility of an EU instrument compared to a national instrument and the fact that a project financed by a portfolio of MSs could reduce the contingency risk. The impact on the improvement in financing costs could be significantly high, since financing risks often outweigh the impact of resource conditions when it comes to financing costs (Brückmann 2015).

2.1.3 Economies of Scale

Economies of scale are present if specific costs decrease with larger production facilities, since certain cost components are fixed, independent of the level of output, so that the need for input factors increases at a disproportionately lower rate than output (Panzar and Willig 1977). RES-E generating technologies exhibit some of the features that typically allow for scale economies: they are modular in type and the costs of capital typically account for the largest share of the costs. Cost components in the erection of new RES-E infrastructure that typically have these properties include production facilities for RES-E plants, market intelligence, permit procedures or certain construction-related costs. This implies that higher output in terms of capacity serving higher demand is associated with lower costs. The level of RES-E capacity expansion required to exploit the full potential of scale economies might however be too great to be covered by the expansion target of a single MS alone, thus offering the potential for cooperation gains. Economies of scale from higher output have to be traded off against the increase in marginal generation or integration costs.

2.1.4 Intertemporal Economies of Scope and Scale

The timing of RES-E capacity expansion is not directly another source of synergy, but it adds a time dimension to economies of scope and scale, which provides further potential for cooperation. The reason for this is that constraints, both on the supply and on the demand side, determine the potential for synergies at any given point in time: on the supply side a more rapid scale-up might be constrained by diffusion constraints in the energy (innovation) system (Gallagher et al. 2012; Grübler et al. 1999); that is, the transformation can only take place at limited speed, due to, for instance, physical or legal boundaries (e.g. land-use regulation) or costs increasing at an exponential rate when production capacity is already fully exhausted. On the demand side the limited adaptability of the residual system due to the longevity of pertinent infrastructure (Dangerman and Schellnhuber 2013) can limit the flexibility of the residual system to adapt to increasing shares of RES-E generation.

The essence of what has been said above is that options for the least-cost deployment and integration of RES-E generation are not uniformly available, but differ in their constitution both in space and time. Therefore MSs can cooperate by pooling their resources and balancing their demands for RES-E expansion, such that the spatial and temporal allocation of RES-E expansion takes place in a way that exploits synergies and minimizes the total joint costs.

2.2 Multilateral Externalities

Besides synergies through more efficient resource usage, another rationale for cooperation is given by the presence of externalities where the efficient level of RES-E capacity can only be determined jointly by all MSs concerned.

In the electricity sector externalities are present where the RES-E capacity expansion decision of one MS also affects other MSs. This is due to the particular network structure of the electricity system, where new RES-E capacity, once provided, is shared between all interconnected MSs and its power output is allocated to where it is most valuable. These externalities share, to some extent, the characteristics of a public good. If one MS provides an additional unit of RES-E capacity, all MSs can partially benefit. Therefore without cooperation each MS has an incentive to enjoy the benefits of RES-E capacity provided by others while providing it insufficiently itself (Mas-Colell et al. 1995).

3 Barriers to Market Formation

Despite strong rationales, potential synergies and political interest, cross-border support for RES-E capacity has not gained any significant momentum yet. This is due to the presence of several persistent barriers.[1] The most comprehensive investigation of these barriers at EU level has been conducted in two research projects.

In a study for the EC by Klessmann et al. (2014) the following barriers were detected:

1. "Political barriers include public acceptance for cooperation mechanisms, the determination of governments to engage in cooperation on RES target achievement and uncertainty on the continuity of the RES framework beyond 2020" (Klessmann et al. 2014, p. 11). For instance, public acceptance critically depends on governments' ability to communicate to the national electorate the benefits of cooperation over domestic resources—with their various perceived benefits (European Commission 2013).
2. "Technical barriers include barriers that prevent countries with political will to engage in cooperation from doing so. Interviews with Member States conducted in this study have shown that there is still a high degree of uncertainty on quantifiable costs and benefits (i), design options of cooperation mechanisms (ii) and difficulties for Member States to forecast their own RES target fulfillment (iii). Uncertainty also surrounds the sanctions for non-compliance of the RES targets (iv). Lacking transmission infrastructure and market integration were also mentioned as barriers for cooperation (v)" (Klessmann et al. 2014, p.11).
3. "Legal barriers include potential incompatibility of cooperation mechanisms with national and EU legislation" (Klessmann et al. 2014, p. 11). This refers to, for instance, the applicability of state aid provisions to the cooperation mechanisms.

A research paper by Klinge Jacobsen et al. (2014) identifies, in addition, the following partially related issues:

4. Distributional effects may be significant in some cases (i); apparently, benefits outside the power system carry more weight from the perspective of MSs in this

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[1] We use the numbering (1…6-i…v) in the following to refer to the individual barriers throughout the text where applicable.

respect. A directly related problem is the difficulty of finding compensatory prices for cross-border effects (ii). This relates to public acceptance regarding fair cost-benefit sharing.

5. Another relevant barrier is the one arising from the different policy objectives of the support schemes such as maintaining support for diversified technologies in order to increase political acceptance (i) or targeting the support in order to develop specific RES-E technologies and industries (ii), which is not necessarily consistent with the—short-term—cost savings perspective that is often at the forefront of the discussion about the cooperation mechanism.
6. Finally, the questions how to structure the agreements legally or how to allocate costs of joint support into the Public Service Obligations payments for consumers, are issues that can constitute further possible barriers.

These findings conform to earlier communication by the EC in this regard (European Commission 2013). Broadly speaking, the barriers described above can be grouped into two categories: *technical barriers* (2., 4.), i.e., relating to the identification of costs and benefits and the concrete design of the cooperation agreement, and *political/legal barriers* (1., 3., 5., 6.), i.e., the acceptance of cooperation based on perceived benefits, and the challenge of integrating the cooperation agreement into the wider policy and legal framework. Our approach primarily aims to address the technical barriers. However, we do think that solving the technical barriers is also key to overcoming the political/legal barriers, or that our approach is at least compatible with solutions for overcoming them and we will elaborate further on this in the conclusions section.

In the following we paraphrase the technical barriers (2., 4.) described above from an economic theory angle in order to detect suitable entry points for economic instruments to address these barriers. We identify four characteristics of the market for RES-E capacity that contribute to the failure of the market as is.

First (4.-i), the costs and benefits of adding a unit of RES-E capacity are not borne fully by MSs making the expansion decision; that is, RES-E capacity generates externalities in the market. If one MS provides an additional unit of RES-E generating capacity, all MSs benefit. The failure of each MS to consider the benefits to others of its provision of RES-E capacity is often referred to as a free-rider problem: each MS has an incentive to enjoy the benefits of RES-E capacity provided by others, while providing it insufficiently itself (Mas-Colell et al. 1995). Therefore, bilateral negotiations alone are unlikely to result in efficient RES-E capacity levels.

Second (4.-i), significant information asymmetries exist: the willingness of MSs to pay for RES-E capacity and the cost of firms supplying that capacity is the private information of individual MSs and RES-E generators respectively. Strategic considerations cause these actors to misrepresent this private information in negotiations, leading to inefficient outcomes.

Third (2.-i), information regarding the costs and benefits of RES-E expansion is partially missing, uncertain or complex to assess. This pertains to both their overall monetary valuation and their distribution across MSs.

Fourth (2.-ii.), the transaction costs of bilateral or multilateral negotiations are very high since they require parliamentary approval in several MSs. The lack of a standardized, scalable framework for cooperation agreements means that each project has to do its own cost-benefit calculations and this involves lengthy negotiations on the allocation of costs and benefits. For instance, establishing the share of costs and benefits, in particular, seems to have derailed cooperation between Sweden and Norway (Klessmann et al. 2010).

In combination (4.-ii), these market characteristics have hampered the formation of a price signal that would allow for efficient trade in RES-E capacity. Instead, when identifying possible cooperation projects, national political priorities have often been in the foreground, making it questionable whether cooperation would lead to any efficiency gains at all.

4 Proposal for a Novel Mechanism for Cross-Border Support of RES-E Capacity

In this section we propose a new mechanism that addresses the current technical barriers and related shortcomings. The new mechanism we propose consists of two main elements:

1. A technology-specific *cross-border impact factor* (CBIF) that indicates the spill-over of impacts across MSs[2] induced by an additional unit of RES-E capacity. The impact[3] in this regard can be any metric that can be regarded as a plausible proxy for all effects (physical and economic) from RES-E generation that induce and account for the benefits MSs are willing to pay for (e.g. saved fuel costs, avoided emissions or employment and innovation effects). In general these effects spill over according to different logics. In the following we limit our scope to effects that spill over according to the logic of coupled electricity markets, which however captures many of the relevant benefits and could at least serve as rough proxy[4] for

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[2] We propose that the system boundaries for calculating the impacts and constituting the auction bidding zones are set at MS level, which appears politically to be the most intuitive. The concept could also be applied with alternative zone configurations.

[3] Here we use the rather abstract metric 'impacts' instead of 'benefits', due to the implicit notion that benefits can generally be expressed in monetary terms. It might however be difficult to coherently valuate all relevant effects *a priori*. In several cases where effects can be monetized by (e.g. market-based) prices, they can be directly translated into monetary benefits (e.g. generation cost savings induced by changes in generation mixes) and thus impacts and benefits are quasi synonyms. On the other hand, certain impacts are likely subject to more individual valuation (e.g. avoided air pollution or generally the value of being 'green' and thus already assuming a generalized monetary valuation would preempt the individual valuation by MSs of these effects.

[4] The effects which possibly are not adequately represented by the limited scope of the metric typically account for a smaller portion in terms of the overall benefits. Thus in our view a certain deviation of calculated impacts from actual reality is acceptable if the essential complexity

effects that are not captured by this logic. Since we are looking at the relative distribution of impacts (rather than absolute impacts) the proxy metric can be based on an easier to assess and trace sub-set of these effects (e.g. generation cost savings) without losing too much information as long as it represents the effects not considered somewhat proportionally. Under these premises we claim that CBIFs approximately indicate the distribution of benefits induced by an additional unit of RES-E capacity—according to the distribution of impacts across MSs.

2. A technology-specific *EU wide cross-border auction* in which MSs and generators of RES-E bid to either buy or supply additional RES-E capacity. The auctioneer uses a CBIF matrix (containing the CBIFs across all combinations of MSs) to determine the aggregate cross-border willingness to pay for additional RES-E capacity in each MS and selects the set of bids, which maximizes the EU-wide surplus (willingness to pay net of costs). The outcome of the auction also determines a cross-border cost allocation ensuring that all costs from selected supply bids are covered by the aggregate willingness to pay for this capacity and allocated according to each MS's share in the aggregate willingness to pay for the selected supply bids' capacity locations.

In the following we explain how the features of the proposed mechanism can help to overcome the technical barriers described in Sect. 3. Figure 1 provides a graphical illustration of the new elements in relation to the barriers.

We have shown that RES-E capacity expansion is associated with significant externalities. The new mechanism incorporates these externalities into prices for capacity in two steps ensuring that choices reflect the true costs and benefits. The CBIF matrix provides for each location a consistent measure of how the benefit from a unit of RES-E capacity is distributed across MSs, which makes it possible to determine MSs' willingness to pay for this respective location. The cross-border auction aggregates the willingness to pay of all MSs to indicate the system-wide demand, vis-à-vis costs, for each location.

The willingness of MSs to pay for RES-E capacity and the cost of firms supplying that capacity is the private information of individual MSs and RES-E generators respectively. Strategic considerations cause these actors to misrepresent this private information in negotiations, leading to inefficient outcomes. The mechanism we propose seeks to minimize the incentives for actors to do so. In the mechanism a cross-border cost allocation between MSs emerges as the equilibrium of a competitive bidding process. In this way a level playing field is created with all information which is required for efficient trade to take place being transparently available.

We have argued that information regarding costs and benefits of RES-E expansion is partially missing, uncertain or complex to assess. The CBIF approach provides a standardized, systematic procedure to tackle this shortcoming in all three dimensions: the impact metric of the CBIFs should be based on effects that serve as a good proxy (e.g. based on underlying correlations) for all relevant effects, including

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reduction can be achieved in turn. The effective and tolerable level of deviation should be subject to further research and may imply the development of a separate CBIF for effects where effects do not spill over according to the logic of electricity markets.

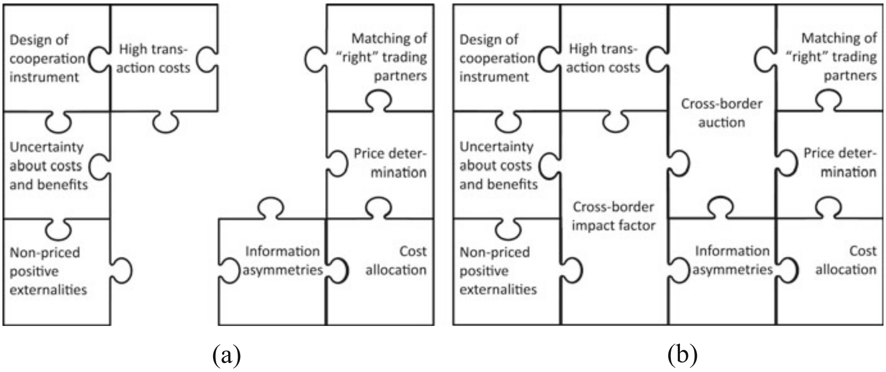


Fig. 1 Barriers to cooperation in RES-E capacity expansion and solutions based on two new elements. (**a**) Barriers, (**b**) Solutions

those where concrete information is missing and whose spill overs across the electricity system are well traceable. The uncertainty can be considered by constructing the CBIF matrix for different scenarios of plausible developments of the power system and averaging these into a single representative matrix. The complexity of assessing costs and benefits in the power sector with a certain accuracy requires the use of sophisticated modeling tools and the specialized competence to conduct the analysis, which may not be readily available at the MS level or at project developer level. In the mechanism we propose the assessment of cross-border impacts should be conducted centrally, so that it could be carried out by the institution with the most competence in this regard. A systemic procedure ensures the equivalent applicability of the assessment to and comparability across individual projects.

The need to reevaluate costs and benefits for each individual project, as well as questions about the specific design of the cooperation agreement for any new project, including legislative approval, lead to high project-specific transaction costs. The new mechanism can overcome this barrier by providing a standardized, scalable framework for assessing costs and benefits, so that these costs can be shared among all new projects. The guiding idea behind the CBIF approach is that it makes it possible to move away from the individual project-level evaluation to the system level, which brings with it several advantages: First of all, the way the distribution of benefits would be calculated becomes more transparent, reproducible and consistent, but most importantly, as the analysis is conducted simultaneously for all candidate projects, the transaction costs for assessing cooperation projects would be significantly lowered. Moreover, abstracting away from the project- level evaluation would mean that the financial responsibility for any new project could be more easily divided between a larger group of MSs.

Finally, experience with the cooperation mechanisms has highlighted the difficulty of finding prices that would determine an allocation of costs and benefits which is perceived as fair and makes all involved parties better off. The mechanism can relieve MSs of this burden, as they now only have to know their individual (rather than cross-border) willingness to pay for new RES-E capacity and the mechanism finds the efficient transfer prices for them, such that the highest possible cooperation gains are realized.

5 Relating the Mechanism to Economic Theory

The mechanism we are proposing corresponds to some concepts from economic theory and in this section we discuss this relation. Let $I = \{1, 2, \ldots, n\}$ be the set of MSs, each experiencing a benefit $b_i(x)$ subject to a vector $x \in R^I$, denoting the level of RES-E capacity expansion in each MS. Strictly speaking, the benefits induced by RES-E capacity in the electricity system arise from the amount of electricity generated by this capacity. However, since capacity and generation are linked by a fixed proportion, the former implies the latter. We therefore speak of producing and consuming units of RES-E capacity and actually mean in these cases the production and consumption of the generated electricity that stems from that capacity. In the context of interlinked electricity markets the function $b_i(x)$ is dynamic and characterized by techno-economic conditions of the underlying power system. In economic terms the good RES-E capacity partially has characteristics that are similar to the characteristics of public goods, namely non-rivalrousness and non-excludability (Eecke 2013; Gronberg n.d.).

Due to the underlying techno-economic conditions governing the power flow in inter-linked electricity systems, the benefit of additional RES-E capacity cannot be directly allocated to one single counter party, but is rather distributed throughout the whole system. In practical terms MSs cannot influence the parameters that determine the future distribution of benefits occurring over the lifetime of a new unit of RES-E capacity. Therefore, each MS consumes its individual (quasi non-allocable) share in benefit from an additional unit of RES-E capacity, which implicitly relates to non-rivalrousness. Furthermore, a MS investing in a new unit of RES-E capacity cannot exclude another MS from receiving a share in the benefit, which fulfills the requirement for non-excludability. According to (Mas-Colell et al. 1995) the analytical implications of rivalrousness, but non-allocable externalities parallel those of non-rivalrousness ones in the economic analysis. From this, we can conclude that RES-E capacity shares public good characteristics in the sense that it is non-excludable and non-allocable (implicitly non-rivalrous).

A market institution that, in principle, can address the externality caused by the public good-type characteristics of RES-E capacity is known as the *Lindahl equilibrium* (c.f. Mas-Colell et al. 1995), which can be thought of as having for each MS a personalized market of its willingness to pay for the benefit it consumes from a unit of RES-E capacity. In this concept the costs of providing new RES-E capacity would be split according to each MS's individual valuation of the additional capacity. In that way non-allocable externalities can be considered in pricing. A critical prerequisite of the Lindahl equilibrium, like all other approaches to address the externality problem, is that the individual willingness to pay of all MSs is known transparently in order to provide for efficiency. The question of how to design a mechanism that provides incentives for truthful reporting and as a consequence leads to efficient outcomes has been addressed in work by Clarke (1971), Groves (1973) and Groves and Ledyard (1977) known as Vickrey-Clarke-Groves (VCG) auctions. They have shown how the Vickrey auction (Vickrey 1961) can be used to overcome the free-rider problem and reveal true willingness to pay for a public good. Due to some weaknesses of the VCG-type mechanisms in practical terms, more recent work has focused on mechanisms whose outcomes obtain from the Nash equilibrium behavior and refinements thereof (Healy 2007).

6 Elaboration of the Mechanism Concept

It is at the core of this work's contribution that we introduce the CBIF approach to account for spatial preferences in the Lindahl equilibrium; that is, we adapt the Lindahl equilibrium for the pure public goods case to the impure public good characteristics of RES-E capacity. In the pure public good it is assumed that each MS consumes the same amount of the public good—in our case benefits induced by RES-E capacity. In contrast, in our impure public good setting each MS's share in the full benefit from the RES-E capacity is different, due to special properties that determine how benefits spill over in electricity markets. We propose that any kind of recognized model able to quantify physical and/or economic impacts of additional RES-E capacity, e.g. the ENTSO-E common grid and/or market model(s) used in the development of the Ten-Year Network Development Plan (TYNDP) (ENTSO-E 2018), can be applied to derive marginal *cross-border impact factors CBIFi,j* determining the average impact change a certain unit of additional RES-E capacity installed in MS *j* causes in MS *i*. Such changes can e.g. comprise impacts on generation mixes, electricity prices, generation costs or rents. These CBIFs should reflect the average impacts a certain amount of additional capacity has over a longer period of time to account for a broad range of system conditions. By making use of these factors the impact that MS i experiences from additional capacity installed in MS j can be expressed as

$$CBI_{ij} = CBIF_{ij}{}^{*}\ x_j \text{ for all i, j.} \tag{1}$$

We furthermore assume that the overall CBI of MS i is the sum of impacts derived from capacity expansions in all MSs j,

$$CBI_i = \sum\nolimits_{\mathrm{j}} CBI_{ij} \quad \text{for all i.} \tag{2}$$

That is, we assume that cross-border impacts fulfill the property of superposition. In general, this assumption is not valid due to the inherent non-linear features of electricity systems (e.g. grid congestion). However, it will be subject to further research to identify the maximum size of additional RES-E capacity expansion x, where the assumption of superposition still holds. If a significant amount of additional capacity expansion occurs and the CBIF matrix thus loses its validity, i.e., a certain tolerance band between actual and calculated impacts is violated, a recalculation of the CBIF matrix based on the new system conditions would have to be performed.

The overall benefit a MS i derives from RES-E capacity additions is then given as

$$b_i(x) = \mathrm{f}(CBI_i\ (\mathrm{x}))\ \text{for all i.} \tag{3}$$

The function f accounts for the individual valuation of RES-E capacity x by MS i and translates cross-border impacts into benefits, based on the MS's aggregate valuation of all relevant effects for which CBIs are a proxy.

For the amount of additional RES-E capacity $\mathrm{x_j}$ installed in MS j to be optimal, the sum of marginal benefits consumed by each MS i has to equal the marginal cost of providing it.

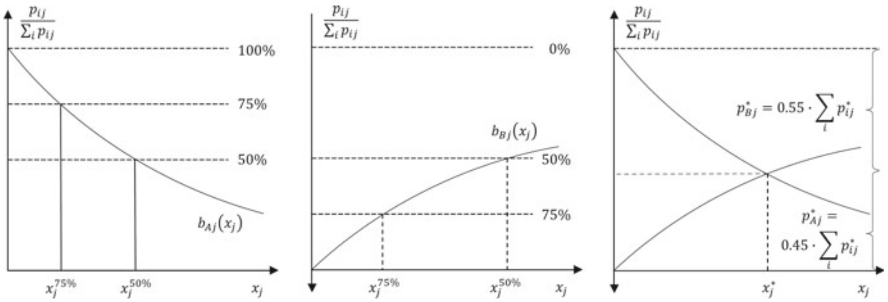
$$\sum\nolimits_{\mathrm{i}} b'_{ij}(x_j) = c'(x_j)\ \text{for all j.} \tag{4}$$

This relates to the *Samuelson condition* (Samuelson 1954) for the efficient provision of public goods. Therefore, the optimal price $\mathrm{p_{ij}}$ paid by each MS i for the provision of a unit of RES-E capacity $\mathrm{x_j}$ has to equal the marginal benefit it derives from its share in consumption of this unit. Prices, which fulfill these equilibrium conditions, assure that all costs are allocated and overall welfare is maximized.

Figure 2 illustrates this for a case of two MSs A and B (cf. Sanders 2006). Let us first take a look at panel a. It shows for MS A an illustrative demand curve of type $b_{ij}(x_j)$, i.e., the benefit MS i derives from additional RES-E capacity installed in MS j. The vertical axis does not show as usual the full price of a unit, but the individual price share that is allocated to MS A; for instance if MS A's price share in the new unit of RES-E capacity were 100%, its demanded capacity would be zero. Panel b shows the demand curve of MS B, who sees the price axis flipped the other way around. Like MS A, MS B's demand for additional RES-E capacity increases as its share in the full price decreases. In equilibrium, which is where the two demand curves intersect, both MSs demand the same amount of RES-E capacity and prices cover the costs of additional RES-E capacity exactly. By drawing a line over to the price axis from the point of intersection, we get each MS's share in the full price that needs to be paid for $x\star$ units of RES-E capacity. In our example MS A's price share is 45% and MS B's price share is 55%.

Now that we know that efficient prices can be found, the next step required for achieving efficiency is to implement incentive structures, such that MSs reveal their true valuation of additional RES-E capacity and generators of RES-E their true costs. This can in general be achieved through an auction. Two things need to be defined in this regard: (i) the structure of the input parameters and (ii) the solution concept for reaching an equilibrium.

Above we have said that the optimal price p_{ij} paid by a MS for a new unit of RES-E capacity should equal the marginal benefit it derives for its share in consumption of this unit. In general, however, because information on spillovers of



(a) (b) (c)

Fig. 2 Illustration of efficient (Lindahl) pricing. Prices reflect marginal benefits from RES-E capacity and in equilibrium costs are exactly covered and allocated. (**a**) Demand curve for MS A, (**b**) Demand curve for MS B, (**c**) Equilibrium prices

benefits is partially missing and complex to assess (cf. Sect. 3), the function $b_{ij}(x_j)$ is not known to MS i. However, it is then possible to create an auction where MSs only have to know $b_i(x)$; that is, their individual valuation of additional unit RES-E capacity as if they were to consume a full unit[5] and the market clearing algorithm finds $b_{ij}(x_j)$ for them, respecting Eqs. (1)–(3) and solving for optimal x_j, so as to maximize the system-wide net benefit $(\sum_{ij} b_{ij}(x_j) - c(x_j))$ across all MSs j.

The auctioneer could then collect bids by MSs and RES-E generators composed of price quantity pairs $(p_i,x; p_j,x_j)$ indicating their valuation $b_i(x)$ or costs $c(x_j)$, respectively, of additional RES-E capacity. The incentive for MSs and RES-E generators to report prices indicating their true valuation/costs of RES-E capacities depends on the properties of the solution concept. A class of mechanisms that make truthful reporting a dominant strategy are surplus-maximizing mechanisms (Börgers 2015). The auction we are sketching out here seeks to maximize the EU-wide surplus of RES-E capacity expansion and could be implemented similarly to a surplus-maximizing mechanism proposed by Young (1998) where efficient prices could be discovered in a multi-round bidding process.

7 Implementation of the Mechanism into the Existing Regulatory and Market Framework

In this section, we present how the proposed mechanism could be integrated within the prevalent and emerging regulatory and market framework in Europe and we also propose possible institutional affiliations for the two new elements of the mechanism. We discuss the incentive structures and interactions of the different actors within this framework with the help of Fig. 3.

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[5] In practical terms this could be something like Euros per MW consumed, where MW is a proxy for all desired effects associated with RES-E expansion.

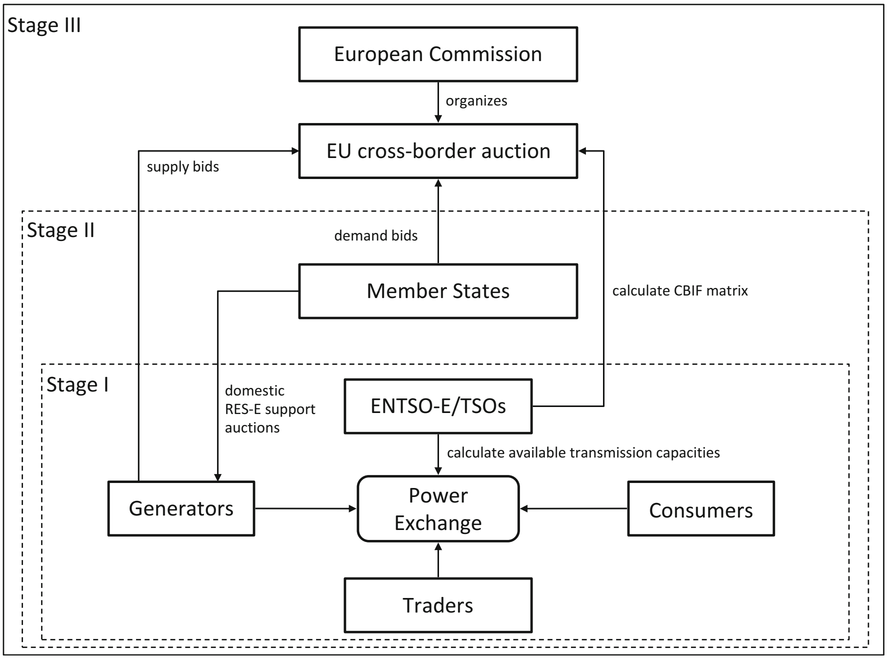

Fig. 3 Possible integration of the mechanism into regulatory and market framework

The bottom level (stage I) represents the EU internal electricity market. Several actors, such as electricity generators, electricity consumers or electricity traders are active in this market. They decide on investment and generation or consumption levels in order to maximize their revenues from the trade of electricity at the power exchange. The actors are situated at different nodes of the electricity network, which are linked by transmission system operators (TSOs). Electricity generators sell electricity to the market zone that their node is situated in and the different market zones are linked by a (flow-based) market coupler that aims to minimize price differentials between the market zones. Besides selling their generation to the electricity market, RES-E generators can gain revenues by offering capacity at different auctions that are organized in the upper stages.

In the middle level (stage II) are the EU MSs. On this level we assume that in the future—in line with the state aid guidelines—auctions will be used as the default national instrument to determine the level of the support premium. MSs aim to maximize the benefit from RES-E generation and therefore can choose technologies and sites that they offer to be auctioned. Besides setting up a domestic auction, a MS can also decide to submit bids in the EU cross-border auction.

In the upper level (stage III) is the EU cross-border auctioneer who maximizes the EU-wide surplus of RES-E capacity expansion; this role could for instance be situated at the EC, or the EC could nominate some party, e.g. a power exchange, to conduct the auction on its behalf. In order to determine the EU-wide surplus, the auctioneer receives information inputs from the lower levels; MSs and generators of RES-E bid prices which indicate their willingness to pay for or their costs of additional RES-E capacity. In addition, based on the market structure of stage I, ENTSO-E/TSOs calculate the CBIF matrix. The calculation could become part of the TYNDP process to ensure regular updates, consistency with transmission planning and the competence required to perform the analysis.

8 Conclusions and Discussion

We have shown is this chapter that cooperation in RES-E capacity expansion can create value. The two main rationales we identified for this are synergies in different types of cost components and the presence of multilateral externalities associated with RES-E capacity expansion. Despite the strong prospects for cooperation, several political/legal and technical barriers have hampered the formation of a market for cooperative provision of RES-E capacity thus far. In order to tackle the technical barriers we propose a novel mechanism for cross-border support of RES-E capacity, which consists of two main elements: (i) a *cross-border impact factor* that approximately indicates the distribution of benefits from an additional unit of RES-E capacity and (ii) an *EU-wide cross-border auction* in which MSs and generators of RES-E bid to either buy or supply additional RES-E capacity. The auctioneer uses the CBIF matrix in order to determine the cross-border willingness to pay for additional RES-E capacity and selects the set of bids, which maximizes the EU-wide surplus (i.e. net benefit). Then we discussed how the mechanism could implement an adapted version of the Lindahl equilibrium in order to induce efficient outcomes.

The complexity reduction achieved through the CBIF approach leading to a level playing field at EU level has to be traded off against a loss of accuracy. Specifically, due to the inherent simplifications, i.e. the underlying assumptions regarding the proxy metric and the superposition (both of which should be the subject of further research) the calculated CBIF matrix will likely not be close to a correct representation of reality, but in our view it will be accurate enough to spur efficiency improvements in the right direction compared to the status quo. An analogous example are the recent developments in congestion management with the gradual replacement of the net transfer capacity-based approach through the concept of flow-based market coupling.

How realistic is the implementation of such a mechanism at EU level in practice? The mechanism concept elaborated in this chapter is largely compatible with the emerging regulatory framework. The new RES directive and Energy Union governance currently under discussion in principle provide the ground for a new EU instrument such as the proposed cross-border auction, while the CBIF matrix could be embedded in the TYNDP creation process. The crucial factor for implementation will, however, be the political will for such a new mechanism, which leads us back to the political/legal barriers which have not been addressed explicitly in the text thus far. MSs and their societies are more likely to agree to cross-border support of

RES-E if they see a clear, communicable benefit. This is what the CBIF approach is about. It provides for a holistic, transparent measurement to reveal the positive cross-border impacts of RES-E capacity. This obviously counts in both directions; that is, it also sheds light on the benefit spillover of domestic RES-E capacity which is often perceived to deliver mostly national benefits. Moreover, the mechanism by design implies reciprocity of support. Other barriers that are not explicitly addressed by the mechanism include difficulties for MSs to forecast their own RES target fulfillment (2-iii), sanctions for non-compliance to the RES targets (2-iv), lacking transmission infrastructure and market (2-v), different policy objectives (5) or legal barriers (3, 6). These barriers, however, should either no longer apply in the period beyond 2020 (2-iii and 2-iv due to lack of national targets), or at least the design of the mechanism would be consistent with overcoming these barriers. Lacking transmission infrastructure would implicitly be reflected in the coefficients of the CBIF matrix and different policy objectives can be addressed by making the mechanism technology specific and participation voluntary. Despite obvious benefits and the potential to boost cross-order support of RES-E, MSs might nevertheless be reluctant to apply the mechanism if they perceive the partial delegation of coordinative capacity to a central entity as a loss of control, or if they would like to pursue other objectives through cooperation that are not reflected in the "logic" of the mechanism. In these cases it would still be advantageous to implement the mechanism at least partially: the CBIF matrix alone can be a very useful tool to help MSs evaluate their cross-border willingness to pay in bilateral cooperation agreements with different MSs and to facilitate dialogue on cross-border impacts among concerned actors in light of the further development off the power system. In the cross-border auction (ensuring efficient EU-wide coordination), the MSs could also indicate their cross-border willingness to pay "manually" based on their individual objectives rather than having it determined by a central entity through the CBIF matrix calculation.

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On the Alleged Need to Strictly "Europeanize" the German Energiewende

Sebastian Strunz, Erik Gawel, and Paul Lehmann

Abstract Germany has embarked on an ambitious project to transform its energy system until 2050—the so-called Energiewende. Some critics contend that the Energiewende imposes unnecessary and avoidable welfare losses due to a lack of integration within the EU. In contrast, these critiques largely miss the point because the asserted lack of integration cannot be pinned on the Energiewende and the welfare consequences of EU-wide integration are less clear than the critiques imply.

1 The Critique of Germany's Energy Transition

Germany's transition towards a completely renewable-based energy system—the *Energiewende*—is in full progress. In 2022 an important milestone will be reached with the last nuclear power plant to be shut down. Currently, Germany debates the timeline and necessary interventions to subsequently phase out coal. All the while, production capacities for renewable energy sources (RES) are continuously being added; by 2050, at least 80% of overall electricity supply shall be covered by RES (in 2017, the share passed 36%). International attention and respect for its ambitious aims notwithstanding, some domestic critics judge very harshly about the transformation project. Specifically, they claim that the *Energiewende* is a unilateral

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S. Strunz (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: Sebastian.strunz@ufz.de

E. Gawel · P. Lehmann
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

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approach that fails to reap potential benefits of an EU-wide approach (Acatech 2015; Weimann 2012; Monopolies Commission 2017). It has even been suggested that Germany, by rolling out *Energiewende* polices, acts as a kind of wrong-way driver heading in the opposite direction of a presumed mainstream of European energy policy (Sinn 2012). In consequence, the critics contend that Germany should only proceed with its energy transition policies in case they are aligned within a common EU-framework. On top of that, there is doubt with regard to the general economic rationale for an explicit transition toward renewable energy (Weimann 2013); also, the limits of transnational buffering of volatile renewable feed-in are stressed (Sinn 2017).

The critics bring forward two main economic arguments: First, the spatial allocation of electricity infrastructure (generation facilities and transmission lines) could be more efficiently organized on the EU level (Acatech 2015; Frondel et al. 2013; Mundt 2013). Second, the technology portfolio that emerges from Germany's feed-in tariff for RES is said to be inefficient compared to an EU-wide scheme of tradable green electricity quotas (Hübner et al. 2012; Haucap and Kühling 2012). In the following, the validity of these arguments is questioned. We argue that—while technically correct—they only hold under very narrow assumptions, which all but nullifies their warranted assertion.

Therefore, the perspective should be broadened so as to provide a more comprehensive picture. In particular, the following aspects are indispensable for an overall assessment of Germany's energy transition policies within the EU-context:

- How strong is the economic case for EU-wide integration of energy transition policies? This normative question is not reducible to the issue of geographical production costs of RES: instead, a range of arguments concerning general issues (e.g., decentral vs. uniform provision of public goods) and specific aspects of the energy transition are to be considered here. For instance, a complete evaluation needs to take possible preference heterogeneity concerning externalities from electricity production (e.g. nuclear risks, landscape impacts of renewable energy plants) into account.
- Specific questions on the appropriateness of particular policy instruments must not be conflated with the analysis of the adequate governance level for energy transition policies. For instance, the issue whether a feed-in tariff or a quota system is preferable for supporting RES needs to be separated from the question whether RES-policies should be implemented on the EU-level or on the level of Member States.
- Does Germany's energy policy empirically stand out compared to its neighbors? In fact, the analysis shows that the claim of unilateralism cannot be substantiated because the main pillars of the *Energiewende*, the RES support policies (objectives as well as instruments) as well as the nuclear phase-out, are not unique within the EU; the same also goes for Germany's RES shares and mid-term renewables goals up to 2020 that are completely in line with the EU average (Table 1). Furthermore, since energy policies are, on the whole, rather diverse in

Table 1 Share of RES at final energy consumption and EU targets for 2020

	RES share 2016 (%)	RES target 2020 (%)
EU-28	*17.0*	*20.0*
BE	8.7	13.0
BG	18.8	16.0
CZ	14.9	13.0
DK	32.2	30.0
DE	*14.8*	*18.0*
EE	28.8	25.0
IE	9.5	16.0
EL	15.2	18.0
ES	17.3	20.0
FR	16.0	23.0
HR	28.3	20.0
IT	17.4	17.0
CY	9.3	13.0
LV	37.2	40.0
LT	25.6	23.0
LU	5.4	11.0
HU	14.2	13.0
MT	6.0	10.0
NL	6.0	14.0
AT	33.5	34.0
PL	11.3	15.0
PT	28.5	31.0
RO	25.0	24.0
SI	21.3	25.0
SK	12.0	14.0
FI	38.7	38.0
SE	53.8	49.0
UK	9.3	15.0

Source: Own illustration based on Eurostat. http://ec.europa.eu/eurostat/web/energy/data/shares

the EU, any perceived lack of integration cannot be blamed on one particular Member State.

- Finally, assuming that closer cooperation on some aspects of *Energiewende* policies is to be welcomed, which pathways are most conducive towards integration, given specific legal and politico-economic side constraints? Against the background of past developments in EU energy policy, it is clear that bottom-up processes are far more likely to facilitate cooperation than centralization and forced top-down harmonization of policies.

Thus, the abovementioned critiques of the energy transition are, at the end of the day, hardly ever convincing and should not guide policy advice: an EU-wide scheme of tradable green electricity quotas neither is a readily available policy option, nor should it constitute the goal of German energy transition polices. The rest of this paper demonstrates that neither implication is valid by setting out the above points in more detail.

2 Harmonization and Centralization of Energy Transition Polices?

In order to address the question how "Europeanized" Germany's energy transition policies should be, it is necessary to clarify analytically what "Europeanization" actually means (Gawel et al. 2014; Strunz et al. 2015). On the one hand, Europeanization might refer to the degree of homogeneity of policies across the EU. On the other hand, Europeanization might refer to the location of decision making power on a continuum from completely decentralized on the level of Member States to fully centralized on the EU-level. Based on this differentiation, then, specific criteria for more integration on each of the dimensions could be set up. For the scope of this contribution, however, it suffices to point out that there are two aspects to Europeanization and that these need not necessarily align: for example, a more homogeneous pattern of policies might be achieved by centralized decision-making at the EU level as well as via decentralized cooperation between Member States.

In general, a tension exists between the EU's aim of a common internal market for energy and the Member States sovereignty over energy policy (see also Buchan and Keay 2016). This tension materializes both legally and economically. Legally, the Treaty for the European Union (TFEU) is sufficiently vague in providing both supranational EU-institutions and the Member States with competing and overlapping competences (see also below). Economically, the welfare benefits from an internal market need to be traded off with possible welfare losses from overriding national peculiarities—the case of the *Energiewende* is a prime example in this respect, as will be argued in the following.

To what extent, then, would an EU-version of the *Energiewende* be desirable? As regards the nuclear phase-out, the obvious heterogeneity of policies in the EU challenges the notion that there might be welfare gains from harmonizing policies: The diversity of nuclear policies points to an underlying diversity of preferences about the risks associated with nuclear power. In particular, (hypothetically) imposing a nuclear phase-out on France would imply overriding French risk preferences. Certainly, also the systemic costs of a rapid French nuclear phase-out related to the much higher dependence on nuclear power compared to Germany would be huge. Certainly, some supranational coordination may be warranted as some nuclear risks may be transboundary. However, such issues do not necessarily call for a uniform EU-wide approach but may also be addressed by bilateral agreements.

Turning to the deployment of RES: assume, for the sake of argument, that there was a clean sweep and Europe's energy supply could be rebuilt from scratch. In order to minimize production costs, RES should be allocated according to most favourable geographical conditions, placing photovoltaic installations in Southern Europe and distributing windmills along the shores. Taking continental weather patterns into account would allow to minimize overall RES deployment costs (Grams et al. 2017). Additionally, a European-wide supergrid could be implemented, possibly including North African deserts as large-scale production location and Norway's fjords as storage facilities (cf. Macilwain 2012). Such seems to be the hidden vision behind some of the *Energiewende* critiques.

Yet, this counterfactual scenario is no appropriate yardstick for assessing current RES policies. Sure enough, there are sizable benefits from coordinating RES-support schemes to be expected (Bigerna et al. 2016; Unteutsch and Lindenberger 2014). However, this does not necessarily imply that a completely harmonized approach should be aimed for. Firstly, RES-related preference heterogeneity has to be taken into account: negative external effects of RES are highly technology-specific but mostly local (compare wind and biomass), so potential benefits from economies of scale in centralizing RES at geographical hotspots have to be traded-off with according negative externalities in the form of acceptance problems. EU-wide optimization of production facilities would also lead to increased need for transmission line extensions—current protests in Germany against new transmission lines attest to the related difficulties. Additionally, the idea of transforming Norway into a "green battery" for Europe should not be taken as a politically available short-term option due to ambivalent Norwegian preferences (landscape conservation vs. economic benefits from storing electricity) and the prevalent political culture of incremental change (Gullberg 2012). For the same preference-related reason, it is not clear whether the use of Norwegian fjords as "green batteries" would really improve the overall efficiency including environmental and resource costs of land-use change. Thus, spatially allocating RES is not reducible to a one-dimensional optimization problem following geographical patterns of energy yields and direct generation costs. Secondly, beyond these RES-specific aspects, there is a more general issue that deserves consideration: decentralized regulatory "experiments" may improve the overall result of policy intervention (aka the laboratory federalism argument). In case of uncertainty about the best regulatory solution to address a given problem, trial-and-error on lower government scales supposedly yields faster feedback-processes and policy adaptation and reduces societal learning costs compared to a uniform top-down EU approach.

In sum, a thorough and rapid "Europeanization" of German energy transition policies is unlikely to constitute the adequate policy recommendation from a comprehensive economic point of view. Instead, while more coordinated RES-support seems worthwhile for increasing production cost efficiency, a fully harmonized EU support scheme is not to be called for. In case of nuclear power, broad policy diversity in the EU means that a fully harmonized approach would override diversity of risk preferences.

3 RES-Support: Distinguishing “on What Level?” and “by Which Instrument?”

The above-mentioned argument that Germany’s RES-support scheme leads to an inefficient technology portfolio unduly mixes two levels of analysis: a given preference for regulating RES-policy on a specific governance level does not entail a distinct preference for a specific instrument. While the proponents of the argument suggest (partly implicitly, partly explicitly) that a trading scheme for green electricity certificates—analogous to the emissions trading scheme—is the most appropriate for an EU-wide approach towards RES, such a general proposition is not warranted. In the following, we outline some criteria by which to evaluate the question of how to support RES.

Assuming, for the sake of argument, that a harmonized RES-support scheme is desirable—how to decide upon the best instrument to reach a common EU-target for RES? Naturally, each instrument exhibits specific (dis-)advantages. Focusing on feed-in tariffs and quota schemes allows us to see the according pros and cons in more detail. Since Weitzman’s seminal 1974 study (Weitzman 1974) it is common wisdom in economics that the relative slopes of marginal costs and marginal benefits are crucial when deciding between a price (feed-in tariff) and a quantity (quota) instrument.[1]

Thus, the question becomes one of determining and evaluating costs and benefits from deploying RES. It has been argued that a stronger focus on the cross-boundary benefits of RES would speak in favor of feed-in tariffs: in particular, benefits of increased security of supply (due to lower fossil fuel imports from potentially unstable world regions) might be rather constant over the whole range of RES-deployment, which would speak in favor of a price instrument (Söderholm 2008). In contrast, if local employment impacts are of main concern to policy makers, benefits from RES may mainly accrue in the early stages of deployment, suggesting preferability of a quota scheme. The latter point, however, is somewhat self-defeating: in case local benefits are a main driver of RES-support, political willingness to coordinate across boundaries will usually not be given in the first place (see also below). Likewise, common arguments in favor of quantity instruments, cost efficiency and precise regulation of progressive damage functions, seem to cancel each other out in the case of RES: consider wind energy, which, as cheapest volatile RES, would mostly benefit from a quota scheme. However, the negative externalities (i.e., the aesthetic impact on landscape scenery and the ecological impact on bird populations) are increasing per windmill built. So in order to limit these progressive damages, regulators might want to set technology-specific quotas.[2]

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[1] Without uncertainty about marginal costs and benefits, both approaches are theoretically equal because the regulator can either set a quantity target or implement an equivalent price instrument.

[2] Ensuring grid stability by putting a portfolio of complementary RES in place is another reason why technology-specific quotas would be preferable (e. g., a combination of wind and solar is more robust to meteorological fluctuations than each of the technologies by itself).

Then again, this technology-differentiation would reduce the benefits of a quota scheme in terms of cost savings from supporting only the cheapest technologies.

Apart from these issues, there is another, energy system-related objection to be made against the "inefficient technology portfolio" charge that is meant to prove the superiority of the quota scheme: the argument is based on a static conception of efficiency, which is somewhat at odds with the long-term project of the *Energiewende* and general characteristics of the energy system (path-dependency, lock-in effects) suggesting we should rely on a dynamic perspective. Under simple quota systems, private actors may fail to take optimal long-term investment decisions for a variety of reasons, including externalities (knowledge spillovers), myopic decision-making or improper consideration of uncertainty. In the presence of these market failures, feed-in tariffs might be preferable in addressing the long-term market prospects of specific RES—particularly those that are in rather early development stages and, therefore, would not benefit from a pure quota scheme. For instance, the feed-in tariff-driven, large-scale deployment of photovoltaic installations in Germany during the last decade contributed to driving down module costs (Wirth 2014).

Summing up, there is no theoretical reason a priori to prefer a specific instrument to support RES. Considering the actual distribution of instruments in the EU (as outlined above), however, it might be argued that since feed-in tariffs (or feed-in premiums) are more common than quota schemes, the former could more easily be merged into a joint, supranational support scheme. In the following, we describe the conditions for more coordinated RES-policies.

4 Are Germany's Energy Transition Policies an Exception Within the EU?

To which extent can the main pillars of the electricity-related *Energiewende*, the specific RES support policies and the nuclear-phase out, be considered as outliers in the EU?

First, regarding the targets for RES expansion by 2020, Germany might even be considered as below-average, as Table 1 shows. In fact, both Germany's share of RES at final energy consumption in 2016 and the corresponding target for 2020 are slightly below the average on EU-level. Thus, any claim about exceptionality of Germany's RES policies must refer to the 2050 horizon, where Germany's RES targets are indeed ambitious and other Member States lack comparative long-term frameworks. In a sense, the ambition of Germany's energy transition lies not so much in the mid-term targets for RES, but rather in the fact that a thoroughly industrialized country, which often praises itself for being "World Champion" in exporting goods, aims at completely transforming its energy system in the long run. However, other European countries will be forced to set appropriate energy policy goals for 2050 in line with the overall EU decarbonisation scheme for the energy sector. Comparing German 2050 goals with present-day EU-wide energy policies does not make much sense.

Furthermore, Germany's support scheme for RES is no misfit within the EU. The Renewable Energy Sources Act ("EEG"), which prioritizes RES as regards electricity feed-in into the system and traditionally guaranteed a fixed remuneration for every kWh of RES-electricity produced, had been introduced in 2000. At the time, only six other EU-Member States had implemented similar RES support policies. However, by 2010 this form of support via feed-in tariff had become the mainstream way of pushing RES in the EU (see Strunz et al., "Policy Convergence as a Multifaceted Concept: The Case of Renewable Energy Policies in the EU" in this volume). In this respect, Germany might, therefore, be seen as a frontrunner whose example was followed by other EU Member States. Interestingly, also the recent revisions of the EEG are perfectly aligned with the general development of support policies: In 2012, Germany introduced a premium scheme in order to steer dispatchable RES. Questions about the economic merit of this measure notwithstanding (cf. Gawel and Purkus 2012), it directly corresponded to the continuous EU-wide trend of complementing feed-in schemes by premium schemes. In 2014, the first step toward tender schemes (i.e., auctioning of RES capacities to the lowest-cost provider) was made with several prototype auctions. Subsequently, the most recent revision of the EEG in 2016 broadly fostered the shift away from feed-in tariffs and towards tender schemes. Again, this conforms to the overall direction that the EU Commission's guidelines on state aid for environmental protection and energy stipulate (cf. Gawel and Strunz 2014).

On the basis of these general trends, and more detailed analyses of parallel developments in some EU countries, some have argued that there is evidence of bottom-up convergence of RES policies (Jacobs 2012; Kitzing et al. 2012). More generally, one might say that there is a trend towards more complex RES support schemes that combine different aspects, such as feed-in tariffs, premiums and tender schemes in a variety of ways (see Strunz et al., "Policy Convergence as a Multifaceted Concept: The Case of Renewable Energy Policies in the EU" in this volume). In any case, what the analysis clearly demonstrates is that Germany's RES support policies are far from being an outlier or a wrong-way driver in the EU; to the contrary, in comparison to the quota scheme, both Germany's introduction of a feed-in tariff as well as the recent switch toward tender schemes can reasonably be considered as mainstream policies.

Second, should Germany's phase-out of nuclear power considered an outlier? Across Europe, a rather diverse picture emerges: Table 2 displays the number of nuclear reactors, which are currently in operation, under construction or in planning within the EU-28 Member States and Switzerland. Several observations seem noteworthy. To start with, there is a huge spread between the countries that do rely on nuclear power: on the one hand, the nuclear share of overall electricity production in France reaches almost three quarters; on the other hand, the nuclear share in the Netherlands stands at slightly below 3%. In addition, a number of EU-Member States do *not* rely on nuclear energy, among them Italy, Austria, Portugal and Ireland. An exception is Poland, which currently does not have nuclear plants but

Table 2 Nuclear power in Europe (EU-28 plus Switzerland)

	Country	No. of reactors in operation	Nuclear share at overall electricity supply (%)	Future development
Countries that rely on nuclear power or intend to phase in	Netherlands	1	2.9	–
	Slovenia	1	33.4	–
	Bulgaria	2	33.2	–
	Romania	2	21.2	–
	Finland	4	33.3	1 reactor in construction
	Hungary	4	51.5	–
	Slovakia	4	54.7	2 reactors in construction
	Czech Republic	6	35.9	–
	Spain	7	19.7	–
	Sweden	10	42.6	–
	UK	16	18.8	1 reactor in planning
	France	58	73.6	1 reactor in construction
	Poland	–	–	2 reactors in planning-
Countries that have no nuclear power or intend to phase out	Austria	–	–	–
	Croatia	–	–	–
	Cyprus	–	–	–
	Denmark	–	–	–
	Estonia	–	–	–
	Greece	–	–	–
	Ireland	–	–	–
	Italy	–	–	–
	Latvia	–	–	–
	Lithuania	–	–	–
	Luxembourg	–	–	–
	Malta	–	–	–
	Portugal	–	–	–
	Switzerland	5	36.4	Nuclear phase-out by 2034
	Belgium	7	52.1	Nuclear phase-out by 2025
	Germany	9	15.4	Nuclear phase-out by 2022

Source: Own illustration based on European Nuclear Society [http://www.euronuclear.org/1-information/maps.htm (Data for 2014)] and Eurostat [http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production_and_supply_statistics#Source_data_for_tables.2C_figures_and_maps_on_this_page_.28MS_Excel.29 (Data for 2013)] envisages building two plants in the future. Furthermore, two European countries, Switzerland and Belgium, also have recently decided to phase out nuclear power. Summing up, portraying Germany's nuclear phase-out as an outlier somewhat distorts the actual status-quo of nuclear power in Europe. As there is no discernable trend or mainstream to which all nuclear policies could be said to converge, singling out Germany's phase-out as unilateral seems unjustified.

5 Fostering the EU-Embedment of RES Policies: Bottom-Up Instead of Top-Down

The historical development of RES policies in the EU has shown, above all, that Member States consistently resist the Commission's attempts to implement an EU-wide quota scheme: the origins of both the directive 2001/77/EC and the substituting directive 2009/28/EC have been interpreted as failed attempts to do so (see Jacobs 2012). Recently, the Commission seems avid to push Member States into the direction of uniform tender schemes (EU Commission 2014). Given the history of Member States' refusal to adopt top-down harmonization and their insistence on national sovereignty over the energy mix in the Lisbon Treaty—article 194(2) TFEU affirms "a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply"—the prospects for the success of this plan could be meager.

Furthermore, the European Court of Justice (ECJ) has upheld Member States' rights to pursue purely national RES-policies: in its decision concerning Finish Åland Vindkraft's complaint to access the Swedish RES-support scheme, the ECJ stated that although national support schemes might be distorting the internal market, they can be justified as policy interventions aiming at the common interest (environmental protection, combating climate change) (Gawel and Strunz 2014). Hence, both from a political and a legal point of view, the future of RES-policies in the EU is likely to be decided bottom-up rather than top-down.

Clearly, the politico-economic interests giving rise to this constellation should be acknowledged within policy recommendations. In other words, as Member States' politicians are motivated by protecting regional and national energy infrastructures (so as to secure voter support), policy advice that ignores actual political decision processes renders itself irrelevant. A completely technology-neutral RES-support scheme without reference to national peculiarities would imply structural reallocations that are not politically palatable: if, for instance, support for photovoltaic installations in Germany were to cease—in favor of more convenient locations from a meteorological point of view—, considerable political protests from beneficiaries and lobby groups would have to be overcome.

Given these restrictions, what is the most realistic pathway towards more cooperative RES policies that take cross-boundary benefits into account? Interestingly, the relevant legal provision, the directive 2009/28/EC, already provides for cooperation between Member States (statistical transfers, joint projects, joint support schemes). So far, these cooperation mechanisms have not been used, however. On the one hand, from a pessimistic outlook, one could argue that if not even these existing options are realized, RES policies are likely to remain mostly national issues for the time being. The fact that the RES target for 2030 is not specified for the individual countries should rather be interpreted as a regression in this respect: Without identifying clear responsibilities for specific Member States the EU-target can hardly be considered as legally binding. On the other hand, the hypothesis of bottom-up convergence implies that explicit cooperation between Member States is not necessarily the crucial *mechanism* at work. Instead, some of the benefits of allocating RES on above-Member-State-level could be indirectly secured—by different national policies aligning (e.g. via spill-over of best-practice regulations) providing a more levelled playing field for RES across the EU. Additionally, the other instruments such as the EU emissions trading scheme and increased cooperation regarding transnational transmission grids would also contribute to integration on RES.

6 Conclusion

Criticizing Germany's *Energiewende* as a unilateral approach that inhibits an EU-wide optimization of energy transition policies is misleading. To begin with, the two main pillars of the energy transition project, the nuclear phase-out and the deployment of RES, are less exceptional than sometimes suggested. Nuclear policies in the EU are highly diverse and Germany's support scheme for RES is very similar to the other Member States' schemes. Regarding the 2020 horizon, Germany's RES targets might even be considered as below-average; as for the 2050 horizon, Germany's RES targets are surely very ambitious. On the other hand, as Germany stands alone with respect to these long-term targets, a comparison with comparative policies is not yet possible.

Moreover, in case of nuclear power, an EU-wide approach would probably not be—due to preference heterogeneity—desirable in the first place. As the nuclear phase out can and should not be imposed on neighboring countries that use nuclear power (France, Czech Republic), a national approach including bilateral negotiations on near-border power plants (e.g., Fessenheim in France, Temelin in the Czech republic) seems more appropriate. Sure enough, phasing-out nuclear power in Germany (and subsequently coal) must be complemented by an according increase in RES deployment so as to avoid substituting domestic with imported conventional energies. Regarding support policies for RES, increased cooperation would increase the cost efficiency of RES deployment in the EU. Yet, concerning the externalities of specific RES, there might be preference heterogeneity as well and the argument for laboratory federalism should caution us against unambiguous calls for a completely harmonized EU-wide approach.

Furthermore, the suggestion that a German switch to a green electricity quota scheme would mark the beginning of policy harmonization flies in the face of the actual developments in EU energy policy during the last two decades. The quota scheme has always remained a niche of RES support in the EU. In contrast, feed-in tariffs and feed-in premiums, such as implemented in Germany, proved to be most common in the past; in the next years, tender schemes, as required by the EU Commission, are set to become the new mainstream (or various combinations of tariffs, premiums and tender schemes).

So, the *Energiewende* is not such an outlier in Europe as some of its critics would have it. Certainly, as energy policy remains predominantly national, there are non-coordinated spill-over effects from one country to another—and in this sense some refer to German energy policy as "unilateral" (cf. Grossi et al. in this volume). However, it needs to be acknowledged that until energy policy is completely harmonized and centralized (and, as pointed out above, there are valid economic reasons for retaining some heterogeneity), Germany, as any other Member State, is perfectly entitled to pursue its own, ambitious energy transition goals. Looking ahead, an often neglected third way in between centralized and national approaches is also worth noting: An alliance of several ambitious Member States—a "coalition of the willing", in other words—might constitute a realistic option in the medium term.

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Germany: Frontrunner in Europe with Respect to Energy System Transition?

Stefan Vögele and Christopher Ball

Abstract In Europe, Germany is the greatest emitter of greenhouse gas emissions. With ambitious targets regarding reduction of greenhouse gas emissions and use of energy carriers, Germany aims to be a frontrunner in Europe with respect to energy and environmental policy. However, increasing problems after harvesting "low-hanging" fruits and increasing activities of other countries strengthen the impression that Germany may not be a "frontrunner" or a "leader" anymore. Using indicators with respect to greenhouse gas emissions, to energy use and supply, as well as to technological aspects, we analyze the role of Germany in the European context. The results show that other countries demonstrate partially better performances. Germany can still be regarded as a leader with respect to PV and wind power plants. However, there are signs that Germany could lose some of its remaining advantages. Thus, for Germany, the label "frontrunner" should be used more carefully.

1 Introduction

"Pioneer," "leadership," and "leader" are terms that have often been used in association with German energy and environmental policy (see, e.g., Quitzow et al. 2016; IRENA 2015b). Reports that Germany is likely to miss its ambitious GHG reduction targets (2020 and 2030) (German Federal Government 2017), problems in the transition of the transport sector, losses of jobs in the PV sector (IRENA 2014, 2015a, 2016, 2017), and increasing activities of other countries with respect to energy system transitions (see, e.g., IEA 2017b) strengthen the impression that Germany may not be a "frontrunner" or a "leader" anymore.

In this study, we want to analyze the role of Germany in the European context with respect to greenhouse gas emissions, energy use and supply, as well as technological aspects. We focus on areas in which Germany was named as frontrunner. By providing additional information, we will stress how the

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S. Vögele (✉) · C. Ball
Institute of Energy and Climate Research – Systems Analysis and Technology Evaluation (IEK-STE), Forschungszentrum Jülich GmbH, Jülich, Germany
e-mail: s.voegele@fz-juelich.de

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classification of Germany as frontrunner is/was appropriate, whereas we define frontrunner as someone doing something that other people and organizations later develop or continue to do. Following the definition of Steinbacher/Pahle for leaders, we assume that frontrunners “seek to generate followers on the basis of their pioneering policies with a view to reaching a collective goal beyond their strict self-interest” (Steinbacher and Pahle 2016: 73).

Frontrunners trigger the exploration of novelties comprising, e.g., new technologies, new institutions, as well as new kinds of policy measures. Great efforts are necessary to meet ambitious targets like the ones specified in the Paris climate conference (COP21). In view of this, there is a need for frontrunners in Europe that want to remain ahead of the game. We will analyze the development of Germany’s position as a possible frontrunner in a continuously evolving context. By taking a broad range of indicators into consideration, we will analyze to what extent “frontrunner” means leader in a selected field and, thus, should always be used with consideration given to the underlying context.

The chapter is organized as follows. The methodical aspects are presented in Sect. 2. In Sect. 3, we conduct the analysis and provide detailed information on the different indicators. In Sect. 4, we draw conclusions and discuss the scope for further research.

2 Methodology

In the following section, based on a set of indicators, we will assess the role of Germany as key player in Europe with respect to environmental and energy issues. The selection of the indicators is based on the 20-20-20 targets of the EU[1] and on fields in which Germany has been named as pioneer or key player (e.g., phasing out of nuclear, promotion of renewable technologies).

In addition to indicators which refer to a specific year, indicators referring to changes in time will be used. Beise/Rennings and Rennings/Smidt highlight factors that support becoming or remaining a leading market for a particular technology. The set of factors include price advantages, factors leading to strong demand, transfer advantages, export advantages and market structure advantages (Beise and Rennings 2005; Rennings and Smidt 2010). Since these factors vary between countries, countries face different difficulties in becoming a pioneer or leader. Focusing on public and industry-financed R&D expenditure, capacity for innovation, as well as “ease of doing business”, Germany ranks among the top five countries worldwide (OECD 2016, WEF). Thus, Germany is well suited to play a key role with respect to innovation processes.

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[1] The 20-20-20 targets are for the year 2020 and include 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables, and 20% improvement in energy efficiency (European Commission 2017).

Countries like Germany, France, Spain and Great Britain have advantages in financial and human resources compared to “small” countries (e.g., the Netherlands, Denmark, and Portugal). On the other hand, in absolute terms, more effort could be necessary to transform their energy systems. In this instance, countries with a less complex energy system could have advantages.

In order to take such effects into account and to be able to compare countries appropriately, indicators set in terms of relative values are used in addition to indicators set in terms of absolute values. Since announcing ambitious targets could also indicate that a country wants to be a pioneer, we also include targets set by governments in our list of indicators.

The indicators used for the evaluation of the role of Germany are grouped into indicators which are related to greenhouse gas (GHG) reductions, directly to energy supply and consumption and to technologies. In addition, phasing out of nuclear, implementation of e-mobility and other factors will be discussed as possible fields where Germany could act as a frontrunner.

For the sake of simplicity, we assume that a country is a frontrunner or belongs to the group of frontrunners (with respect to a specific topic) if the country is featured at the top of the list of the corresponding indicators. Focusing on quantitative factors limits the analysis of Germany’s role as frontrunner because its role in international environmental negotiations and other kinds of formal and informal activities will be ignored (see, e.g., Quitzow et al. 2016). On the other hand, the selection of quantitative indicators allows an appropriate comparison of countries using official and well-documented information. Putting information on all indicators together helps to assess the overall performance of Germany and to check if Germany could serve as an example for other countries.

3 Results

3.1 Indicators relating to GHG

Figure 1 compares the GHG reduction targets on which European countries agreed in 1997. Germany was one of the countries with the highest targets for reducing the GHG emissions in the first commitment period specified in the Kyoto Protocol. Countries like Great Britain, France, and Spain committed to lower targets. Since the countries differed with respect to the installed power plant stock, the availability of resources, the GHG emission levels in the initial year and in the expected economic dynamics, the level of the announced reduction target did not reflect how ambitious the targets were for the individual countries. Some countries might reach the targets more easily than others. With a high number of nuclear power plants, France had more difficulties in reaching higher GHG reduction targets than Germany. Since Spain expected strong economic growth, it agreed on reducing the growth rates of its emissions but not to decreasing those emissions below the 1990 level. Regarding the setting of ambitious targets, Germany has been a frontrunner. In terms of the

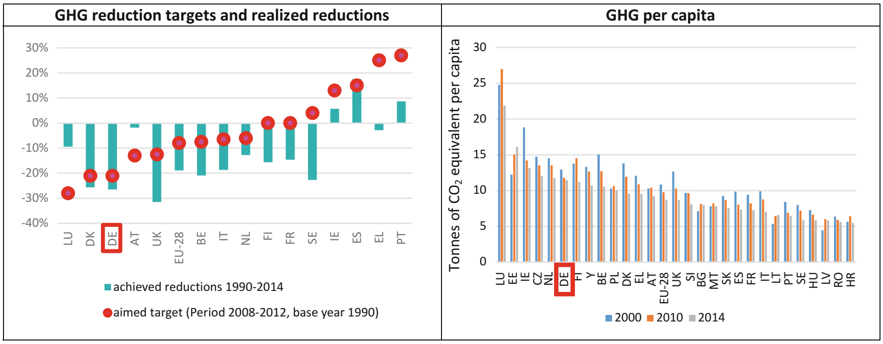


Fig. 1 Aimed and achieved changes in GHG emissions. Source: Eurostat (2017b, c)

reductions implemented, other countries also performed well. Although Germany is not ranked first in the list of the best performers, it belongs to the top three in Europe.

Regarding specific GHG emissions, Germany still belongs to the group of countries with the highest emissions per capita (Fig. 1). In the past, although the specific emissions have been reduced significantly, other countries have performed better. To a certain extent, the high emissions per capita could be explained by economic activities in Germany. However, a comparison of the GHG emissions per unit GDP shows higher values for Germany than for, e.g., Great Britain, Spain, and France (see, e.g., The World Bank Group 2017). Focusing only on specific GHG emissions and ignoring development on sectoral or technological level, Germany can hardly be called a pioneer.

3.2 Indicators relating to energy

In addition to reductions in GHG emissions, increases in the use of renewable energy are usually applied to assess the environmental friendliness of a country. Figure 2 shows the share of renewables in the final energy consumption in combination with the targets set for this share for 2020 (European Parliament & Council of the European Union 2009). In 2015, renewable energy sources contributed to nearly 15% of final energy consumption in Germany. Higher shares are calculated, e.g., for France (15.2%), Spain (16.2%), Italy (17.5%), and Denmark (30.8%), whereas the United Kingdom (8.2%), Belgium (7.9%), and the Netherlands (5.8%) show a below-average performance. In order to reach its target, Germany has to increase the share of renewable energy sources in final energy consumption by roughly 3% points. Denmark and Italy have reached their targets, whereas France, the United Kingdom, and the Netherlands have some way to go. Again, the development of this share and the specification of the target have to be assessed in relation to the availability and cost of renewable energy sources in the respective country. Countries with, e.g., high hydroelectric potential, have advantages with respect to the level

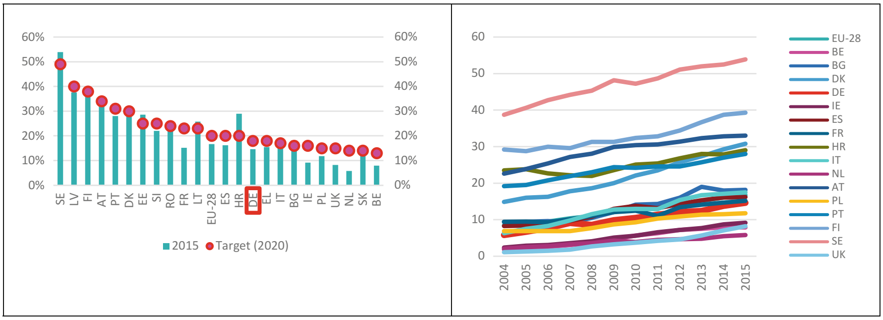


Fig. 2 Share of renewable energy in gross final energy consumption. Source: Eurostat (2017a)

of the share. Thus, the change of the share over time should be included in the assessment, too. In Germany, in the period 2004–2015, the renewable energy generation (REG) share increased by more than 150%. Higher increases were seen in the Netherlands (176%), Italy (178%), and the United Kingdom (645%). All in all, with respect to the renewables, Germany performed well. Among the bigger countries, only Italy shows a slightly better performance (with respect to the absolute level of the share and to the dynamics).

Apart from GHG reduction and increasing use of renewables, enhancing energy efficiency is a pillar of energy system transitions. With a share of 20% of the total primary energy consumption in Europe, Germany plays a central role with respect to changes in energy consumption (Eurostat 2017a). A lot of measures has been implemented to increase energy efficiency (IEA 2017b). Examples include regulations with a focus on building sector, R&D programs (e.g., fuel cells, e-mobility), and the electricity sector. According to BMWi (2017), in Germany, the gross inland consumption of energy decreased by 0.4% on average from 2000 to 2016 annually.

To compare energy consumption with the Europe 2020 targets, the primary energy consumption is used as the official indicator. Primary energy consumption corresponds to the **gross inland consumption of energy**, excluding all non-energy use of energy carriers. A comparison of the figures for the primary energy consumption of 2005 with primary energy consumption targets listed in European Commission (2015) shows that France and the United Kingdom have especially ambitious reduction targets. Like Italy, Germany wants to reduce its primary energy consumption by 13% by 2020 (in comparison to 2005). Comparing the reduction reached so far, Germany has succeeded less than, e.g., the United Kingdom.

The primary energy consumption strongly depends on the development of economic and social frameworks. Thus, in addition to changes in efficiency, reductions in energy consumption can also be related to reductions in economic activities. According to the data presented by Eurostat, the primary energy consumption per capita in Germany is higher than the average in the EU. Regarding the changes since 1990 among the big countries in Europe, only the United Kingdom performed better (Fig. 3).

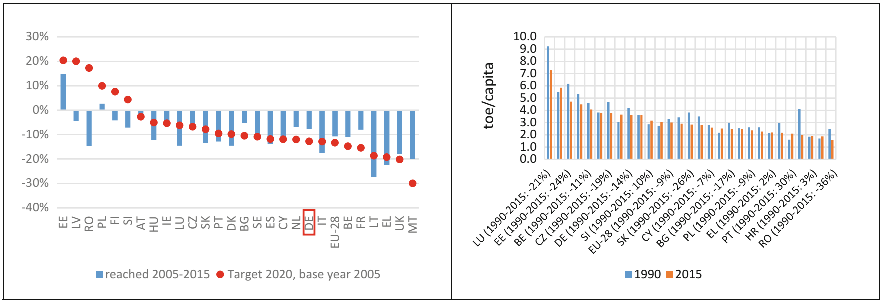


Fig. 3 Primary energy consumption. Source: Eurostat (2017a)

3.3 *Indicators relating to technology*

In 1990, a feed-in tariff system was implemented in Germany to support renewables as green technologies. Since PV and wind power plants were identified as technologies in which Germany could become a global leader, a feed-in tariff system (which has been continuously adjusted) and further supporting measures (incl. public R&D expenditures) for these technologies have been implemented (IEA 2017b).

Further tightening of GHG reduction targets and soaring oil prices strengthen the support for PV and wind power plants. Accordingly, the installed capacity increased significantly. Other countries followed Germany, encouraged by strong decreases in the cost of PV and wind plants. With a capacity of 44 GW, more than 30% of the wind power plants in Europe are located in Germany (Fig. 4). In Spain which ranks second, "only" 23 GW is installed. The picture will look different if the electricity production of wind power plants is expressed in relation to gross electricity production: under this measure, Denmark ranks first, followed by Ireland, Portugal, and Spain. Germany ranks sixth (EWEA 2016).

In 2016, the capacity of PV installed in Germany reached the value of 40 GW. With 18 GW, Italy ranked second. Taking the gross electricity production into account, Italy, Greece, and Malta are ahead of Germany. Comparing the total installed capacity on an international level, Germany ranks second for PV (only China has more PV capacity installed) and third for wind (China, 145 GW; Unites States, 74 GW) (REN21 2016).

With respect to the dynamics of additions to net capacity, China, Japan, the United States, the United Kingdom, and India perform better than Germany (REN21 2016): in 2015, the installed capacity in China increased by 15.2 GW, in Japan by 11 GW, in the United States by 7.3 GW, and in the United Kingdom by 3.7 GW, whereas in Germany only 1.5 GW was added. Regarding wind power capacity additions, Germany still features among the top three.

In recent years, there have been large job losses in the PV industry in Germany. Taking indirect jobs into account, the number of jobs has decreased from 90,000 in 2012 to 32,000 in 2016. At the same time, in China, the number of jobs increased significantly. Furthermore, other countries extended their activities in the PV and

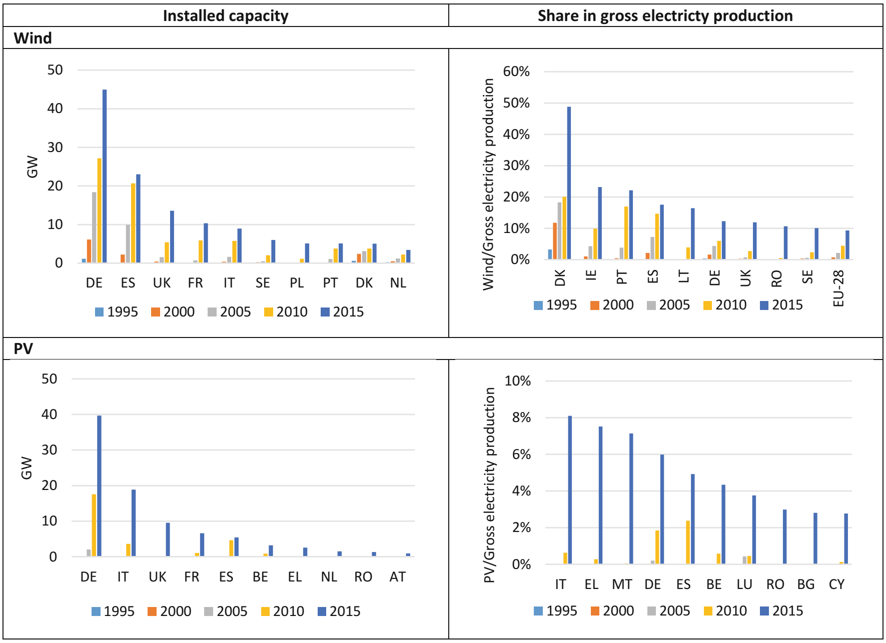


Fig. 4 Wind and PV: Installed capacity and electricity production. Source: IEA (2016); EWEA (2016)

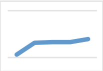
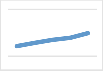
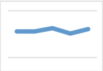
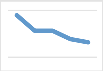
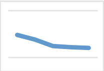
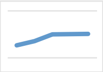
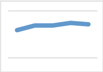
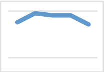
centralized solar power (CSP) sector. As far as the wind industry is concerned, there have not been significant job losses in Germany (see Table 1).

The development of the export of wind turbines and photovoltaic cells supports the statement that the German PV industry faces more and more difficulties, whereas the wind industry is still developing well. One reason might be the low transportation cost for PV modules which helps China to sell modules in Europe (Fig. 5).

The decline in the number of patents by the German PV industry is often cited as an indicator for the decline of the PV industry in Germany. Indeed, in contrast to patents linked to wind, the number of new PV patents has decreased more strongly. Since the number of patents depends strongly on the patent strategy in a particular country and the maturity of the corresponding technology, the number of patents is an indicator which has many shortcomings (BMWi 2016).

With respect to the indicators related to PV and wind power plants, Germany can be identified as pioneer. However, increasing activities in other countries in combination with economic problems in the German PV industries lead to serious doubts that Germany could keep the flag flying.

Table 1 Estimated direct and indirect jobs in renewable energy in 1000 persons

	World	China	United States	India	Japan	Bangladesh	Germany	Rest EU
Solar PV and CSP								
								
2012	1360	300	107[a]	112			90	242
2013	2316	1580	143[a]	112		100	57	192
2014	2517	1641	174[a]	125	210	115	57	122
2015	2786	1652	198	103	377	127	39	110
2016	3118	1973	247	121	302	140	32	86
Wind								
								
2012	753	267	81	48			118	152
2013	834	356	51	48		0.1	138	190
2014	1027	502	73	48	3	0.1	138	182
2015	1081	507	88	48	5	0.1	149	182
2016	1155	509	103	61	5	0.3	143	187

Remark: [a]incl. solar heating/cooling. Source: IRENA (2013, 2014, 2015a, 2016, 2017)

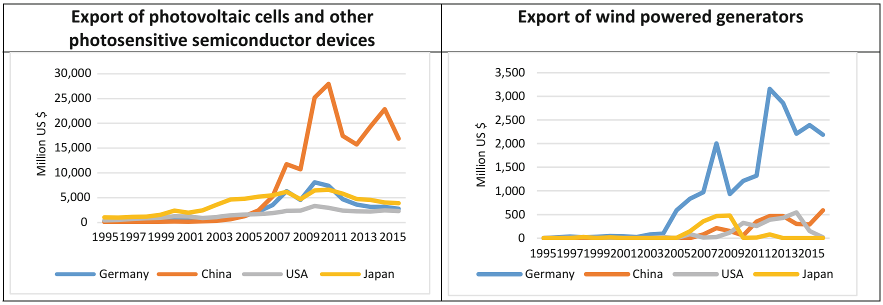


Fig. 5 Exports of photovoltaic cells and wind-powered generators. Source: UN Comtrade (2017)

3.4 *Other Indicators*

Apart from GHG reduction, decreases in energy consumption, and increases in the use of renewables, the phaseout of nuclear is mentioned as a key element of the transition of the German energy system (see, e.g., BMWi 2016). In the year 2010, nuclear power plants had a share of nearly 22% in gross electricity production. Since then the share has decreased continuously (BMWi 2017). According to the announced timetable, the last nuclear power plant should cease operating in 2022. Considering the large number of nuclear power plants and their utilization rates, the phaseout of nuclear can be regarded as a great feat. In principle, in the European context, the discussion on the phasing out of nuclear power plants is nothing new. Apart from Austria and Italy which decided not to use nuclear plants decades ago, in Sweden, the Netherlands, Belgium and Switzerland, there have been extensive discussions and various decisions on limiting the operating life for nuclear power plants (see, e.g., Brendebach et al. 2015). In view of the large number of nuclear plants which are being phased out, Germany could serve an example for other countries.

Quitzow et al. (2016) highlighted the role of Germany with respect to the introduction of a feed-in tariff system for renewables. A lot of other countries followed the example of Germany and enacted similar measures. With increasing additional burdens for private households resulting from increases in the renewable energies act levy, the government implemented substantial modification of the feed-in tariff system (e.g., by introduction of an auction system). The experiences Germany had with its feed-in tariff system can help other countries to choose and adjust support systems for renewables.

In addition to increasing the use of renewables and phasing out nuclear power, one key element of Germany's energy system transition is the transformation of the transport sector. The government aims to put one million electric cars on the road by 2020 (see, e.g., OECD 2012). According to the statistic of the Kraftfahrt-Bundesamt (KBA 2016) in 2016, only 25,500 electric cars and 130,365 hybrid cars were registered. Thus, the target of one million cars seems to be unrealistic. Other countries selected successful measures like tax exemptions, waivers on fees, and

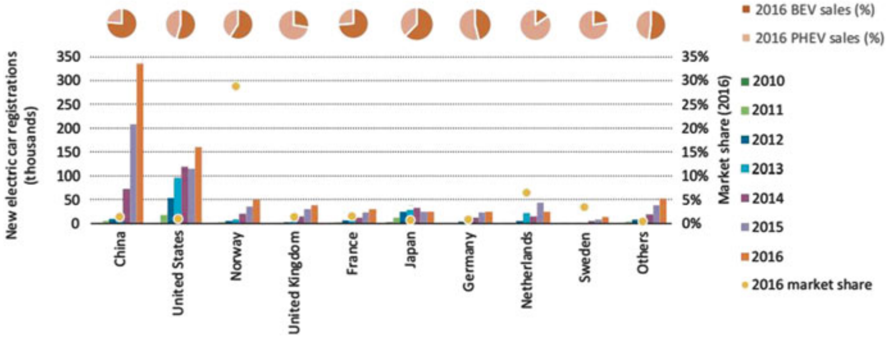


Fig. 6 Electric cars (battery electric and plug-in hybrid), market share by country. Remarks: *BEV* battery electric vehicles, *PHEV* plug-in hybrid electric vehicles. Source: IEA (2017a)

free access to bus lanes (IEA 2017a). Among these countries are those with powerful car industries (e.g., France) (Fig. 6).

In 2016, the market share of electric vehicles in France (1.46%) was twice as high as in Germany (0.73%). In Norway (28.76%), Sweden (3.41%), the Netherlands (6.39%), and the United Kingdom (1.41%), the market share of electric vehicles was also higher than in Germany. Thus, with respect to e-mobility, Germany seems to be a laggard.

4 Conclusions

In recent decades, the German energy system has changed significantly. According to Weidner/Mez, German climate policy can be explained “by the combined effects of a certain ‘path dependency’, ‘enlightened, far-sighted self-interest’ (ecological modernization), a basic moral preference for ‘equity’ as an organizing principle and the ‘opaqueness’ of the distributional effects of climate policy within Germany” (Weidner and Mez 2008: 374). A great part of the transition process resulted from restructuring the eastern part of Germany. Great reductions in the GHG emission and in energy consumption encouraged Germany to become a frontrunner in Europe. The transformation process has been backed up by putting the *Energiewende* on the political agenda. Ambitious reduction targets for GHG emissions and energy consumption were specified and supported the impression that Germany is a frontrunner in Europe. However, other countries demonstrate a partially better performance (e.g., with respect to the achieved reductions). Regarding the use of PV and wind power plants, Germany became a pioneer. Germany can still be regarded as a leader in this area of technology. However, there are signs that, especially in the PV sector, Germany could lose some of its advantages.

As a country with extensive financial capabilities, Germany has advantages with respect to the development and implementation of new technologies. Because the energy systems of big countries like Germany are very complex, more efforts might be necessary for the transformation of such systems than for the energy systems of smaller countries. Thus, it is not surprising that some smaller countries transformed their energy systems partially faster than Germany. Among the big countries in Europe, Germany still belongs to the group of frontrunners even if Germany has not performed well with respect to all areas of energy and climate change policies.

Differences in starting points make it difficult to compare the role of countries as forerunners. Thus, the label "frontrunner" has to be considered in terms of the country context. The analysis shows that, in Europe, a lot of countries could be labeled as frontrunners if comparability problems are ignored. Since having the status of frontrunner will motivate countries to reinforce favorable policies, the label of frontrunner should be used, despite problems with respect to comparability. Competition with respect to the pole position in selected fields encourages individual countries to explore new mitigation measures. The sense of achievement could help to enhance environmental policy on European level, e.g., with respect to the definition of GHG reduction targets.

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Part III

Is There a “Dark Side” to Germany’s Energy Transition?

The Myth of the Dark Side of the *Energiewende*

Conrad Kunze and Paul Lehmann

Abstract Germany's large-scale deployment of RES-based power generation has not resulted in a significant decline of its energy-related CO_2 emissions. The reason for this emissions trend was the constantly high level of coal-fired power generation in Germany. Consequently, it has been argued that the German coal binge may be the "dark side" of the Energiewende. We point out that this argumentation is flawed. In fact, the increase in coal-fired generation has been strongly driven by developments on international fuel and carbon markets—and not only, if at all, by the phase-out of nuclear and ongoing RES deployment.

1 Introduction

The German energy transition, often referred to as *Energiewende*, aims at reducing greenhouse gas emissions by 40% by 2020 (80–95% by 2050), compared to 1990 levels. Primary energy consumption shall be reduced by 20% by 2020 (50% by 2050). The share of renewable energy sources (RES) in gross final energy consumption shall be increased to 18% in 2020 (60% in 2050). This latter target will particularly affect the future of power generation: in 2020 35% shall be RES-based, and at least 80% in 2050. Simultaneously, nuclear power generation will be phased out completely by 2022 (BMWi 2016).

So far, Germany has been particularly successful in promoting RES deployment for power generation—with already more than one third being produced from RES at the moment (BMWi 2016). The major driver behind this development has been

C. Kunze
Environmental Policy Research Centre (FFU) at the Otto Suhr Institute of Political Science,
Freie Universität Berlin, Berlin, Germany

P. Lehmann (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig,
Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany
e-mail: paul.lehmann@ufz.de

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the German feed-in tariff which was implemented in 2000 to promote RES power generation (for a brief history, see, e.g., Hoppmann et al. 2014; Strunz et al. 2016).

However, Germany's large-scale deployment of RES-based power generation has not resulted in a significant decline of its energy-related CO_2 emissions. Figure 1 illustrates that these have rather stagnated since the RES feed-in tariff was introduced in 2000. In fact, post-2000 years saw a slight increase in emissions. This only ended with the 2007/2008 global financial crisis, which resulted in an economic downturn and respective emission reductions. Afterwards, emissions increased again until very recently. The reason for this emissions trend was the constantly high (or even growing) level of coal-fired power generation in Germany (see Fig. 2).

Due to these developments, the German *Energiewende* has come in for a good share of mockery in the international media, especially in the Anglo-Saxon and French press. Most commentators swiftly linked this trend—increases in CO_2 emissions and coal-fired power generation—to Germany's energy transition. National Geographic (2014) wrote in February 2014: "Some blame the return of coal on the imminent end of Germany's nuclear power industry". In the same month, the New York Times (2014) agreed: "But Germany's sudden hunger for coal has emerged as the dirty side of Ms. Merkel's ambitions to shut down the country's nuclear power plants by 2022 and eventually move Germans mostly to renewable energy." And the Guardian (2014) repeated the story in August, embellishing the claim by specifically making a nuclear-lignite connection: "Lignite (. . .) consumption in Europe has remained stable since the late 1990s, but grew slightly over the past few years on the back of high gas prices and the scaling back of nuclear power in Germany." The commentators thus seem to suggest that the objectives of the *Energiewende*—reducing CO_2 emissions, phasing in RES and phasing out

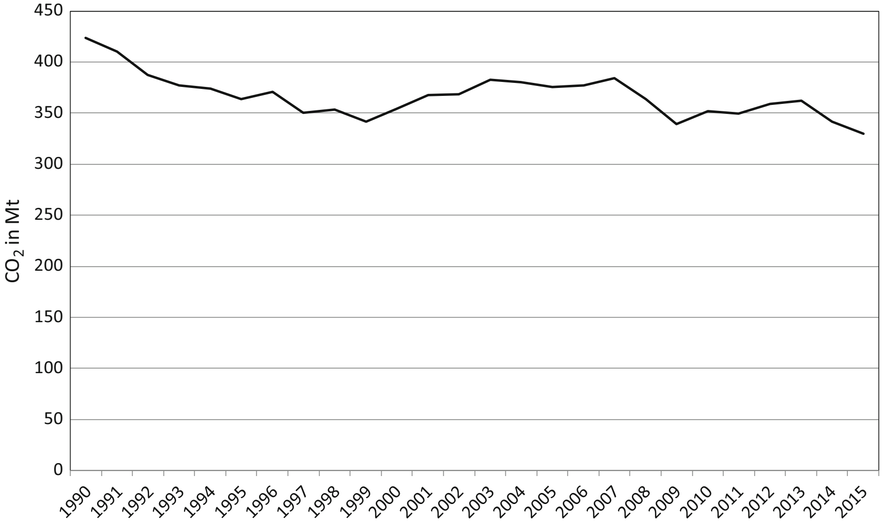

Fig. 1 Historic energy-related CO_2 emissions in Germany. Source: Based on data from UBA (2017)

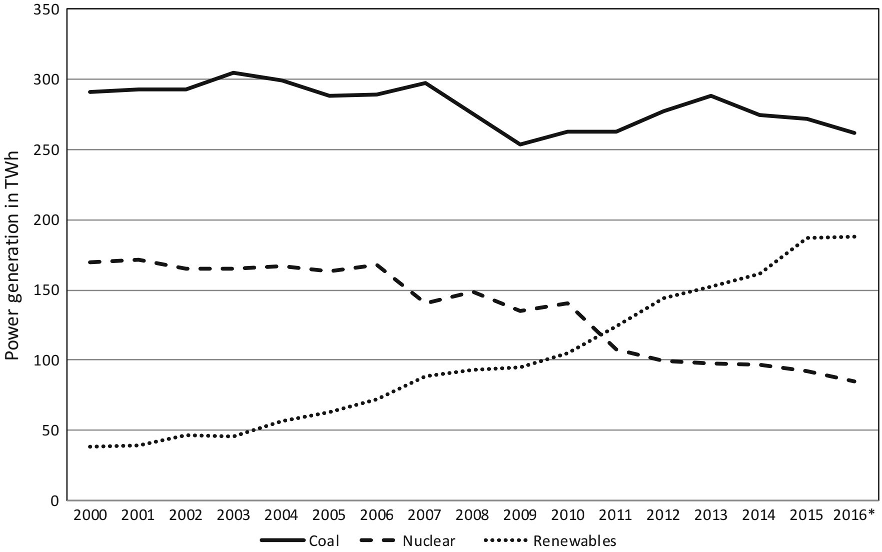

Fig. 2 Development of power generation from coal (lignite and hard coal), nuclear and renewable energy sources in Germany (in terrawatt-hours, 2016* data partly estimated). Source: Based on data from AGEB (2017)

nuclear—may be incompatible. Is this narrative true? Is the German coal binge really the "dark side" of the *Energiewende*?

To answer this question, we will first look at the recent evolution of power generation and consumption in Germany in Sect. 2. In Sect. 3, we then examine the global and domestic drivers that have been underlying this development. We conclude our discussion in Sect. 4.

2 Evolution of Power Generation with the *Energiewende*

2.1 Renewables Closed the Nuclear Gap

The narrative of Germany's dirty *Energiewende* first of all rests on the idea that renewables could not live up to their promise to fill the gap of retiring nuclear reactors. Consequently, that gap needed to be closed by power generation from coal. This was expected in diverse scenarios of the nuclear phase-out (see, e.g., Bruninx et al. 2013; Pahle 2010).

Certainly, however, Fig. 2 provides a more qualified picture. The dashed line in Fig. 2 above depicts how the amount of power from nuclear declined from 2000 to 2016. Due to the decommissioning of old plants, nuclear power had been declining steadily. When the German government decided on the phase-out, in 2011, some nuclear power stations were shut down immediately and the output went down more quickly. Afterwards, the steady decline continued once more.

The dotted line in Fig. 2 shows the steady rise of renewable energy in the same period. Since 2011, more electric energy has been provided from RES each year than from all nuclear facilities. So, at least at the aggregate annual level, RES have substituted the falling nuclear production in terms of total annual power generation and are very likely to continue doing so until 2022 when the last nuclear plant will be shut down. Certainly, a more careful assessment also needs to account for intra-annual variation of RES feed-in and its implications for non-RES generation. We will get back to this discussion in Sect. 3.

2.2 Firing Coal for Exported Power

But if RES generation compensated for the nuclear phase-out at least at the aggregate, how could coal generation increase after the 2007/2008 global financial crisis. There is in fact a ready explanation. As RES and coal-fired generation rose, and nuclear generation dropped, overall power generation in Germany increased from 632 to 649 terrawatt-hours (TWh) from 2010 to 2016. Yet, this development did not reflect an increase in domestic power consumption. In fact, domestic power consumption declined from 614 to 595 TWh during the same period (AGEB 2017).

Figure 3, which shows power exports and imports, throws light on the question. The dashed line in the graph depicts the amount of imported power in TWh. From 2000 to 2007 imports stayed level, despite a brief increase. The continuous line stands for the amount of exported energy. In 2002 exports started to rise steeply and stayed well above the dashed line representing power imports. In other words, since

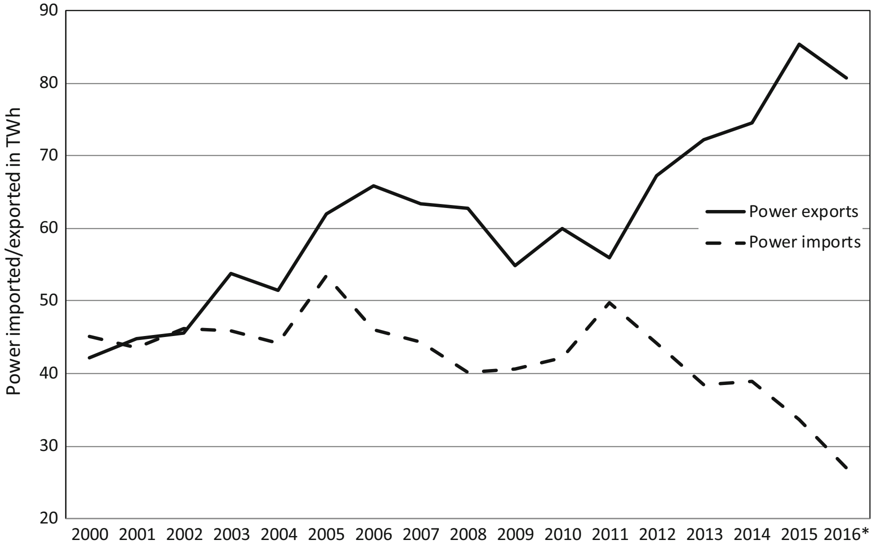

Fig. 3 Power imported to and exported from Germany (in terrawatt-hours, 2016 data partly estimated). Source: Based on data from AGEB (2017)

2002 Germany has been a power exporting country. It also imports, but exports exceed imports. There is a drop in power exports in 2011, the year in which the decision to phase out nuclear was taken. But even with that reduced production capacity in 2011, Germany still exported more than 50 TWh. The country has never become a power importer again, despite the nuclear phase-out. More importantly, since 2012, exports have been thriving. We may deduce, then, that the German coal binge is related to the increase in overall power generation and exports, not to the *Energiewende* as such. But what have been the drivers behind this development?

3 Drivers Behind the German Coal Binge

An assessment that aims to understand the drivers behind the German coal binge needs to go beyond looking only at the composition of the power mix. In the following we investigate potential global as well as domestic drivers for increased coal-fired generation in Germany.

3.1 International Drivers

So why has coal generation been thriving? The actual story has got little to do with the German *Energiewende*, and a lot with international markets. In fact, the cost of generating power from coal has declined over the past years. World market coal prices, and thus German import prices, have dropped significantly by more than 30% since 2011 (see Fig. 4). Prices have been driven down by a large oversupply of coal,

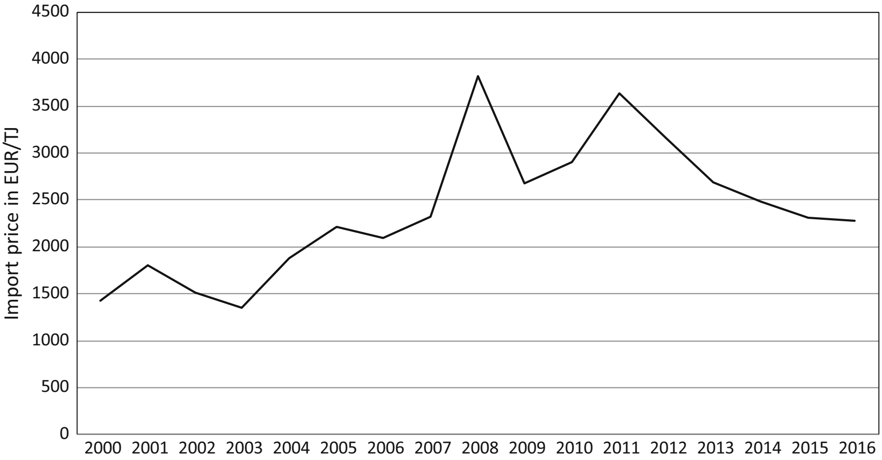

Fig. 4 German import price for hard coal (in Euro/terrajoule). Source: Based on data from BAFA (2018)

Fig. 5 EU allowances prices (in €/tonne of CO_2). Source: Based on data from EEX (2018)

partly as a result of the shale gas boom in the United States, but also thanks to increasing production capacities in Asia. This downward trend was only stopped in 2016 due to China's coal policy (IEA 2016).

What is more, the prices of CO_2 allowances, which need to be held by the operators of fossil-fuelled power plants, have collapsed—from 15–17 €/tonne of CO_2 in the late second phase of the EU Emissions Trading Scheme (EU ETS, 2008–2012) to 4–8 €/tonne of CO_2 in its current third phase (2013–2020) (see Fig. 5).

Both effects—the drop in coal and CO_2 allowance prices—have increased the profitability of coal-fired generation again, compared to other low-carbon generation technologies. Notably, both developments started in 2011, the year of the nuclear phase-out. Given Germany's large stock of existing coal-fired power plants, it is no surprise that coal-fired power generation and exports have increased significantly since then. Moreover, favourable market conditions for coal-fired power generation coincided with the onset of a new investment cycle in Germany's power sector (Pahle 2010). It is thus obvious that the German coal binge has been strongly driven by the developments on international fuel and carbon markets—and not only, if at all, by the phase-out of nuclear and ongoing RES deployment.

3.2 *Domestic Drivers*

The importance of global drivers notwithstanding, domestic drivers (beyond the nuclear phase-out), particularly the support of RES deployment, may also have had an impact on the development of coal-fired generation.

First, RES support schemes and the EU Emissions Trading Scheme interact. RES support frees up allowances in the power sector. Consequently, the allowance price declines (for a conceptual discussion, see Lehmann and Gawel 2013). Domestic RES support may thus have been an additional driver behind decreasing allowance prices. As has been pointed out above, lower allowance prices make coal-fired generation relatively more profitable, compared to gas-fired generation, for example. Therefore, RES support may eventually result in more coal used for power generation—the green serves the dirtiest, as Böhringer and Rosendahl (2010, 2011) put it. However, the empirical evidence on the actual importance of this interaction effect is very mixed and inconclusive (for a review, see Hintermann et al. 2016).

Second, the majority of RES generation fed into the German power system is intermittent. It therefore calls for back-up capacity to cover shortages throughout the year when the wind is not blowing and the sun is not shining. Such gaps need to be closed by power generation from other, non-renewable sources. Yet, it is not necessarily coal-fired power plants that fill this breach. Natural-gas fired power plants are more suitable to respond to sudden changes in renewables supply since they can be ramped up more quickly than coal-fired power plants (Ueckerdt et al. 2013). Only under certain conditions, power generation from coal—particularly hard coal—will also be required to meet residual load (Nicolosi 2010).

Overall, the evidence for domestic RES support benefiting coal-fired generation is thus less clear-cut than for the global drivers discussed above.

4 Conclusion

Many observers simply do not believe that it is possible for a modern industrial nation to phase out both nuclear and fossil power plants, as the *Energiewende* is aiming to do. In that sense the *Energiewende* has become a great test case for the possibility of a post-fossil *and* post-nuclear energy economy. Is it passing that test?

If the German *Energiewende* rests on these two pillars—getting rid of the old nuclear-fossil power plants and setting up new, renewable capacity—the second one is certainly holding up. Renewables rose to an all-time high of contributing roughly one third to Germany's power production. The other pillar, however, is only half-standing. Nuclear plants are gradually shutting down, but coal-fired generation has been thriving. Consequently, the French-German TV station Arte commented on the expansion of one open cast lignite mine as "the dark side of the *Energiewende*" (Arte 2014). The underlying intuition is that a high level of coal-fired generation logically follows if base-load nuclear generation is phased out and intermittent RES generation is phased in simultaneously.

Yet, our analysis has shown that this reasoning is not comprehensive enough. In fact, global drivers—low coal and carbon prices—most likely have been more decisive for the coal binge. Blaming it on the *Energiewende* alone—and thereby drawing the *Energiewende* into question—is too simplistic. In fact, it may be fair to assume that a good share of the coal revival would have occurred also without the *Energiewende* ever occuring.

This qualification notwithstanding, the coal binge also illustrates that the *Energiewende* is incomplete without a stringent political strategy to phase out coal. The most effective and efficient means to do so would be the tightening of the European Emissions Trading Scheme (ETS), e.g. by reducing the overall emissions cap or by implementing a price floor. Admittedly, this option may be limited due to political objections from some Member States, notably Poland (Gawel et al. 2014b; Strunz et al. 2015). Additional domestic measures, such as a politically mandated phase-out of coal, as currently discussed for Germany, may therefore be necessary.

Moreover, it is important to emphasize that the *Energiewende* is not only about climate change mitigation. It also pursues the overall objective of making power generation more sustainable in a broader sense. It is meant to address quite diverse issues next to climate change, such as nuclear hazards, local environmental problems, fuel import dependency and even a democratisation of the energy economy (Gawel et al. 2014a; Kunze and Becker 2014; Lehmann et al. 2019; Smith et al. 2019). Consequently, any assessment of the *Energiewende* must not be based on CO_2 reduction only, but on all relevant societal benefits (and costs).

In Germany it took a long time for renewable energy not to be portrayed anymore as a niche activity, unable to provide large-scale power. In international debates this notion still seems commonplace—mistakenly, as we have tried show. Certainly, concluding that the *Energiewende* has taken the right direction is not to say that it has overcome all major challenges. Important issues still need to be solved, such as safeguarding security of supply with high shares of volatile renewables or mitigating social and ecological conflicts associated with renewables. These are the real challenges that should be spotlighted when discussing the future of the German energy transition.

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Ensuring Industrial Competitiveness with a Unified European Approach to Sustainable Energy

Hubertus Bardt and Thilo Schaefer

Abstract German energy-intensive and highrevenue companies are postponing investments due to energy policies and the regulatory framework. Although this applies only to a number of companies, it shows that rising costs and uncertainty about the future energy policy agenda influence companies' decisions to invest. But only a few companies are planning to intensify foreign investments for these reasons. However, the present rules installed to prevent carbon leakage are limited in time and are in danger of becoming modified particularly at the expense of energy-intensive companies. Such uncertainties and unilateral strains that are restricted to Germany or Europe are a threat to innovations and the necessary investments which industries here need to make for low carbon and more efficient production. In order to achieve the energy transformation targets, there is a need for efficient measures that limit total expenditures as far as possible and prevent domestic companies from unilateral cost burdens.

1 The *Energiewende*: A German National Project

Germany's reorientation of its energy policy involves not only a fundamental reconfiguration of energy supply systems and the energy industry but also affects other sectors of the economy that consume large amounts of energy and emit greenhouse gases. After electricity generation, transportation and buildings have become increasingly important subjects of political discussion. Thus far, the primary focus has been on transitioning to environmentally friendly sources of energy. Alongside the phase-out of nuclear energy, agreed upon in 2011 and to be completed by 2022, the centrepiece of this transition has been the German federal government's politically established goal of meeting at least 80% of electric power demand from

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Parts of this paper are based on Bardt and Schaefer (2017).

H. Bardt · T. Schaefer (✉)
German Economic Institute, Cologne, Germany
e-mail: thilo.schaefer@iwkoeln.de

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renewable resources by the middle of this century. Other goals and necessary consequences are readily derived from this: the contribution of other energy sources to power production will decline, networks will need to be expanded and power supply systems will have to be made more secure through the development of backup capacities, storage or demand flexibility. Further improvements to energy efficiency (Bardt 2013) contribute to achieving the high targeted market share of renewable energies and the underlying emission reduction goals.

The German energy transition (so-called *Energiewende*) was decided on with no involvement from its European neighbours. This is especially striking in the area of power generation and supply, where physical interconnectivity with neighbouring countries through the international power grid is particularly dense. Even in the more advanced stages of planning for the transition in German energy policy, other European countries have scarcely been taken into consideration, despite the fact that securing the power supply in both the short and long term depends in part on supply from Germany's neighbours. This applies in the short term to supplying power at specific times and in the long term to the use of topographical structures of individual countries to support the construction of pumped storage plants that can help to even out fluctuations in the quantity of power supplied by wind and solar power plants.

As a result, there are two specific advantages of stronger European integration that are not being exploited. First, by putting European potentials to use, renewable energy could be deployed at appropriate locations. This would lower the overall cost of using renewable energy. Second, improved European integration could serve to establish a better balance among the various supply-dependent energy sources, e.g. if wind blows more reliably in a larger geographical unit than in Germany's smaller-scaled areas.

The set of regulations that has thus far been at the core of Germany's shift in energy policy, the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz* or EEG), is a national law which supports renewables feed-in to the German grid. Apart from a few new exemptions, the EEG is restricted to power plants within Germany. As such, fewer power plants are supported overall than would be possible at the same cost if European potentials were exploited. On the other hand, this also means that German electricity consumers are not involved in financing the expansion of renewable energies in other EU countries.

Support for renewable energies that is limited to the national market makes access more difficult for foreign suppliers. Within Germany, renewable energy from other countries must manage without financial support, so that at best, access to a level playing field is limited to technologies not supported by the EEG. To eliminate these obstacles to a single European power market, auctions could be opened for bidders regardless of the feed-in location (first small tenders already have to be opened for European suppliers). In the long term, emissions trading would allow for a technology-independent system for all of Europe. However, the current EEG is only a first—but important—step away from the traditional national and technology-specific support and towards a pan-European, technology-neutral support programme.

The German energy transition, and especially the expansion of renewable energies that it requires, is justified on the basis of various goals. These include contributing to climate protection, developing new technologies, conserving natural resources and achieving greater independence from imports of raw materials.

- **Climate Protection**

  Alongside the phase-out of nuclear energy for power generation, the major justification for the German energy transition is a reduction in greenhouse gas emissions, aimed at climate protection. To this end, Germany has been adding vast amounts of power-generating capacity from renewable energy sources. Within the framework of European carbon emissions trading, however, the expansion of renewable energies in Germany has no effect on emissions levels, given current ETS caps. Since electric power generation is subject to emissions trading, a certificate must be presented for every tonne of carbon dioxide. As the expansion of renewable energies results in lower emissions, fewer certificates need to be held. The unused certificates are offered on the market and sooner or later used by other emitters in Europe. The result is a decline in the price of emissions allowances, but not in emissions themselves. Since the recent ETS reform, it is possible for Member States to buy out or under certain conditions even delete certificates as a direct contribution to climate protection. Taking a medium- or long-term perspective, however, positive climate effects can be achieved by developing, marketing and reducing the cost of technologies which, in conjunction with increasingly strict climate goals and higher certificate prices, can make an economic contribution to electric power generation.
- **Developing New Technologies**

  Another frequently discussed goal of the energy transition is the promotion of certain technologies that are expected to contribute to climate protection in the future while operating at lower costs than current technologies with their associated cost structures. Support for renewable energies that are not currently cost-effective is justified primarily with the technological argument and learning curve effects. However, there is considerable debate as to which tools to use, since the current approach to promoting technologies is linked to high costs. While traditional support for renewable energies in the photovoltaic sector is associated with positive learning curves and volume effects, but also with low industry research expenditures (Bardt et al. 2012), increased research funding could be an alternative driver of technological development.
- **Resource Conservation**

  The conservation of natural resources is also discussed as a goal of climate and energy policy. The emissions produced in extracting and using resources are one reason for this, and the finite supply of natural resources is another. For energy resources in particular, future scarcity and corresponding price developments are a source of concern but also of critical discussion (Bardt 2008). A potential increase in prices due to lasting shortages would certainly have an economic impact. However, there is little reason to assume that government authorities are better able to identify such a situation than market participants. Expecting increasing prices is no sufficient reason for government intervention. On the other hand, potential scarcity also does not guarantee that the use of fossil fuels would decline far enough to limit climate change.

- **Independence from Imports**

  Often discussed alongside the above goals is the objective of greater independence from imports of raw materials. The reorientation of energy policy can be characterised as facilitating an increase in renewable energies' share of the energy supply sector. This applies to the supply of electric power, to the coverage of heating needs and to the transportation sector. While renewable energies' market share should and will grow, the share occupied by fossil energy sources will decline. If energy consumption remains stable or goes down, the need for fossil resources will also decline in absolute terms. This will lead to decreased imports of energy resources too in the coming decades. This is frequently seen as a particular benefit of the shift in energy policy as it represents increased independence from international energy imports (and the associated expenditures).

  However, if it really was a matter of reducing energy imports, and thereby reducing the importance of the international energy trade, then using renewable energy would just be one of many options. Using domestic energy resources would also be a useful measure for reducing dependence on energy imports. The United States is taking this approach by replacing oil imports through increased use of domestic natural gas and regional oil. Germany's self-sufficiency share in energy supply has traditionally been relatively low. Yet there are domestic sources: lignite (brown coal) plays an important role in power production, and 100% of Germany's use comes from sources inside the country. Natural gas and oil are also produced in smaller amounts (AG Energiebilanzen 2016). All in all, 30.8% of energy used in 2015 was covered by domestic sources; excluding renewable energies, this proportion was 18.1%. Within the non-renewable portion of the energy supply, 20.6% of energy was covered by domestic sources (Fig. 1).

2 International Differences in Electricity Costs

The goals of reorienting the national energy supply, and the associated ecological and other benefits, do not come without a price. There are various drawbacks as well, starting with the ecological costs of changes to the landscape and including the risk of shortages of raw materials needed for certain elements of a new energy supply system. One especially pertinent example is lithium, a necessary component of the batteries that are essential to the expansion of electric mobility (Leopoldina, acatech, Akademieunion 2017).

A secure energy supply at competitive prices is particularly important for an industrial country like Germany. High reliability is a key requirement for many different industrial processes. Even brief fluctuations or interruptions can lead to production cutbacks or stoppages, which in turn cause large and unpredictable costs.

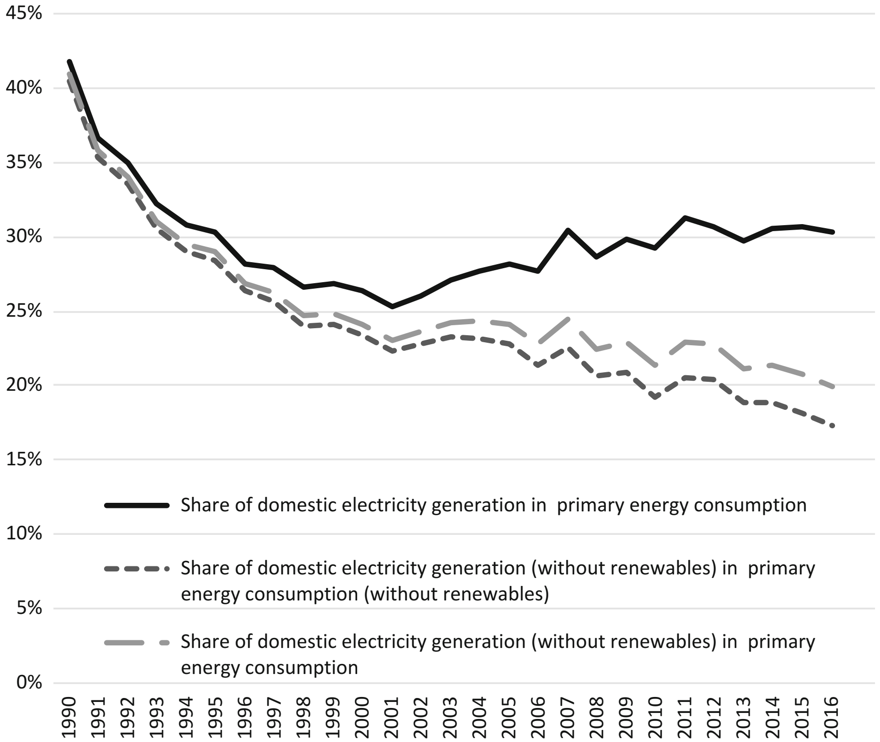

Fig. 1 Share of domestic production 1990–2016. Own illustration, sources: AG Energiebilanzen, Cologne Institute for Economic Research

Spending more money on security of supply, e.g. through the use of financial incentives to switch off sources of demand in periods of reduced electricity production from solar and wind facilities, represents an implicit increase in costs, whereas this qualitative advantage could generally be taken for granted in Germany in the past.

Besides the security of the energy supply, it is also important to consider the costs of the energy transition. The most recent reforms to the EEG were aimed in part at limiting future cost increases (BMWi 2016). On the one hand, the total costs of the energy transition are relevant here and are estimated at up to EUR 520 billion for the period from 2000 to 2025 (Haucap et al. 2016). More important for the concrete impact on business decisions in Germany, however, are the current and expected costs for industry.

Costs can be problematic for companies from two distinct perspectives. On the one hand, the costs themselves must be considered, e.g. the EEG levy that actually has to be paid out, resulting in an additional cost category (and for large electricity consumers, quite a significant one). On the other hand, uncertainties about future costs are also an important factor. Even if a company can take advantage of extensive (though not comprehensive) exceptions, uncertainty about the stability of these exceptions, for which there is constant political pressure to justify their existence, makes it impossible to plan for the medium term. At the very least, a company can hardly rely on the assumption that current exceptions will remain valid and unchanged for years on end. The costs imposed by the government are therefore problematic if they are either too high or potentially too high in the future for companies to be able to produce competitively.

Besides the absolute level of costs and/or rates of change, the relative positioning of those costs in comparison to other countries is also highly relevant. Nowadays, business decisions are made in the context of a variety of international options. Therefore, price and cost relationships must be considered in this international context. This means that special burdens associated with a specific country, which are not present in competing countries, are crucial.

The merit-order effect should also be considered from this perspective. It describes how market prices for energy go down when renewable energies act as additional suppliers to the market at very low marginal costs or none at all. The opposite effect occurs with the shutdown of nuclear power plants. At issue here is not a full cost analysis including all subsidies and distribution effects but only the influences on the market price. So if renewable energies have a downward effect on prices on the market and, at the same time, a company only has to pay a reduced burden to finance supply through a reduced EEG levy, it would even seem to have a pricing advantage when compared to its competitors from other countries. However, this is only true when the electricity markets are sufficiently decoupled from one another. In closely linked markets, market prices largely follow parallel trajectories or are even at the same level. In this case, the merit-order effect also benefits consumers in other countries, even though they have no additional costs through special country-specific burdens.

Industrial electricity prices in Germany have been trending upwards for a number of years. But things have developed very differently in the United States. There, increased natural gas supplies acquired by unconventional extraction techniques (fracking) have allowed prices to remain stable. Despite the lack of coupling between the US and German electricity markets (apart from global fuel prices), and even when taking the merit-order effect into account, we observe a clear deterioration in the price competitiveness of German energy consumers (Fig. 2). Although industrial electricity prices in Germany were actually below those in the United States at the turn of the millennium, they are now almost twice as high, even after a drop in German prices in 2015 (however, as prices differ between regions and scale of demand, there are also examples of large power consumers working with similar price levels in the United States and Germany). It is implicitly assumed here that higher costs cannot be systematically compensated for by lower consumption. This is as expected for new plants, since any efficiency differences are very small—or in any case, significantly smaller than for existing plants. Germany is well-positioned with regard to energy efficiency, which makes up for the existing cost differences to a certain degree (Bardt 2013; Neuhoff et al. 2016).

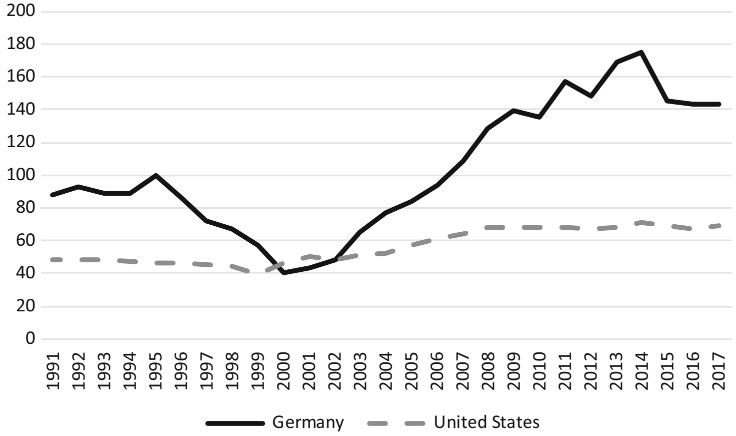

Fig. 2 Industrial electricity prices in Germany and the United States in US dollars per MWh. Own illustration, source: IEA database, accessed 14 December 2018

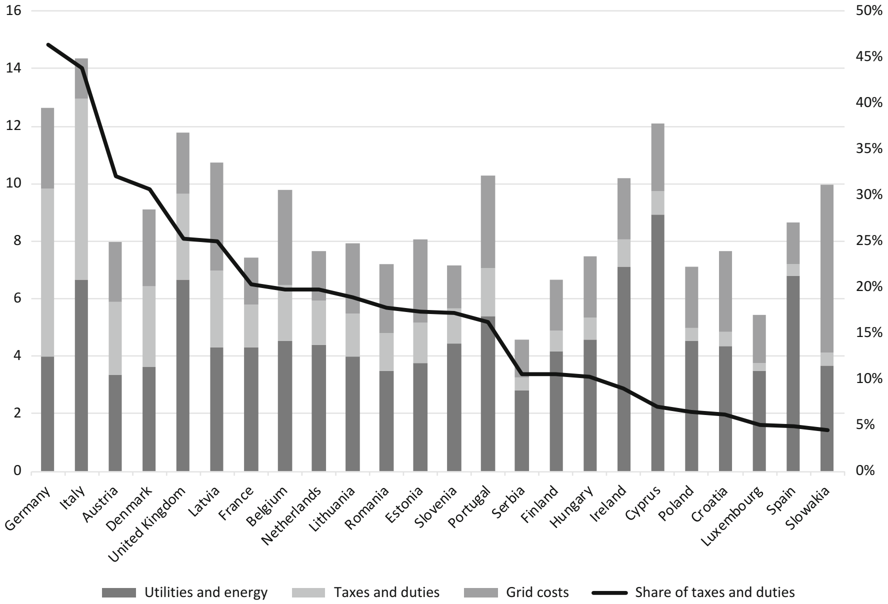

Fig. 3 Electricity price components. Cents per kWh and share in percent. Own illustration/calculation, source: Eurostat

But even within the European Union, there are substantial differences in electricity costs and the underlying taxes and levies. For instance, Germany is traditionally one of the European countries with the highest industrial electricity prices (Fig. 3). Although net electricity prices often follow similar curves—after all, fuel prices are determined at a cross regional or even global level, and interconnections among national electricity markets have increased significantly—taxes and levies are very different from one country to the next. In Germany, they have developed primarily through cost allocations associated with the energy transition. Just a decade ago, they were in the average range for Europe, but they are now far above average. This is not a consequence of the shift in energy policy per se but a consequence of its purely national implementation and the lack of integration with the rest of Europe.

3 Weak Investment by Energy-Intensive Industries

Although price developments for large power consumers differ from average, it is important to ask whether there is a negative economic impact of high electricity prices and uncertainties on investment of energy-intensive industries. To describe the investment activity of energy-intensive industrial companies in comparison to less energy-intensive industries, we will consider two sets of data: First, we will examine activity at the industry level with the help of investment appraisals from the German Federal Statistical Office in the context of National Accounts (Statistisches Bundesamt 2017). Second, we will consider results of analyses at the level of individual companies that were investigated with the help of Official Business Data (*Amtliche Firmendaten*, or AfiD).

The aggregated analysis by industry sector allows for a longer-term view of gross and net capital investment development over time in different industries. We will distinguish here between energy-intensive industries and less energy-intensive industries. The former group includes the paper, chemical, glass/ceramics and metal production and processing industries, while the latter group covers the rest of the manufacturing sector. Of course, not every company in the energy-intensive sector is necessarily characterised by relatively high energy consumption; similarly, there may be energy-intensive companies in industries that use less energy on average. However, it is reasonable to assume that there are denser interconnections within each branch of industry than between industries, so a general reluctance to invest on the part of a given industry might also affect a company that is not suffering directly from high energy costs.

Figure 4 shows the results of the analysis: while the less energy-intensive industries were able to offset more than 100% of their depreciation with investments in 11 of the past 15 years, the energy-intensive industry branches only managed to achieve this twice. Only in 2000 and 2008 did these industries show slightly positive net investments. In many years, however, net investment was very negative; in some cases, only 80–85% of depreciation was replaced with new investments. Although the industrial sector as a whole has managed to report positive net investment since 2000, the situation has been consistently worse for energy-intensive industries, with investment falling about 10% short on average. In addition, the difference between the funding ratio for depreciations in energy-intensive and less energy-intensive industries has increased significantly since the 1990s.

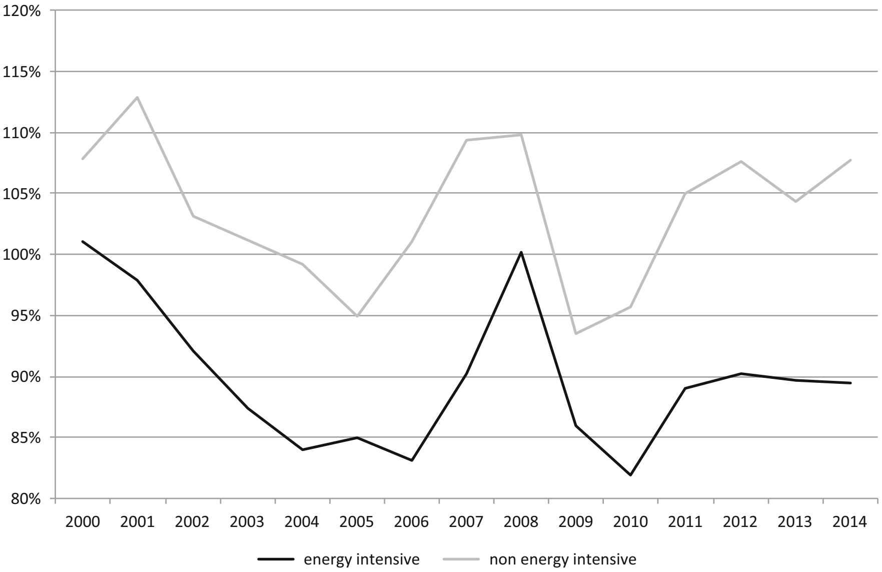

Fig. 4 Energy-intensive industries invest unsustainably. Net investments as percentage of depreciation. Energy-intensive industries: paper, chemicals, glass/ceramics and metal production and processing. Own illustration, calculations, source: German Federal Statistical Office 2017

From this industry perspective, we can observe that energy-intensive industries have a level of investment far below the average in terms of their net investment and that they have managed to offset their depreciation in only a few individual years. In other words, what we observe here is ongoing asset erosion. This surely cannot be attributed to differences in energy costs alone. Investment decisions are always based on multiple factors, including expected market growth, which is greater in other countries and world regions than in Germany for the foreseeable future. However, the deterioration of Germany's competitive position on the cost of electric energy has surely also played a role in investment behaviour.

This rough assessment of investment behaviour in different industries is confirmed by analyses at the level of business data. For example, Chrischilles (2015) analysed the Official Business Data (AfiD) from the German Federal Statistical Office. The performance of power-intensive companies was compared to that of other companies with regard to export activity, investment activity and value added. The "power-intensive" category included the 10% of companies with the highest electric power intensity, i.e. the highest electricity consumption per euro of gross value added. Using this definition, electricity consumption of 0.99 kWh/€ of gross value added was considered power-intensive.

Comparing the two groups reveals a number of striking differences (Fig. 5):

- The gross value added for the 10% of most power-intensive companies decreased by 12% in the period from 2003 to 2012, while it increased by 20% for the other

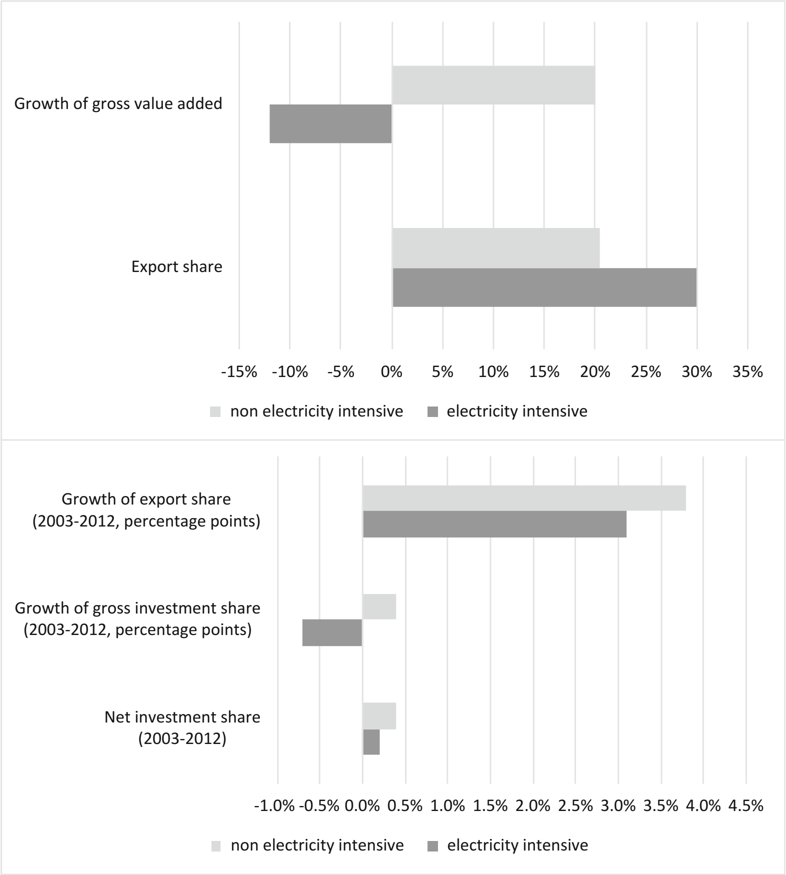

Fig. 5 Comparison of power-intensive and non-power-intensive companies. Own illustration, source: Chrischilles (2015), based on AfiD data

companies. So contrary to the overall growth trend, power-intensive companies shrank significantly.

- The export ratio for power-intensive companies is 30%, significantly higher than the 20% seen in the comparison group. This means that international competition is presumably more intense for power-intensive companies than it is for others. Therefore a slip in competitive positioning due to higher electricity costs and uncertainties at the national level is all the more critical. The export ratio for the power-intensive companies showed a smaller-than-average increase, which is in line with the former observations.
- The result for investments is also worse with power-intensive companies. For example, the gross investment rate dropped by 0.7%, versus an increase of 0.4% in the comparison group. The net investment rate was just 0.2% for the power-

intensive companies in the observation period, just half as much as for the other companies.

This view of the micro level further confirms the picture we saw at the industry level, according to which energy- or power-intensive companies have experienced weaker economic performances in Germany for the past few years than companies that are less affected by the cost burdens and cost uncertainties associated with the shift in national energy policy. This becomes clear from a look at several different criteria. Even if no single cause or simple, direct connection can be established between the orientation of Germany's national energy policy and industrial companies' economic performance, the data clearly reveal the difficulties faced by those companies—which would be amplified still further by any additional increases in national taxes and levies.

4 Future Investment Plans

The investment decisions that companies make today will determine future economic trends. These decisions cannot be identified in statistics that simply reproduce past investment decisions at a later date. So survey results are used to predict future investment activity. To this end, we went back to an initial survey from 2013, which collected responses from over 700 companies from industry and industry-related service sectors about delays and geographic shifts in investment activity. In a survey conducted in 2017 as part of the "IW Zukunftspanel" of the German Economic Institute, the questions were asked again in a similar way. The larger sample provided by the IW Zukunftspanel allows for more differentiation, and at least the most fundamental performance trends (or lack thereof) can be identified as well.

The first block of questions is based on the proposition that energy policy and the resulting uncertainty have an influence on companies' investment decisions. This is true more frequently than the average for industrial companies. Some 12.4% of industrial companies agree with this proposition, while only 9.1% of all companies postpone their investments due to energy policy. The situation has eased in comparison with 2013 in that another 11.4% at that time answered this question with "somewhat agree". This answer option was not available in the new 2017 version of the survey.

Large (i.e. high-revenue) companies indicated more frequently than smaller companies that they put off their investment decisions due to energy policy. In comparing the survey results, it is striking that in contrast to all industrial companies, the 2017 value for "agree" is approximately equal to the sum of "agree" and "somewhat agree" from 2013. It appears from this result that energy policy decisions and the resulting risks are especially important for high-revenue companies. Since companies with high revenues also have relatively large investment potential, their reluctance to invest is particularly significant. Energy policy is certainly only one factor among many that guide investment decisions. Nevertheless, it is a relevant issue for more than one third of large companies.

Breaking the responses down by industry, companies from the construction and metal production and processing industries were especially likely to indicate that their investment decisions were influenced by energy policy. Even in 2013, they postponed their investments more frequently than other industries did (Fig. 6). In machine construction, the electronics industry and vehicle construction, on the other hand, the influence of energy policy declined. In service industries, only a few companies reported that energy policy plays an important role with regard to investments.

The second block of questions concerns potential geographic transfers in production capacity through increases in future investment outside of Germany. Here as well, companies who agreed could respond with either "agree" or "somewhat agree", whereas the only options in 2017 were agreement or disagreement.

For industrial companies, the results of comparing the two surveys are not entirely clear, as more companies chose the "agree" answer in 2017 than in 2013

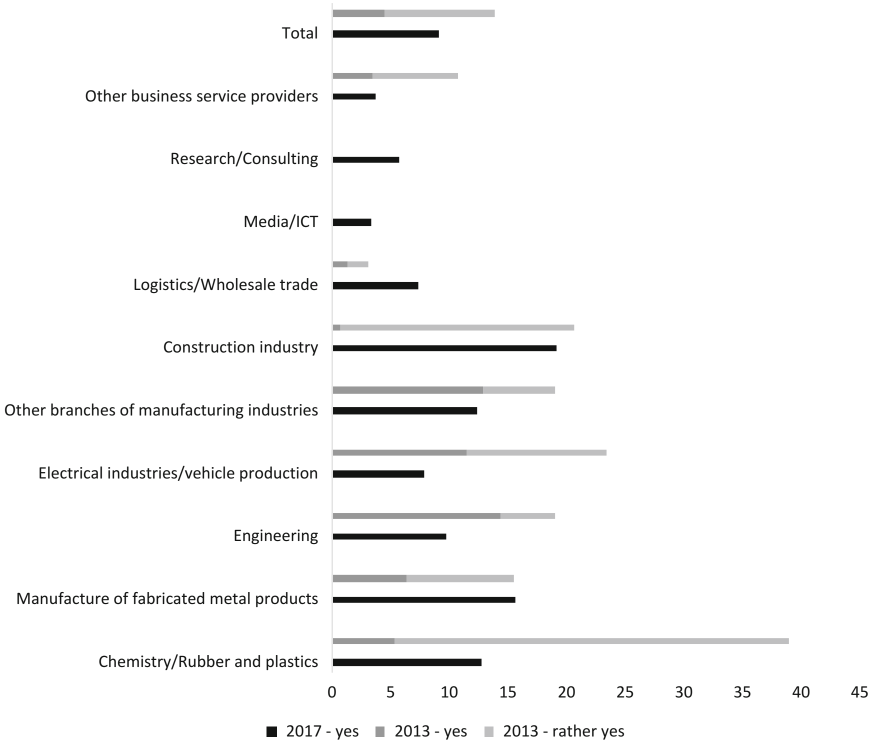

Fig. 6 Postponing investment decisions in Germany. Percent of respondents who agree. Own illustration, Data source: German Economic Institute (Surveys "IW Zukunftspanel 2017; IW Business Vote 2013")

but still not as many as the sum of "agree" and "somewhat agree" answers in the earlier survey. Finally, industrial companies' agreement with the increased foreign investment thesis was indeed higher than that of all companies surveyed (2.2%); overall, however, there are only a few individual companies that actually invest more outside of Germany, whereas most companies have no such plans. High-revenue companies expressed their full or partial agreement much more frequently in the 2013 survey, so that in total, more than a quarter of large companies were at least considering increased investment outside of Germany. In 2017, this figure is significantly lower. Even among high-revenue companies, over 93% are not planning to shift their investments anywhere else.

In many industries, among those companies whose "mostly agree" answer in 2013 with regard to planned increases in foreign investment can potentially be interpreted as indicating that such a step was being considered, only a few agreed in 2017 to the idea of increased investment outside of Germany. Only in the chemical, rubber and plastics sector are more than 5% of companies planning to invest more in production capacity outside of Germany than in the past (Fig. 7). In light of low CO2 prices and the carbon leakage rules in effect (for now), only very few companies are reacting by shifting more investment to other countries.

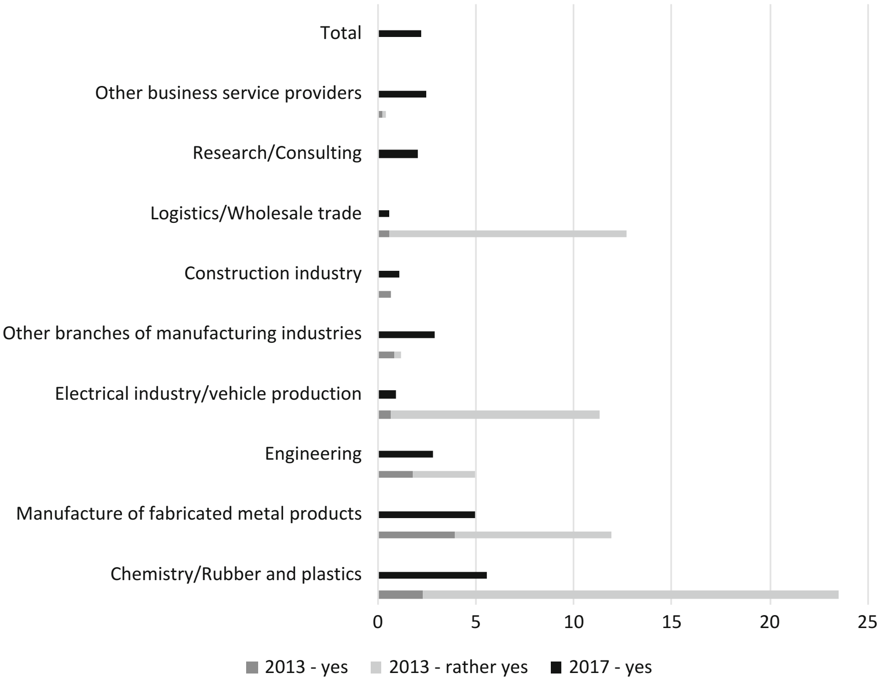

Fig. 7 Increased investment in production capacities outside of Germany. Percent of respondents who agree. Own illustration, Data source: German Economic Institute (Surveys "IW Zukunftspanel 2017; IW Business Vote 2013")

5 A European Approach to Energy Transition

Germany's energy transition is not aimed solely at transitioning the energy system in order to achieve Germany's ambitious climate protection goals. In an industrial country like Germany, in which national economic strength and stability is based to a large degree on the manufacturing sector and associated services, this technically oriented shift is not sufficient. One important constraint is that the costs of the transformation must not be too high, in order to avoid putting the competitiveness of the country's economic core at risk. That core includes the energy-intensive industries, without which the advantages of the largely complete value chains could no longer be maintained. This is not a case of subsidising industries that could no longer be economically successful in Germany due to market and competitive conditions. However, the shift in energy policy should be designed in such a way as to minimise distorting effects that impose burdens on specific sectors of the economy. This is especially true in a situation in which relocating investments reduces production within Germany but simultaneously expands it elsewhere, so that none of the desired ecological effects are achieved through relocation alone. On the other hand, the efficiency-boosting effect of price signals is desirable. However, especially power-intensive companies reduce their energy consumption to decrease costs anyway and thereby contribute to a high level of efficiency in the German industrial sector (RWI 2016). Hence, this effect of the additional costs is presumably not particularly large.

The energy transition cannot succeed if countries go it alone with no consideration of international networks and connections. Rather, the challenges associated with this policy shift can only be overcome through the use of open markets and international networks and by reaping the benefits of international specialisation. In the context of the shift in German energy policy, five major fields can be identified in which the energy policy goals of efficiency, security of supply and environmental sustainability can be achieved more effectively through the use of international networks than with a go-it-alone approach.

- **Compensating for Power Fluctuations**

  Power generation from renewable energies is characterised by a large degree of natural fluctuation. This does not apply to biomass electricity generation, which can be controlled according to the demand for electricity, and applies only to a limited extent to offshore wind, which is available with high reliability. Onshore wind and photovoltaic generation, however, vary widely as a function of current wind levels and solar radiation. The guaranteed capacity that is always available from these facilities is therefore only a fraction of the nominal capacity. Since the grid must be balanced at all times, i.e. the same amount of electricity must be produced and consumed, these fluctuations mean that the grid must be able to supply electricity from other sources at any time and at short notice. This balance can be achieved through controllable renewable energy sources or storage facilities but relies primarily on the use of conventional domestic power plants or electricity imports. At the same time, due to the systems' large installed capacity, significantly more electricity is produced in high sun or wind conditions

Fig. 8 Electricity import and export shares in percent. Sources: AG Energiebilanzen, German Economic Institute

than is consumed. Unless this electricity flows into storage facilities, or unless generating plants are shut off, the electricity must be exported into networks outside of Germany.

As a result, foreign trade activities in the electricity industry have increased significantly in recent years (Fig. 8). The export share has increased from less than 6% in 1990 to over 12% today. Imports, on the other hand, were relatively stable; only in recent years have they seen a significant decline, to just 4% today. The sharp increase in renewable energies in Germany has led to an expansion of export surpluses, but this should be interpreted less as a function of demand than as a reaction to temporary overproduction. This share is expected to increase even further in years to come as the proportion of renewable energies continues to grow.

Without international balancing, Germany will not be able to build a system of electricity generation based primarily on fluctuating renewable sources. In other words, the energy transition is structurally dependent on international balancing and open electricity markets. The energy transition is therefore fundamentally irreconcilable with a go-it-alone approach.

- **Renewable Energy Sites**

  The costs of promoting renewable energies can be significantly reduced by exploiting the benefits of European specialisation. For example, location-based advantages that offer especially favourable conditions for wind or solar energy could be leveraged on such an approach. By optimising the choice of sites, more electricity could be produced from renewable sources for the same investment costs. This would be economically advantageous for electricity consumers who bear the brunt of additional costs. Increased internationalisation in promoting renewable energies, together with an appropriate expansion of the electrical grid, would make the energy transition more efficient and therefore more successful. A go-it-alone policy would leave these opportunities unexploited.

- **Competition in the Electricity Market**

  Since the late 1990s, electricity markets in Europe have been systematically opened and exposed to competition. As a result, new suppliers have appeared at each of the various stages of the value chain. This has affected electric power distribution first and foremost, with a somewhat less pronounced effect in electric power generation. However, there are varying degrees of competition in the different EU countries. Even in highly advanced countries like Germany, measures of concentration are relatively high compared to competitive standards and comparison values from other industries (Bardt 2013). Further moves to increase Europe-wide competition, through which the relevant market would be seen at a European level rather than a national level, would lead to a significant reduction in concentration measures. Companies that seem large in a national context would simply be one of many suppliers at the European level. By opening markets further, concerns about competition in the electricity market would be eliminated once and for all.

- **Reduced Cost Distortions in Industry**

  Further moves to establish Europe-wide regulations could also eliminate the negative effects on competition that have resulted from the German energy transition. The biggest problem in German industry, compared to its European competitors, lies in the additional burden imposed by taxes and levies at the national level. A unified European approach would significantly reduce cost distortions and thus avoid putting the competitiveness of entire industries at risk as a direct result of a go-it-alone regulatory approach. Here, too, attempts to restrict policy to the national level pose a threat to jobs and prosperity.

Germany's energy transition cannot succeed if it is founded on a purely national vision of energy supply and energy policy. Increased integration with Europe in energy and electricity policy is of critical importance. This is not only true for Germany's approach but for any European country that tries to transform their energy production system. In particular, the promotion of renewable energy is a core element of the shift in energy policy that can only be efficiently accomplished if as many potentials as possible are exploited. Achieving a single European electricity market will not only lead to less expensive environmentally friendly electricity and a more secure supply of power but will also make room for European competition in this larger electric power generation market. For example, using the best sites for renewable energy sources in Europe would result in lower costs. In addition, improved European integration could serve to establish a better balance among fluctuating renewable energy sources. Secure, inexpensive and environmentally friendly power generation cannot be guaranteed with a go-it-alone vision for electricity markets. Separate policies at the national level are an obstacle to integration and should no longer be pursued. Without a single European electricity market, important efficiency advantages and competition effects cannot be put into effect (Zachmann 2013). Future market models must not run contrary to the idea of a single electricity market but must rather be aimed at European integration.

An affordable and secure approach to energy supply that also protects the environment should be based on comprehensive integration with European and international markets. The advantages of international trade apply to energy supply systems every bit as much as to industrial goods and services. Germany's prosperity depends to a significant extent on the integration of its national economy with the global economy. Energy supply systems will also have to be based on a sustainable international foundation. A go-it-alone approach to energy policy can only lead us in the wrong direction. The opportunities provided by the international division of labour must be exploited if the vision of a paradigm shift in energy policy is to be implemented successfully.

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Rising Energy Prices Due to Inefficient Support for Renewables: An Economic Assessment of the Status Quo and Alternatives in Germany

Ruth Delzeit, Gernot Klepper, and Mareike Söder

Abstract At the European national and subnational levels exists a multitude of laws and programmes for the promotion of renewable energies. Taking Germany's energy transition as an example, the most important regulations for the electricity, heat and transport fuel markets are the Renewable Energy Sources Act (EEG), the Renewable Energies Heat Act (*EEWärmeG*), the Law on Cogeneration of Heat and Power (KWKG), the Energy Tax Law and the Biofuel Quota Act. In addition to market incentives directly linked to the renewable energy markets, the electricity and heating sector is influenced by the regulations of the European Union Emissions Trading System (EU ETS). Comments on these support programmes and targets range from scathing to praising. We argue that a fundamental reform of the support system for renewable energies in Germany is required if the largest possible contribution to climate mitigation is to be achieved at the lowest possible cost. We show how such a support system could be designed in practice. Since the support system for renewables in Germany is not independent from European climate policies, we discuss possible support systems under the assumption that the EU ETS remains in place.

1 Introduction

A more ambitious target can hardly be formulated: "I therefore want Europe's Energy Union to become the world number one in renewable energies" (EU President Junker 2014). This is in line with the European Union's (EU) objective to reduce greenhouse gas emissions (GHGs) by a minimum of 40% by 2030, compared to 1990 levels, with 27% of the total energy mix made up of renewables (European Council 2014).

Today, at the European national and subnational levels, a multitude of laws and programmes for the promotion of renewable energies are in place. Taking

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R. Delzeit · G. Klepper · M. Söder (✉)
Kiel Institute for the World Economy, Kiel, Germany
e-mail: Mareike.soeder@ifw-kiel.de

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Germany's energy transition as an example, the most important regulations for electricity, heat and transport fuel markets are the Renewable Energy Sources Act (EEG 2014), the Renewable Energies Heat Act (*EEWärmeG* 2008), the Law on Cogeneration of Heat and Power (*Kraft-Wärme-Kopplungsgesetz* 2002), the Energy Tax Law (*EnergieSTG* 2006) and the Biofuel Quota Act (*BioKraftQuG* 2007). In addition to market incentives directly linked to the renewable energy markets, the electricity and heating sector is influenced by the regulations of the European Union Emissions Trading System (EU ETS) which covers all energy production sites greater than 20 megawatts (MW) which includes most of the fossil electricity production. It requires that energy producers hold tradable emission permits for all generated end-of-pipe CO_2, N_2O and CFC emissions (EC 2014). Other GHGs such as methane generated along the process chain or by smaller energy production facilities are not covered by the current EU ETS. Thus, there is no consistent incentive scheme for controlling GHGs.

In addition to achieving climate protection, Germany's energy transition consists of several sub-targets: it shall enable Germany to phase out nuclear power by 2022, contribute to modernising Germany as a location for industry and thereby generate growth and employment and reduce its import dependency on oil and gas (BMWi 2015). The two main pillars of the climate aspect of the transition are renewable energies and energy efficiency.

Comments on these policy instruments and targets range from scathing to praising. Supporters emphasise the success apparent in the impressive development of wind and solar plants which resulted in a renewable energy growth rate that hardly anybody had expected (*Agora Energiewende* 2015). Critics emphasise the high electricity prices for private households (*Handelsblatt* 2014) since—despite the various reforms of the EEG—the overall EEG payments to electricity producers and the surcharge per kilowatt-hour for electricity consumers have increased substantially in the last 10 years. In addition they question the ability of the current support system to achieve the national GHG reduction targets (IW Consult 2014).

As a reaction to increasing cost, the latest reform of the EEG in 2017 (EEG 2017) established a paradigm shift: since January 2017, the amount of feed-in tariffs (FITs) paid to producers of renewable electricity to compensate for high production costs is no longer set by the regulatory authority but determined in a process of public tendering where the cheapest tender for building and operating a renewable energy plant (in terms of price per MWh produced) gets accepted by the Federal Network Agency (BMWi 2016). The tendering procedure always relates to a specific type of renewable energy technology (onshore wind, offshore wind, photovoltaic and biomass), while a maximum volume of MW to be supported via the tendering process is established for each type of energy technology. Thereby, the EEG reform intends to increase competition between different operators of renewable energy plants and reduce cost. However, it does not establish any link to the regulation of fossil electricity in the EU ETS or the electricity from biomass which has its own support policy.

We argue that the latest reform of the EEG still does not overcome the uncoordinated measures of the renewable energy support system in Germany. A fundamental reform should replace these inefficient measures with a consistent regulatory approach. Ultimately, renewable energies shall replace fossil energy sources and nuclear power, thus significantly contributing to climate protection. The basic principle of an efficient strategy for climate protection is to choose instruments with which GHG emissions are avoided at the lowest cost possible. One condition for this is uniform prices for emissions. In order to illustrate the advantages of such a change we calculate the economic cost of the current support scheme. In addition, we discuss options for designing an efficient support scheme. Since the support scheme for renewables in Germany is not independent from European legislation, we discuss possible support schemes under the assumption that the EU ETS remains in place.

2 Literature Review

Environmental policy instruments can be assessed and compared by criteria such as their economic efficiency, ecological effectiveness and dynamic incentive effects on innovation (cf. Endres 2013; Perman 2011). These criteria are defined as follows: (1) A policy instrument is *economically efficient* if a given objective such as reducing GHG emissions is achieved at lowest costs (e.g. abatement costs). (2) The ability to achieve a given target (e.g. increasing the share of renewable energies in total energy consumption) is defined as *ecological effectiveness*. (3) An environmental policy has a *dynamic incentive effect* if it induces progress in environmental technologies (Endres 2013).

The economic cost of different environmental policies has been assessed in a number of studies. For the electricity market, Krewitt and Schlomann (2006) and Jacobsson and Lauber (2006) compare the external costs of renewable and fossil power generation. They do not differentiate between different policy instruments. In other studies price-driven instruments such as the Renewable Energy Sources Act (EEG) and quantity-driven instruments such as certificate-based quotas are compared (e.g. Sijm 2002). Sijm (2002) concludes for the case of wind energy that feed-in tariffs (FITs), the dominating instrument in Europe, are an effective instrument to support innovation in renewable power generation, but in the long term, they can be inefficient and price-distorting. He argues that the choice of policy instruments shall be targeted to the national conditions. At the same time, it should be recognised that policies designed on the national scale might conflict with the proper functioning of the common European market.

A review of the historical development of the EU ETS can be found in Ellerman et al. (2014). Several studies find evidence for an effective reduction of greenhouse gas emissions (e.g. Petrick and Wagner 2014). At the same time, several studies emphasise necessary reforms of the EU ETS that could increase its efficiency (e.g. Branger et al. 2015; Ellerman et al. 2010; Hermann et al. 2014). A major point of discussion is related to the factors influencing the currently low allowance prices (e.g. Rickels et al. 2015; Boersen and Scholtens 2014; Brink et al. 2014). Several studies propose an extension of the scope of the EU ETS to other sectors in order to assure long-term price stability and to efficiently achieve climate policy goals in Europe (e.g. Buchholz et al. 2012; Böhringer and Lange 2012; Hermann et al. 2014; Nader and Reichert 2015). Also Borghesi (2011) argues that support polices for renewable energies can only contribute to reducing GHG emissions if they are applied to sectors not covered by the EU ETS. To include sectors with several small emitters such as road transportation, Hermann et al. (2014) and Nader and Reichert (2015) recommend an upstream ETS rather than the current downstream ETS. Other topics discussed are, e.g. the role of the allocation rule for emission allowances (e.g. Álvarez and André 2015; Juergens et al. 2013).

With respect to the relation between the EU ETS and the support of renewable energies, the German Advisory Council on the Environment (SRU 2013) proposes to focus more on the EU ETS as the central instrument of European climate strategy and to reduce the national, partly counterproductive support of renewable energy strategies.

Other literature on the support of renewable energies focuses on the reform of the national EEG. Studies mostly agree that the recent reforms of the EEG did not introduce more market forces into the support of renewable energies since the market premium in the EEG is still paid to compensate for production costs that are higher than their fossil competitors and consequently lower market prices for electricity (e.g. Purkus et al. 2014; Bardt 2014). The German Advisory Council on the Environment (SRU 2013) supports this concept as the SRU expects that future electricity prices will not be high enough to cover the capital costs of renewable energies. In order to avoid an unlimited increase in the FITs, they propose that the supported amount of energy produced be restricted and the FIT be continuously adapted to market and technology developments by a public agency. Further, the SRU 2013 criticises the EEG as inappropriate since many large electricity consumers are exempted from financing the FITs. This unequal distribution of the cost of the EEG is becoming more urgent since electricity prices are falling due to the merit order effect and due to the low prices of CO_2 certificates in the EU ETS. Diekmann et al. (2012), on the other hand, argue that most of the current problems of the EEG result from structural issues outside the EEG such as the regulation of the electricity net, the design of electricity markets and the support of innovations.

A fixed and binding quota for renewable energies is proposed by Frondel et al. (2012) and Haucap and Kühling (2012) with the aim of increasing the competition between different technology options and controlling the total amount of renewable energy produced. However, Diekmann et al. (2012), Bofinger (2013) and Leprich et al. (2013) expect an increase in the cost of renewable energies for consumers if a fixed quota were to be introduced since producers would include a risk premium for varying electricity prices into their pricing decision. In order to avoid such a risk premium but to increase competition, Bofinger (2013) and Leprich et al. (2013) propose that the desired amount of renewable energy production be auctioned and that prices be guaranteed for the time span of the auction.

Most of these studies acknowledge that increasing the share of renewable energies provides benefits beyond climate mitigation (e.g. SRU 2013; Diekmann et al.

2012) such as reducing the dependence on fossil fuels or accelerated technological innovation.

3 The Cost of the Renewable Energy Market in Germany

The support of renewable energies in Germany has been quite successful in the sense that renewable energies have reached a substantial share in all main energy markets (in 2016 about 31.7% in electricity, 13.4% in heating and 5.1% in transportation). Hence, the EEG fulfils the criterion of ecological effectiveness. The overall emission savings of the renewable energy sector amount to 159 million tonnes of CO_2 equivalents (according to the AGEE Stat database in 2017). Our analysis shows that this success has indeed been bought dearly with high economic costs.

The EEG supports wind and solar electricity through FITs based on the quantity of energy supplied. In the heating sector, biogas facilities and combined heat and power stations using biomass receive special funds from the EEG. Biofuels are indirectly promoted through the compulsory requirement for mineral oil companies to reduce the GHGs of the fuels they sell. Besides the EU ETS, this GHG savings quota is the only regulation that focusses directly on climate mitigation. In this way, it favours biofuels with particularly high GHG savings.

In the past, EEG payments were not based on the actual production cost but on the difference between the guaranteed FITs for electricity from renewable sources and the electricity prices at the power exchange. However, the initial high FITs had been accompanied by falling system costs, and lately the rewards were far above the production cost. In fact, the production costs of many renewable electricity options have fallen to a level comparable to the range of production costs of fossil electricity options. Figure 1 provides an overview on the range of production costs of different technology options in the electricity sector in 2013. Production costs include capital costs, fixed and variable production costs and fuel costs. Figure 1 is adapted from Delzeit et al. (2014).

In 2013, producers of renewable energy received almost 22 billion euros in revenues in the context of the EEG alone. Delzeit et al. (2014) estimate that the additional cost of producing electricity from those renewable sources amounts to only 5 billion euros. Underlying the assumption that FITs are supposed to compensate for higher production costs in order to stimulate technology development and adoption, almost 17 billion euros would have been overspent. Extrapolating this system to the targets of the German government for 2030, it becomes clear that achieving the desired 27% share of renewable energies with such a support scheme would be extremely costly.[1]

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[1] At the same time, the number of producers exempted from payments for the EEG tripled between 2010 and 2014 and reached a production volume of almost 18% of total electricity production (Delzeit et al. 2014).

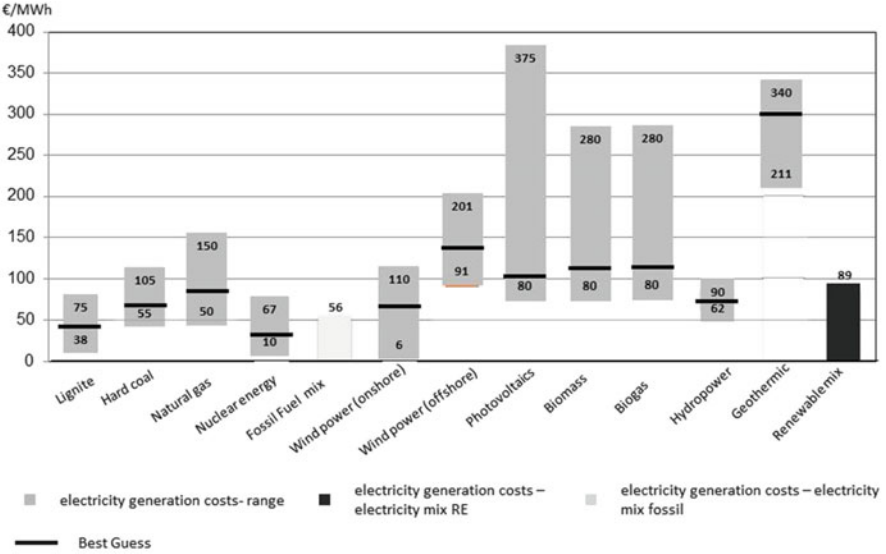

Fig. 1 Production cost of different technology options in the electricity sector in 2013. Source: Delzeit et al. (2014): electricity generation costs include capital costs, fixed and variable operating costs, fuel costs; fossil electricity mix and renewable electricity mix calculated based on the weighted best guess values

Increasing competition between plant operators within a specific type of energy does indeed decrease these costs. However, the latest reform still does not account for differences in GHG emissions of different types of plants and renewables energies. The fixed annual volume of production capacity increases for each type of renewable energy (e.g. in 2021, 2900 MW onshore wind, 500 MW offshore wind, 600 MW photovoltaic and 200 MW biomass) does not take into account differences in abatement costs between these different types of renewable energies.

Figure 2 gives an overview of the overall FIT paid before the latest EEG reform, the emission balance expressed in million tonnes of CO_2 equivalents per MJ and the average abatement cost (in 2013). Despite the fact that the exact amount of abatement costs is debatable and decreasing for all types of renewable, the relative average levels alone are quite informative. While onshore wind energy can save GHGs at about 83 euros/tonne, abatement costs of electricity from biomass amount to 250 euros/tonne and photovoltaics to 538 euros/tonne. The newest installations exhibit even lower costs with a continued falling trend. Despite its high abatement costs, more than half of the overall amount of FITs before the latest reform of the EEG had been paid to the photovoltaic sector. The lower capacity increases for photovoltaic compared to wind energy account only partly for the differences in abatement costs.

In order to illustrate that the fixed volumes per type of renewable energies as well as the lack of competition between renewable energies still lead to avoidable

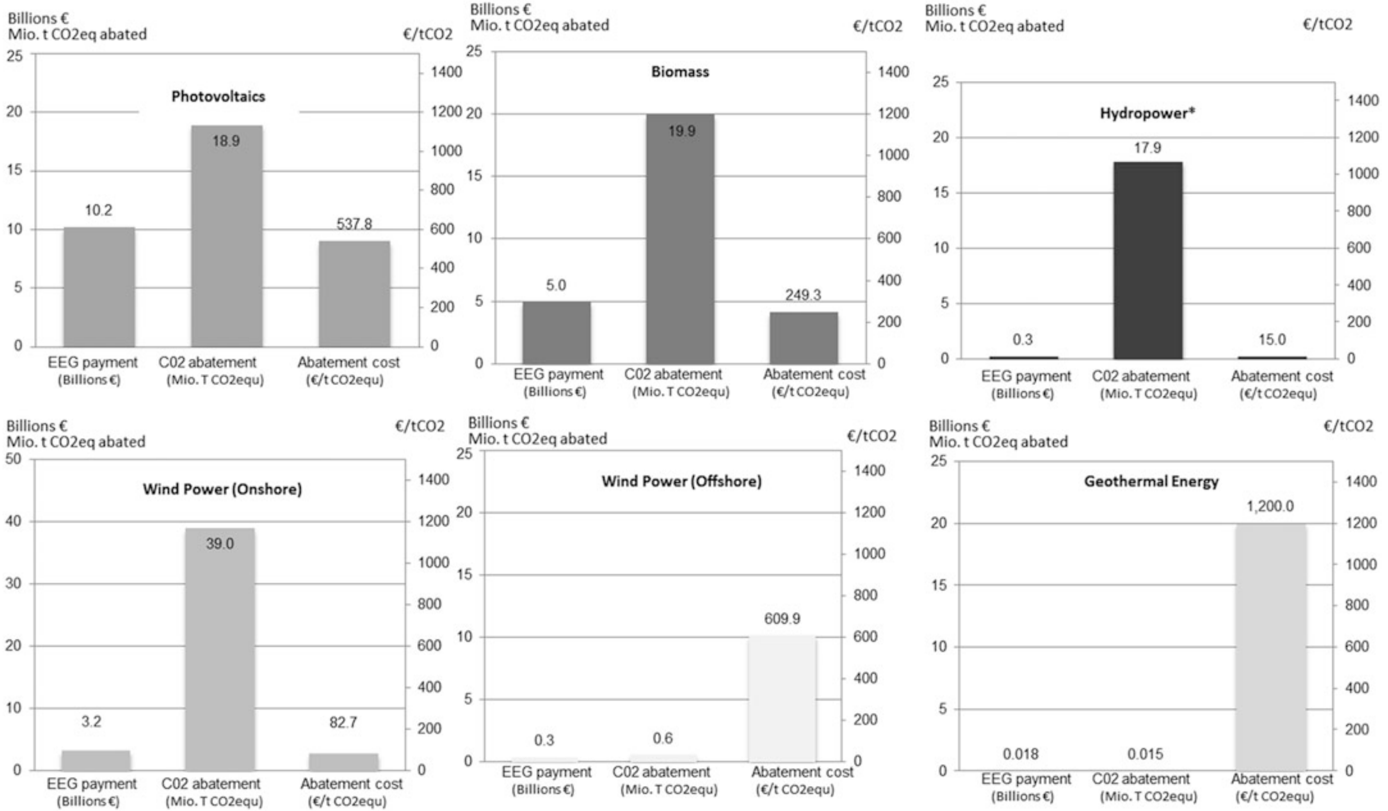

Fig. 2 Total feed-in tariffs, emission balances and average abatement cost of different renewable energies. Source: Adapted from Delzeit et al. (2014). *Many old facilities; stock is mainly not in the EEG

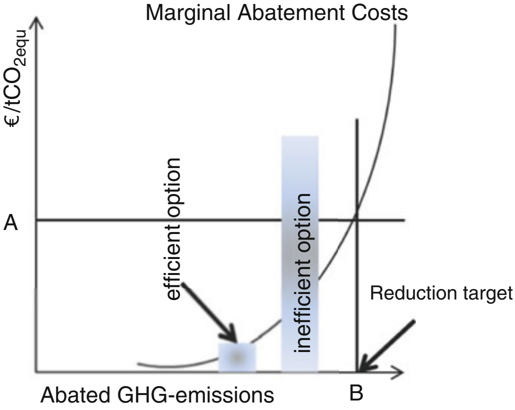

Fig. 3 Efficiency of technology options under a marginal abatement cost function

economic costs, we outline the concept of an efficient support scheme (see Fig. 3). Policies for an efficient GHG abatement in an economy would support GHG abatement at the lowest cost possible. We calculate these economic costs by comparing the current GHG abatement costs with the GHG price of an efficient system. All renewable energy options which have GHG abatement costs above the GHG price of an efficient system can be considered economic costs.

These costs could be avoided by implementing a climate mitigation policy which supports the mitigation options (renewable energies or other mitigation options such as energy savings due to increases in energy efficiency) with the lowest cost per saved emission unit. Figure 3 further illustrates this concept. To reach a certain climate target, e.g. a reduction of GHG emissions by 40% (point B), one should choose mitigation options with a cost per unit of mitigated GHG emissions below or equal to A. Then, the climate target of B is reached at minimal cost. The marginal abatement cost curve indicates the different costs of renewable energy options including options for saving energy. It becomes clear that such an efficient system requires competition between the different renewable energy options and also between renewable energies and other climate mitigation options such as increases in energy efficiency. Both are restricted by the fixed volumes per type of renewable energy and a missing link to other climate policies such as the EU ETS.

We calculate these economic costs by taking into account the range of GHG abatement costs provided by the literature (see Fig. 4). The lower bound of the range is the “best guess” indicating the most likely average abatement costs mentioned by sector experts. Depending on the carbon price in an efficient system, economic costs range from 5.9 to 16.7 billion euros given the market shares of different types of renewable energies in 2012. Since wind energy capacity is growing at a faster pace than electricity production from photovoltaics as intended by the latest EEG reform, these costs are expected to decrease in the future.

Despite the high cost of support schemes for renewable energies, some studies have discussed rationales that may justify such high costs. Among the arguments are technology market failures (Fischer and Newell 2008; Lehmann 2013; Schneider

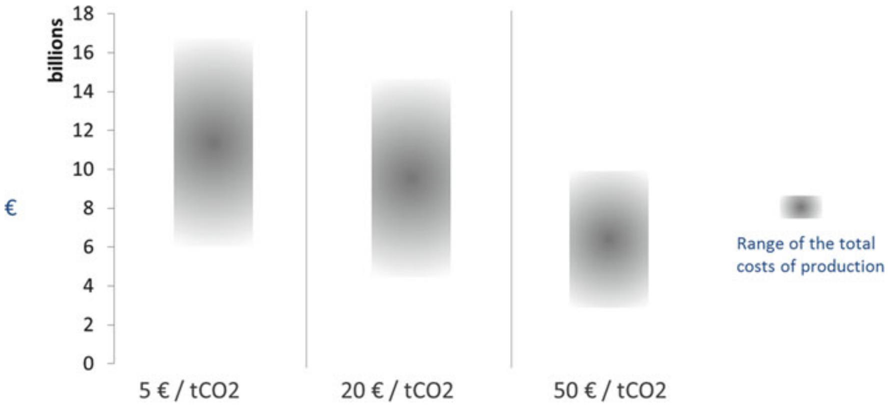

Fig. 4 Economic costs of renewable energy support under different CO_2 prices. Adapted from Delzeit et al. (2014). The range of the aggregate costs is defined as the difference between the CO_2 abatement costs for the total renewable energies and the emission abatement evaluated at different CO_2 prices. An estimate for the probable mean costs ("best guess") has been made for the calculation of the aggregate costs. The "best guess" helps as the basis for the calculation of the lower bound. The upper bound is determined by the highest abatement costs which is not transferable to the total number of plants

and Goulder 1997; Lehmann and Gawel 2013; Gawel et al. 2016), path dependencies in power and innovation systems (Acemoglu et al. 2012; Aghion et al. 2009), the failure of emission policies to fully correct environmental externalities from non-renewable power generation (Kalkuhl et al. 2013; Palmer and Burtraw 2005; Gawel et al. 2016) or obstacles to long-term risk-taking (Gawel et al. 2016). In an overview of these diverse economic rationales, Lehmann and Gawel (2013) argue that the first and most important rationales for combining the EU ETS with support schemes for renewable energies "may be restrictions to technology development and adoption. These may be attributed to the failure of markets as well as policies, and more generally to the path dependency in socio-technical systems. Under these conditions, RES-E schemes are required to reach sufficient levels of technology development. In addition, it is highlighted that in contrast to the EU ETS RES-E support schemes may provide benefits beyond mitigating climate change". However, our analysis in this chapter shows that there are technologies available which exhibit low GHG emissions, have reached marketability in terms of scale and production costs and are fully independent of energy commodity imports. In addition, part of the market failures depend on the design of the climate mitigation policy which supports the mitigation options with the lowest cost per unit of saved emissions and on policies in related sectors. Finally, such a climate mitigation policy and the additional support of technology development and adaptation are not mutually exclusive.

4 Alternative Support Measures

To meet the criteria of ecological effectiveness, economic efficiency and dynamic incentive effects, political support for renewable energies should not be based on production costs but on the contribution to climate mitigation at least costs. There are many ways in which a consistent support policy could be designed. We look at three options that can be considered as measures to reduce the multiplicity of measures currently in place. We assume that the current EU ETS remains in place and therefore aligns all options to the current sectoral coverage of the EU ETS.

4.1 Reform and Enlargement of the EU ETS

A consistent incentive scheme for GHG reduction which covers all emissions is to extend the EU ETS to those emission sources for which it currently does not price emissions. Even though many GHGs substantially contribute to climate change (IPCC 2013), the current EU ETS covers only the GHGs, CO_2, NO_2 and FCKW, but not methane and nitrogen oxides. Two-thirds of those emissions originate from agriculture and are thus also attributable to the production of bioenergy. In addition, the current EU ETS captures only end-of-pipe emissions. However, an equal price signal for all emissions from different energy sources would demand not only the capture of end-of-pipe emissions but also all GHGs generated along the process chain. Implementing such a system along the value chain (we call it EU ETS 2.0) is relevant for all measures we discuss. A second step would involve extending the current sectoral coverage of the EU ETS to production sites smaller than 20 MW and sectors such as households, agriculture and transportation other than air transportation within the EU. All sectors would be included into one single instrument supporting the climate mitigation contribution of renewable energies by pricing GHGs equally. As such, we argue in line with, e.g. Buchholz et al. (2012), Böhringer and Lange (2012) and Nader and Reichert (2015).

Implementing such an EU ETS 2.0 would be comparatively easy as long as imports from outside the EU and exports from the EU are not taken into account. Since all fossil energy users would be required to possess emissions certificates denoted in CO_2 equivalents, the coverage of the supply chain would be automatically secured. The inclusion of small emitting sources would require an adjustment of the end-of-pipe orientation of the EU ETS for small emission sources. Wholesalers or traders could be made responsible for holding emission permits.

The treatment of goods imported into the EU creates a problem. This is especially important in the case of bioenergy, both because bioenergy is imported in significant quantities and because its supply chains are integrated in global markets. Additionally, many intermediate inputs in the domestic (EU) production processes include fossil energy. For an efficient EU ETS which does not create distortions between domestic and imported goods or negative effects on the competitiveness of German or European economic activities, a solution for the treatment of imported embedded GHGs needs to be implemented.

In the case of biofuels, the current regulation in Germany has already established a system that accounts for GHGs emitted domestically and abroad along the process chain. It is implemented on the basis of the sustainability certification required by the Renewable Energy Directive (EC 2009) and represents an already established process where GHGs are monitored and verified.

4.2 Tax on Fossil Energies Not Included in the EU ETS

Given that the current EU ETS remains in place but is not changed, an alternative instrument is a GHG tax on the emissions of those sectors currently not included in the EU ETS. Thus, all electricity sites smaller than 20 MW transport fuels, and most of the heating generation would have to pay an emission tax for those GHGs not captured in the EU ETS.

In order to set an equal price signal for all sectors, the tax would have to be coupled to the EU ETS price. Apart from the installations subject to the EU ETS, the tax would have to be paid on all end-of-pipe GHGs and all GHGs generated along the process chain. Similar to the extension of the EU ETS towards the EU ETS 2.0, the combination of the current EU ETS and an emission tax would efficiently support renewable energies by equally pricing GHG emissions, given that the tax level is continuously adjusted to the EU ETS prices.

As for the reform of the EU ETS (Sect. 4.1), the accounting of GHGs could be based on experiences with certification in the biofuel sector. In addition, to capture small emitters not included in the EU ETS, the emission tax would need to be imposed not as an end-of-pipe measure but further upstream on the retail level. GHGs already captured by the EU ETS would need to be excluded from the tax.

The embedded GHGs from imported goods would not be subject to the EU ETS or the emission tax. In this case some form of a border tax adjustment would need to be considered if equal treatment of all commodities is to be achieved and carbon leakage avoided.

In the case that the EU ETS is not reformed towards an EU ETS 2.0 with the addition of the other GHGs, an equal price signal for emissions inside and outside the EU ETS requires a tax only on those GHGs currently covered by the EU ETS. Such a tax would affect mostly fossil fuels in the transport and heating sector. Other important sources of GHGs along the process chain, e.g. from fertilisers in agriculture, would not be captured.

4.3 Subsidy for Renewable Energies

In this option, the EU ETS is aligned with a subsidy on GHG savings generated by renewable energy replacing fossil fuels. As for the tax, the amount of the subsidy needs to be connected to the EU ETS price.

In order to determine the subsidy level, the GHG savings of each unit of renewable energy needs to be calculated by comparing the GHG balance of the renewable energy option with the GHG balance of a fossil energy alternative. Since in many energy markets there are several fossil energy options, it is impossible to uniquely identify the fossil energy alternative. The average GHG balance of the typical fossil energy mix in each energy sector can be used as an approximation. Moreover, in the case that GHGs of the respective fossil energy alternative are already captured by the EU ETS, these GHGs need to be excluded from the emission balance of fossil fuels since they have been already charged for their GHG emissions. Otherwise the subsidy would constitute a double compensation of the renewable energy option for its GHG savings. In the case that only a part of the fossil energy alternative is already charged for their GHG emissions in the EU ETS, such as in the case of electricity generation installations above 20 MW, it is conceptually not feasible to identify the GHG balance of the fossil fuel alternative.

Furthermore, without covering all GHGs and all GHGs along the process chain (in the case that the current EU ETS remains unreformed), implementing a subsidy on renewable energy sources would be distorting. This problem particularly relates to the emission balance of bioenergy, which contains a considerable share of GHGs not captured in the current EU ETS. By not including these emissions, bioenergy would be considered essentially free of GHGs which, in fact, is not the case.

5 Discussion and Policy Implications

The currently low price for emission permits under the EU ETS constitutes one of the main reasons why the German government's target for the share of renewable energies in the energy supply will most likely not be reached. Most producers of renewable energy cannot compete with the current price of 7 euros/tonne of CO_2 for a certificate. Thus, reducing the supply of emission permits is mandatory in order to provide the necessary incentives for the implementation of the energy transition. Only in such a setting would a structural reform of climate policies towards an efficient incentive system with equal prices for GHG emissions make sense. On the other hand, a reduction of the cap of the EU ETS with substantially higher prices would increase the distortions and inefficiencies of the current system where only half of the emissions are covered by the EU ETS.

Provided that prices in the EU ETS are high enough, what would constitute a fair competitive framework in which fossil energies and renewable energies can compete? In theory, one can find several possible solutions; however in practice most of them are difficult if not impossible to implement if they are introduced alongside the current EU ETS. We show that it is conceptually infeasible to calculate the reference of the fossil fuel alternative for subsidising renewable energies because of the selective coverage of the EU ETS across the different energy markets. A GHG tax which is imposed on those energy options not covered by the EU ETS requires a continuous alignment of the tax level with EU ETS prices in order to guarantee equal prices for GHGs generated inside and outside the EU ETS. This does not seem very practical under continuously changing prices within the EU ETS.

A radical but feasible option is the expansion of the current EU ETS to all GHGs and all emissions sources, the EU ETS 2.0. This may seem politically infeasible at first sight, but it is efficient and practically implementable. However, several adjustments need to be made, the most important being the combination of the current downstream EU ETS which controls end-of-pipe emissions with an upstream system which will need to cover mobile and small emission sources. This is mainly owed to the operational feasibility and monitoring costs.

Providing consistent support for renewable energies requires expanding the EU ETS to cover all GHGs and along all process chains. Without the GHGs currently not covered, bioenergy would gain a competitive advantage because of its large share of non-CO_2 gases generated along the process chain. All GHGs can be treated equally on the basis of CO_2 equivalents and thus be made tradable on a permit market such as the EU ETS. The greatest challenge for all options is the treatment of imported goods from non-EU countries which are not currently subject to the EU ETS regulations. Germany has a strongly export-oriented economy, and, therefore, how climate policy and the energy transition handle imports of energy-intensive commodities as well as exports of climate-friendly goods is of great importance. Imports into the EU of rape seed and soy beans, which are used to produce biofuels, provide one example. Substantial distortions would result if only German farmers were required to hold permits for their GHGs, but importers to the EU were not obligated to cover the GHGs embedded in their agricultural export products.

One solution is to calculate the GHG content of a product along the international process chain. This is a routine feature of biofuels certification schemes. The scheme's costs across the entire supply chain are judged to lie well below 1% of the product price. The sustainability certification of biofuels also has the positive side effect that agriculture and processing companies have begun to systematically analyse options for GHG reductions and to introduce suitable measures.[2]

In addition, other regulations and specifics of the different energy sectors need to be taken into account. The heating and the transport sector is covered by the energy tax law which defines different taxes for the use of fossil fuels. The tax structure and the EU ETS would need to be realigned with each other. Simply replacing the energy taxes by the EU ETS would ignore the fact that energy taxes are imposed for many

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[2] Based on personal correspondence of the authors with the certification system International Sustainability and Carbon Certification (ISCC).

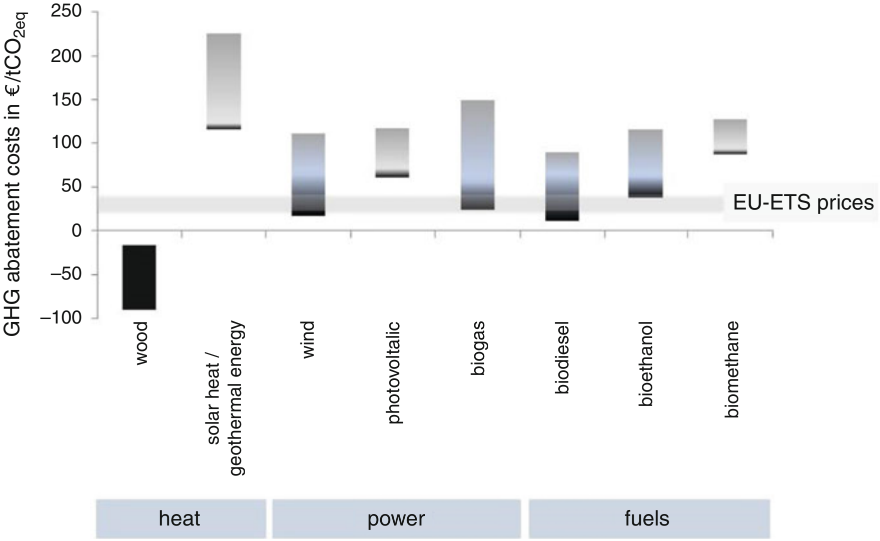

Fig. 5 GHG abatement costs of different renewable energies and energy markets. Source: Adapted from Delzeit et al. (2014)

reasons other than climate change mitigation. The assessment of an appropriate tax level for the different externalities and public goods provided would need to be done in order to achieve an efficient instrument mix. Existing taxes in the transport and heating sector would need to be reformed in such a way that they only cover public goods and externalities not related to climate change mitigation. Thus, reforming the support of renewable energies towards an efficient climate mitigation policy does not imply that other energy transition goals cannot be pursued. However, it does require that they be controlled through appropriate policy instruments.

In addition, possible market effects need to be considered. The proposed reform of the support of renewable energy results in a fundamental change of the market incentives for renewable energy production. The portfolio of renewables in the energy market is likely to change. The analysed support schemes provide equal price incentives to reduce GHG emissions and thus support renewable energies in terms of their emission savings compared to fossil fuels. These incentives will in many cases differ significantly from the current incentives.

Figure 5 illustrates the effect that a uniform price for GHG emissions in the range of 30–50 euros/tonne of CO_2 equivalents would have on the different renewable energy sources in three energy markets. It shows that electricity produced with wind energy and biogas is more likely to benefit from an efficient climate policy instrument. Others, like photovoltaic installations, at least currently, still have much higher abatement cost.

6 Conclusions

The analysis has shown that without a reformed EU ETS, an efficient climate mitigation system is largely impossible to implement. Further, we illustrate that the current support scheme indeed results in a high cost to the economy. We argue that the main reason for the inefficiency originates in the different support schemes. Price distortions are created through the different treatment of renewable energies and their price support policies for GHG savings across different sectors and renewable energy technologies. We show that the best option for moving towards an efficient system would be an EU ETS 2.0 with expanded coverage of all GHGs and coverage of all emission sources. Within such a system, all GHG emissions would face the same price in terms of CO_2 equivalents and thus equal incentives for emissions reductions. Although this is theoretically obvious and easily stated, it becomes quite complicated if introduced in practice. It requires that:

- All types of GHGs would have to be measured and verified.
- All GHGs along the process chain would have to be captured.
- GHGs embedded in imported products would have to be reflected in the GHG market in order to avoid a globally inefficient allocation of resources and a loss in competitiveness of domestic industries.
- All product prices would have to reflect their accompanying costs of GHGs.

The computation of specific GHGs, both for renewable energies produced in the EU and for imported energy sources, has long been considered impossible. However, the developments in the biofuel market over the last 5 years have shown that this is feasible. These experiences can be utilised in the electricity and heat market within a reformed EU ETS. It requires the political will to fundamentally change the support of renewable energies towards an efficient system taking dynamic incentive effects and ecological effectiveness into account.

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Import Dependency and the Energy Transition: A New Risk Field of Security of Supply?

Sebastian Strunz and Erik Gawel

Abstract The transition towards renewable energies yields challenges for security of supply, for instance, as regards the need for low-emission backup capacities. This paper explores how the different dimensions of security of supply are affected by the energy transition. In particular, the paper discusses whether the EU's import dependency with respect to natural gas poses a problem for the transition pathway. Overall, the energy transition implies not only short-term challenges but also long-term synergies for security of supply. Hence, while concerns about security of supply need to be addressed, they do not put the general transition pathway into doubt.

1 Problem Statement

With the expansion of renewables, new records are being set every year in terms of the contribution of volatile renewables to electricity consumption (see Fig. 1 on the shift in the contribution of individual energy sources to gross electricity production since 2000). In 2015, for example, the combined share of wind and solar energy in gross electricity consumption rose to 21% (Neon 2016). However, the fluctuating nature of the supply of wind and solar energy creates new challenges, such as

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S. Strunz (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: sebastian.strunz@ufz.de

E. Gawel
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

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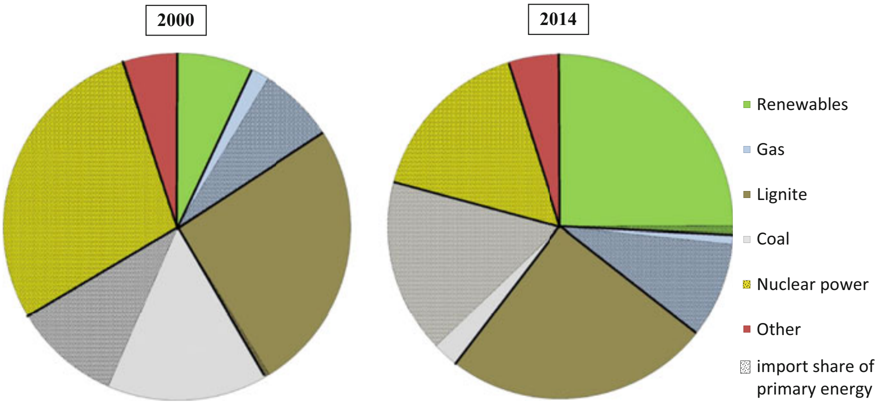

Fig. 1 Gross electricity generation in Germany: shares of primary energy sources and their respective import quotas (2000 and 2014) (Source: own illustration based on BDEW and Eurostat data) (In the interests of clear representation, a detailed breakdown of the energy source groups "renewables" and "other sources" (e.g. household waste, pumped storage) is not given here. However, it should be pointed out that in the area of bioenergy, biomass may not be imported at the expense of environmental sustainability in order to be compatible with the objectives of the energy transition). ▨ Import quota for primary energy sources. 🟩 Renewables, 🟦 Natural gas, 🟫 Lignite, ☐ Hard coal, 🟨 Nuclear power, 🟥 Other sources (e.g. household waste)

providing flexible backup power plants to cover the demand when feed-in from renewables is low.

In the literature, the connection between energy transition and security of supply is discussed mostly with respect to adequate generation capacity and a possible aggravation of the missing money problem (see overview in Reeg et al. 2015). But security of supply is a multilayered concept which includes the permanent and sustainable meeting of energy requirements in terms of long-term adequacy of supply (availability of primary energy sources, availability of production capacity) as well as the short-term safeguarding of network stability (BMWi 2012). This chapter, however, focuses on the availability of the primary energy sources themselves—i.e. especially the question of whether the energy transition has an import dependency problem. In particular, this concerns gas, which is not only ideally suited as a flexible backup technology but also mainly imported, with Russia as the largest single supplier (BAFA 2016).

In this context, it is worth noting that the conflict in the Ukraine has been interpreted in diametrically opposing ways as regards the possible consequences for the energy transition: on one side, some authors seize on an increasing dependence on Russian gas in the course of the energy transition as an argument against it: "If we shut down those of our nuclear power plants that are still in operation, as planned, and focus entirely on wind and solar power, our dependence on Russia is going to increase further—and security of supply will decrease" (Sinn 2014) (own translation). Should Germany therefore put the energy transition on ice so as to not increase its import dependency even further? Or is the conflict in the Ukraine, as

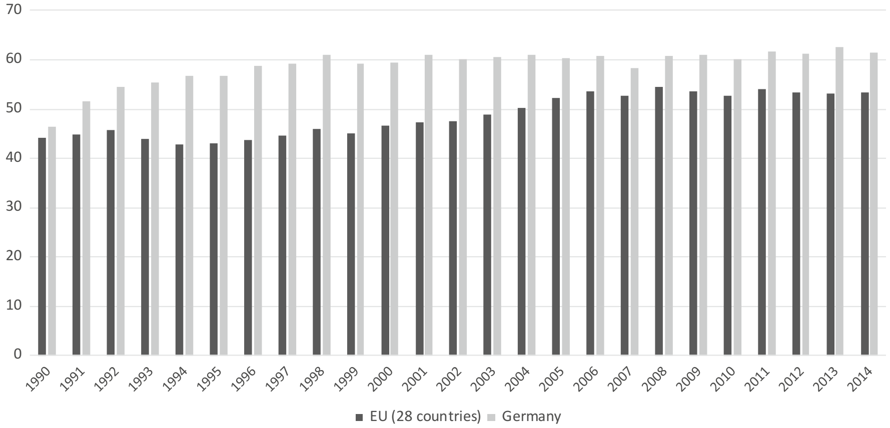

Fig. 2 Share of net imports in gross energy consumption in Germany and the EU (for the period 1990–2014). Source: Eurostat

others claim, “a good argument to speed up the energy transition” (Hanselka 2014)? An accelerated energy transition, especially in the heat sector, could be enough to substitute gas consumption in the amount of the Russian gas imports by 2030 (IWES 2014).

This is also where the current discussion about a European “energy union” ties in. The European Commission has declared the diversification of gas supply as a key building block for increasing energy security (EU Commission 2015). In other words, Europe’s dependence on Russian gas imports is to be reduced. But the EU’s dependence on energy imports has in fact been rising since the 1990s due to the declining extraction of fossil fuels (see Fig. 2). Even the Commission does not anticipate a reversal of this trend until after 2030 (EU Commission 2014a: 93). Moreover, whether the corresponding declarations of intent will be followed by a substantial integration step towards a common understanding of security of supply or even a transfer of hitherto national decision-making powers to the EU seems doubtful (Fischer and Geden 2015).

So, at first glance, the discussion about energy transition and import dependency appears muddled: a wide range of arguments (geopolitical, sustainability-related, economical) are being put forward to steer energy transition policy in various different directions (speed up/slow down the energy transition, accelerate EU integration). This chapter therefore aims to provide a systematic overview of the respective interrelationships. In doing so, the chapter is structured around three key questions: (1) Why is import dependency an economically relevant problem in the first place? (2) How does the energy transition affect import dependency? (3) Does gas supply represent the Achilles’ heel of the energy transition?

2 Import Dependency as an Economic Problem

First, we have to ask why import dependency should be discussed as a problem in the first place. After all, from an economic theory perspective, trade can increase overall welfare (e.g. Weimann 2009). German electricity consumers profit from imports of cheap hard coal by comparison with domestic production of hard coal, which is expensive and can only be produced economically through subsidies. However, the energy sector is characterised by several special features which call into question the absolute advantageousness of increased foreign trade.

Primary energy imports are associated with price and quantity risks which are attributed not only to market forces but also to a large extent to geopolitical influences in combination with a limited number of suppliers. This also distinguishes the energy sector from the agricultural sector, which—with by all means comparable essentiality of the supply mandate—we readily entrust to international, market-coordinated division of labour. The high geographic concentration of oil and gas resources in an imaginary "strategic ellipse" from the Middle East across the Caucasus to Russia goes hand in hand with the tendency to form cartels as well as a political mix of instability and foreign policy coalition-building across numerous conflict hot spots. A number of "rentier states" finance themselves through the export of resources and in doing so know how to use their resources as a foreign policy instrument (Mahdavy 1970). The industrial nations, as oil consumers, became conscious of this with the oil crises provoked by OPEC during the 1970s. Gas conflicts between the Ukraine and Russia had already occurred prior to the political escalation in 2014: as early as January 2009, there was "a disruption of supplies of nearly two weeks, an event unprecedented in the international gas trade, which not only contradicted any decent business practice, but also violated bilateral and multilateral agreements" (Westphal 2009: 5). Conversely, the West's sanctions against Iran, which were lifted only recently, show willingness on the demand side to stage geopolitical feuds in the energy sector. In other words, the frequently invoked benefits of free trade do not come into full effect for oil and gas, insofar as the market principle is overridden by other political considerations.

In the current German debate, however, the argument stubbornly persists that the Soviet Union, even in the "darkest hours" of the Cold War, was always a reliable gas supplier (e.g. Hanselka 2014). The fact that the import of natural gas from the UdSSR was precisely a product of the 1970s policy of détante is largely ignored ("change through trade"). The "darkest hours" of the East-West confrontation were long over at the time. At best, the subsequent cooling-off of the East-West relationship in the 1980s could be used to support this argument—besides, it appears inadmissible to deduce future decisions from past developments.

At the same time, the oil and gas markets appear quite functional in respect of their main economic function of reporting scarcity signals through prices. The oil oligopoly, which consists of many individual exporters, could also be described as a resilient system in which a disruption in the production of one member can be compensated by the other parts. Indeed, here, the lifting of sanctions against Iran adds an important new element to the system.

So, the extent to which trade and management of natural resources is hindered or promoted by geopolitical circumstances can vary widely from case to case. On account of the public goods characteristics of security of supply, dependency on imports of primary energy resources can certainly be discussed as an economic problem. Therefore, the following section will focus on the different impacts of the energy transition on the necessity to import primary energy resources.

3 Energy Transition and Import Dependency

Figure 3 shows the different channels through which the energy transition influences import dependency. Because the primary objectives of the energy transition (a reduction of CO_2 emissions by at least 80% and a renewables share of at least 80% by 2050) are fairly general, there is of course no "one" effect of the energy transition on import dependency, rather there are different effects, each with their own specific impacts.

- The ambitious targets of the energy transition are to be achieved in particular also by reducing consumption. By 2050, there is to be a 50% reduction in primary energy consumption in comparison to 2008 levels. Obviously, every reduction in energy consumption, ceteris paribus, translates into lower import dependency. For example, the Commission expects a 2.6% fall in gas imports in the EU for every additional 1 percentage point in energy savings (EU Commission 2014b).
- Substitution of fossil energy sources by renewables: In the electricity sector, hard coal and lignite are to be completely replaced. Leaving aside domestic lignite, fossil fuels account for import quotas of at least 87% today (see Figs. 1 and 4). Insofar as renewables substitute hard coal or gas, the expansion of renewables reduces imports of the latter.
- The nuclear phaseout by 2022 implies a substitution of nuclear power by renewables and therewith lower import dependency.
- Because there has been no extraction of uranium in Germany since reunification, all supplies of this primary energy source must be imported. Based on the data of EURATOM (2014), almost 88% of the uranium consumption in the EU is imported from outside the EU, with Kazakhstan and Russia as the most important

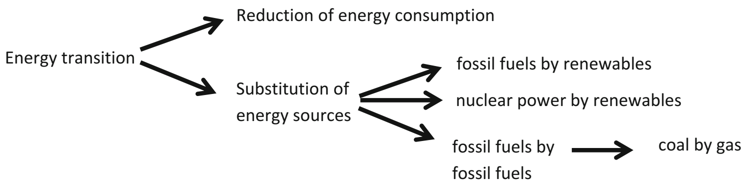

Fig. 3 Diagram of effects of the energy transition on import dependency (own illustration)

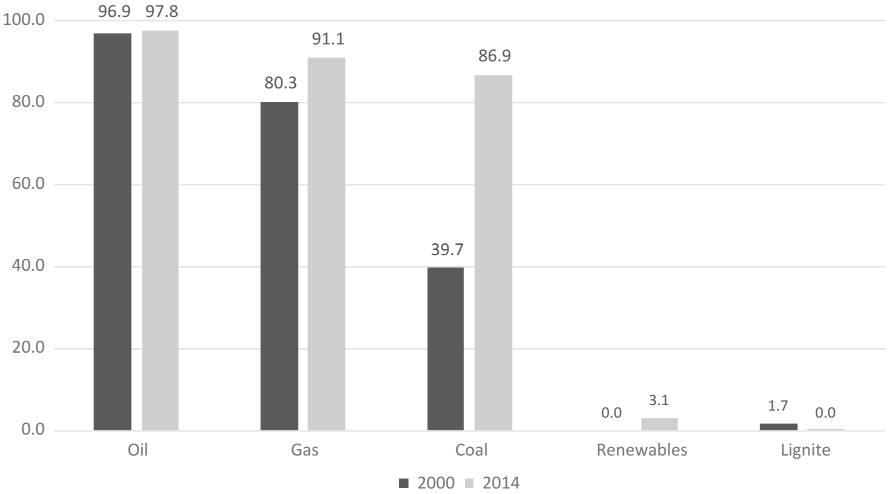

Fig. 4 Primary energy sources in Germany according to import quotas (for the years 2000 and 2014). Source: Eurostat

importers—the rest is accounted for by reprocessed fuel rods and a small fraction of uranium extracted in the EU.

- On the other hand, the objectives of the energy transition also lead to substitution within the fossil fuels. The planned phaseout of coal would have to come at the expense of lignite, for instance, through the shutting down of lignite-fired power plants in the context of the so-called capacity reserve—so far, admittedly, the decline is more evident in hard coal-fired power generation (see Fig. 1). In the longer term, coal is expected to be substituted by gas: the CO_2 intensity of hard coal, measured in terms of electricity consumption, is indeed only marginally better than that of lignite, while gas performs significantly better than both types of coal. Moreover, fluctuating renewables require flexible backup solutions to ensure an uninterrupted supply of electricity: due to their flexibility, gas power plants provide an ideal solution, not only for the notorious “dull week in November with no wind or sun” but also for very short-term fluctuations in the supply of renewable energy. So, if domestic lignite is substituted by imported natural gas or hard coal, import dependency will increase.[1]

Additional complexity results from the fact that the individual effect paths are interdependent. For example, an import quota of 50% with different absolute

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[1] So far, the import quota for natural gas has been higher than that for hard coal (see Fig. 4). However, domestic hard coal mining is only being kept alive with subsidies until 2018. Once the subsidisation ends, as legally agreed, all hard coal must be imported. In 2014, Russia was the largest single importer delivering 27.7% (see Umweltbundesamt: Daten und Fakten zu Braun- und Steinkohlen. p. 29. Dessau 2015. Available at: https://www.umweltbundesamt.de/publikationen/daten-fakten-zu-braun-steinkohlen).

consumption levels can imply completely different quantity and price risks. Furthermore, the electricity/heat/transport sectors are characterised by different problem areas, though coupled. While the energy transition has so far been primarily an "electricity transition", the heat and transport sectors are lagging behind. The transport sector remains dependent in an extreme form on mineral oil and therewith on imports; the government's target of getting 1 million electric cars on the road by 2020 will most likely be missed by a clear margin. Here, there is a clear need for action to speed up the transformation, which at the same time would lower the sector's import dependency (of course, an increase in electromobility would in turn lead to increased demand in the electricity sector). In the heat sector, the goal is to achieve a nearly climate-neutral building stock by 2050. To this end, the annual refurbishment rate is to be increased from currently 1 to 2%. However, the success of the instruments introduced to meet this target (EWärmeG, MAP) has been relatively modest so far (Adolf and Bräuninger 2012). Since gas is the most important source of energy in the heat sector (almost half of all homes in Germany are heated directly with gas), a reduction in the demand for heat would also reduce import dependency.

Generally, it can be said that the energy transition triggers different (partly opposed) effects, which must be evaluated in their entirety: To what extent is energy consumption reduced? Which fossil fuels are substituted and what are they substituted by? For the remaining imports of primary energy sources, is diversification of the portfolios in terms of minimising price and quantity risks taken into consideration? The substitution of domestic lignite by imported natural gas, in particular, would involve increased risks. This raises the question of whether the energy transition actually faces a fundamental problem here, as will be discussed in the following section.

4 Dependency on Gas Imports: The Achilles' Heel of the Energy Transition?

In the *long-term* timeframe, the energy transition and the reduction of Germany's dependence on imported energy sources are synergistically connected (reduction of energy consumption and changeover to domestic renewables). The transformation may however trigger an increase in import dependency in various other sectors caused, for example, by imports of rare earths for photovoltaic installations or battery storage systems in the area of strategic raw materials. But the example of gas, in particular, shows that long-term policy choices could influence the parameters favourably. Although the import quota for gas has been increasing in recent years (see Fig. 4), this trend could also reverse in the long run. For instance, the feed-in of biogas into the gas network—currently less than 1 billion cubic metres—is expected to increase to 10 billion cubic metres by the year 2030 (although these "legally fixed targets seem hardly achievable at present" (own translation), see *Bundesnetzagentur* (German Federal Network Agency) (2014). Furthermore, from around 2030 power-to-gas may also become economically profitable for the energy industry (Schmid 2012): with growing production capacities, the temporary surpluses of electricity from renewable energy sources that cannot be absorbed by the electricity network but could be fed into the gas network by synthetic methanation will increase.

With the 2050 timeframe and the target of 80% renewables, alternative flexibility options such as battery storage, which will probably be used mainly in other sectors such as transport at first, will eventually also become relevant for the electricity sector (Agora 2014). To that extent, the claim that "the energy transition makes us dependent on Putin" ignores current policy options which make long-term alternatives possible in the first place. Overall it must be stressed that any geopolitically motivated readjusting of policies related to gas can certainly not call into question the long-term goal of the system transformation, which is based on sustainability-related and economic arguments.

But what about the *short-term* relationship between the energy transition and import dependency? Germany covers 38% of its energy consumption with Russian natural gas (BDEW 2015). And if gas is used as a bridging technology in the electricity sector until economical flexibility options become available, this dependence could be further exacerbated to start with. First and foremost, diversification in the gas sector—which in the past received only insufficient attention—can hardly be attributed to the energy transition. Moreover, quite different assessments have been presented concerning the potential implications of a politically motivated halt in the supply of Russian gas for the supply of gas in Germany (cf. Engerer et al. 2014; Hecking et al. 2014). Thus, all in all, there is definitely a need for action—for the short and medium term, diversification of gas imports is indicated, whereas for the long term, sector-based course-setting is needed.

5 Conclusion: The Energy Transition Does Not Have an "Import Dependency Problem"

Import dependency "in itself" is not a problem. In the energy sector, too, it is not import quotas that should be discussed as a problem, but only the specific price and quantity risks associated with imports of primary energy carriers. Against the background of geopolitically shaped oil and gas markets on which profit-making is assigned reduced importance, there is a definite need for action. Of course, the dependency that arose in the past, especially on Russian gas imports, cannot be attributed to the objectives of the energy transition. Nonetheless, in order to prevent natural gas from becoming the "Achilles' heel" of the energy transition, import dependency should be addressed in a cause-based way, i.e. diversification of the supply should be introduced in the short and medium term, while in the long term, other flexibility options should be incentivised.

Regarding the controversial topic of fracking—a potential substitute for gas imports—two things should be taken into consideration. First, the option value of this extraction technology should be taken into account (Konrad and Schöb 2014).

On the other hand, it must be clear that even gas, which compared to coal is more climate-friendly, as a fossil fuel is not compatible with the objective of a sustainable energy supply. Nuclear power and carbon capture and storage are still unsustainable pseudo alternatives. In the long term, the synergistic effects between energy transition and import dependency therefore seem obvious: the reduction of energy consumption and the expansion of renewables will reduce and ultimately replace the import of primary energy sources such as uranium, hard coal, gas and oil.

There's no denying a possible shift of the import problem in the course of the transformation to new technologies such as photovoltaic installations with battery storage (buzzword "rare earths"). Indeed, rare earths are not really rare but currently quasi-monopolised—a clear argument for the diversification of the procurement structures. So, here again, targeted policy measures (such as the diversification of the import structure) should be the method of choice for solving the problem and not, however, a mixing of the levels of argumentation: no more than the current dependency on Russian gas represents an a priori argument *for* or *against* the German energy transition, the fundamental transformation of the energy system towards greater sustainability cannot be challenged by geopolitical deliberations regarding the availability of high technology raw materials.

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Combining Climate Protection and Nature Conservation: Requirements for an Environmentally Friendly Energy Transition

Kathrin Ammermann, Jens Ponitka, and Christoph Strauß

Abstract Germany, like most countries around the globe, has made a commitment to undertake ambitious efforts to prevent human interference with the climate system, but also to protect nature and to safeguard humanity's natural life-support systems. Given that climate change poses a severe threat to species and habitats, a transition of the energy supply system and the development of renewable energies are necessary also from a nature conservation perspective. At the same time, renewable energies have strong impacts on objects of nature conservation. Germany, with its Renewable Energies Act (EEG) to promote renewable electricity, is one of the pioneers of the energy transition, and the country has seen a strong increase in new plants producing renewable energy. In this paper we discuss this field of tension from the specific perspective of nature conservation and focus on three technologies: wind energy development—both onshore and offshore—and biogas production. Based on this, requirements for an energy transition that is compatible with nature conservation targets are derived. We conclude that, rather than dealing with the consequences of unwanted side-effects, nature conservation issues should be included in energy transition efforts at an early stage. Overlapping targets, such as energy efficiency, should be supported, and research, technology development and discourse are essential.

1 Introduction

1.1 Climate Protection Goals and Biodiversity Targets: Synergies and Conflict Potential

The Earth is increasingly exposed to anthropogenic pressures, and nature and biodiversity as one of humanity's natural life-support systems are affected by

K. Ammermann (✉) · J. Ponitka · C. Strauß
Department of Nature Conservation and Renewable Energy, German Federal Agency for Nature Conservation (Bundesamt für Naturschutz - BfN), Leipzig, Germany
e-mail: Kathrin.Ammermann@BfN.de

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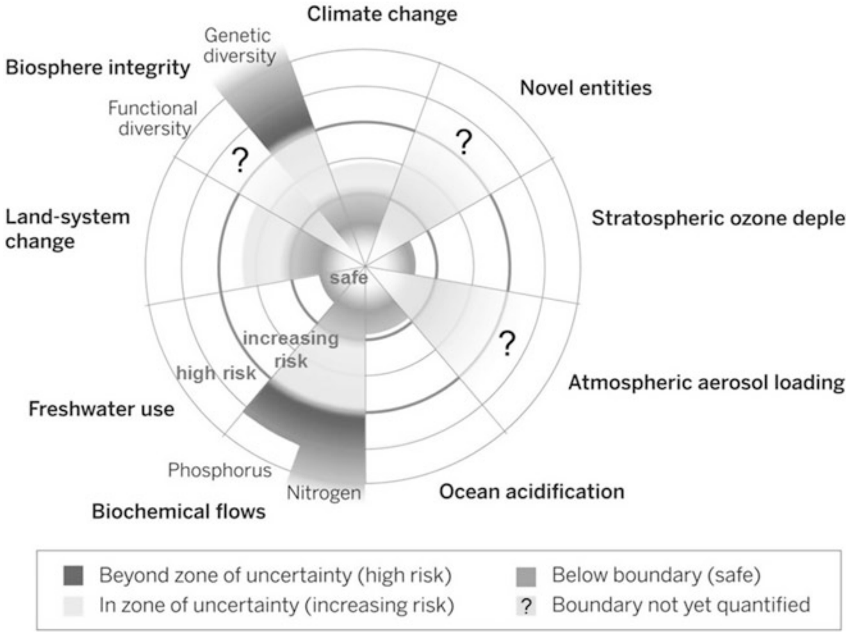

Fig. 1 Climate change and biodiversity in the context of planetary boundaries [concept according to Rockström et al. (2009); Source: Steffen et al. (2015), modified]

various threats. According to the concept of Rockström et al. (2009), a range of interlinked processes determine the resilience and stress limits (planetary boundaries, see Fig. 1) of the planet. Already today these processes are characterised by strong human interference. Four of the nine boundaries are already under threat or have been exceeded (Steffen et al. 2015; Fig. 1). One of the areas estimated to be at high risk due to a clear exceedance of thresholds is the rate of extinction in the context of biosphere integrity. Climate change, located in the zone of increasing risk, represents an additional stress factor for ecosystems, their biodiversity and performance (cf. IPCC 2012). This approach helps to understand and consider the conflicts between human action—such as building and operating renewable energy infrastructure—and biodiversity.

The international community, for the most part, has made a commitment to reduce anthropogenic interference with the climate system (UN 2015) and at the same time has set ambitious targets to protect biodiversity and thus secure the foundations for human and natural life (UN 1992; Secretariat of the Convention on Biological Diversity 2005). However, according to the global status report of the Secretariat of the Convention on Biological Diversity (2014), in the area of biodiversity protection, only a small number of the 20 Aichi Targets defined within the framework of the CBD/UN Decade on Biodiversity 2011–2020 are currently being met. Some targets are moving away from the goal, or little progress is being made towards the goal, and without additional efforts, many of the targets will likely not be achieved by 2020. Germany, too, has set itself wide-ranging climate protection and biodiversity protection targets based on the global commitments. But here, too, the assessments of developments in both German climate protection (BMWi 2016a; Löschel et al. 2016) and a large portion of the biodiversity targets and indicators (BfN 2017; BMUB 2015, 2017) reveal that the targets will most likely not be met and that the efforts undertaken to date will not suffice.

Given that climate change poses a severe threat to species and habitats (Leadley et al. 2010), a transition of the energy supply system and the development of renewable energies are favourable solutions also from a nature conservation perspective. At the same time, renewable energies have strong impacts on objects of nature conservation. Germany, with its Renewable Energies Act (EEG) to promote renewable electricity, is one of the pioneers of the energy transition, and the country has seen a strong increase in the number of new plants producing renewable energy. In Germany, in connection with the *Energiewende* and an accelerated withdrawal from nuclear power, studies began at an early stage to analyse the potential effects of the use and expansion of renewable energy sources (e.g. accompanying ecological research of the BMU 2007; Peters et al. 2011). Wherever there is an indication of potential conflicts between climate protection, the expansion of renewable energies and nature conservation through human activities, measures to avoid or minimise conflicts are to be taken. With the progressive expansion of renewable energies in agricultural areas and even forests and the possibility of increasing conflicts, the incentive mechanisms and regulatory frameworks (e.g. wind energy ordinances and species protection guidelines) but also the research themes need to be continually adapted to the requirements and latest scientific findings in nature conservation. These efforts are to follow the government's current clear policy objective to design Germany's energy transition in a way that is compatible with the environment (German Federal Government 2013). It can be assumed that rather than dealing with the consequences of unwanted side-effects, nature conservation issues should be included in energy transition efforts at an early stage. Overlapping targets, such as energy efficiency, should be supported, and research, technology development and discourse among all participants and parties concerned are essential.

This article analyses selected aspects of the German *Energiewende* of the past years from the specific perspective of nature conservation objectives. The specific target that the energy transition should not take place at the expense of biological diversity is addressed. Fields of tension with nature conservation and landscape management are exemplarily discussed with the focus on three technologies: wind energy development—both onshore and offshore—and biogas production. On this basis 'lessons learned' and conclusions for a nature-compatible energy transition are formulated. The article altogether aims at deriving requirements for a path forward which is compatible with nature conservation targets at various levels, explicitly including the European perspective with its ongoing promotion and expectable expansion of renewable energies in the future.

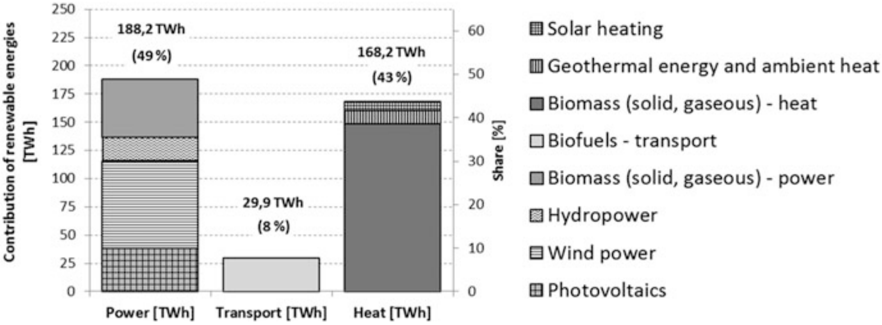

Fig. 2 Energy supply from renewable energy sources in 2016 with a total renewable energy supply of 386.3 TWh (own representation based on UBA 2017)

1.2 The Development and Current State of Germany's Energy Transition

The share of energy from renewable sources in the final energy consumption increased strongly in the last few years and reached 386 TWh (or 1390 PJ) in 2016; this corresponds to nearly 15% of Germany's final energy consumption.

The various pathways of production and use of renewable energies are associated with very different effects on nature and the landscape and a very unequal expansion. In the case of electricity consumption in particular, the share of electricity from renewable energy sources increased from roughly 6% (36 TWh) in the year 2000 to 31.5% (188 TWh) in 2016 as a result of the highly dynamic growth in new installations.

The different renewable energy sources also contribute to varying degrees to the supply of energy (see Fig. 2). While bioenergy continues to dominate in the heating and transport sectors, the development in the electricity sector is attributable in large part to the dynamic growth of wind energy but also of bioenergy and photovoltaics. Wind energy (with a 20% share of all renewables) and bioenergy (heat, electricity and fuel) are the most important sources of renewable energy, currently (2016) accounting for almost 85% of all renewable energy sources.

Germany, with about 28,000 onshore wind power installations (2016, 49.5 GW in total, 45.4 GW onshore and 4.2 GW offshore), accounts for roughly 10% of the total installed generating wind capacity worldwide (487 GW) (REN21 2017). Alone in 2016 about 5 GW of new wind power capacity was installed in Germany. The particular relevance for nature and landscape conservation results from the large number of wind installation sites in a country with a comparatively high population density and landscape heterogeneity. Increasingly, new wind turbines are also being installed in forests: in 2016 almost every fourth, new installation was erected in a forested area (FA Wind 2017).

Photovoltaics already accounts for a share of 10% (38.2 TWh in 2016) of the power supply from renewable energy sources. According to the BNetzA (2015), about one-third of the total capacity is installed in open spaces. It cannot be ruled out that the installation of photovoltaics in arable land and grassland, which already occupies a surface area of a several thousand hectares, may lead to undesirable impacts (see Table 1).

The provision of heat through biogenic fuels, primarily wood, at 38% (148.1 TWh) of the total energy generated from renewable sources, remains the most important utilisation pathway and is of vital importance in the heating sector. The biogenic fuels and gases for electricity supply (13%) and biofuels in transport (8%) are based (in addition to waste and residual materials) primarily on agriculturally produced biomass (in the case of biogas and biofuels). In the electricity sector, the use of wood also plays a role in cogeneration plants. In the future, a growing demand for wood for raw material and energy uses could adversely affect forest biodiversity. Over the past 20 years, bioenergy has become increasingly important, and this is reflected in the use of agricultural and forest areas. More than 2.4 million hectares of agricultural land in Germany are now used for bioenergy production, which corresponds to roughly 13% of the total agricultural area (FNR 2016). At the same time, the growing use of wood for energy production means that its energy use is now quantitatively more significant than its material use (Jochem et al. 2015; Mantau 2012).

According to the expansion targets of the Renewable Energy Sources Act (EEG) and the government's current policy objectives, further growth can be expected especially in the area of wind energy (onshore and offshore) and photovoltaics (EEG 2017; Creutzig et al. 2017; UBA 2016; Kost et al. 2013). The significance of electricity as an energy carrier within an energy system based largely on renewable energy sources is expected to further increase due to technical and climate policy developments and the growing use of electricity in the heating (via heat pumps) and transport (electromobility) sectors (Quaschning 2016; UBA 2014).

1.3 Tension Between Nature Conservation and RES

The expansion of renewable energies and the conservation of nature and the landscape are connected in many different ways. Because climate change represents one of the most important threats to biological diversity, effective climate protection is a primary objective of nature conservation. The expansion of renewable energy sources is a key building block of Germany's climate protection strategy. Because of the lower energy density of renewable energy sources and resulting need for extensive expansion, this transformation gives rise to a high potential for conflict with nature conservation objectives. In addition to the effects caused by the installations' consumption of metallic and non-metallic raw materials (UBA 2016), the construction and operation of the installations can adversely affect nature and the landscape (UBA 2016). Even among the renewable energy sources, the energy yields per unit area of land utilised or claimed again vary widely.

Along with the addition of a growing number of buildings to the landscape, technical infrastructures and usage forms come with a variety of effects on nature

Table 1 Overview of the most important impacts and potential conflicts relevant today in the renewable energies and electricity network sector with respect to nature conservation and landscape management [non-exhaustive list compiled by the authors based on: BfN (2011, not dated), Peters et al. (2011), BMU (not dated), BfN (unpubl.), Jessel (2016)]

	Current impacts—potential conflicts		
Technology	Ecosystem functioning (natural dynamics of soil, water, ecosystems)	Biodiversity (biotopes, species)	Landscape/human perception and recreation
Wind power (onshore)	– Soil compaction during construction of the installation and access routes as well as soil sealing – Potential impairment of water balance	– Risk of collision (birds and bats) – Potential population effects (development of the landscape, habitat impairment) – Disturbance/scarring effect – Destruction of habitat (breeding sites) and legally protected biotopes – Impairment of protected areas	– Impairment of the visual appearance of the landscape (spatial effect of the installations) – Impairment of recreational function (adverse effects during operation, e.g. through noise)
Wind power (offshore)	– Destruction of biotopes (foundations) – Creation of locally atypical habitats – Soil warming	– Killing/injury/disturbance through noise input (ramming of the foundations) – Habitat loss – Individual losses – Scarring effect (resting birds) – Barrier effect (migratory birds) – Impairment of protected areas	– Impairment of the visual appearance of the landscape
Utility-scale photovoltaics	– Soil compaction, erosion and sealing	– Withdrawal and fragmentation of animal habitats (fencing)	– Marking of the landscape by technology (e.g. spatial effect, light reflection)
Bioenergy	– Impairment of soil function (sealing) – Contamination of groundwater and surface waters (through intensification of the nutrient loads, increase in risk of erosion through increased cultivation of crops that are susceptible to erosion, potential failures)	– Direct change of land use – Indirect effects through highland consumption (e.g. habitat losses through grassland intensification and ploughing) – Change in cropping intensity and loss of biodiversity and agrobiodiversity (e.g. tight crop rotations	– Impairment of landscape-related recreation (e.g. monotonisation, tall energy crops create visual barriers) and recreation close to home (e.g. operation of bioenergy plants) – Impairment of the landscape

(continued)

Table 1 (continued)

Technology	Current impacts—potential conflicts		
	Ecosystem functioning (natural dynamics of soil, water, ecosystems)	Biodiversity (biotopes, species)	Landscape/human perception and recreation
		in the cultivation of energy crops) – Intensification of timber harvesting (loss of forest habitats)	
Hydropower	– Passability of river ecosystems (aquatic fauna during directed migration) – Influence on the water level of waterbodies (e.g. effect on the groundwater level, dynamics of water level fluctuations and/or shifting processes with impacts on floodplains)	– Increased mortality risk – Impacts on animal and plant communities (algal growth and hence impacts on the food web based on it) – Habitat loss (reduced current and sediment deposits) – Altered aquatic plant community (reservoir areas)	– Landscape (altered water retention) – Noise emissions
Electricity grid expansion-above-ground cables	– Soil compaction and erosion during grid construction – Groundwater impairment (foundation measures)	– Losses of individuals (collisions) – Habitat loss (biotope loss) – Barrier effect (migratory birds) – Impairment of populations (habitat degradation, indirect effects through creation of corridors)	– Landscape – Recreational function
Electricity grid expansion-underground cables	– Soil compaction and erosion – Protection of groundwater and drinking water (foundation measures) – Abiotic soil function and habitat function (warming)	– Habitat loss (forest clearance and underground engineering) – Creation of corridors (indirect influence on habitat) – Adverse effects on populations (structural changes in the habitat network)	

and the landscape. In the different renewable energies, these lead to specific effects and potential conflicts. It is not possible to generalise the negative effects of renewable energy technologies on the protected assets of the ecosystem and the landscape. They are dependent in each individual case on technical, site-specific and management variables. Another important factor is the sensitivity and/or preload of the respective site. The majority of new renewable energy technologies in Germany are not without ecological risks (BirdLife Europe 2011). Therefore, good site planning and an environmentally sound use of technology in particular are needed to protect the ecosystem and the landscape.

The objectives of nature conservation and landscape management are given concrete form in the Federal Nature Conservation Act (BNatSchG 2017). It provides for the protection of biological diversity (animal and plant species diversity including intraspecific diversity and a diversity of forms of biotic communities and biotopes), the performance and functional capacity of the ecosystem (soil, water, air, climate, animals and plants as well as their interactions between one another) and the diversity, uniqueness and beauty as well as the recreational value of nature and the landscape. Depending on the respective technology used, protected natural assets are affected by construction activity, land consumption, the operation of the installation (e.g. mortality risk for animals) or in some cases by barrier effects which lead to disturbance and/or habitat loss. The effects are differentiated into construction-related, operations-related and installation-related impacts. Which of those impacts lead to significant impairments shall be determined during the planning and authorisation phase of projects or installations. These result only from the consideration of the intensity of the effect and the sensitivity and/or importance of the protected asset, which are derived on the basis of specialist principles by means of legal and normative requirements (e.g. in the context of environmental impact assessments, FFH compatibility assessments or in the course of the provisions on interventions in nature conservation as well as in species conservation assessments). Certain effects such as cumulative effects with longer-term population impacts have not been fully examined so far.

An overview of the conflicts and impacts of renewable energies and electricity networks on the assets protected by the BNatSchG (2017) and according to the Environmental Impact Assessment Act-UVPG (2017) is presented in Table 1. A comparative or conclusive evaluation of a particular technology or the extent of a specific intervention is, however, only possible on the basis of an individual case study. Direct and indirect effects in varying degrees are caused by the construction and operation of the plants and/or by the plants themselves with almost all protected assets and/or also their interaction with one another. Especially relevant for the conservation of nature and the landscape are not only spatial and functional aspects such as land consumption, loss of habitat, impairment of soil function and waters and impairment of the natural landscape as a result of technical imprinting but also the impacts on certain animal species groups and on humans and their health (recreation). In the course of species conservation assessments, the conditions for prohibition (e.g. prohibition of killing, prohibition of disturbance, loss of habitat) are considered for certain, specially protected species groups.

2 Experiences with Biogas and Wind Energy Within Germany's Energy Transition

Germany's expansion of renewables in the electricity sector was mainly made possible through the Renewable Energy Sources Act (EEG), which provided fixed prices (tariff or premium) for every kilowatt hour (kWh) produced, priority grid access and priority transmission and distribution for renewables. Additional costs for renewable energy production are offset through an EEG levy (2017—6.88 ct/kWh) paid by end consumers (with exemptions for energy-intensive industries) (Freier 2017).

The EEG proved to be a very powerful instrument to incentivise the expansion and to involve a large variety of investors and producers but also a variety of small- to medium-size production units. From the year 2000 onwards, a vast number of plants were installed—especially for photovoltaics (more than 1.5 million grid connections) but also for other electricity-producing plants (with several tens of thousands of grid connections). German planning approval law ensures that nature conservation aspects, such as the impact on protected areas and on the conservation of specially protected species, are reviewed and taken into account before the development of installations for generating energy. Production of bioenergy crops is an exception as they are produced in an agricultural context.

But the rapid expansion of renewable energies also revealed a number of conflicts and highlighted the need for further integration of nature conservation objectives into the German energy transition process.

2.1 Example 1: Biogas Production

Electricity production from bioenergy developed at a relatively slow pace until the EEG was amended in 2004. One of the central motivations in the field of bioenergy was to address the "large utilisation potential of biomass from agricultural and silvicultural sources" (EEG 2004). The validation of this potential was based on the assumption that Germany's declining population and rising yield levels would further support a trend towards a high availability of agricultural land (Fritzsche et al. 2004). In the frame of the EEG, a new bonus, valid for renewable material from agricultural and silvicultural material, was introduced. It was explained by the higher cost of renewable raw material production.

The combination of feed-in tariffs and bonuses which were paid for electricity from renewable raw materials, including energy crops, provided for a very stable basis, especially in times of large uncertainty on conventional agricultural markets. From 2004 to 2014, there was a rapid development of the sector in Germany.[1]

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[1] Tariffs set by the EEG guarantee reimbursement for electricity generated from biogas for a period of 20 years. Thus, although more recent amendments of the feed-in law disestablished such special

During this period, a large percentage of more than 9000 biogas plants currently running in Germany went into operation—most of them agricultural biogas plants with substrate provision largely based on the use of maize silage. Today, almost 20% of all arable land (about 13% of agricultural land) is used for energy cropping.

During the beginning of the biomass-for-energy boom, various hopes for more diversity and sustainable development opportunities within the agricultural sector were formulated, but the development itself brought about some disappointments. Based on this backward-looking perspective, some conclusions can be drawn.

The incentive structures set by the EEG to expand electricity production put biogas plants in a relatively good position as actors in the agricultural landscape. Compared to other demands (including nature conservation and agri-environment schemes), in the competition for agricultural space and its utilisation, biogas producers had very good means to actively establish substrate production regimes.

Today, the effects are relatively well known. Studies on Lower Saxon (Theuvsen et al. 2011), Bavarian (Kilian et al. 2012) and German land rent markets in general (Garvert 2017) showed that biogas had a significant effect on land rent prices. This effect is highest in the vicinity of biogas plants in intensive livestock production areas. Thus, large portions of the 6 billion euros in subsidies currently deployed to support energy provision in the bioenergy sector (BMWi 2016b) are used for safeguarding substrate production.

The resulting shift towards energy crop production was based on a displacement of less profitable and more extensive production possibilities, which were—from an economic point of view—less interesting to farmers. Extensive production systems were substituted, part of which was the loss of permanent grassland. Concurrence of regions with biogas plants and regions with grassland loss has been relatively high (Fig. 3). Evaluations from North-Western Germany show that the rate of conversion (ploughing) in farms with energy cropping was very high compared to other farm types (Laggner et al. 2014). Some parallels with the international discussion on energy cropping, e.g. in the context of the European directive 2009/28/EC (RED 2009), are obvious: Induced demand leads to market reactions that are, in many cases, hard to predict—and induce conflicts with other targets.

Looking at the direct effects on land use, one major difference can be pointed out, which provides for some learning effect: While sustainability criteria prevented the conversion of valuable grasslands for energy crops in the biofuels/transport sector, the sustainability provisions of the German biogas-for-electricity sector relied entirely on existing rules within the agricultural sector, highlighting the fact that—for the protection of valuable grasslands—the rules (set by the CAP and its national implementation) that existed during this time span were not sufficient.

Besides the increase in bioenergy, the overall increased trend towards intensification of agriculture probably contributes to negative impacts on species diversity and landscape quality. As a sub-indicator of the sustainability indicators, the

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bonuses for agricultural biomass, most biogas plants still receive such bonus payments today because they were granted for 20 years of operation.

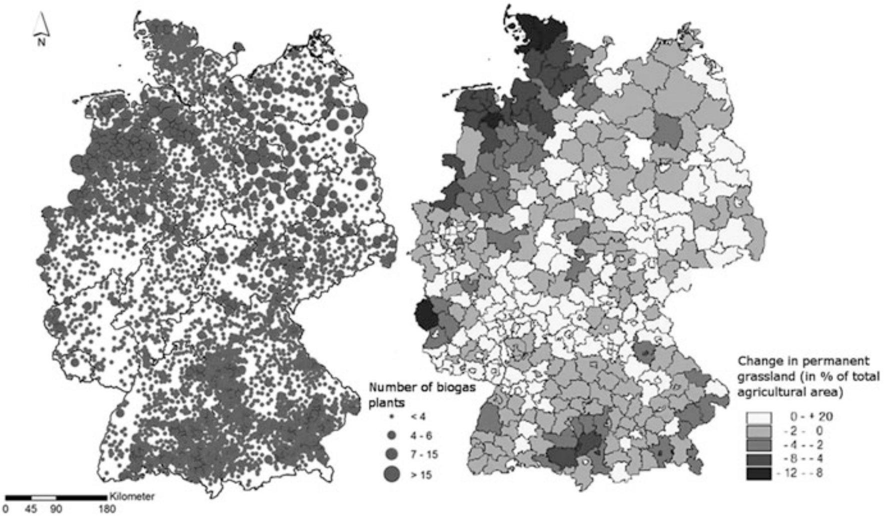

Fig. 3 Number of biogas plants in 2014 and the change in permanent grassland in the years 2003–2010 (Scheftelowitz et al. 2013, 2015)

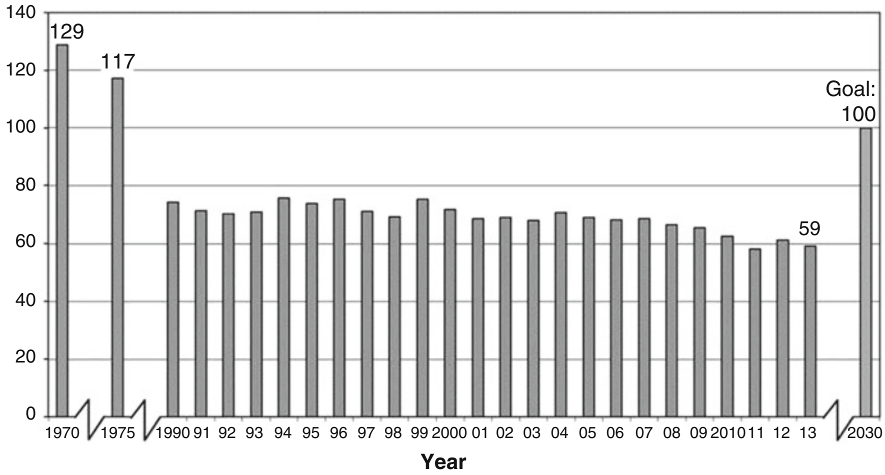

Fig. 4 ‘Farmland’ sub-indicator of the ‘species diversity and landscape quality’ indicator. The sub-indicator comprises the following species: red kite, northern lapwing, black-tailed godwit, little owl, red-backed shrike, woodlark, skylark, winchat, corn bunting and yellowhammer. Source: BfN (2017), based on data from DDA—Dachverband Deutscher Avifaunisten

‘farmland’ indicator of the Federal Agency for Nature Conservation (BfN 2017) exemplarily shows a negative trend (Fig. 4) for so-called agricultural birds, that is, birds that breed in agricultural landscapes.

Parallel to the international discussion on biofuels and indirect land-use change, the rise of land rents and the amount of production substituted serve as an indicator for the increased pressure on agricultural production by biogas production. In Germany indirect effects on land use also play a role, despite the fact that these effects are still not easy to quantify.

Disappointments with regard to partially ineffective bonus payments should also be mentioned. Two payments that are relevant from a nature conservation perspective were the bonuses for the utilisation of manure and the bonus for the utilisation of landscape management materials (*Landschaftspflegebonus*). The latter (in the 2009 version of the EEG) was paid for material harvested from sites on which agri-environment schemes had been granted (Clearingstelle EEG 2009). This also included schemes that had little to do with conservation targets—such as the introduction of reduced tillage systems or reduced emission plant nutrition (DVL and NABU 2010).

The bonus for manure was intended as an incentive to use more manure in anaerobic digestion plants. The bonus was granted for plants that used at least 30 mass per cent of manure and resulted in a higher payment for all electricity produced—including the large share of the electricity produced from maize (up to 70%). So, instead of reducing land demand and competition, this bonus served as an extra bonus for energy crop substrates—especially in regions with highland competition and livestock cropping (Gömann et al. 2013).

Furthermore—apart from the aspect of land competition and especially due to the concentration of digestion plants in livestock-producing regions—the rise of energy cropping for biogas led to an aggravation of nutrient surpluses. The displacement of fodder by energy maize production resulted in an increase of nitrogen from organic sources, according to Wüstholz et al. (2014). In regions with 'tense' nitrogen balances due to high amounts of organic fertilisers from feedstock production (>120 kg N/ha, Fig. 5, left), additional nitrogen amounts from energy crops (Fig. 5, right) impede an efficient utilisation.

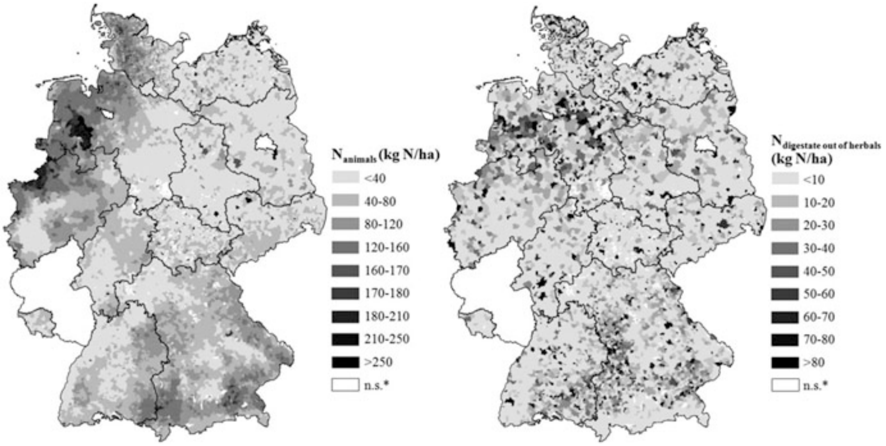

Fig. 5 Yearly nitrogen accruing from organic sources per hectare of agricultural space from livestock sources (left) and the additional load from energy crop sources (right) (Wüstholz et al. 2014)

All in all, some conclusions can be drawn from these experiences:

- For the future, biomass potential studies should be regarded with caution. On the one hand, potentials frequently do not cover all (conservation) needs and issues in the agrarian landscape linked to stated land biomass resources. On the other hand, mobilisation of the stated potential base is most likely associated with a large variety of effects, and existing rules are often not strong enough to prevent negative effects on conservation issues.
- Additional demand ‘shocks’ from energetic (land-based) biomass use are therefore to be regarded very critically. If the energy transition is to rely on further demand for biomass, the associated risks need to be identified well in advance and interdependencies need to be well researched under the paradigm of the precautionary principle. Also, the extent to which the existing rules are able to bolster negative effects of additional demand should be questioned. In Germany, the rules for the protection of grassland areas as well as for efficient nutrient management did not prove sufficient during the years of the biomass boom.

Shifting the focus—away from first-generation bioenergy, as in the current discussion on the amendment (see EC 2017) of the Renewable Energy Directive (RED 2009)—is therefore positive from a nature conservation perspective. On the other hand, placing a stronger focus on advanced biofuels, e.g. from forest biomass, may be counter-productive. So far there are no safeguards against negative effects: Just as in the case of biogas utilisation in Germany, an additional demand for woody biomass triggered by the amendment might lead to negative effects associated with a more intensive utilisation of forests (probably with an international dimension with rising wood imports)—including negative impacts for biodiversity.

2.2 *Example 2: Wind Energy*

Since the introduction of the Act on the Sale of Electricity to the Grid (StrEG) and later the Renewable Energy Sources Act (EEG) with an obligation to purchase electricity generated from renewable sources and minimum feed-in tariffs for the producers, in addition to the other technologies, especially installed wind energy capacity has witnessed a dynamic growth. Both onshore wind energy and the installed offshore wind energy capacity have grown steadily. The latest version of the EEG now defines expansion corridors in the form of upper limits for each individual renewable energy source. For example, wind energy expansion (gross) is currently set at 2800 MW. Various studies on wind energy potential which take technical, legal and in some cases also ecological restrictions into account (UBA 2013; BMVI 2015) have found significant potentials for further utilisation of wind energy in Germany. Also in scenarios (long-term scenarios, energy reference projections, climate protection scenarios) on climate-friendly, renewable energy supply (Nitsch et al. 2012; Schlesinger et al. 2014; Oeko-Institut and Fraunhofer ISI 2015), wind energy is an important component with continuously increasing high shares in electricity production in the period up to 2050.

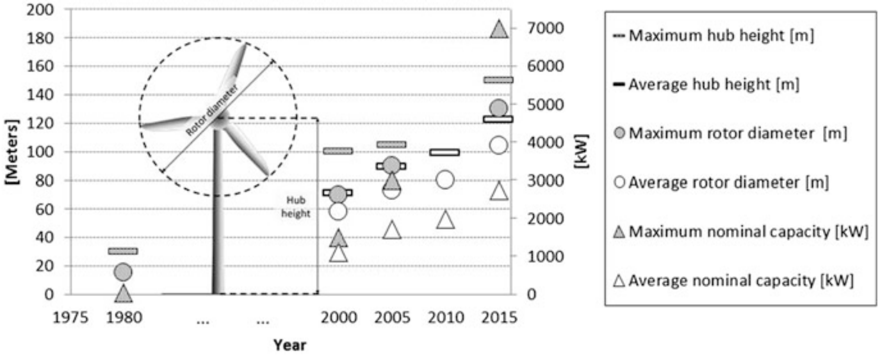

Fig. 6 Technological evolution of wind turbines (Own representation based on BWE 2017a, b; FA Wind 2016)

2.2.1 Onshore Wind Energy

As a result of their visual appearance and growing size, wind energy plants are infrastructures with various effects on nature and the landscape (see Table 1). The ongoing trend of growing size and capacity amplifies a lot of the effects. For instance, the maximum hub height has increased threefold from 50 metres in 1990 to 150 metres today. Also the average total height of wind turbines almost doubled from 100 metres in 2000 to over 180 metres in 2016 (see Fig. 6). Wind turbines that are over 200-metre high are already built.

The rapid addition and operation of new and larger wind energy installations, in view of the potential impacts, sometimes leads to conflicts. Besides the direct land consumption and soil sealing of wind energy plants, aspects that dominate the discussion are, in particular, the impairment of the landscape and its recreational function and the risk of bird and bat collision, which can result in animals being killed or injured.

Even after careful planning, a potential collision risk for certain species or species groups remains. Therefore, in recent years, operation algorithms were developed for practical applications [such as that of Behr et al. (2016) for bats] which significantly reduce the conflict risk of plant operation with only slight economic disadvantages. Also, the recent introduction, or in some cases adjustment, of minimum distances to, for example, bird species that are sensitive to wind energy or vulnerable to impacts (“Helgoland position paper”, LAG VSW 2014) or the consideration of population density such as that of the red kite in Baden-Württemberg (LUBW 2016) has helped to improve bird protection. Over the past years, recommendations have been adopted in most of the wind energy guidelines or species protection advices of the federal states and, hence, in the permit granting procedure.

In addition to the risk of collision, disturbances of sensitive species must also be taken into consideration. According to the legislation on species protection (BNatSchG 2017), any significant disturbance of specially protected species is prohibited. This applies when the conservation status of the local population worsens. With the increasing development of the landscape through technical infrastructures and the corresponding encroachment on habitats, future population effects cannot be excluded, but at the same time, they must be examined and substantiated in a very exacting manner. The disturbance of animals by wind energy in forests, for example, has been investigated as a research topic (Reichenbach et al. 2015). However, further research is needed here. Besides species protection, landscape impairment by widely visible wind turbines and turning rotors also has to be taken into account. Owing to the ever-increasing height of the turbines (see Fig. 6), wind energy installations can be seen even at great distances, and their spatial effects interfere with the appearance of the landscape (for more on spatial significance, see BMVBS 2011). This rapid and significant alteration of the landscape is increasingly leading to acceptance problems among the general population.

Other adverse impacts that affect human health and recreational function are countered by adherence to minimum distances, for example, to settlements. These are implemented in site planning (e.g. land-use planning or regional planning) through the designation of priority and suitability areas for wind farms and in the course of the permit granting process for wind energy installations.

The spatial steering of wind energy installations to low-conflict sites and the concentration of turbines in wind parks are the main adjustment mechanisms used to reduce the impacts mentioned above. Spatial control at the land-use management and planning level is the responsibility of the federal states and/or the respective planning consortiums. As a result, in Germany, the designation of priority and suitability areas for wind installations within the regional planning procedure is very heterogeneous. In the area of species and territorial protection, for example, different specifications for distances to wind energy installations, areas that are to be kept free of wind energy installations, and consideration of birds and bats are defined for the permit granting process. Considering species protection at the regional planning level is also difficult, because the exact interventions usually first come to light during the permit granting process. Species protection aspects relating to the construction and operation of wind energy installations can be better taken into account through transparent procedures in the context of planning, environmental impact assessments or authorisations. In addition to the direct participation of residents in the form of citizen participation or citizens' energy projects, this also contributes to increasing public acceptance.

2.2.2 Offshore Wind Energy

The development of wind energy at sea has clearly gained momentum in recent years. During 2016, 136 new installations, amounting to a capacity of 696 MW, were built. In the expansion of offshore wind energy, too, careful site selection is the best way to avoid negative impacts on nature and the landscape. The Offshore Wind Act (WindSeeG 2017) introduced a completely new system for future project planning. Under the new law, the selection of sites as well as the preliminary examination of the sites is to be performed by state authorities. After that, an operator will be found via an invitation to tender for the installation of capacity at these sites. For projects that are already in the advanced stage of planning or approval, a transition model is provided.

When selecting sites, consideration must be given to avoid encroachment on legally protected biotopes as well as species protection and landscape conservation requirements. In the following section, the case of a specially protected species is described as an example.

One of the most important impacts during the construction of offshore wind installations was initially the killing/injury of the harbour porpoise (*Phocoena phocoena*), the only whale species found in Germany. This species is highly dependent on its hearing capacity, for both orientation and communication as well as for foraging. The sudden noise load triggered by the construction (mainly ramming) of the foundations is loud enough to cause at least temporary damage to the hearing of the porpoise. Moreover, the porpoises were displaced over a large area by the sound vibrations. Since 2013, the Concept for the Protection of Harbour Porpoises from Sound Exposures during the Construction of Offshore Wind Parks in the German North Sea (Sound Protection Concept) (BMU 2013) dictates for the German North Sea how the prohibition of killing as well as significant disturbances of this species can be avoided. In the Sound Protection Concept, it is assumed that killing can be avoided by adhering to a so-called sound exposure level threshold (i.e. 160 decibels at a distance of 750 metres to the ramming site) while at the same time ensuring displacement of the animals from this radius. To avoid disturbance a spatial concept was developed which incorporates the distribution as well as the ecology (e.g. reproduction stage) and the protection status of the species.

In parallel, over the past few years, technical measures aimed at reducing sound levels were successfully developed and improved in practice during noise-intensive construction work to instal foundations (Koschinski and Lüdemann 2015). Today, in general, the sound protection requirements for the protection of the harbour porpoise can be met. Furthermore, technological advances have been made that could be applied in other countries as well.

3 Germany’s Energy Transition: Outlook and Lessons Learned for an Environmentally Compatible Path Forward

Meeting the climate protection targets of the Paris Agreement—even with the partial steps already taken towards implementing—the energy transition remains a huge challenge for Germany.

A review of the development of the expansion of renewables shows that there is now a wealth of experience on how the impacts of the individual renewable energy infrastructures on nature and the landscape can be avoided or minimised. Site selection is identified as a key adjustment mechanism for avoiding conflicts at an early stage (e.g. onshore and offshore wind power). Technology development is also an appropriate way to minimise impacts at the installations themselves (e.g. shutdown algorithms at wind farms) or during their construction (e.g. noise mitigation measures). This requires open dialogue and the willingness of all actors involved and, ultimately, also practical implementation and enforcement. But a forward-looking approach and a good knowledge of the interdependencies and conflicts involved are also crucial if the expansion of renewable energies is to be designed in a way that is compatible with the environment.

Also, the scenario planning method—used so far to demonstrate possible options for the further implementation of the energy transition in Germany, often from an economic perspective—is already being applied in the field of nature conservation. A recent approach analysed an ambitious energy transition together with the conservation and development of nature and the landscape, aiming at the reconcilability of the two target areas (Walter et al. 2017). On this basis a spatial analysis of potential energy production and estimated sensitivities of spatial impacts of the production in 2050 was conducted, and starting points for various actions were identified. Key features of an ambitious strategy to protect humans and nature in the context of the energy transition derived from this study's scenario analysis are:

- Importance of energy efficiency and sector coupling
- Focus on wind and solar energy in the electricity sector and the development of those technologies
- Preference for generation in close proximity to buildings (reduced use of open spaces)
- Providing the remaining fuel requirements as a major challenge
- Development of bioenergy based on residues and waste materials
- Implementation of forward-looking planning

In general, the scenario approach highlighted the fact, that in view of the ambitious target of entirely decarbonising the German energy system, there is a scarcity of available area that can be used without or with only minimal conflicts; thus a space-efficient development and adequate planning and governance should be safeguarded. The approach can support minimising conflicts in an anticipatory way by making nature conservation targets in the context of energy transition transparent, by showing major trade-offs and synergies like energy efficiency or energy saving and by providing constructive proposals for early actions.

Conclusions for the European energy transition process can also be drawn from the study. Accordingly, European energy policy should likewise prioritise energy efficiency. In addition, efforts should be targeted at a space-saving, renewables-based, electricity-dominated energy supply system. From the perspective of nature conservation, incentive mechanisms should focus more on promoting stronger electrification of the transport sector, for example, and less on areas where quick successes can be achieved or on measures which cannot be conclusively assessed in terms of sustainability, such as the wider use of forest wood, as currently discussed in the context of the revision (see EC 2017) of the RED (2009). Greater emphasis should be placed on regulatory approaches, for example, on efficient and low-emission electromobility rather than on mandates for advanced biofuels at the

European level. By focusing today on setting the course not just for tomorrow but for the distant future, risks for developments that are unsustainable in the long run and damaging to the environment could be avoided. At the same time, there is a need to integrate ambitious nature conservation targets into legal regulations and to ensure that nature and landscape conservation is not pushed into the background.

4 Conclusions

The further expansion of renewable energies opens up the possibility of a more sustainable energy supply and is a necessity for meeting climate protection objectives. Since climate protection equally serves both humans and the natural resources that support life, the expansion of renewable energies is a high priority. From the perspective of nature conservation, the following thematic areas deserve special consideration.

4.1 Overlaps Between Climate Protection and Nature Conservation Goals Should Be Exploited and Promoted

Although this chapter has focused on the adverse impacts of renewable energies as well as the management of those impacts, there are indeed synergies between the two objectives. Improvement of energy efficiency as well as a frugal use of energy are likely to be important adjustment mechanisms for meeting climate protection and nature conservation targets and should be given high priority. In addition, solutions for the generation and utilisation of electricity within or near buildings and infrastructure-integrated systems should be promoted, because such solutions avoid large-scale land consumption. Especially with construction-related technologies and concepts, for example, thermal insulation of buildings, opportunities to simultaneously implement measures to protect animal species that inhabit buildings should also be exploited. Such synergies can also be realised with energy-saving lighting solutions and the protection of insects, for example.

4.2 Early Incorporation of Nature Conservation Objectives

Careful selection of the sites for installations for the generation and utilisation of renewable energies has already been mentioned. Given the comprehensive expansion of various new installations, however, there are still significant knowledge gaps in the assessment of the interaction between different installations, whether with the same technology or across different technologies, that have to be filled (so-called cumulative effects). This may be an important field of future research, and the relevant findings could be incorporated into the further design of energy transition policy. Overall it can be said that it is important to incorporate nature conservation objectives into expansion planning at an early stage. Due to the many years of experience gained and an increased level of knowledge, for example, contentious technology paths or sites are already known today.

Another important task arising from the diverse impacts of renewable energies on nature and the landscape, the potential conflicts and the need for management is the research and development of strategies for avoiding conflicts between nature conservation and renewable energies, but also for supporting synergies between RES expansion and the conservation of biological diversity (see e.g. Santangel et al. 2016; BfN (Ed.) 2010). The current and ongoing challenges that need to be further addressed are[2]:

- Planning and conceptual approaches (e.g. assessment of the landscape, environmentally sustainable energy concepts, nature conservation testing at preliminary level, etc.)
- Appropriate technical measures at installations or during their operation (bird protection markers on overhead lines, collision avoidance measures at wind power installations, etc.)
- General (encompassing all protected assets) consideration of landscape changes caused by renewable energy installations and how they relate to acceptance
- Guide rails for the future design of the energy transition (such as proposals for site-optimised control, development of data collection standards and protective measures—see the example of bats)

It is essential that each of these findings is secured in relation to the national level, communicated and then implemented in the course of the planning and realisation of projects.

4.3 *Conflict Minimisation Measures Should Be Applied Consistently, Also to Existing Plants*

As the examples listed above show, there is a potential to minimise known conflicts by adjusting plant operations, technical measures or site optimisation in the context of repowering. These options should also be taken into account consistently and implemented in plant permits, plant approvals and, if the latest technology standards have been achieved, in the recommendations and guidelines. When designing incentive mechanisms for the further expansion of renewable energies, also at EU level, potential impacts on nature and the landscape should be taken into consideration at an early stage in order to avoid unwanted side-effects.

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[2] For more information on related projects in the research framework of nature conservation and renewables, go to: https://www.natur-und-erneuerbare.de.

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The Relevance of Consumer Preferences and Behaviour for Climate Policy Design: Evidence from Germany

Peter Heindl, Anna Wolff, Ines Weber, Christiane Reif, and Bernhard Gill

Abstract The transition of the energy system and radical decarbonisation of the economy represents a strong change in a rather short period of time. In this article, we discuss the relevance of aspects of behaviour in relation to the transition of the energy system. We focus on three aspects: First, the benefits and disadvantages of local policies and initiatives. Second, aspects of behaviour relating to adaptation to technology based on a field study on energy-efficient refurbishments. Third, distributive effects of ambitious climate policy and expected changes in consumption patterns and welfare of households. Overall, preferences and behaviour have important implications for the effectiveness and long-term success of (ambitious) climate policies and should therefore receive greater attention in policy design.

1 Introduction

Economic theory suggests that pecuniary incentives (e.g. carbon taxes) to shift consumption away from greenhouse gas-intensive goods and to provide incentives for the development and deployment of 'climate-friendly' technologies are the backbone of meaningful policies against climate change (Baumol and Oates 1988). Apart from the canonical complaint that such incentives should be present, there is much room for rational dissent on *how* such incentives should be provided in detail. However, it is clear from the very nature of the underlying problem that climate policy requires societal cooperation over an extended period of time and long-lasting public support.

P. Heindl (✉) · C. Reif
Department of Environmental and Resource Economics, Centre for European Economic Research (ZEW), Mannheim, Germany
e-mail: heindl@zew.de

A. Wolff · I. Weber · B. Gill
Department of Sociology, Ludwig-Maximilians Universität Munich (LMU), Munich, Germany

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To secure such support, climate policies need to be workable in practice. Most EU policies are designed with a strong focus on institutional arrangements to allow harmonisation of policies between member states. Aspects of behavioural economics usually play little or no role in this context, and the details of policy design are often delegated to member states. However, behavioural aspects can play an important role with respect to climate policy, as we will argue below. From this perspective, a stronger role of the EU in the design and implementation of climate policy would require a shift in perspectives—at least to some degree—including a move from 'rule-based' EU directives to more comprehensive policies. Whether or not such a move is desirable or feasible remains an open question. While centralised policies clearly provide the opportunity to foster economic efficiency, e.g. by providing a uniform EU-wide carbon price, there are some disadvantages, which are related to information processing, closely related to the principle of subsidiarity.

People's preferences differ and so too do their interests, needs, abilities, and cognitive capacities. This apparently innocent observation has far-reaching consequences because it requires accounting for heterogeneity of agents. In this article, we take a closer look at behavioural aspects in relation to climate policy. Since this is a large field, ranging from political philosophy to the psychology of agency, from behavioural economics to sociology, the following discussion will necessarily be partial: we focus on three issues we regard as important: (i) the willingness of people to contribute to public goods in relation to social identity, (ii) impediments to the effectiveness of energy-efficient technologies due to human-technology interactions, and (iii) household energy consumption and the consequences of climate policy for wealth and welfare.

All three topics mentioned above are discussed as important branches of research. It is for instance held that there is a 'energy efficiency gap', viz. underinvestment in energy-efficient technologies, which to a large extent is attributable to behavioural anomalies and failures such as misinterpretation or misunderstanding of costs and benefits associated with energy-efficient technologies (Gerarden et al. 2017; Gillingham and Palmer 2014). Nevertheless, there are other aspects which are often overlooked: the deployment of energy-saving technologies requires in some cases a change of user routines or 'sticky' behaviour. In particular, in the case of residential energy use, there is ambiguity regarding the costs which are associated with certain behaviour or routines in energy consumption. Both aspects may lead to a situation in which the technical possibilities of energy-efficient technologies are not fully reached. Behavioural aspects of energy consumption will therefore cause a deviation of actual energy savings from technical energy-saving potentials, which are partly attributable to a technology design that ignores the user's perspective.

The distribution of the costs of public good provision is an important topic in political philosophy and economics alike (Musgrave 2002) and is often at the centre of political debates. Ambitious climate policy will cause direct and/or indirect costs for consumers, and it is natural to ask how these costs affect the wealth and welfare of households. Patterns of consumption and the substitution of goods are important in this respect. A sound understanding of household behaviour is instrumental for learning about the effects caused by certain policies, both in terms of changes in consumption and the resulting welfare effects (Deaton 2016).

Finally, the willingness of people to protect the environment is crucial to achieve long-lasting support for climate policy. There are ex ante reasons to believe that this support might be contingent on the visibility of certain climate protection actions. Actions or policies on a local level may provide two types of benefits. First, an immediate feedback effect to people, whereby the action undertaken may be perceived as positive or prosocial and may therefore provide a warm glow. Second, the possibility to influence local actions, which may be regarded as part of procedural justice and which will therefore allow for continued cooperation in society (Konow 2003). However, if local initiatives were less effective and/or more costly compared to alternative approaches, there clearly would be a trade-off between the benefits of local action and the occurring (opportunity) costs.

Before we continue to discuss some behavioural problems in relation to climate policy in Sect. 3, we briefly focus our attention on the historical development of environmental policy-making in Germany in Sect. 2. Since there are often path dependencies related to political decisions, for instance, because of agenda-setting power (Tullock 1981), we hope to deepen the understanding of how environmental policy-making has evolved in Germany and later in the EU. We then present the most important aspects from the historical perspective and the discussion of recent research to identify fields in which strong interaction between climate policy and other branches of policy-making exists. By doing so, we identify some underexposed aspects of climate policy, in particular, topics which contribute to long-term success and support but which have been addressed inadequately so far. Section 4 concludes.

2 From National to European Policies (and Back Again?)

Even though attempts at European cooperation date back to the 1950s, energy and environmental policy have been dominated by national interests throughout the second half of the twentieth century. Prior to the first oil crisis in 1973, energy conservation was hardly on the political agenda (Gerber 2015; Suding 1989). However, by that time there was a growing interest in ecological problems, mostly related to 'local pollutants', as the foundation of the German Advisory Council on the Environment (SRU) in 1971 and the first 'energy policy programme' of the German Government in 1973 shows. With the beginning of the 1973 oil crisis, saving energy became a major political interest (Horn 1977). In 1974, the 'Federal Environment Agency' (UBA) was founded, and the first 'Federal Immission Control Act' was passed. The act regulated polluting activities of industrial installations and products. Overall, environmental awareness in Germany increased in the 1970s and 1980s. The Green Party was founded in 1980, which marks the rise in awareness of ecological problems. In the 1980s, air pollution (related to NOx), the hole in the ozone layer (related to CFCs), and forest dieback (related to SO_2) became major

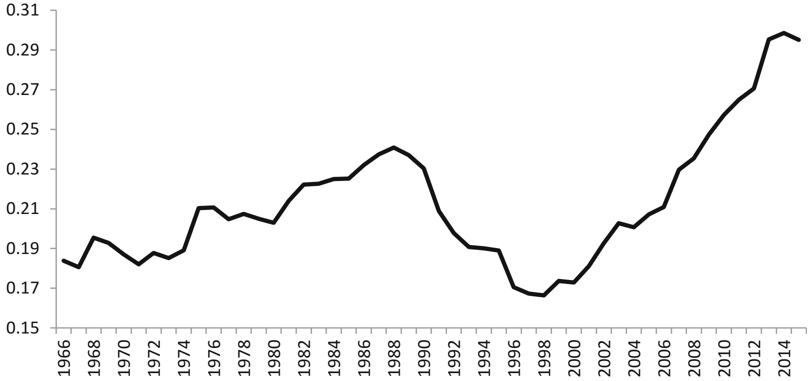

Fig. 1 Household electricity prices in Germany (1966–2015) adjusted for inflation in Euro at the price level of 2015 (Source: Federal Statistical Office of Germany and own calculations)

concerns. In parallel, a political movement against nuclear energy evolved which gained significant public support during the 1980s, inter alia because of the Chernobyl nuclear plant accident in 1986.

Due to German reunification, economic and employment policies (in contrast to environmental policies) took centre stage at the beginning of the 1990s (Kern et al. 2003). That decade saw a significant shift in the academic and public debate about environmental problems. While air pollution, water pollution, waste management, the preservation of the ozone layer, and nuclear power had dominated the discussion in the 1980s, climate change and the emission of greenhouse gases became increasingly important during the 1990s. These developments resulted in the Kyoto Protocol in 1997, the first international attempt to regulate greenhouse gas emissions. This international development had a bearing on national environmental policies and movements. Under the coalition of social democrats and greens, a number of ambitious energy policies were implemented in the late 1990s and early 2000s: the Law for the Introduction of an Ecological Tax Reform (*Gesetz zum Einstieg in die ökologische Steuerreform*, ÖSR) was adopted by the German parliament in 1999.[1] The Renewable Energy Sources Act (*Erneuerbare Energien Gesetz*, EEG) followed in 2000. The former introduced moderate additional charges on fossil fuels and electricity (Bach et al. 2002). The latter provided subsidies for renewable energy sources. Both the EEG and the ÖSR contributed to an increase in energy prices on average, as illustrated by the development of real household electricity prices (Fig. 1).

Starting with guidelines on the liberalisation of European energy markets in the late 1990s, the European Union gained influence on German energy markets, in

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[1] Similar instruments were implemented by Finland, Norway, Sweden, Denmark, the Netherlands, Belgium, Austria, and Slovenia prior to 1998 (Kern et al. 2003).

which especially the electricity sector has been characterised by monopolistic structures (Hirschl 2008). The liberalisation of the European energy markets primarily aimed at increasing consumer surplus with very little direct relevance for environmental issues. In 2001, Directive 2001/77/EC of the European Parliament on the promotion of electricity produced from renewable energy sources in the internal electricity market (EU 2001) was introduced.

Possibly the most significant piece of EU regulation of relevance for environmental policy is the EU Emissions Trading Scheme (EU ETS), introduced in 2005 based on Directive 2003/87/EC. Unlike previous directives from Brussels, which had usually left much leeway for member states regarding the details of implementation, the EU ETS directive established a harmonised and mandatory emissions trading scheme in *all* member states with the primary aim of reducing greenhouse gas emissions over time (Ellerman and Buchner 2007). Another important piece of EU policy was the definition of the EU's 2020 Climate and Energy Package in which climate policy objectives have been redefined and reshaped: the aim is to reduce greenhouse gas emission by 20%, to generate energy from (at least) 20% renewable sources, and to increase energy efficiency by 20% by the year 2020. Overall, from 2000 onwards, EU legislation has exerted a growing influence on national environmental and energy policy. However, this does not imply that environmental policies and energy markets in all EU member states are harmonised. EU legislation usually provides common guidelines and/or objectives related to specific aspects of policy. National policies and perspectives still dominate in many ways. One of the most salient aspects is the *ambition* of national environmental policies. Germany's *Energiewende* (energy transition) is a case in point. The various objectives of the energy transition clearly exceed the ambitions of EU strategies, and the convolution of measures and policies to achieve these goals—partly existing ones and partly new ones—in many cases comes 'on top' of EU legislation.

This brief history of environmental policy shows that perspectives and objectives are constantly changing: while objectives shifted from the avoidance of local pollutants to the mitigation of greenhouse gases, perspectives shifted from the supply of cheap energy to a preference for renewable energy sources. The type of dominant regulation changed from technology standards or command and control to price and quantity regulation (including subsidies). Finally, the level at which the most important decisions are made shifted from the national level to the EU level and (at least very recently in Germany) back to the national level. Against this backdrop, we also note that national preferences differ strongly in relation to path dependencies and pre-existing capital stock: France, for instance, depends heavily on nuclear power, and the Polish energy system is dominated by coal-fired power plants. Germany, in contrast, objects both types of technologies and aims at deploying a high share of renewable energy. One of the main challenges of the harmonisation of European climate policy, therefore, is to find a compromise given differing political preferences, living standards in the EU, and the pre-existing capital stock.

3 Individual Preferences and Behaviour: Implications for Climate Policy

In this chapter, we address three questions which we regard as important with respect to climate policy. First, we ask how environmental policies should be organised: Should they have a strong focus on local communities? Or should they be coordinated at the national or even supranational level? Second, we investigate the way people adopt new and energy-efficient technologies in everyday life, in particular, peoples' habits and routines with regard to space heating and the interaction with modern heating systems. We find that energy consumption decreases strongly after energy-efficient retrofitting. However, in many cases, (energy) cost savings do not outweigh the costs incurred for the investment in energy-efficient technology. Costs generally play a crucial role. Higher energy prices will incentivise energy conservation. However, since housing and energy services have the notion of basic goods and there are limited possibilities for substitution of these goods, we investigate demand and welfare effects originating from changes in relative prices in Germany.

3.1 Local Identity, Individual Preferences, and Public Good Provision

Some policies related to Germany's energy transition focus explicitly on local communities. Examples are collaborative projects in which citizens invest in renewable energy sources in their region, e.g. wind turbines or photovoltaics, or participate in the planning process for new wind farms or power lines. It is held that projects and initiatives with a strong local focus allow people to benefit from climate policy and help to secure long-lasting public support. Various forms of public participation are seen as an important feature of the energy transition. Despite the generally positive perception of local participation, there is one important difficulty which so far has not received sufficient attention in public and academic debate: While local initiatives may foster support for certain policies or activities and may even be able to break opposition or resolve dissent, they *can* be less efficient (or more costly) than other initiatives or policies. In this case, a trade-off between the benefits of local initiatives (e.g. public support originating from local identity) and the disadvantages of opportunity costs arises. Such a trade-off would suggest that both, the advantages and the disadvantages, must be balanced against each other to decide if and to what extent local initiatives are desirable.

What are the benefits of local initiatives? Behavioural economics suggests that group identity (or social proximity) strongly affects the willingness of people to collaborate and to provide public goods. Even if groups are exogenously assigned in an artificial way (e.g. in lab experiments), in-group favouritism and out-group discrimination occur. There is evidence that identity shapes economic decisions to a great extent (see, e.g. Chen and Li 2009). It is even held that '[the] choice of identity may be the most important "economic" decision people can make' (Akerlof and Kranton 2000). There are two important effects of local identity and social proximity. First, many people are intrinsically motivated to contribute to a public good. However, contributions are usually contingent on contributions made by others. Sen (1967) has pointed out that 'assurance' against behaviour, which is disadvantageous from a social welfare perspective, can even incentivise socially optimal behaviour of purely self-interested individuals under certain circumstances. Public good provision focusing on the local level allows people to observe the behaviour of others and to act based on their observations. This usually increases or sustains their willingness for voluntary collaboration and public good provision. However, it also suggests that in the absence of group identity or a lack of information on local group affiliation, crowding out of the willingness to contribute to a public good on a voluntary basis may occur, viz. contributions are lower as a result.[2] A second effect related to in-group favouritism is that people might overestimate the effectiveness (or underestimate the costs) of local initiatives compared to alternative, more centralised actions and policies. This effect is supposed to be higher when group identity strongly affects economic decisions and lower otherwise.

The trade-off between identity and efficiency has been examined in an artefactual field experiment with more than 600 individuals from the Rhine-Neckar Metropolitan Region in Germany. Gallier et al. (2017) analyse how local identities of neighbourhoods, which are considered naturally grown groups, interact with efficiency concerns when public goods can be provided at different levels. Participants were part of a group of eight people and could decide on how to distribute their initial endowment. Based on the different provision levels of public goods, participants could contribute either to their private account benefiting only themselves, a local account benefiting only their local group consisting of four people (local public good), or a regional account benefiting all eight actors (regional public good). Thus, benefits for individuals depended on individuals' and group decisions. To determine whether local identity harms the efficient provision of public goods, the disclosure of group affiliation and the relative efficiency of the regional and local public good were varied. The study confirms that local identity influences economic decisions, but on average, these local preferences do not interfere with efficiency, even if people feel strongly connected to the local group. Overall, the findings lead to the conclusion that even in naturally grown groups with local attachment, local identity does not inevitably hinder efficiency gains. In other words, local identity does not necessarily outweigh considerations of (cost) efficiency.

What are the implications for climate policy? Group attachment or local identity influences people in their decisions on the provision of public goods. This effect can be exploited to motivate people to engage in (local) climate initiatives. Thus, local actions provide a clear benefit. However, the experimental study by Gallier et al. (2017) implies that there are preferences for non-local policies if they are more efficient. Aspects of efficiency (on average) outweigh aspects of group identity in

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[2] See Buchholz and Heindl (2015, p. 337) for a comprehensive overview of theoretical concepts in game theory (in German).

this case. This suggests that neither fully local nor fully centralised solutions are ‘optimal’. Both represent corner solutions. In this light, an optimal policy mix would consist of both centralised and localised components (as the principle of subsidiarity suggests). The challenge for a cost-efficient policy design is to find the right spatial and political level of provision.

3.2 Energy Efficiency and Individual Behaviour: A Tale of Two Cities

About two-thirds of the energy consumption of private households is used for space heating (UBA 2015, p. 34), and in most cases, fossil fuels are used. Therefore, the reduction of the energy intensity of space heating is an integral part and important objective of the energy transition. Regarding the existing building stock, the most important measures are retrofitting of insulation and the replacement of heating systems by modern, energy-efficient ones.

Such a renovation process has been investigated in a long-term field study in two cities in Southern Germany. Data on building physics, flat size, and heating costs according to bills have been gathered from 189 households, augmented by 80 semi-standardised interviews (Wolff et al. 2017). This allows for a detailed assessment of energy demand prior to and after the retrofit, and it is possible to link the observed *changes* in energy demand to household and building characteristics. Two important effects occur, which influence the difference between *expected* energy savings and *actual* savings after the retrofit. First, energy performance measures (EPR), which provide the baseline for the calculation of expected energy savings, usually assume a ‘standard user’ who prefers a constant room temperature of between 19 °C and 21 °C in *all* rooms. Thus, energy demand of buildings prior to the retrofit is often overestimated; an effect known as the ‘prebound effect’ (Sunikka-Blank and Galvin 2012). Actual consumption of non-retrofitted buildings is about 30% lower on average than expected by EPR calculations. Second, behavioural change after the retrofit often is associated with the standard ‘rebound effect’, so that energy-saving potentials are partly offset by changed user routines. Overall, a technology-centred perspective dominates, while the user side of technology is often simplified or omitted. However, energetic retrofits face complex human-technology interactions, where routinised practices and habits in the handling of technology meet different ideas of comfort and living.

The field study revealed that energy savings per square metre amount to 140 kWh on average, which is equal to a reduction of about 70%. However, there is large variance in energy consumption, even between identical flats in the same building. This suggests that individual behaviour is of great importance. The empirical results show that the actual indoor temperature in the different rooms of a flat and ventilation habits are important determinants of energy demand (Guerra-Santin et al. 2016; van Raaij and Verhallen 1983). The range of reported indoor temperatures in the field study is rather high (18–25 °C) and is strongly connected to ideas of comfort and values such as ‘having a cosy home’. Many households struggle to understand or adjust to the new energy-efficient heating system in combination with better insulation. They report slow temperature adjustments, i.e. that the new system does not provide immediate thermal feedback and that it takes a long time for the flat to heat up. Some households also report feelings of ‘overheating’ because the highly insulated walls keep the warmth inside once the flat is heated up (while the heating system reacts slowly). In order to cool the flat down, increased ventilation occurs after retrofitting (Tweed et al. 2015; Wolff et al. 2017). Households also reported problems with perceived poor indoor air quality after retrofitting, which likewise leads to increased ventilation.

The available data do not allow an assessment of learning effects. However, the literature suggests that individuals receiving information or feedback adapt to new technologies, but the rate at which such learning effects occur is unclear (Calì et al. 2016; Way and Bordass 2005). Such feedback mechanisms, which link heating behaviour and occurring costs and energy consumption, seem to play an important role with respect to learning. More than 80% of the households in the field study had problems understanding their heating energy bill. After receiving the bill, households often recognise whether they had returns or need to make additional payments. However they usually have difficulties understanding whether this is the result of changed energy prices, changed weather conditions, or adjustments in their own heating behaviour. This problem is also relevant with respect to pecuniary incentives for energy conservation. If consumers fail to link individual behaviour to the resulting costs, pecuniary incentives will have a rather indirect effect on behaviour. One possible option to address these problems is to simplify energy bills, e.g. based on a comparison with other households with similar expected energy demand. As space heating demand is contingent on a number of exogenous factors other than individual behaviour (building physics, outdoor temperature), information and communication technologies (ICTs) or ‘smart metres’ could help to provide better feedback to households regarding their energy consumption and the resulting costs (Hargreavesn et al. 2010).

One of the most interesting questions with respect to energy retrofits is: Who pays? Are retrofits generally beneficial for tenants? In Germany, up to 11% of the costs of an energetic retrofit can be passed through to tenants per year (according to law). After the modernisation, costs are added to the rent, and landlords are not allowed to increase the rent further until the local rent level is reached. What is meant to protect the tenants can actually lead to discriminating effects. It might give landlords incentives to perform costly modernisations in order to achieve long amortisation times (Gill et al. 2016). It is often held that there is an agency problem between landlords and tenants, where it is stated that tenants profit from energetic retrofits while landlords do not (Enseling and Hinz 2008). This argument rests upon energy performance ratings, suggesting that savings in energy costs (to the benefit of tenants) exceed the costs of retrofits (Henger and Voigtländer 2011; KfW/IW Köln 2010). The results of the field study do not confirm this expectation: The average reduction in energy consumption amounted to about 70% (which met the expectations, i.e. no significant rebound effect), while the rent has been increased by less than one-quarter of the possible 11%. Nonetheless, we find that a majority of about two-thirds of the households are financially worse off after the retrofit (Wolff and Weber 2017). The increased rent outweighs energy cost savings, especially for households with relatively low consumption prior to the retrofit. Taking the price increase into account, one-third of the households are still financially worse off after the retrofit in 2015 compared to 2010.

While the building sector is of great importance as regards energy conservation and climate protection policies, it appears to be one of the least understood. Current approaches often seem to be rather technology-centred, while neglecting the user perspective. Our results suggest that behavioural aspects of energy usage lead to a situation in which actual energy savings after energy-efficient retrofitting will lag behind expected savings. This has important implications for consumers (tenants), who will save less than expected, and for producers (landlords), who will have fewer incentives for energy-efficient retrofits if the tenancy law and funding instruments remain unchanged. This would either lead to a lower than expected rate of energy-efficient retrofits or to a situation in which welfare is transferred from consumers to producers, which in turn would lead to climate policy having unintended distributive effects.

3.3 Energy Consumption and Distributive Effects

Ambitious climate protection policies will inevitably have a bearing on relative prices. For example, Germany’s energy transition has had significant effects on electricity prices, as briefly discussed above (see Fig. 1). Changing prices will affect the welfare of households, and it is interesting per se to investigate how the direct or indirect costs associated with the energy transition will affect households at different loci of the income distribution. The most important figures in this respect are *price and expenditure elasticities*, which indicate how demand for certain goods changes as a result of changes in income or prices. The standard tool for such assessments is ‘demand systems’, which investigate household consumption and substitution of goods under consideration of the whole consumption bundle, the budget constraint, and based on an implicit utility function (Deaton 2016).

Price elasticities for electricity in Germany are in the range of about −0.35 (Espey and Espey 2004) to −0.43 (Schulte and Heindl 2017). This suggests that electricity demand is inelastic. An expenditure elasticity of about 0.40 (Schulte and Heindl 2017) further suggests that electricity demand rises less than proportional to expenditure, which in turn implies that electricity has the notion of a basic good. However, average figures are of limited use if we want to learn more about distributive effects across the income distribution. ‘Demographic translation’ can be used to estimate disaggregated figures for several household types. Schulte and Heindl (2017) use demographic translation to investigate price and expenditure elasticities for several goods across the four quartiles of the income distribution and for six different household types (household or family composition). There are only minor differences in price and expenditure elasticities with respect to household type. However, there are pronounced differences with respect to expenditure (which is strongly correlated with household income). If we consider a single household whose expenditure profile belongs to the 'poorest' 25% (the lowest expenditure category), Schulte and Heindl (2017) find a price elasticity of −0.18 for electricity demand and −0.21 for space heating demand. In contrast, a single household, which belongs to the highest expenditure profile (top 25%), has—according to the study—a price elasticity of −0.57 for electricity and −0.62 for space heating.

The findings have two important policy implications: First, expected energy savings of low-income households (as a result of increasing energy prices) will be rather low. In particular, they will be lower compared to 'richer' households. This may be due to the fact that initial energy consumption of low-income households is moderate, inter alia because of strong budget constraints (Aigeltinger et al. 2017). The observed effects are related to decreasing marginal utility of consumption. The welfare loss of a reduction in energy consumption is lower for a consumer with a high consumption profile (e.g. scrapping one of two TV sets) when compared to an equal reduction of a consumer with a low consumption profile (e.g. scrapping the only TV set).

Second, the observed consumption and substitution patterns will cause unequal welfare effects in the presence of rising energy prices. The relatively low substitution of energy goods (i.e. with respect to households with a low consumption profile) will eventually cause an increase in the budget share spent on energy goods if energy prices rise. The resulting welfare effects can be assessed based on the 'compensating variation', the amount of money a household would need to receive to be left as well-off as before the price change. In this regard, there is clear evidence that relative burdens of changing prices are higher for low-income households when compared to high-income households (Schulte and Heindl 2017). This result has been confirmed by several studies in recent years, and there is evidence that the energy transition policy contributed to an increase in economic inequality and deprivation in Germany (Grösche and Schröder 2013; Heindl and Liessem 2017; Schröder and Grösche 2015).

Such *regressive effects* of environmental policies or energy taxation are not a new phenomenon. Probably the first account of the problem appears in Adam Smith's 'Wealth of Nations' of 1776 (Book V, Part 2). Baumol and Oates (1988) devote a whole chapter to the discussion on the relationship between environmental policies and the distribution of income (Chap. 16). From a policy perspective, there are two important questions: First, how significant or strong will the (expected) distributive effects of a policy be? In this regard, it is important to assess the expected distributive or social impacts of a policy before its introduction, namely, in the design phase. Such assessments had played little or no role in the past, as Sect. 2 illustrates. Nevertheless, since policies like the energy transition, which aim at a fast and radical reform of the energy system, are very ambitious, distributive effects will likely be a relevant problem, which deserves attention. The second question—of course—concerns the mitigation of distributive effects, where necessary. There is a menu of possible options ranging from simple transfers (e.g. via the social security scheme) to tax reforms (e.g. the reduction of other taxes and levies in exchange to increase taxation of greenhouse gas emissions). However, the resulting effect is contingent on the pre-existing social security scheme as well as the existing tax scheme, and there is no ‘one size fits all’ solution.

In summary, we must expect a nonuniform impact of ambitious climate policies on the welfare of households, usually to the disadvantage of ‘poorer’ households. Thus, there is interaction of climate policy with other fields, e.g. social policy, the existing social security schemes, and policies for poverty alleviation. This observation is highly relevant with regard to the question whether a policy like energy transition should be a centrally coordinated European project or whether it is better to leave it to member states to decide on the details of their national energy system and climate protection policies. Since social security schemes and tax schemes are organised and decided upon at the national level, member states are currently the most relevant actors to harmonise taxes and benefits so as to address possible unintended distributive effects of climate policy.

4 Summary and Conclusion

In this chapter, we argue that individual preferences and behaviour should be taken into account to design climate policies that are efficient and workable. Our (necessarily incomplete) discussion focusses on three aspects: First, we look at the benefits and disadvantages of policies with a strong local focus. Local initiatives allow people to identify with these actions and to influence decisions on a local scale. However, if such policies are less cost-efficient compared to action on national or supranational level, local initiatives may in fact be disadvantageous from a social welfare perspective. In practice, Germany’s energy transition, which goes beyond the ambitions of most EU-wide climate policies, can be seen as a type of ‘local action’. EU-wide harmonisation of efforts for climate protection necessarily requires compromise, including the possibility that some member states commit to policies which are less ambitious than they would be without such a compromise. Not least from the perspective of climate protection, voluntary ambitions should not be dampened by such arrangements—a strong argument in favour of local policies which are supported by some type of ‘minimum standard’ agreed upon at the EU level. However, local ambitions or unilateral efforts above the average can also be harmed by EU-wide policies. For instance, unilateral efforts towards greenhouse gas mitigation may be ineffective if there is ‘carbon leakage’ within the EU, namely, through the channel of the EU Emissions Trading Scheme (Heindl and Kanschik 2016). We will not elaborate on this issue here, but note that EU-wide policies can provide a solid and cost-efficient framework for (minimum) efforts agreed upon by all member states while simultaneously allowing for additional climate protection efforts by member states, regions, or even local communities. From this perspective, EU-wide and national or local initiatives are neither friend nor foe but merely complements.

Second, we review the main results of a field study in which energy-efficient renovation projects in two German cities were analysed in detail. The study suggests that the energy efficiency improvements (i.e. decreased energy costs) did not necessarily outweigh the costs incurred by tenants (i.e. higher rents). Energy savings are lower than expected because the initial energy demand by households tends to be overestimated and many households have problems adapting to the new technology. The interplay of insulation and the newly installed energy-efficient heating system spurred ‘inefficient’ behaviour. Since current measures to improve energy efficiency in the housing sector are often characterised by a strong focus on (cost-intensive) technological solutions, we therefore suggest a stronger focus on users’ needs and practices. In addition, even though a substantial energy saving of 70% has been achieved in the case study, especially households economising on heating energy are worse off financially due to the increased rent, representing a flaw in the current retrofit financing model. The field study provides evidence that the omission of important behavioural aspects with respect to space heating has led to a situation in which Germany’s policy to improve the energy efficiency of buildings lagged behind expectations and is less effective than initially expected. From this perspective ‘learning’ seems to be important with respect to climate policy design, implying that policies need to be updated and improved over time if new information becomes available and contingent on local conditions at the housing market. Based on the concept of subsidiarity, this line of thought provides an argument against strongly centralised, ‘rule-based’ EU-wide policies to allow quick and effective information processing.

Third, climate policy can be quite regressive, meaning that households with lower incomes face larger (relative) burdens compared to others. Housing costs are one example. In this case, a necessity (housing) becomes more expensive so that large burdens fall upon poorer people. The situation is similar in the case of rising energy prices. If electricity prices or heating costs increase as a result of climate policy (or for any other reason), low-income households are often affected the most, and there is evidence that such a development also tends to increase economic inequality. This will not necessarily imply (social) injustice (Frankfurt 2015) or excessive burdens (Heindl 2017) for low-income households. However, it is important to keep the general problem in mind and to assess the social consequences of climate policies ex ante as well as to track ex post developments. Indicators of energy affordability are one possible tool that can be used for such assessments. Against the backdrop of highly different living standards across the EU and because of the great differences in the revealed preferences and the ability for redistribution across member states, there will hardly be a uniform EU-wide scheme to mitigate burdens from changing relative (energy) prices for the poor. The existing national tax and transfer schemes are the natural point of departure to address social problems in relation to energy affordability or the affordability of homes.

Climate policies require long-lasting public support in a liberal and democratic society. To receive such support, they must be ‘workable’ in practice. Peoples’ preferences and individual behaviours need to receive special attention in this respect. The avoidance of large financial burdens for citizens may be *one* key element. A strong focus on cost-efficiency of policies can help to contain costs and can therefore help to secure public support. Coordinated and common EU-wide policies (e.g. a uniform ‘carbon price’) are certainly important in this respect, since economic theory suggests that a single price on emissions is a highly efficient instrument to incentivise ‘green innovation’ and lower greenhouse gas emissions in the long run (Baumol and Oates 1971). However, ambitious climate policy will ultimately change economic conditions, and this transformation will generate winners and losers. It is important to aim to minimise losses and to avoid situations in which parts of the society feel alienated. Solid knowledge of individual preferences and behaviours can help to avoid such situations by understanding the driving forces of (unintended or unexpected) developments induced by climate policy. Against this backdrop, the three examples above provided arguments that centralised EU-wide policies may be disadvantageous because they necessarily require compromise and possibly important information (which allows for ‘learning’ and updating of policies) is best processed at the national or regional level.

A broad and fast ‘transition’ clearly goes far beyond the questions and methods usually addressed in the fields of energy or environmental economics. At least with respect to private households, this suggests that a broader set of problems needs to be considered and a broader scope of methods should be used to inform about the consequences of reforms. Ultimately, further improvements of economics methods seem necessary (Farmer et al. 2015) as well as a stronger focus on ‘the economics of households’, distributive effects, and behavioural aspects of public good provision, energy consumption, and the improvement of energy efficiency over time.

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Part IV
The Energy Policy Mix from a Political Economy Perspective

Cooperative Renewable Energy Expansion in Europe: Cost Savings and Trade Dependencies

Yvonne Scholz

Abstract Using the best variable renewable energy (VRE) resources available for power generation and exploiting spatio-temporal balancing effects of renewable power generation and electricity demand can help to minimize capacity requirements and thus costs for future power supply. The larger the region, the higher the benefits. From the EU perspective, it is therefore clear that markets should be coupled and policies harmonized as far as possible. One question that arises in this context is whether VRE capacity expansion should be planned and executed cooperatively in Europe to maximize the benefits. From the perspective of individual countries, the potential benefits are accompanied by a potential increase of national import and export dependencies. This chapter deals with the questions: How high are the potential cooperation benefits? How high can import and export dependencies become?

1 Energy Policy Goals and VRE Capacity Expansion

The European Commission (EC), referring to the goals of its energy policy, states: "The goal of a resilient Energy Union with an ambitious climate policy at its core is to give EU consumers—households and businesses—secure, sustainable, competitive and affordable energy" (EC 2015). The reasons for these goals are universally valid—not just for a union of countries like the EU but for individual countries as well. Referring to security of supply, the EC explains "The European Union's prosperity and security hinges on a stable and abundant supply of energy" (EC 2014). Sustainability of supply primarily refers to greenhouse gas emissions: "The EU has brokered the Paris Agreement last December (. . .). The implementation of the EU's ambitious Paris climate change commitments is now the priority and depends to a large extent on the successful transition to a clean energy system as two

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Y. Scholz (✉)
German Aerospace Center, Institute of Engineering Thermodynamics, Energy Systems Analysis, Stuttgart, Germany
e-mail: yvonne.Scholz@dlr.de

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thirds of greenhouse gas emissions result from energy production and use". Concerning competitiveness and affordability of supply, the essential goals are affordable gas and electricity prices for businesses: "The price difference with other economies has an impact on the competitiveness of our industry, in particular our energy-intensive industries" (EC 2015). "The energy sector is important for the European economy: energy prices affect the competitiveness of the whole economy" (EC 2016).

From the perspective of the European Union, further integration of the energy supply of all European countries into one system is expected to benefit security, sustainability and affordability of supply. This is due to economies of scale: higher system inertia due to bigger system size, spatial load and generation pattern balancing and optimized exploitation of variable renewable energy (VRE) sources, reducing capacity requirements and expenditures. However, increased integration of energy markets in Europe may also be associated with drawbacks for some participating countries: environmental impacts may concentrate on regions with high resource quality; import and export dependencies may develop. Import dependencies, in particular, can be in conflict with energy policy goals on the national level: they are considered to reduce the level of security of supply. Of course, free trade can always lead to import and export dependencies, but as stated by the European Commission (see above), the good "energy" is of fundamental importance for the prosperity of a region, so that actions are taken to monitor (see indicators in (EC 2013)) and guarantee security of energy supply on EU territory.

To provide a basis for national and European policy measures aimed at compatibility of European and national energy policy goals, the potential cost reduction through cooperation in VRE capacity expansion in Europe was assessed, and the corresponding exchange balances were analysed. The results are presented and discussed in this chapter.

2 Assessing Cost Reduction Potentials of Cooperative VRE Capacity Expansion

In order to quantify system costs and to evaluate exchange balances for VRE capacity expansion scenarios, an energy system model that minimizes overall system costs, i.e. that takes the perspective of a social planner of the total supply system, is required. The model must have sufficient spatial and temporal resolution to adequately capture load and generation patterns of VRE capacity, and it must include backup, storage and transmission technologies. The German Aerospace Center (DLR) has been developing the linear optimization model REMix (Renewable Energy Mix) since 2006. It has the required characteristics and was used in this study for the assessment. Detailed model and data descriptions can be found in Gils et al. (2017), Tena (2014) and Scholz (2012).

2.1 Scenario Set-Up

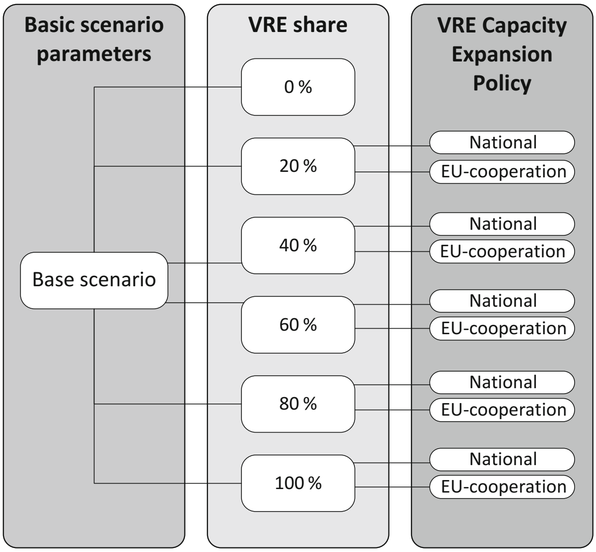
To study cost benefits through cooperative VRE capacity expansion, a partial greenfield approach was chosen that is easy to parameterize in REMix. It allows us to investigate the upper limit of potential cost benefits. Real benefits might be lower due to additional constraints such as lock-in effects.

A very similar set-up was applied in the ADVANCE project (EU FP7 project 308329) and is described in Scholz et al. (2017), where all assumptions are presented in detail. Here, only a short description of the scenario set-up is given. The difference between (Scholz et al. 2017) and this assessment is that in (Scholz et al. 2017), a minimum national domestic supply of 50% was assumed. Here, no such domestic default was preset because it would reduce cost benefits and exchange balances, opposing the aim of finding the upper limit of potential cost benefits. Furthermore, in Scholz et al. (2017) a more comprehensive parametric study was performed. The results indicate that solar power-dominated systems have higher system costs than wind power-dominated systems and that systems with equal shares of solar and wind power have only slightly higher costs than wind power-dominated systems. Based on this finding and to account for diversity of supply, equal shares of solar and wind power were defined in this assessment.

The area considered is the whole of Europe, clustered into 15 regions to reduce the running times of the model (see Fig. 1). An overall power demand of 3650 TWh was assumed, with a peak load of 586 GW. Power demand and technology

Fig. 1 Definition of regions. Alps: Austria, Switzerland; BalkansNorth: Bosnia and Herzegovina, Romania, Serbia, Montenegro; BalkansSouth: Albania, Bulgaria, Greece, Macedonia; Baltic: Estonia, Latvia, Lithuania; Benelux: Belgium, Luxembourg, the Netherlands; Central East: Czech Republic, Poland, Slovak Republic; CentralSouth: Croatia, Hungary, Slovenia; Denmark-W: Denmark West; East: Belarus, Moldova, Ukraine; France; Germany; Italy; Iberia: Portugal, Spain; Nordel: Denmark East, Finland, Norway, Sweden; UK-IE: Ireland, the United Kingdom

Fig. 2 Scenario tree



parameters were assumed for the middle of the century. VRE technologies considered are photovoltaics, concentrating solar power and onshore and offshore wind power plants. Other renewable technologies considered are run-of-the-river hydroelectricity, hydro-reservoir, biomass and geothermal power plants. Conventional technology options are gas turbines, combined cycle gas turbines and coal and nuclear power plants; the fossil power plants are additionally considered as options with carbon capture and storage. Transmission lines are HVDC overhead lines. Storage technologies considered are pumped storage hydro (with fixed reservoir capacity), redox flow batteries (energy-to-power ratios of 4, 7 and 24) and hydrogen storage (energy-to-power ratios of 100, 400 and 800).

Today's hydro power plant infrastructure was assumed to remain active. All other power generation, transmission and storage capacities are model results. No default was set for national domestic supply or national capacity requirements. The price for CO_2 emissions was set to 150 €/t.

As shown in Fig. 2, two types of scenarios were set up: cooperative and national VRE capacity expansion ("VREexpCoop" and "VREexpNat"). In VREexpCoop the VRE shares were set for Europe as a whole, not for regions. In VREexpNat, VRE shares were set for the individual regions. Scenarios were defined for the following VRE shares: 0%, 20%, 40%, 60%, 80% and 100%. The contributions of wind and solar to the total VRE share were set to 50% each in all scenarios, not fixing the proportions of onshore and offshore wind and those of photovoltaics and concentrating solar power, i.e. leaving these as decision variables of the model. For each scenario, 1-year model runs were performed with hourly resolution.

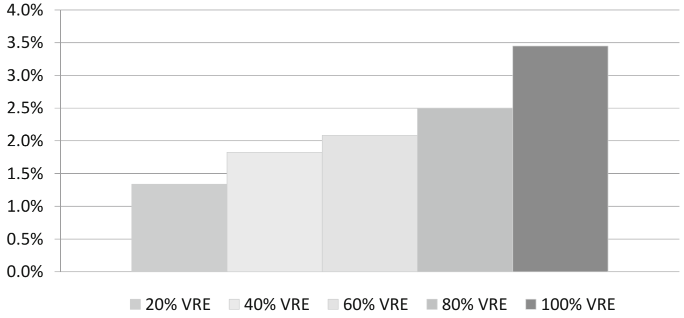


Fig. 3 Reduction of supply costs through European cooperation

3 Supply Cost Reduction Through Cooperation

Figure 3 shows the reduction of the total system costs that occurs when, for each VRE share, the cooperative VRE capacity expansion scenario is compared to the national one. The cost reduction increases with increasing VRE shares, reaching its highest value of 3.4% when the VRE share is 100%.

Unteutsch and Lindenberger 2014 find slightly higher system cost reductions of 3–5%[1] at a VRE share of 55%. Fürsch et al. 2010 find higher harmonization gains (cost reductions) of almost 20% over a 12-year period from 2008 to 2020 with growing renewable energy shares reaching a maximum of 34%. That the gains are higher in the shorter term is probably due to the fact that the technologies are still more expensive, such that reduced capacity requirements must lead to higher savings.

To get a feeling for what a saving of a few percent in annual expenditures for electricity supply means, one measure that can be used is the range of electricity prices in European countries reported by Eurostat (2016a, b): electricity prices for households ranged between 0.094 €/kWh (Bulgaria) and 0.307 €/kWh (Denmark) in the year 2015. The highest price thus equalled 326% of the lowest one. In industry, the maximum price for electricity in the year 2015 was 0.16 €/kWh (Malta), equalling 262% of the minimum price of 0.061 €/kWh (Denmark). This means that, in the past, countries have been willing to tolerate price differences of up to 300% among their competing neighbours within Europe. So whilst a saving of some few percent is of course desirable, whether it incentivises countries enough to give away parts of their national competencies—e.g. to ensure enough generation capacity on their own territory or to influence the structure of the generation capacity on their own territory—is at least unclear.

The VRE capacity allocation in the cooperative scenarios can be very heterogeneous, so that some countries might export and others might import large amounts of electricity. Potential developments of exchange balances and thus of import or export

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[1] These values were derived from the numbers given in Unteutsch and Lindenberger (2014).

dependencies might influence countries' considerations concerning national or cooperative VRE expansion. The developments in the investigated scenarios are shown and discussed in the next section.

4 Import and Export Dependencies

Increasing VRE capacities must involve grid expansion to enable spatial balancing. This is especially true for wind power, since wind regimes differ more spatially than solar irradiance does (Schaber et al. 2012; Scholz et al. 2017). Grid sizes in TWkm have been calculated by summing up the products of line length and capacity of all transmission lines. Without any power generation from VRE, a grid size of 21 TWkm is planned by the model. Moving to a 20% VRE share, the grid size doubles in the national VRE capacity expansion scenario (43 TWkm) and almost triples in the European cooperation scenario (59 TWkm). At VRE shares of 100%, the grid size grows to 223 TWkm in the national VRE capacity expansion scenario and even to 290 TWkm in the European cooperation scenario. As a figure for comparing orders of magnitude, a virtual number can be calculated to characterize the European transmission grid as it was in the past: the products of interconnector net transfer capacities for the years 2010/2011 (ENTSO-E 2011) and distances between geographical centres of the corresponding countries add up to a grid size of 28 TWkm.

The increased grid size enables transmission of higher amounts of power between countries. For individual countries, the annual exchange balance, i.e. the sum of imports (+) and exports (−), is of interest, since net exports can mean an increase of the national GDP and net imports can mean a reduction of expenditures for electricity but at the same time reduced value creation on national territory. The term "import (export) dependency" is used here to describe the net imports (exports) related to the annual final electricity demand of a region. Figure 4 shows the import and export dependencies per region in the national VRE capacity expansion scenarios and in the EU cooperation scenarios, ordered by the values in the scenarios with a 60% VRE share. The import dependencies have positive and the export dependencies have negative values. In the national scenarios, import dependencies reach up to 28% and export dependencies up to 54%. In the cooperation scenarios, import dependencies reach 72% at most, and export dependencies reach up to 220%.

According to (EC 2013), the average import dependencies in the EU reached up to an exceptional 60% in one small country (Luxembourg) and up to 15% in larger countries (Hungary and Italy) in the years 2006–2010. Export dependencies reached values of around 25%.

A comparison of the past values with the model results shows that at higher VRE shares, import dependencies can be expected to grow moderately in the national VRE expansion scenario and considerably for some countries in the European cooperation scenario. Export dependencies can grow even more in some countries, possibly reaching multiples of national electricity demands.

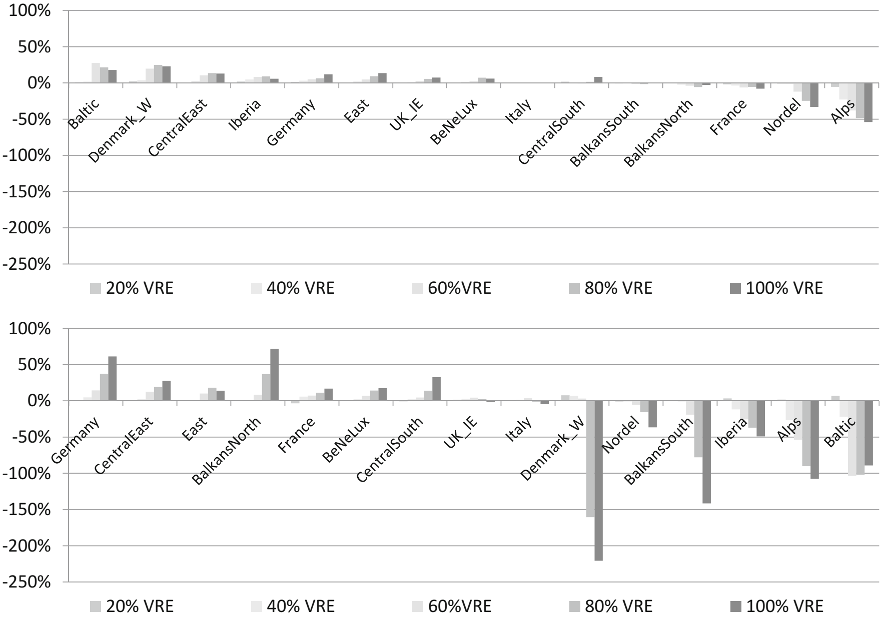

Fig. 4 Electricity import and export dependencies in the national VRE expansion scenario (above) and in the European cooperation scenario (below)

Taking the example of Western Denmark, it also becomes clear that a country or region can even play opposing roles in the two scenarios: having been a moderate exporter in the past (4% of national final energy demand), Western Denmark could either import up to 25% of its supply in a national VRE capacity expansion scenario or export up to 220% of its own final energy demand in the European cooperation scenario. Germany, as an example of a large state in the EU which was a moderate exporter in the past (3% net export), imports up to 61% of its supply in the European cooperation scenario and also becomes an importer in the national VRE capacity expansion scenario (12% of its supply).

5 Summary and Conclusion

VRE capacity expansion requires grid extensions across Europe. Using a grid size indicator calculated with 2011 interconnector data as a reference, the grid must be extended to up to eight times its current size in national VRE capacity expansion scenarios and up to around 13 times in the European cooperation scenarios. Given the current resistance to new transmission lines among the population, even the slightly lower expansion in the national VRE expansion scenarios will probably be hard to achieve. This has to be considered when planning concrete policy measures on the EU level as well as on national levels to achieve the overarching energy policy goals.

Comparing cooperative to national VRE capacity expansion scenarios with different VRE shares of up to 100% shows less than 4% savings in expenditures for European electricity supply. Considering the high uncertainties in the input parameters and due to the model detail, it is reasonable to register savings in the order of magnitude of only a few percent at VRE shares of around 100%.

At the same time, import dependencies of around 70% can occur in the case of European cooperation—40% points higher than the maximum import dependencies of around 30% in the national VRE capacity expansion scenarios. The import dependencies are very heterogeneously distributed. Even large member states that currently export electricity can become major importers of more than half of their own supply at VRE shares of around 100%.

If European countries want to exploit the savings that cooperative VRE capacity expansion can offer, the corresponding policy agreement should consider the fact that exchange dependencies may grow as pointed out above. Price stability and reliability of supply are criteria that countries will most likely weigh up. This is true not only for potential future importers, but for exporters as well, since export opportunities are dependencies at the same time. With growing VRE capacity expansion, they can grow to a multiple of national power demand and can thus become an important contribution to national GDP. Potential risks for the individual member states should therefore be reflected in EU-level policy, which so far focuses only on potential synergies.

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Energy Transition Implications for Demand and Supply of Power System Flexibility: A Case Study of the Netherlands Within an EU Electricity Market and Trading Context

Jos Sijm, Paul Koutstaal, Özge Özdemir, and Marit van Hout

Abstract The Netherlands is aiming for a more sustainable, low-carbon energy system. For the power system, this energy transition implies (1) a larger share of electricity from variable renewable energy (VRE), in particular from sun and wind; (2) a larger share of electricity in total energy use, i.e. a higher rate of electrification of the energy system by means of electric vehicles, heat pumps, power-to-products, etc.; and—as a result of these two trends—(3) a higher need for flexibility and system integration. This chapter analyses the implications of the Dutch energy transition for the integration and flexibility needs of the Dutch power system within an EU electricity market and trading context. In particular, by means of the EU28+ electricity market model COMPETES, we assess the potential of EU power trading as one of the options to meet these needs besides other domestic flexibility options such as flexible power generation, VRE curtailment, demand response and energy storage. The modelling results show that the flexible power trade potential is rather substantial—and even dominant—depending on the level of interconnection capacity and market integration across EU member states. In addition, we briefly discuss complementary results by means of the NL energy system model OPERA, notably on demand response as a potentially large domestic flexibility option.

1 Introduction

The Netherlands is aiming for a more sustainable, low-carbon energy system. For the Dutch power system, this energy transition implies (1) a larger share of electricity from variable renewable energy (VRE), in particular from sun and wind; (2) a larger

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J. Sijm (✉)
Energy Research Centre of the Netherlands (ECN, now part of TNO), Amsterdam, the Netherlands
e-mail: jos.sijm@tno.nl

P. Koutstaal · Ö. Özdemir · M. van Hout
Formerly ECN, now Netherlands Environmental Assessment Agency (PBL), the Hague, the Netherlands

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share of electricity in total energy use due to the increasing penetration of demand technologies such as electric vehicles (EVs), heat pumps (HPs), power-to-gas (P2G), etc.; and—as a result of these two trends—(3) a higher need for system integration and flexibility.

Against this background, this chapter presents some major findings of the FLEXNET project.[1] In particular, it analyses the implications of the energy transition in the Netherlands for demand and supply of flexibility in the Dutch power system over the period 2015–2050 within an EU electricity market and trading context. More specifically, by means of the EU28+ electricity market model COMPETES, we assess the potential of EU power trading as one of the options for meeting the flexibility needs of the Dutch power system up to 2050, besides other domestic flexibility options such as flexible power generation, VRE curtailment, demand response and energy storage. The modelling results show that, among others, the flexible power trade potential is rather substantial—and even usually dominant—depending on the level of electricity interconnection capacity and power market integration across EU member states.[2]

Chapter Outline

The structure of the current chapter runs as follows. Section 2 presents briefly the FLEXNET approach and major findings with regard to assessing the *demand* for flexibility in the Dutch power system over the period 2015–2050. The focus of the current chapter, however, is on Sect. 3, which presents in some more detail the approach and major results with regard to assessing the supply of flexibility for the Dutch power system up to 2050, in particular some specific outcomes by means of the COMPETES model. Section 4 further qualifies the COMPETES modelling results by briefly discussing complementary results by means of the NL energy system model OPERA, notably on demand response as a major domestic flexibility option (besides cross-border power trade). Finally, Sect. 5 provides a conclusion of the present chapter.

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[1] The overall objective of the project 'flexibility of the power system in the Netherlands' (FLEXNET) was to analyse demand and supply of flexibility in the power system of the Netherlands up to 2050. This project was carried out over the years 2015–2017 by a consortium consisting of the Energy Research Centre of the Netherlands (ECN) and several members of Netbeheer Nederland, i.e. the Dutch branch organisation of energy network operators. For further information on the FLEXNET project and its deliverables, see https://www.ecn.nl/flexnet/.

[2] For a full discussion of all major results of the FLEXNET project, see its deliverables at the project website (https://www.ecn.nl/flexnet/).

2 The Demand for Flexibility in the Dutch Power System, 2015–2050

2.1 Approach

2.1.1 Definition of Flexibility

In the current paper, flexibility is defined as ‘the ability of the energy system to respond to the variability and uncertainty of the residual power load within the limits of the electricity grid’. Major characteristics of this definition are:

- The problem (i.e. the demand for flexibility) is caused primarily by the power system.
- The solution (i.e. the supply of flexibility) may come from the energy system as a whole.
- The focus is on *changes* in *residual power load*, i.e. total power load minus power production from variable renewable energy (VRE), notably from sun and wind.

2.1.2 Three Sources (‘Causes’) of the Demand for Flexibility

Another characteristic of the above-mentioned definition of flexibility is that it refers to the three main sources (‘causes’) of the need for flexibility of the power sector:

1. The demand for flexibility due to the *variability* of the residual power load, in particular due to the variability of power generation from VRE sources
2. The demand for flexibility due to the *uncertainty* of the residual power load, notably due to the uncertainty (or lower predictability) of electricity output from VRE sources *(‘forecast error’*)
3. The demand for flexibility due to the *congestion* (overloading) of the power grid, resulting from the increase and changing profiles of electricity demand—due to the increase in electric vehicles, heat pumps, etc.—as well as the increase and changing profiles of power supply from VRE sources.

In this chapter, we focus only on the first source (‘cause’) of the need for flexibility, i.e. the demand for flexibility due to the variability of the residual load.[3]

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[3] For a discussion and assessment of the other two sources of flexibility needs, see particularly the phase 1 report of FLEXNET (Sijm et al. 2017a), while the options to meet these needs are analysed in the phase 2 report of the project (Sijm et al. 2017b).

2.1.3 Scenarios: Focal Years and Major Characteristics

In order to analyse quantitatively the demand for flexibility in the Dutch power sector over the period 2015–2050, we have developed two scenarios:

- *The reference scenario*. This scenario is based on the 'accepted policy scenario' of the 'National Energy Outlook 2015' of the Netherlands (ECN et al. 2015). Its major characteristics are (1) a strong growth of installed VRE capacity in the power sector up to 2030 and (2) a weak growth of additional electrification of the energy system as a whole. This scenario includes three focal years, labelled 'R2015', 'R2023' and 'R2030' (where the letter R refers to the Reference scenario).
- *The alternative scenario*. This scenario is similar to the reference scenario with one major exception, i.e. it assumes a strong growth of additional electrification of the Dutch energy system by means of electric vehicles (EVs), heating pumps (HPs) and other means of electrification of the energy system in households, services, transport, industry, etc. This scenario includes also three focal years, labelled 'A2023', 'A2030' and 'A2050' (where the letter A refers to the alternative scenario).

Table 1 provides a summary of the major assumptions and input variables of the FLEXNET scenario cases over the period 2015–2050. For each scenario, annual electricity demand and VRE power supply profiles have been developed on an hourly basis for four demand variables (conventional load, EVs, HPs and additional load for other means of electrification) and three VRE supply variables (wind on land, wind on sea and sun PV). Based on these profiles, the hourly variations in the residual power load have been determined in order to derive the resulting demand for flexibility in the power sector.

2.2 Results

2.2.1 Trends in Residual Power Load

Developing hourly electricity demand and VRE power supply profiles for each scenario case and, subsequently, analysing trends and hourly changes in the (residual) power load of the Dutch electricity system over the years 2015–2050 has resulted in some major findings across both scenarios. In summary, these findings include:

- *Total (hourly) power load* increases substantially between 2015 and 2050 and becomes much more volatile, mainly due to the additional electrification of the energy system through the increase in electric vehicles (EVs), heat pumps (HPs) and other means of electrification such as power-to-gas (P2G), power-to-heat (P2H), power-to-ammonia (P2A) or power-to-other-products (P2X).
- *Power output from VRE sources (sun/wind)* increases substantially between 2015 and 2050. Hourly VRE output, however, is very volatile and fluctuates heavily

Table 1 Major assumptions and input values of all scenario cases, 2015–2050

		Reference scenario			Alternative scenario		
	Unit	2015	2023	2030	2023	2030	2050
Electrification							
Share of EVs in total passenger cars	[%]	2.0%	4.7%	9.6%	12.0%	32.0%	74.0%
Share of HPs in total households	[%]	2.1%	6.5%	7.9%	8.0%	20.0%	69.0%
Conventional load	[TWh]	111.8	111.6	112.2	111.6	112.2	112.0
Additional load EVs	[TWh]	0.5	1.2	2.5	3.0	8.4	21.5
Additional load HPs	[TWh]	0.2	0.8	0.9	0.9	2.5	9.3
Add. load 'other electrification'	[TWh]	0.0	0.0	0.0	10.0	30.0	90.0
Total final load	[TWh]	112.5	113.5	115.6	125.5	153.1	232.8
Power from variable renewable energy (VRE) sources							
Installed capacity							
• Wind on land	[MWe]	2630	6020	6330	6020	6330	6800
• Wind on sea	[MWe]	360	4120	6060	4120	6060	28,900
• Sun PV	[MWe]	1530	8640	15,130	8640	15,130	56,100
• Total VRE power capacity	[MWe]	4520	18,780	27,520	18,780	27,520	91,800
Full load hours							
• Wind on land	[hrs]	2310	2670	2860	2670	2860	2900
• Wind on sea	[hrs]	3580	4080	4120	4080	4120	4160
• Sun PV	[hrs]	840	820	820	820	820	820
VRE power generation (uncurtailed)[a]							
• Wind on land	[TWh]	6.1	16.1	18.1	16.1	18.1	19.7
• Wind on sea	[TWh]	1.3	16.8	25.0	16.8	25.0	120.2
• Sun PV	[TWh]	1.3	7.1	12.4	7.1	12.4	46.0
• Total VRE output	[TWh]	8.6	40.0	55.5	40.0	55.5	185.9
Total VRE output (uncurtailed) as share of total final power load	[%]	8	35	48	32	36	80

[a] *Uncurtailed* power generation refers to VRE output *before* any curtailment of electricity production from sun/wind takes place, based on installed capacity and full load hours, whereas *curtailed* power generation refers to VRE output *after* any curtailment of electricity production from sun/wind

over each period considered (day, week, month, etc.). In addition, even in A2050, with a large share of VRE output in total annual power load (80%), there is still a large number of hours (1600–2600) in which VRE output is relatively low, covering only a small part of power demand (10–20%; see Fig. 1). This implies that during these hours, power demand has to be met largely (80–90%) by other supply sources besides VRE output, including other means of power generation (gas, coal, nuclear) or by flexibility options such as power imports, demand response or using electricity stored during other surplus hours.

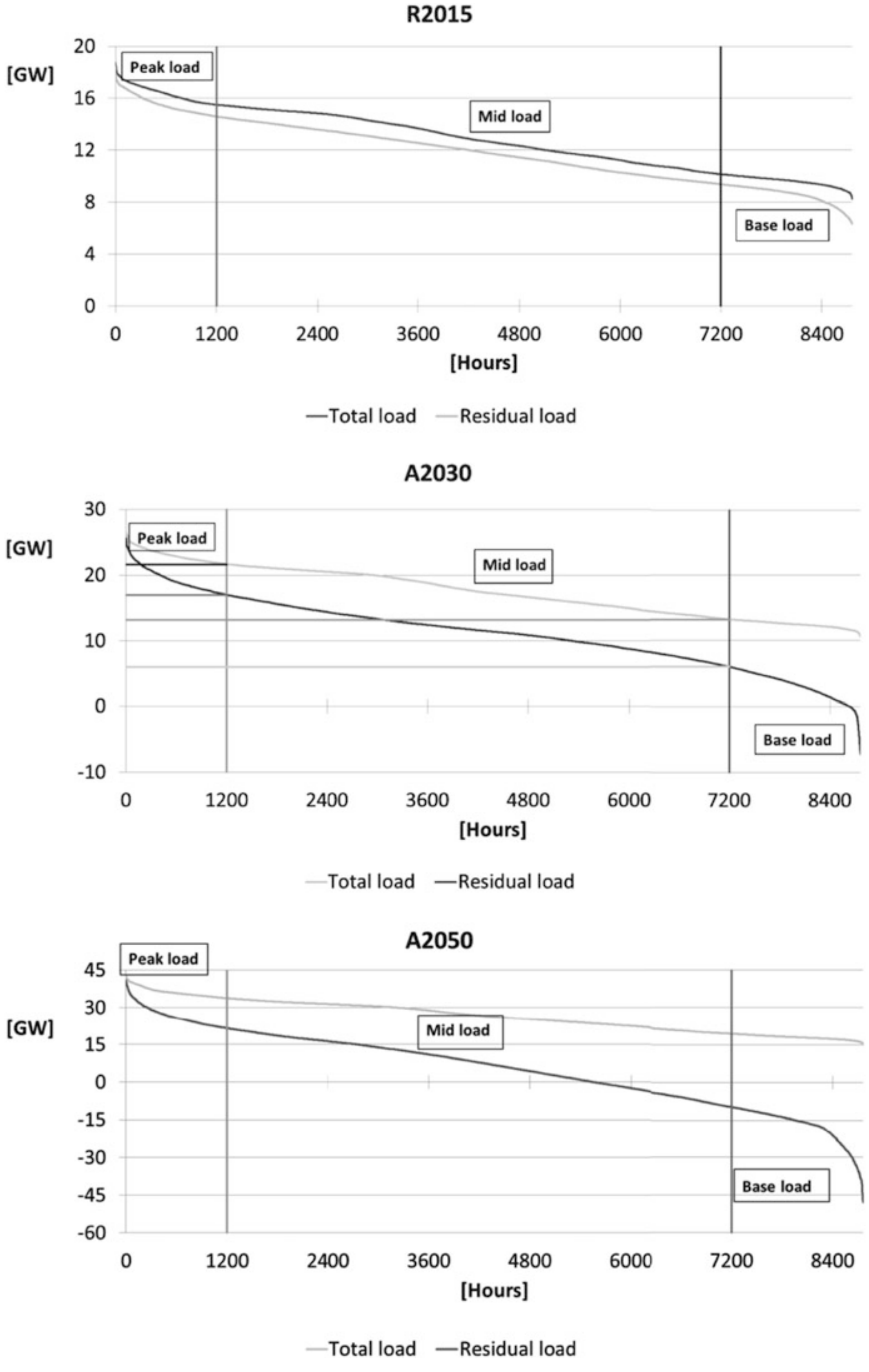

Fig. 1 Duration curves of total load and residual load in three scenario cases. Note: For visibility reasons, the scale of the y-axis differs between the three pictures. As a result, the slope of the

- As a result of the two trends mentioned above, *hourly residual power load* becomes much more volatile (variable) over time. In A2050, it even varies between *minus* 48 GW (i.e. actually, a large *VRE surplus*) and *plus* 41 GW (a large *VRE shortage*), compared to between plus 6 GW and 18 GW in R2015 (see Fig. 1).
- A growing share of power production from sun and wind leads, hence, to a growing variability and an increase in extreme values of residual load, implying a higher need for flexibility to deal with these VRE-induced characteristics of the residual load.

2.2.2 Hourly Residual Load Variations and Resulting Flexibility Needs

Hourly variations (‘*ramps*’) of residual load are defined as the difference between residual load in hour t and residual load in hour $t - 1$ (with $t = 1, \ldots, n$). These variations can be either positive (‘ramp-up’) or negative (‘ramp-down’). Ramp-ups and ramp-downs are major indicators of the flexibility (‘ramping’) needs of the power sector due to the variation of the residual power load. More specifically, the FLEXNET project has distinguished and analysed the following three indicators to assess these needs:

- *Maximum hourly ramp*, either upwards (maximum hourly ramp-up) or downwards (maximum hourly ramp-down), i.e. the maximum hourly variation in residual load—either upwards or downwards—over a year, expressed in capacity terms per hour (GW/h).
- *Maximum cumulative ramp*, either upwards (maximum cumulative ramp-up) or downwards (maximum cumulative ramp-down), i.e. the maximum variation in residual load—either upwards or downwards—during some consecutive hours in a year, expressed in capacity terms per number of consecutive hours (GW/#h).
- *Total hourly ramps*, either upwards (total hourly ramp-up) or downwards (total hourly ramp-down), i.e. the total annual amount of hourly ramps—either upwards or downwards—aggregated over a year, expressed in energy terms per annum (TWh).

In this chapter, we focus only on the third indicator of the flexibility needs of the Dutch power sector over the period 2015–2050, including in particular how these

Fig. 1 (continued) residual load duration curve is actually much steeper in A2050—compared to R2015—than suggested in the figure. Moreover, the difference between the total load and residual load duration curves is actually much wider in A2050—compared to R2015—than suggested in the figure

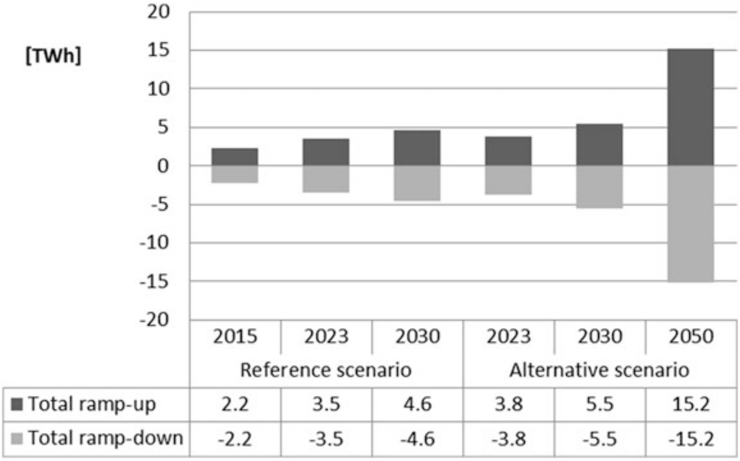

Fig. 2 Need for total annual hourly ramps ('flexibility') in all scenario cases, 2015–2050

needs are met by (hourly variations in) foreign power trade and other (domestic) flexibility options.[4]

Figure 2 presents the total hourly ramps—i.e. the total (annual) demand for flexibility due to the hourly variability of the residual load—for all scenario cases over the period 2015–2050. In the reference scenario, this demand for flexibility increases from 2.2 TWh in R2015 (both upwards and downwards) to 4.6 TWh in R2030 (+110%).

In the alternative scenario case for 2030 (A2030), however, the total annual demand for flexibility due to the variability of the residual load increases to 5.5 TWh (i.e. +150%, compared to R2015). As the output generation from VRE sources (sun/wind) is exactly similar in R2030 and A2030, the difference in total flexibility demand between these two scenario cases is fully due to their difference in additional load, in particular due to the higher penetration of heat pumps (HPs), electric vehicles (EVs) and other means of additional electrification in A2030 (see Table 1).

In A2050, the total demand for flexibility due to the hourly variability of the residual load amounts to 15.2 TWh (both upwards and downwards). Compared to R2015, this implies an increase in flexibility needs over the years 2015–2050 of almost 600%. As the total final load more than doubles over this period (see Table 1), the increase in total flexibility demand as a percentage of total final load is less pronounced although still substantial, i.e. it increases from 2.0% in R2015 to 6.5% in A2050.

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[4] For a discussion and assessment of the other two indicators of flexibility needs—and how these needs are met up to 2050—see the reports of phase 1 and phase 2 of the FLEXNET project, respectively (Sijm et al. 2017a, b).

Overall, the increase in total annual flexibility demand over the years 2015/2050 is due to a mixture of particularly (1) the large increase in power generation from VRE resources (sun/wind) and (2) the increase in total final power demand, including (3) structural changes in the hourly demand profiles of electricity resulting from the increasing penetration of HPs, EVs and other means of electrification.[5]

3 The Supply of Flexibility in the Dutch Power System, 2015–2050

3.1 Approach

3.1.1 Definition and Scope of Flexibility Supply Options

In order to meet the demand for flexibility, the following supply options have been considered in the FLEXNET project:

- *Power generation from (flexible) non-VRE sources*, including conventional sources—in particular (flexible) gas-fired power plants but also, to some extent, other conventional units (coal, nuclear)—as well as ‘other RES-E’ sources (i.e. besides sun/wind) such as hydro or biomass.
- *VRE curtailment*, i.e. limitation of peak power generation from VRE sources (sun/wind).
- *Demand curtailment*, i.e. limitation of peak power demand.
- *Demand response*, i.e. part of total power demand in a certain hour is shifted to another hour of the day, week, month, etc., either forwards or backwards.
- *Energy storage*, including batteries, hydro pumped storage (HPS), compressed air energy storage (CAES) and energy conversion technologies, such as power-to-gas (P2G) or power-to-ammonia (P2A), as far as these technologies are used to supply electricity at a later stage.
- *Power trade*, i.e. hourly variations in (net) imports/exports of electricity.

3.1.2 Energy Models Used

In order to determine and analyse the mix of supply options for meeting flexibility needs due to the hourly variability of the residual load in the Dutch power system over the years 2015–2050 in a socially optimal (i.e. least cost) way, the following two energy models have been used successively:

1. *COMPETES*, i.e. the EU28+ electricity market model developed and applied by ECN over the past 15 years in a large variety of national and EU projects. Major

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[5] Note that these findings are based on the assumption that no demand response takes place (as demand response is treated as a flexibility supply option).

advantages of this model are that it includes (1) detailed information on (flexible) generation technologies in the Netherlands and (2) interconnection capacities and power trade relationships across all EU28+ countries, making it possible to include and analyse electricity trading among these countries as a major flexibility option for the Dutch power system. A drawback of COMPETES is that it includes no demand response as a flexibility option and only limited energy storage options (for details, see Sijm et al. 2017b).

2. *OPERA,* i.e. the NL energy system model also developed by ECN. A major advantage of this model is that it includes detailed technological and socioeconomic information on all sectors and (flexible) technology options of the Dutch energy system as a whole, including demand response and a large variety of energy conversion/storage technologies. As a result, OPERA enables a more detailed, integrated optimisation analysis of the energy system in the Netherlands. A drawback of the model is, however, that it is restricted to the Dutch energy system and has no (trading) links with foreign countries.

Due to the characteristics of the models mentioned above, we first used the COMPETES model to determine and analyse (hourly) power trade between the Netherlands and neighbouring EU countries as well as other domestic flexibility options such as the deployment of flexible generation units or the curtailment of VRE power generation. Subsequently, we used the COMPETES modelling output on hourly power trade volumes as fixed input profiles for the OPERA model in order to further analyse the potential role of other domestic flexibility options, in particular energy storage and demand response by means of EVS and energy conversion technologies such as power-to-gas (P2G) or power-to-heat (P2H).

In the current section, we provide an explanation of the major COMPETES modelling results (see Sect. 3.2 below), preceded by a brief description of the COMPETES model and the modelling steps applied (see current sub-section below). Subsequently, in Sect. 4, we briefly summarise the approach and major results by means of the OPERA model, in particular to further discuss—and qualify—the COMPETES modelling results on the mixture of (domestic) flexibility options to meet the flexibility needs of the Dutch power system up to 2050.

3.1.3 Brief COMPETES Model Description

COMPETES is a power optimisation and economic dispatch model that seeks to minimise the total power system costs of the European power market while accounting for the technical constraints of the generation units, the transmission constraints between European countries as well as the transmission capacity expansion and the generation capacity expansion for conventional technologies. The model consists of two major modules that can be used to perform hourly simulations for two types of purposes:[6]

- A transmission and generation capacity expansion module in order to determine and analyse least-cost capacity expansion with perfect competition, subject to a set of power system constraints.
- A unit commitment and economic dispatch module to determine and analyse least-cost unit commitment (UC) and economic dispatch with perfect competition, subject to an even wider set of power system constraints.

The COMPETES model covers all present 28 EU member states and some non-EU countries (i.e. Norway, Switzerland and the Balkan countries) including a representation of the cross-border transmission capacities interconnecting these European countries. The model has time steps of 1 hour. Consequently, the target (focal) years of the FLEXNET scenario cases are optimised over all 8760 hours per annum.

3.1.4 Modelling Steps

The COMPETES modelling approach consists of the following steps (for details, see Sijm et al. 2017b):

1. Insert the hourly power demand and VRE supply profiles—developed during the first phase of FLEXNET and used to determine the demand for flexibility in the Dutch power sector over the period 2015–2050—as input of the COMPETES model during phase 2 of the project.
2. Expand FLEXNET scenario cases from the Dutch level to the EU28+ level. In particular, similar scenario assumptions and hourly profiles of power demand and VRE generation—based on correlated weather patterns—have been used for the Netherlands and the other EU28+ countries/regions.
3. Determine the baseline scenario—including hourly demand profiles, hourly VRE supply profiles, installed generation and transmission capacities, fuel and CO_2 prices, etc.—as a starting point for running the capacity investment module of COMPETES.
4. Run the capacity investment module in order to calculate the balance of installed generation capacity (new capacity versus decommissioning of existing capacity) and of installed cross-border transmission (interconnection) capacity for the respective FLEXNET scenario cases.
5. Run the unit commitment (UC) dispatch module—including the capacity results of the investment module—in order to determine the modelling output in terms of power generation, trade, electricity prices, system costs, supply of flexibility options, etc.

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[6] For a further discussion of the major characteristics of COMPETES, including its major input values and modelling assumptions, see the phase 2 report of the FLEXNET project (Sijm et al. 2017b).

Table 2 presents an overview of the COMPETES modelling runs in order to determine the outcomes of the FLEXNET scenario cases. It shows, for instance, that in the reference scenario for 2015 (R2015), only the unit commitment (UC) model was run (as both the installed generation and interconnection capacities are assumed to be fixed in R2015). On the other hand, in the alternative scenario cases for 2030 and 2050 (A2030 and A2050), both the capacity investment module and the unit commitment module of COMPETES were run successively.

3.1.5 Additional 2050 Scenario Cases

As part of the COMPETES modelling outcomes, the scenario case A2050 turned out to be characterised by a large ('optimal') interconnection capacity across all European countries covered by the model (including a large expansion of this capacity since A2030). As this variable may be overestimated and appeared to be a key variable for almost all other modelling outcomes, we have defined two additional 2050 scenario cases labelled as 'B2050' and 'C2050'. Both cases are similar to A2050, but in B2050 we have assumed that the expansion of the interconnection capacity since A2030 is only 50% of the ('optimal') expansion in A2050, whereas in C2050 we have assumed that this expansion is 0%. Hence, in C2050 the interconnection capacity across European countries is assumed to be similar to the capacity in A2030 (for details, see below).

3.2 COMPETES Modelling Results

3.2.1 Interconnection Capacity

Figure 3 presents the trend in total interconnection capacity in the EU28+ as a whole over the period 2015–2050, while Fig. 4 shows a similar trend for the Netherlands only. These figures make a distinction between baseline capacity and new transmission capacity. The baseline interconnection capacity is similar to the current capacity (in 2015) and the projected increase in this capacity up to 2030 as laid down in the most recent Ten-Year Network Development Plan (TYNDP) of ENTSO-E (2016). The new transmission capacity is the additional interconnection capacity calculated by the COMPETES model in order to meet the optimal interconnection capacity in the respective FLEXNET scenario cases (i.e. the interconnection capacity resulting in the lowest total system costs across the EU28+).[7]

Figure 3 shows that the baseline interconnection capacity in the EU28+ increases from 62 GW in 2015 to 106 GW in 2030. For A2030, the new (additional)

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[7] For details on the methodology to estimate cross-border transmission (interconnection) capacity, see Sijm et al. (2017b), notably Appendices A, B and C.

Table 2 Overview of COMPETES modelling runs for the benefit of the FLEXNET scenario cases

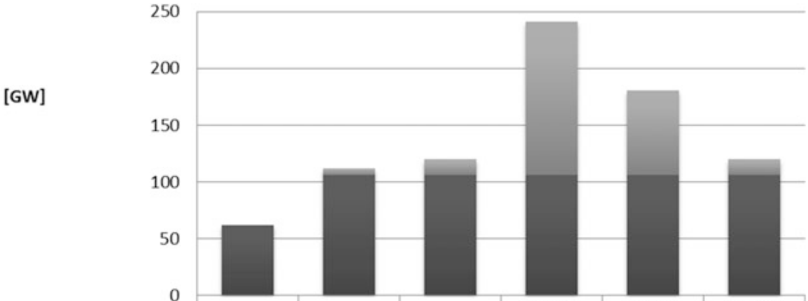
	Reference scenario			Alternative scenario		
Focal years	Generation investments	Transmission investments	Unit commitment	Generation investments	Transmission investments	Unit commitment
2015[a]			✓			
2023[b]	✓		✓	✓		✓
2030	✓		✓	✓	✓	✓
2050[c]				✓	✓	✓

✓ = Module run performed

[a] The alternative scenario does not include the focal year 2015

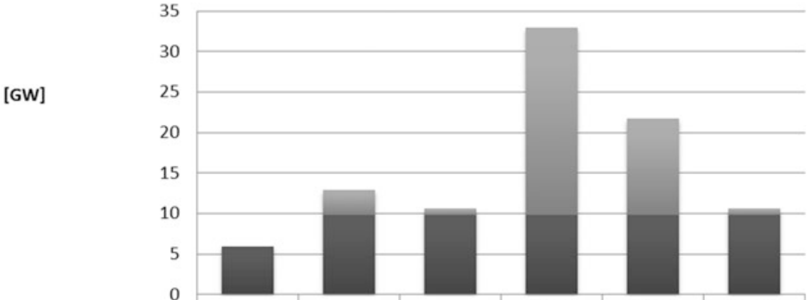
[b] Only decommissioning of generation units

[c] The reference scenario does not include the focal year 2050



	R2015	R2030	A2030	A2050 (100%)	B2050 (50%)	C2050 (0%)
▨ New transmission capacity	0	6	15	135	75	15
■ Baseline capacity (TYNDP2016)	62	106	106	106	106	106

Fig. 3 Total interconnection capacity in the EU28+, 2015–2050

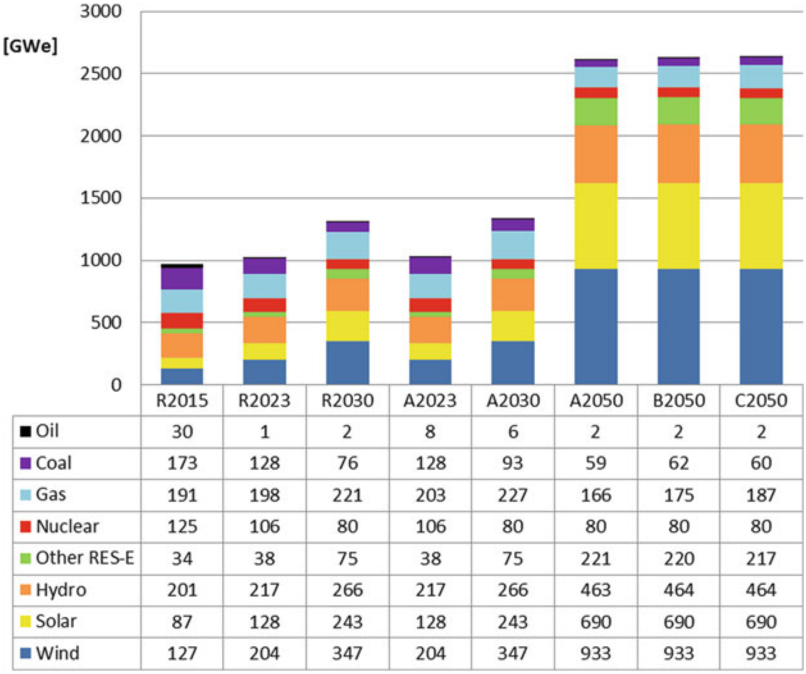


	R2015	R2030	A2030	A2050 (100%)	B2050 (50%)	C2050 (0%)
▨ New transmission capacity	0.0	3.1	0.7	23.1	11.9	0.7
■ Baseline capacity (TYNDP2016)	5.9	9.8	9.8	9.8	9.8	9.8

Fig. 4 Total interconnection capacity in the Netherlands, 2015–2050

transmission capacity is estimated at 15 GW, while for A2050 this figure amounts to 135 GW. For the Netherlands, the baseline interconnection capacity increases from 5.9 GW in 2015 to 9.8 GW in 2030, whereas the additional transmission capacity is estimated at 0.7 GW in A2030 and 23.1 GW in A2050 (see Fig. 4).

As noted above, because of the relatively large expansion of EU interconnection capacities between A2030 and A2050—which may be overestimated—and the importance of the interconnection variable for almost all other COMPETES modelling outcomes, we have defined two additional scenario cases for the year 2050 (besides A2050), i.e. B2050 and C2050 (see Figs. 3 and 4).



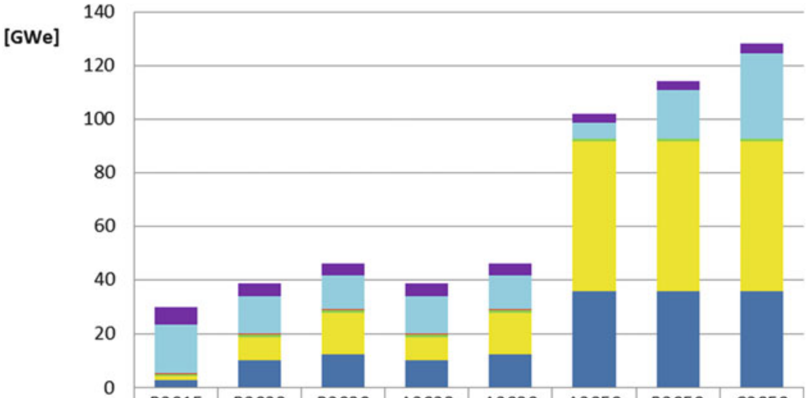
	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
■ Oil	30	1	2	8	6	2	2	2
🟪 Coal	173	128	76	128	93	59	62	60
🟦 Gas	191	198	221	203	227	166	175	187
🟥 Nuclear	125	106	80	106	80	80	80	80
🟩 Other RES-E	34	38	75	38	75	221	220	217
🟧 Hydro	201	217	266	217	266	463	464	464
🟨 Solar	87	128	243	128	243	690	690	690
🟦 Wind	127	204	347	204	347	933	933	933

Fig. 5 Installed power generation capacity in the EU28+, 2015–2050

3.2.2 Generation Capacity

Figure 5 presents the installed power generation capacity mix in the EU28+ over the years 2015–2050, while Fig. 6 provides a similar picture of the generation capacity mix in the Netherlands. For the EU28+, Fig. 5 shows that the installed capacity of electricity from all renewable energy sources (RES-E) increases rapidly from almost 450 GW in R2015 to more than 2300 GW in A2050. This increase in RES-E capacity applies in particular to electricity from *variable* renewable energy (VRE, i.e. sun/wind) but also to hydro and other RES-E (including biomass, geo-energy, etc.). Conventional capacity, however, declines significantly over the period 2015–2050, notably of oil, coal and nuclear. Gas-fired capacity in the EU28+ initially increases from 191 GW in R2015 to 227 GW in A2030 but declines to 166 GW in A2050.

For the Netherlands, Fig. 6 shows that the installed RES-E capacity increases even faster than for the EU28+ as a whole, i.e. from about 5 GW in 2015 to approximately 93 GW in 2050. This increase applies notably to sun and wind and, to a lesser extent, to other RES-E. On the other hand, similar to the EU28+, conventional capacity declines significantly from 25 GW in R2015 to 9 GW in A2050.



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
🟪 Coal	6.6	4.6	4.6	4.6	4.6	3.4	3.4	3.4
🟦 Gas	17.8	13.7	12.4	13.7	12.4	5.6	17.9	31.8
🟥 Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
🟩 Other RES-E	0.6	1.2	1.2	1.2	1.2	1.1	1.1	1.1
🟨 Solar	1.5	8.6	15.1	8.6	15.1	56.1	56.1	56.1
🟦 Wind	3.0	10.1	12.4	10.1	12.4	35.7	35.7	35.7

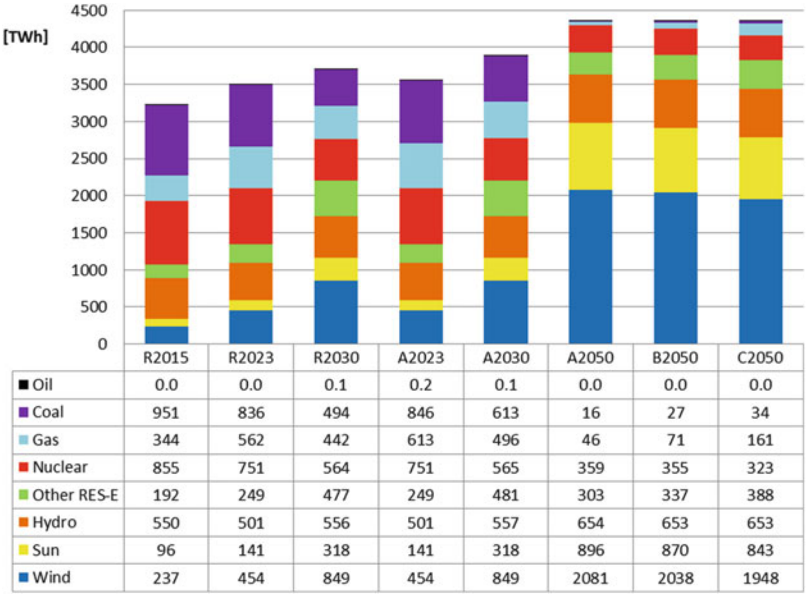
Fig. 6 Installed power generation capacity in the Netherlands, 2015–2050

A striking feature of Fig. 6, however, is that the total gas-fired capacity in the Netherlands increases rapidly from nearly 6 GW in scenario case A2050 to almost 18 GW in B2050 and even to approximately 32 GW in C2050. This increase results from the decrease in interconnection capacity from 33 GW in A2050 to 22 GW in B2050 and to about 11 GW in C2050 (Fig. 4). This implies that in the Netherlands the decrease in cross-border transmission capacity is more than compensated by an increase in the domestic, gas-fired generation capacity.

3.2.3 Generation Output Mix

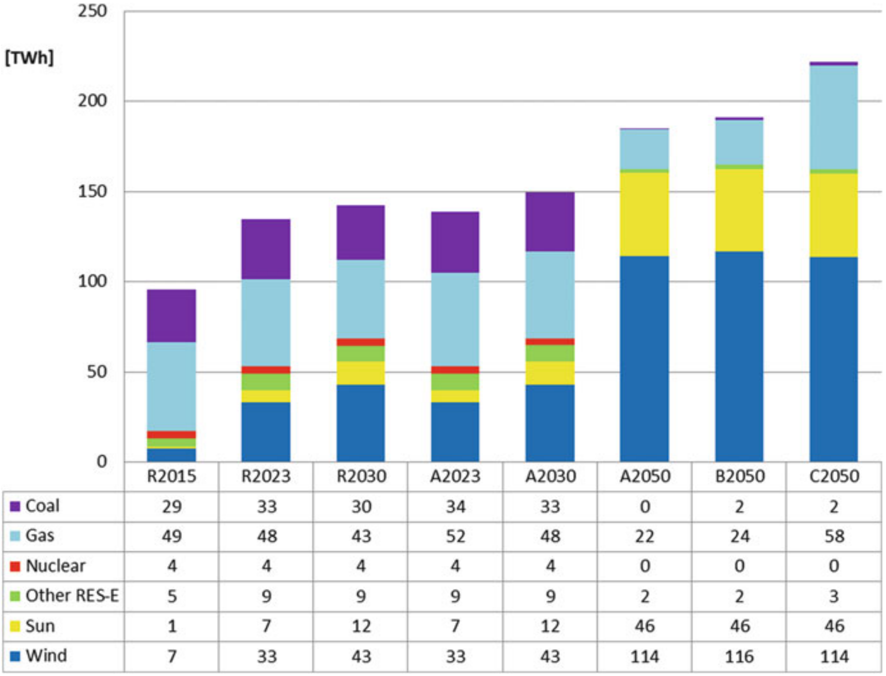
Figure 7 presents the power generation output mix in the EU28+ as a whole over the years 2015–2050, whereas Fig. 8 shows a similar picture for the Netherlands only. In the EU28+, the share of all renewable energy sources (RES-E) in total electricity production increases from 33% in R2015 to approximately 90% in A2050. For *variable* renewable sources only (wind/sun), this share increases from about 10% to 68%, respectively. The shares of conventional generation in the EU28+, on the contrary, decline accordingly.

For the Netherlands, the trends in the power generation show a similar pattern (Fig. 8). Whereas total electricity production doubles in absolute terms from 96 TWh in R2015 to 185 TWh in A2050, the share of sun and wind in total output increases from 9% to 87%, respectively. On the other hand, for nuclear the share in total power



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
■ Oil	0.0	0.0	0.1	0.2	0.1	0.0	0.0	0.0
🟪 Coal	951	836	494	846	613	16	27	34
🟦 Gas	344	562	442	613	496	46	71	161
🟥 Nuclear	855	751	564	751	565	359	355	323
🟩 Other RES-E	192	249	477	249	481	303	337	388
🟧 Hydro	550	501	556	501	557	654	653	653
🟨 Sun	96	141	318	141	318	896	870	843
🟦 Wind	237	454	849	454	849	2081	2038	1948

Fig. 7 Power generation mix in the EU28+, 2015–2050



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
🟪 Coal	29	33	30	34	33	0	2	2
🟦 Gas	49	48	43	52	48	22	24	58
🟥 Nuclear	4	4	4	4	4	0	0	0
🟩 Other RES-E	5	9	9	9	9	2	2	3
🟨 Sun	1	7	12	7	12	46	46	46
🟦 Wind	7	33	43	33	43	114	116	114

Fig. 8 Power generation mix in the Netherlands, 2015–2050

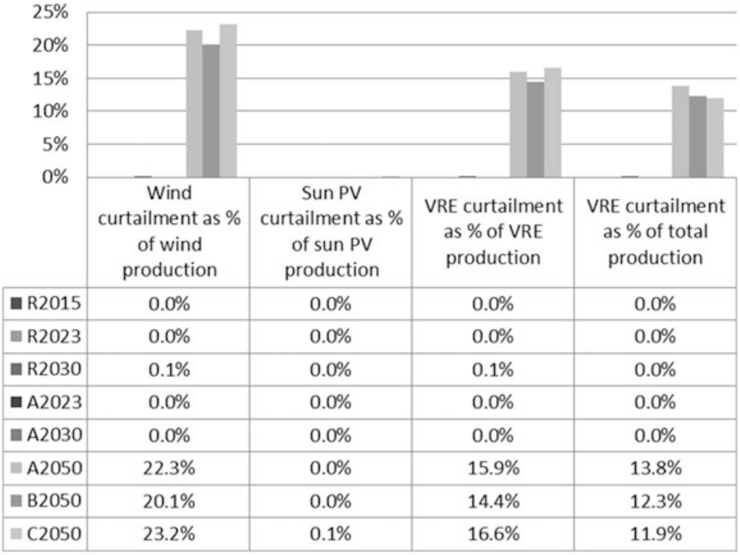
generation declines from 4% in R2015 to 0% in A2050, for coal from 31% to 0.2% and for gas from 51% to 12%.

In C2050—i.e. a scenario case with substantially less interconnection capacity and, hence, less power trade (see below)—electricity production in the Netherlands is significantly higher (222 TWh) than in A2050 (185 TWh). This increase in total output (+37 TWh) is almost fully met by an increase in gas-fired generation only, which rises steeply from 22 TWh in A2050 to 58 TWh in C2050 (i.e. by 36 TWh). As a result, the share of gas in total electricity production increases from 12% in A2050 to 26% in C2050. On the other hand, whereas the total output of electricity from sun and wind in A2050 and C2050 remains the same in absolute terms (160 TWh), the share of VRE generation in total power production declines from 87% to 72% (Fig. 8).

3.2.4 Curtailment of VRE Power Generation

The generation data discussed above do not explicitly consider the possible curtailment of power generation from VRE sources such as sun or wind. Curtailment of VRE generation, however, is a major flexibility option to balance (the hourly variation of) electricity demand and supply, notably in those hours with a (large) negative residual load, i.e. a surplus of VRE power generation.

Figure 9 presents the curtailment of VRE power generation in the Netherlands in relative terms across all FLEXNET scenarios over the period 2015–2050. It shows that up to 2030 there is no VRE curtailment. In A2050, the curtailment of power



	Wind curtailment as % of wind production	Sun PV curtailment as % of sun PV production	VRE curtailment as % of VRE production	VRE curtailment as % of total production
■ R2015	0.0%	0.0%	0.0%	0.0%
■ R2023	0.0%	0.0%	0.0%	0.0%
■ R2030	0.1%	0.0%	0.1%	0.0%
■ A2023	0.0%	0.0%	0.0%	0.0%
■ A2030	0.0%	0.0%	0.0%	0.0%
■ A2050	22.3%	0.0%	15.9%	13.8%
■ B2050	20.1%	0.0%	14.4%	12.3%
■ C2050	23.2%	0.1%	16.6%	11.9%

Fig. 9 Curtailment of VRE generation in the Netherlands, 2015–2050

generation from sun PV is still zero, but from wind it amounts to almost 26 TWh, i.e. 22% of realised (curtailed) wind production, 16% of total VRE output and 14% of total electricity generation by the Dutch power system in A2050.

In C2050 (with 0% interconnection capacity expansion, compared to A2030), VRE curtailment in the Netherlands is slightly higher, compared to A2050 (100% interconnection capacity expansion). More specifically, curtailment of sun PV generation in C2050 amounts to 0.1 TWh and of wind generation to more than 26 TWh, i.e. 0.1% of realised sun PV production and 23% of realised wind production, and—for total VRE curtailment—almost 17% of total VRE production (Fig. 9).

3.2.5 Demand Curtailment

In addition to curtailment of VRE power generation, curtailment of power demand can also be a socially optimal flexibility option for balancing electricity demand and supply, notably in those hours where the residual load is exceptionally high and non-VRE supply capacity—including import capacity—is insufficient to meet this residual demand. Table 3 presents a summary overview of some data on demand curtailment in all scenario cases up to 2050. It shows that in the reference scenario there is no demand curtailment at all, while in the alternative scenario it is restricted to the 2030 and 2050 cases.

More specifically, in the alternative scenario, the number of hours with demand curtailment is limited, varying from 2 hours in A2050 to 6 hours in B2050 and C2050, whereas the maximum demand curtailment per hour ranges from 1.0 GW in A2050 to 9.8 GW in C2050. Overall, total annual demand curtailment is relatively low (compared to total annual demand), varying from 1.3 GWh in A2050 to 17 GWh in C2030 (i.e. <0.01% of total demand).

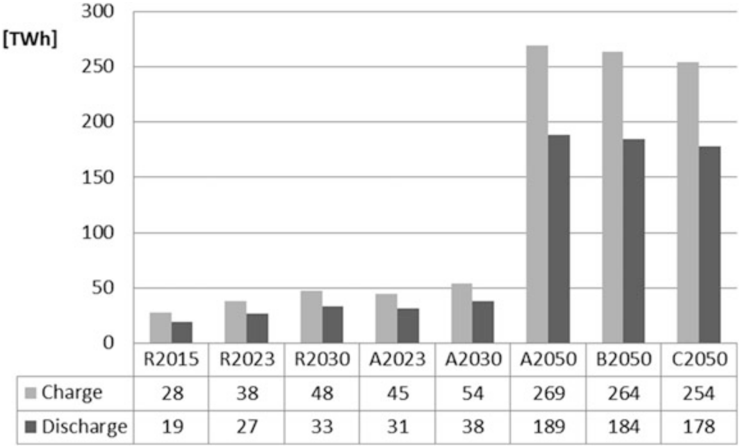
To conclude, in a tiny number of specific (extreme) hours with a large residual power load, demand curtailment can be a socially optimal flexibility option for balancing electricity demand and supply. Overall, however, the role of demand curtailment is, in general, negligibly small (compared to other flexibility options considered in the present study).

3.2.6 Demand Response

In addition to demand *curtailment* (in which power demand is *reduced* and, hence, *lost* in a certain hour by a certain amount), a related flexibility option is demand *response* (in which part of total demand in a certain hour is *shifted* to another hour of the day, week, month, etc., either forwards or backwards). Demand response has not been modelled and analysed by means of COMPETES but has been included as part of the OPERA modelling analysis (see Sect. 4 below).

Table 3 Demand curtailment in all scenario cases, 2015–2050

		Reference scenario			Alternative scenario				
	Unit	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Number of hours with demand curtailment	[#hrs]	0	0	0	0	4	2	6	6
Maximum hourly demand curtailment	[GW]	0	0	0	0	1.5	1.0	2.1	9.8
Total demand curtailment (p.a.)	[GWh]	0	0	0	0	2.5	1.3	4.7	17.1
Value of lost load (VOLL)	[€/MWh]	3000	3000	3000	3000	3000	3000	3000	3000
Total value of lost load	[M€]	0	0	0	0	7.6	3.8	14.1	51.4



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
▨ Charge	28	38	48	45	54	269	264	254
■ Discharge	19	27	33	31	38	189	184	178

Fig. 10 Hydro power storage in the EU28+, 2015–2050

3.2.7 Energy Storage

For the purpose of providing flexibility on timescales of an hour and more in sufficient volumes, the COMPETES model focuses mainly on bulk electricity storage technologies such as hydro pumped storage (HPS) and compressed air energy storage (CAES). These electricity storage technologies are modelled to operate such that they maximise their revenues by charging and discharging electrical energy within a day. By doing so, they are able to increase or decrease system demand for electricity and contribute to the flexibility for generation-demand balancing.

In the baseline scenario of the COMPETES model, storage capacity refers to hydro pumped storage (HPS) only. Investments in new storage capacity—including both HPS and CAES—are, in theory, possible but, in practice, are too expensive and, hence, generate negative net revenues (Sijm et al. 2017b). Therefore, in the COMPETES-FLEXNET scenario cases, electricity storage is restricted to HPS on a daily cycle only.

Figure 10 presents a summary overview of the hydro power storage activities in the EU28+ as a whole over the years 2015–2050. It shows that charging hydro power increases almost tenfold from 28 TWh in R2015 to 270 TWh in A2050, whereas discharging hydro power rises from 19 TWh to 190 TWh, respectively.[8]

In A2050, hydro power charging corresponds to about 40% of total hydro power generation output and to approximately 6% of total power production in the EU28+. In A2050, however, almost 80% of HPS activities are restricted to six EU28+ countries/regions, i.e. Spain, France, Norway, Germany, Austria and the Balkan region. On the other hand, there are five EU28+ countries—including the

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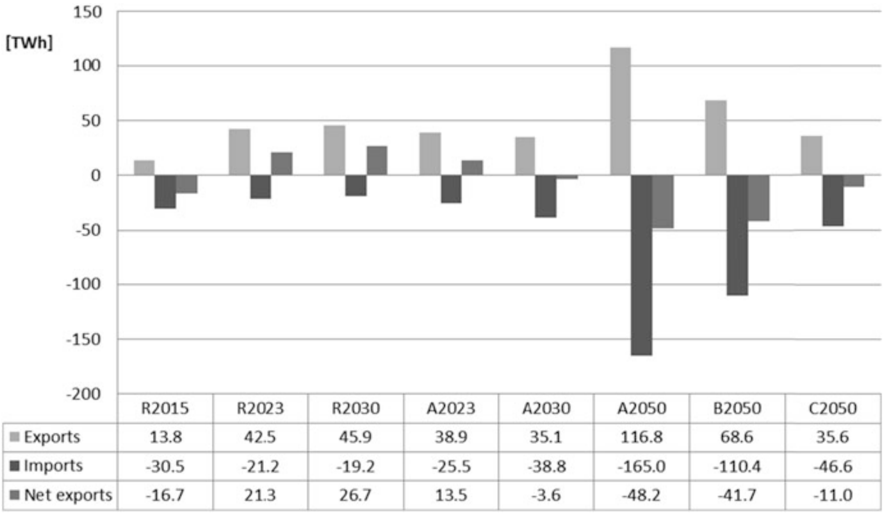
[8] The difference between charging and discharging refers to physical energy storage losses.

Netherlands—which do not deploy any HPS activities themselves over the years 2015–2050. Therefore, (hydro) power storage in the Netherlands is not included as a flexibility option in the further COMPETES-FLEXNET analyses below (although indirectly the Netherlands may benefit from HPS as a flexibility option at the EU28+ level through its power trade relations with other, neighbouring EU28+ countries, including Norway, Germany and France; see below).

3.2.8 Power Trade

Figure 11 presents an overview of the aggregated power trade flows of the Netherlands in the scenario cases over the years 2015–2050. In most hours of the year, the Netherlands is both exporting electricity to (some) neighbouring countries and importing electricity from (other) neighbouring countries. Net power trade—either net imports or net exports—may vary, however, significantly from hour to hour but also, aggregated over the year as a whole, between the scenario cases considered. For instance, Fig. 11 shows that at an aggregated (annual) level, power trade by the Netherlands over the period 2015–2030 varies widely from large net imports in R2015 (17 TWh) to large net exports in R2023 (21 TWh) and R2030 (27 TWh). In the alternative scenario cases, however, the Netherlands becomes a major net importer of electricity again, varying in the 2050 cases from 11 TWh in C2050 (small interconnection capacity) to 48 TWh in A2050 (large interconnection capacity).

In addition, within the scenario years considered, hourly power trade is even more volatile, i.e. varying between the interconnection capacities of the Netherlands in the respective scenario cases. For instance, in A2050 net hourly power trade varies



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
■ Exports	13.8	42.5	45.9	38.9	35.1	116.8	68.6	35.6
■ Imports	-30.5	-21.2	-19.2	-25.5	-38.8	-165.0	-110.4	-46.6
■ Net exports	-16.7	21.3	26.7	13.5	-3.6	-48.2	-41.7	-11.0

Fig. 11 Power trade by the Netherlands, 2015–2050. Note: A negative sign for net exports actually implies net imports

between +33 GW (imports) and −33 GW (exports), whereas in C2050 it varies between +11 GW and −11 GW, respectively.

3.2.9 Net Residual Power Balance

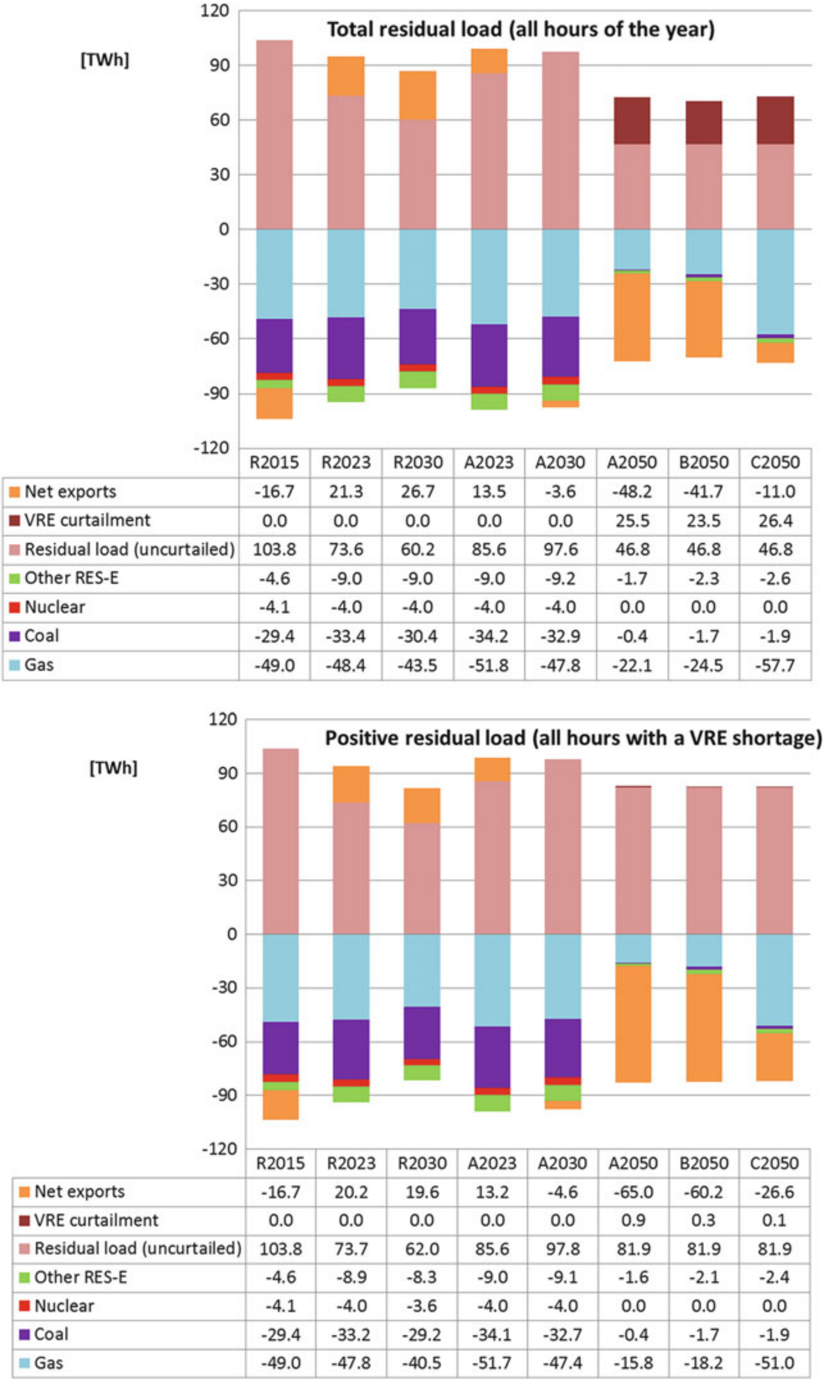
As a kind of summary overview, Fig. 12 presents the annual net residual power balance of the Netherlands, including a distinction of these balances during hours with a negative residual load and hours with a positive residual load (uncurtailed), for all scenario cases up to 2050. The upper part of this figure illustrates the net residual power balance for all hours in the year. On the demand side of this balance, i.e. above the x-axis, it shows the (domestic, uncurtailed) residual load defined as total (domestic) power load minus (uncurtailed) power generation from VRE sources (sun/wind). More specifically, the upper part of Fig. 12 shows that the (domestic, uncurtailed) residual demand declines in the reference scenario from 104 TWh in 2015 to 60 TWh in 2030 and in the alternative scenario from 86 TWh in 2023 to 47 TWh in 2050. In some cases, this (domestic, uncurtailed) residual load is enhanced by net exports—notably in R2023, R2030 and A2023—and/or by VRE curtailment, in particular in the alternative 2050 scenario cases (A2050, B2050 and C2050).

On the supply side of the net residual power balance, i.e. below the x-axis of Fig. 12, the picture shows how the resulting (national, curtailed) residual power demand is met. In the reference scenario cases, R2015–R2030, this demand is primarily addressed by domestic non-VRE power generation, in particular from fossil fuels (coal, gas) and, to a lesser extent, from nuclear and other (non-variable) RES-E, notably biomass. In addition, in R2015 a minor part of the residual power demand is covered by net imports.

In the alternative scenario cases A2023 and A2030, the supply side shows a similar picture: residual power demand is primarily met by domestic power generation, while in A2030 an additional, small part is covered by net imports. In the alternative 2050 cases, however, the situation is quite different. Notably in A2050, about two-thirds of the (national, curtailed) residual power demand is covered by net imports, while the remaining part is addressed by domestic, non-VRE generation.

On the other hand, in C2050 (0% interconnection expansion), the residual supply side is quite different compared to A2050 (100% interconnection expansion). Due to the interconnection restriction, the contribution of net imports to total supply falls from 48 TWh in A2050 to 11 TWh in C2050, whereas the contribution of gas-fired power generation to meet electricity demand increases from 22 TWh to 58 TWh, respectively. As a result, gas becomes by far the most dominant source of total (national) residual power supply in C2050.

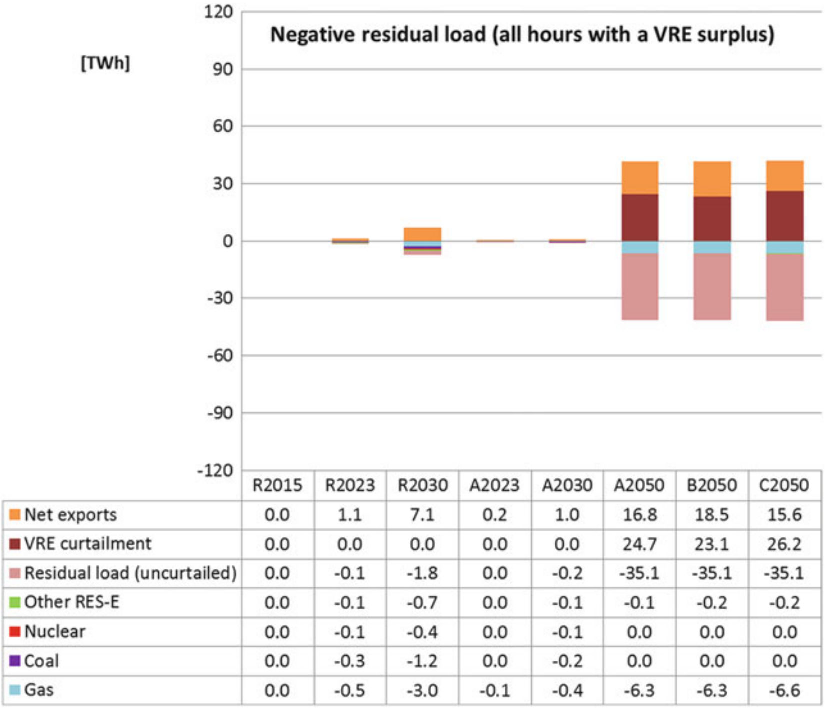
The middle part of Fig. 12 presents the annual net residual power balance for those hours of the year in which there is a positive residual load (‘VRE shortage’), while the lower part provides this balance for those hours in which there is a negative residual load (‘VRE surplus’). Since the number of hours with a VRE surplus and the total annual amount of hourly VRE surpluses is limited between R2015 and A2030



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Net exports	-16.7	21.3	26.7	13.5	-3.6	-48.2	-41.7	-11.0
VRE curtailment	0.0	0.0	0.0	0.0	0.0	25.5	23.5	26.4
Residual load (uncurtailed)	103.8	73.6	60.2	85.6	97.6	46.8	46.8	46.8
Other RES-E	-4.6	-9.0	-9.0	-9.0	-9.2	-1.7	-2.3	-2.6
Nuclear	-4.1	-4.0	-4.0	-4.0	-4.0	0.0	0.0	0.0
Coal	-29.4	-33.4	-30.4	-34.2	-32.9	-0.4	-1.7	-1.9
Gas	-49.0	-48.4	-43.5	-51.8	-47.8	-22.1	-24.5	-57.7

	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
Net exports	-16.7	20.2	19.6	13.2	-4.6	-65.0	-60.2	-26.6
VRE curtailment	0.0	0.0	0.0	0.0	0.0	0.9	0.3	0.1
Residual load (uncurtailed)	103.8	73.7	62.0	85.6	97.8	81.9	81.9	81.9
Other RES-E	-4.6	-8.9	-8.3	-9.0	-9.1	-1.6	-2.1	-2.4
Nuclear	-4.1	-4.0	-3.6	-4.0	-4.0	0.0	0.0	0.0
Coal	-29.4	-33.2	-29.2	-34.1	-32.7	-0.4	-1.7	-1.9
Gas	-49.0	-47.8	-40.5	-51.7	-47.4	-15.8	-18.2	-51.0

Fig. 12 Net residual power balance of the Netherlands, including a distinction between hours with a positive and a negative residual load, 2015–2050



	R2015	R2023	R2030	A2023	A2030	A2050	B2050	C2050
🟧 Net exports	0.0	1.1	7.1	0.2	1.0	16.8	18.5	15.6
🟫 VRE curtailment	0.0	0.0	0.0	0.0	0.0	24.7	23.1	26.2
■ Residual load (uncurtailed)	0.0	-0.1	-1.8	0.0	-0.2	-35.1	-35.1	-35.1
🟩 Other RES-E	0.0	-0.1	-0.7	0.0	-0.1	-0.1	-0.2	-0.2
🟥 Nuclear	0.0	-0.1	-0.4	0.0	-0.1	0.0	0.0	0.0
🟪 Coal	0.0	-0.3	-1.2	0.0	-0.2	0.0	0.0	0.0
🟦 Gas	0.0	-0.5	-3.0	-0.1	-0.4	-6.3	-6.3	-6.6

Fig. 12 (continued)

(see Sect. 2, notably Fig. 1), the net residual power balance for hours with a positive residual demand is largely similar to the balance for total residual demand in these scenario cases (compare the middle part with the upper part of Fig. 12).

On the other hand, in the 2050 scenario cases—with a large VRE surplus over a large number of hours—the residual supply situation is quite different, notably in the hours with a VRE surplus compared to the hours with a VRE shortage (although the situation is quite similar in the hours with a VRE surplus for the three individual 2050 scenario cases, i.e. A2050, B2050 and C2050; see middle versus lower part of Fig. 12). The VRE supply surplus is usually enhanced by non-VRE generation—notably from gas and, to a lesser extent, from other RES-E—because of ‘must-run’ production considerations and/or ample export opportunities in certain hours. The resulting domestic surplus of power supply is predominantly met by VRE curtailment and, to a lesser extent, by net exports.

3.2.10 Hourly Residual Supply Variation and Resulting Flexibility Options

Following hourly variations in residual load (as defined in Sect. 2.2), we have defined hourly variations (‘ramps’) in residual supply as the difference between residual supply in hour t and residual supply in hour $t - 1$ (with $t = 1, \ldots, n$), where residual supply is defined as total (net national) power supply—i.e. including net power trade—minus (uncurtailed) VRE power generation. These variations can be either positive ('ramp-up') or negative ('ramp-down').

In Sect. 2, we have defined and quantified the concept 'total hourly ramps' as one of the main indicators to measure and analyse total annual demand for flexibility due to the hourly variation of the residual load, either upwards ('total hourly ramp-up') or downwards ('total hourly ramp-down'; see particularly Fig. 2). Subsequently, by means of the EU28+ electricity market model COMPETES, we have determined the societal optimal (least cost) mix of flexibility options to meet this demand by calculating and aggregating the hourly variations of the main components of residual supply (either upwards or downwards).[9]

Figure 13 presents the resulting total annual supply of flexibility options to meet the total annual demand for flexibility due to the hourly variability ('ramping') of the residual load, either upwards or downwards), in all scenario cases up to 2050 in both absolute energy terms (TWh) and as a % of total annual demand/supply of flexibility.[10]

Figure 13 shows that the total annual demand for upward/downward flexibility increases from 2.2 TWh in R2015 to more than 15 TWh in the 2050 scenario cases (see also Fig. 2 in Sect. 2). In R2015, this need is predominantly met by (hourly) increases in power generation from gas (49%) and coal (42%), while the remaining part is covered by increases in net imports (9%). In R2023, the total annual demand for upward flexibility increases to 3.5 TWh. However, already in this scenario case, the share of power trade (net imports) increases to 65%, whereas the shares of gas and coal drop to 32% and 4%, respectively.

Figure 13 shows that in the scenario cases A2023 up to A2050, the share of power trade in total flexibility demand (upwards/downwards) is even significantly higher, whereas the share of fossil fuels is lower accordingly. In A2050 (with a socioeconomic optimal expansion of interconnection capacity), the share of net power imports in total annual flexibility demand/supply amounts even to almost 74%, whereas the share of gas and coal amounts to only 4.6% and 0.6%, respectively. The remaining part is largely accounted for by (hourly changes in) VRE curtailment (20%) and, to a lesser extent, by generation from other RES-E (1%).

In the two other 2050 scenario cases—with significantly lower interconnection capacities—the share of power trade in total upward/downward flexibility is significantly lower, while the shares of the other flexibility options are higher accordingly. More specifically, in C2050 (% interconnection expansion), the share of gas-fired generation in total annual flexibility needs increases to 27% (compared to less than

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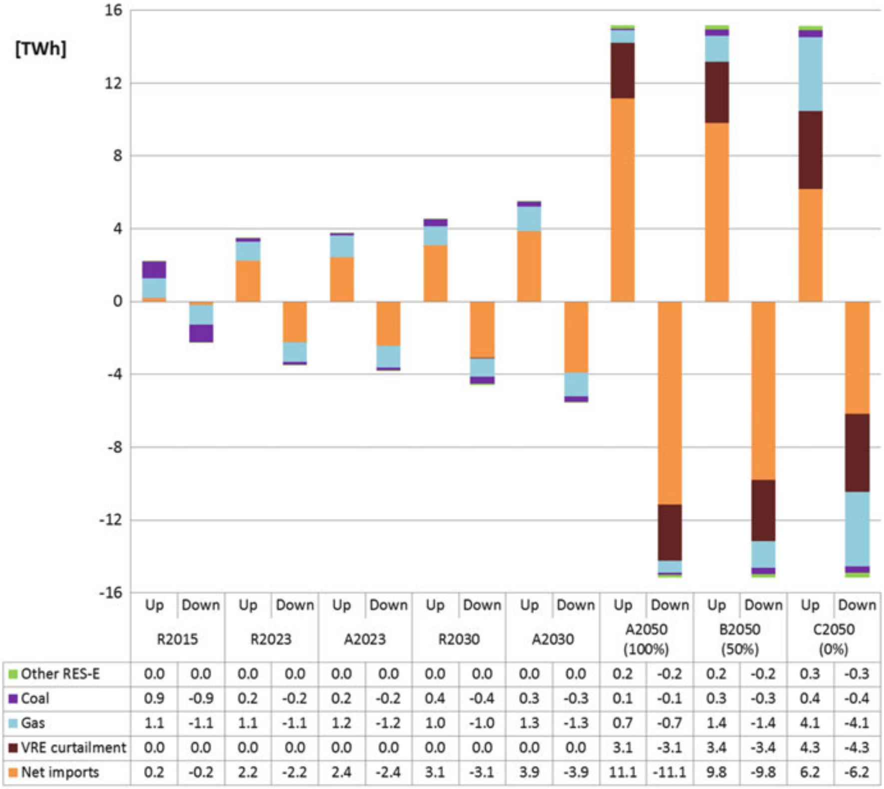
[9] For a further analysis of the trends in hourly variations of residual supply and the resulting mix of flexibility options to meet flexibility needs according to other indicators (besides total hourly ramps), see Sijm et al. (2017b).

[10] As the mix of flexibility options is similar to the mix of downward flexibility options in energy terms (see upper part of Fig. 13), the bottom part does not distinguish between these two categories of flexibility options but actually refers to both categories.



	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	R2015		R2023		A2023		R2030		A2030		A2050 (100%)		B2050 (50%)		C2050 (0%)	
🟩 Other RES-E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	-0.2	0.2	-0.2	0.3	-0.3
🟪 Coal	0.9	-0.9	0.2	-0.2	0.2	-0.2	0.4	-0.4	0.3	-0.3	0.1	-0.1	0.3	-0.3	0.4	-0.4
🟦 Gas	1.1	-1.1	1.1	-1.1	1.2	-1.2	1.0	-1.0	1.3	-1.3	0.7	-0.7	1.4	-1.4	4.1	-4.1
🟫 VRE curtailment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	-3.1	3.4	-3.4	4.3	-4.3
🟧 Net imports	0.2	-0.2	2.2	-2.2	2.4	-2.4	3.1	-3.1	3.9	-3.9	11.1	-11.1	9.8	-9.8	6.2	-6.2

	R2015	R2023	A2023	R2030	A2030	A2050 (100%)	B2050 (50%)	C2050 (0%)
🟩 Other RES-E	0.2%	0.1%	0.0%	1.1%	0.0%	1.1%	1.4%	1.7%
🟪 Coal	42.4%	5.0%	4.0%	8.6%	5.4%	0.6%	1.7%	2.4%
🟦 Gas	48.9%	30.4%	31.5%	22.2%	24.2%	4.6%	9.8%	26.8%
🟫 VRE curtailment	0.0%	0.0%	0.0%	0.3%	0.0%	20.2%	22.1%	28.2%
🟧 Net imports	8.5%	64.5%	64.5%	67.7%	70.4%	73.5%	64.6%	40.8%

Fig. 13 Total annual supply of flexibility options to meet total annual demand for flexibility due to the hourly variability ('ramping') of the residual load, either upwards or downwards, in all scenario cases, 2015–2050

5% in A2050), while the share of VRE curtailment rises from 20% in A2050 to 28% in C2050. In C2050, however, power trade still accounts for the largest share of all flexibility options (41%), while in B2050 (50% interconnection expansion), the share of net imports in total flexibility needs, however, even amounts to 65% (Fig. 13).

To conclude, in R2015 hourly changes in the power generation from non-VRE sources—notably from gas, coal and, to a lesser extent, other RES-E (biomass, hydro)—are the main supply options to meet the demand for upward/downward flexibility due to the (hourly) variability of the residual load. In all scenario cases over the period 2023–2050, however, hourly changes in power trade become the most important (dominant) supply option for addressing the demand for flexibility due to the variability of the residual load.

In addition, in the 2050 scenario cases—which are characterised by a large number of hours with a substantial negative residual load (VRE surplus)—hourly changes in VRE curtailment also become a major supply option for addressing the demand for flexibility due to the variability of the residual load.

As a result, although the demand for flexibility increases substantially over the period 2015–2050, the role of (hourly changes in) domestic power generation from non-VRE sources (gas, coal, nuclear, other RES-E) decreases significantly over this period, notably in relative terms between R2015 and A2050 (but even in absolute terms).

Our analysis shows, however, that the role of the different supply options to meet the need for flexibility depends highly on the assumptions made with regard to the expansion of the interconnection capacities across the EU28+ countries in general and between the Netherlands and its neighbouring (interconnected) countries in particular. For instance, in A2050—which assumes a 100% expansion of the socioeconomic optimal interconnection capacity of all EU28+ countries between A2030 and A2050—the shares of the three main supply categories in addressing total annual flexibility demand—i.e. power trade, VRE curtailment and power generation from non-VRE resources—amount to 74%, 20% and 6%, respectively. On the other hand, in C2050, these shares amount to 41%, 28% and 31%, respectively. In particular, the share of gas-fired power generation increases from 4.6% in A2050 to almost 27% in C2050 (Fig. 13).

4 Discussion: Complementary Modelling Results on Demand Response

As noted in Sect. 3.1, a major shortcoming of the current COMPETES model is that it does not include demand response as a flexibility option (and that it covers only limited options for energy storage in the Netherlands). That is the main reason why—in addition or complementary to the COMPETES model—we have used the NL integrated energy system model OPERA as it includes the option to model and analyse demand response (and includes more detailed energy storage options).

On the other hand, a major drawback of OPERA is that it includes no foreign relationships of the Netherlands with other EU countries and, hence, it is not able to analyse cross-border power trade as a flexibility option. Therefore, as explained, we have first used the COMPETES model to determine power trade as a flexibility option for the Dutch power system within an EU28+ electricity market and trading context. Subsequently, we have inserted the power trade results of COMPETES as fixed (exogenous) inputs into the OPERA model in order to further analyse the domestic flexibility options for the Dutch power system, including in particular demand response (and more detailed energy storage options) as well as the implication for the other domestic flexibility options (notably VRE curtailment and conventional power generation).

More specifically, as part of the OPERA modelling analyses, we have investigated the demand response potential of some selected power demand technologies as an option for addressing the flexibility needs of the Dutch power system up to 2050. These technologies include electric passenger vehicles (EVs) as well as three industrial energy conversion technologies, i.e. power-to-gas (P2G), power-to-heat (P2H) and power-to-ammonia (P2A). At present, the power demand of these technologies is still (negligible) small, but it is expected to grow rapidly in the coming decades and to offer significant potential for demand response as a flexibility option for the Dutch power system, notably beyond 2030.[11]

The OPERA modelling analyses have been conducted for the four most relevant and interesting scenario cases, i.e. R2030, A2030, A2050 and C2050. Figure 14 presents the OPERA modelling results with regard to the total annual supply of upward flexibility options due to the hourly variations of the residual load of the Dutch power system in these four selected scenario cases over the years 2030–2050 and compares these results with similar outcomes from the COMPETES model for these scenario cases (as discussed in the previous section and presented in Fig. 13).[12]

Figure 14 shows that the differences in modelling outcomes between OPERA and COMPETES in terms of flexibility options for the Dutch power system are generally relatively small in the 2030 scenario cases, notably in R2030. On the other hand, in the 2050 scenario cases—and particularly in C2050—the differences in domestic flexibility options are quite substantial. For instance, in C2050 the flexibility offered by means of the hourly variations in total demand response (including all four flexible power demand technologies mentioned above) amounts to 4.8 TWh in the OPERA modelling results, corresponding to almost 32% of total annual flexibility demand/supply—and being the most dominant ‘domestic’ flexibility option in

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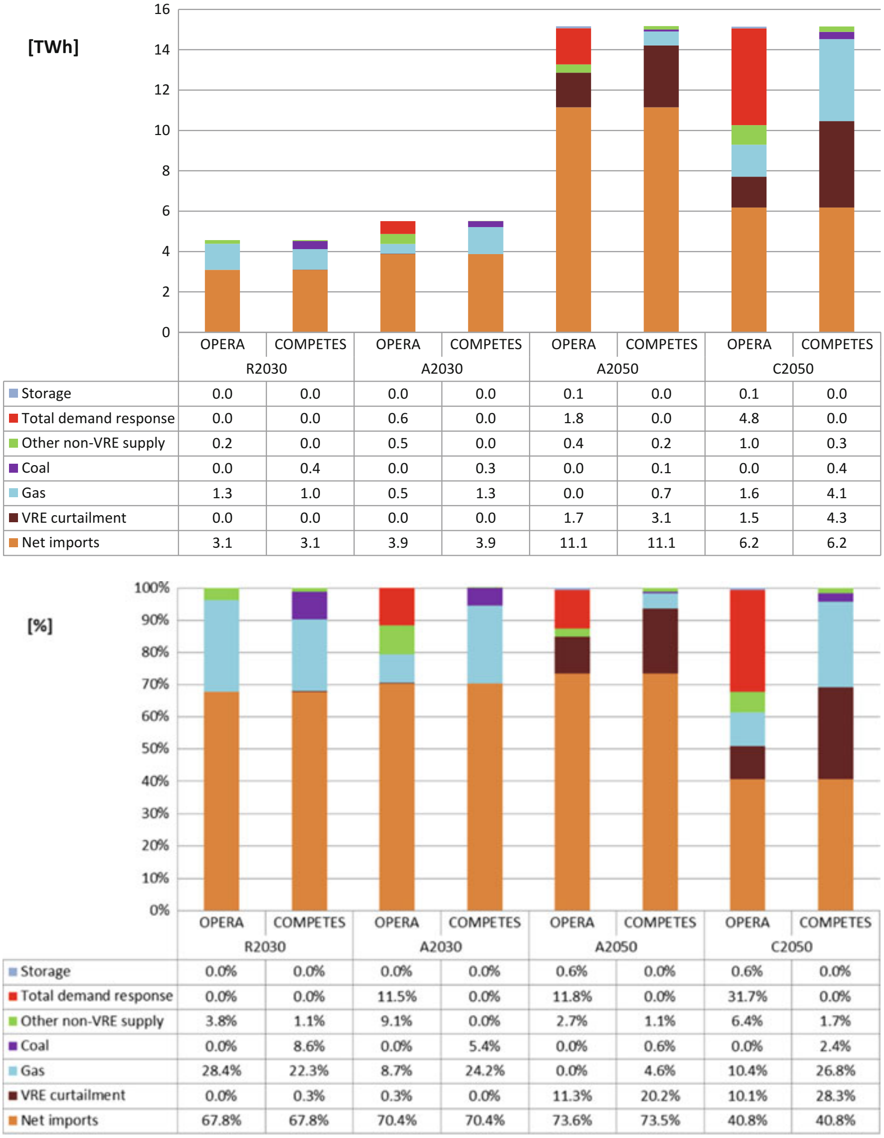
[11] For details on (1) the OPERA model; (2) its approach, input values and other modelling assumptions used to analyse demand response (and other domestic flexibility options); and (3) the outcomes of the OPERA modelling analyses, see the second phase report of the FLEXNET project (Sijm et al. 2017b), in particular Chapter 3 (pp. 107–144) and Appendix D (pp. 209–219).

[12] Note that Fig. 14 shows only a comparison of the *upward* flexibility demand/supply as the downward flexibility demand/supply levels are exactly similar to the upward levels (see also footnote 10).



	R2030		A2030		A2050		C2050	
	OPERA	COMPETES	OPERA	COMPETES	OPERA	COMPETES	OPERA	COMPETES
🟦 Storage	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
🟥 Total demand response	0.0	0.0	0.6	0.0	1.8	0.0	4.8	0.0
🟩 Other non-VRE supply	0.2	0.0	0.5	0.0	0.4	0.2	1.0	0.3
🟪 Coal	0.0	0.4	0.0	0.3	0.0	0.1	0.0	0.4
🟦 Gas	1.3	1.0	0.5	1.3	0.0	0.7	1.6	4.1
🟫 VRE curtailment	0.0	0.0	0.0	0.0	1.7	3.1	1.5	4.3
🟧 Net imports	3.1	3.1	3.9	3.9	11.1	11.1	6.2	6.2

	R2030		A2030		A2050		C2050	
	OPERA	COMPETES	OPERA	COMPETES	OPERA	COMPETES	OPERA	COMPETES
🟦 Storage	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.6%	0.0%
🟥 Total demand response	0.0%	0.0%	11.5%	0.0%	11.8%	0.0%	31.7%	0.0%
🟩 Other non-VRE supply	3.8%	1.1%	9.1%	0.0%	2.7%	1.1%	6.4%	1.7%
🟪 Coal	0.0%	8.6%	0.0%	5.4%	0.0%	0.6%	0.0%	2.4%
🟦 Gas	28.4%	22.3%	8.7%	24.2%	0.0%	4.6%	10.4%	26.8%
🟫 VRE curtailment	0.0%	0.3%	0.3%	0.0%	11.3%	20.2%	10.1%	28.3%
🟧 Net imports	67.8%	67.8%	70.4%	70.4%	73.6%	73.5%	40.8%	40.8%

Fig. 14 Comparison of OPERA versus COMPETES modelling results on the total annual supply of upward flexibility options to meet total annual demand of upward flexibility due to the hourly variations ('ramps') of the residual load in selected scenario cases, 2030–2050

C2050—whereas it amounts to 0 TWh in the COMPETES modelling results (as this option is not covered by this model).

In addition, Fig. 14 shows that in C2050 the flexibility offered by (hourly variations in) VRE curtailment and gas-fired power generation is significantly lower in the OPERA modelling results than in the COMPETES modelling outcomes. For instance, in C2050 the share of VRE curtailment in total annual flexibility supply amounts to 10% in the OPERA results and 28% in the COMPETES outcomes. For gas-fired power generation, these figures amount to 10% and 27%, respectively (see the last two columns in the lower part of Fig. 14).

The differences in modelling outcomes between OPERA and COMPETES with regard to VRE curtailment and gas-fired power generation as flexibility options for the Dutch power system are, of course, closely related to their differences in modelling outcomes concerning demand response. More specifically, in particular during hours with a large *negative* residual load—i.e. hours with a large *surplus* of VRE power generation and, hence, *low* electricity prices—(hourly variations in) *upward* demand response will result in less need for (hourly variations in) VRE curtailment. On the other hand, during hours with a large *positive* residual load—i.e. hours with a large *deficit* of VRE power generation and, hence, *high* electricity prices—(hourly variations in) *downward* demand response will result in less need for (hourly variations in) gas-fired power generation.

Note that the modelling outcomes in Fig. 14 are partly due to the assumption that the 'foreign' (cross-border) flexibility option—i.e. net power trade—is set at the same level in both models (as the power trade output of COMPETES is fixed input into the OPERA model). If the OPERA results on demand response were fed back into the COMPETES model, it could lead to a lower level of the cross-border (power trade) flexibility option and to a similar higher level—and change in the mix—of the domestic flexibility option of non-VRE power generation. Due to time/budget constraints, this exercise has not been conducted in the present study but will be taken up as part of two follow-up projects starting in 2018.[13]

5 Conclusion

Due to the mix of (1) increasing power demand resulting from an increasing rate of electrification of the energy system (EVs, HPs, etc.) and (2) an increasing share of electricity supply from variable renewable energy (sun/wind), the demand for flexibility due the variability of the residual load in the Dutch power system is expected to increase more than sixfold over the years 2015–2050. Analyses by means of (soft linking) two energy systems models developed by ECN, i.e. the EU28+ electricity market model COMPETES and the NL integrated energy system model OPERA, show that this increasing demand for flexibility is met predominantly by (foreign) power trade and (domestic) demand response as well as, to some extent, by conventional generation (gas) and VRE curtailment (but hardly or not at all by electricity storage and demand curtailment). The size and mix of these flexibility options, however, depend largely on the level of interconnection capacities—and, hence, the level of electricity market integration—across EU member

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[13] For details on these follow-up projects, contact the corresponding author of this paper (Jos Sijm).

states as well as on whether and to what extent demand response in the respective models is included as a flexibility option.

A major policy implication of the findings in the current chapter is that the EU, including individual member states such as the Netherlands or Germany, should strive for more integration of the EU electricity market by investing in optimal cross-border interconnection capacities between EU countries as this would make a crucial contribution to addressing the flexibility needs of a sustainable, low-carbon power system in the most cost-effective way.

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A Public Choice View on the Climate and Energy Policy Mix in the EU: How Do the Emissions Trading Scheme and Support for Renewable Energies Interact?

Erik Gawel, Sebastian Strunz, and Paul Lehmann

Abstract In this paper, we analyze the rationale for an energy policy mix when the European Emissions Trading Scheme (ETS) is considered from a public choice perspective. That is, we argue that the economic textbook model of the ETS implausibly assumes (1) efficient policy design and (2) climate protection as the single objective of policy intervention. Contrary to these assumptions, we propose that the ETS originates from a political bargaining game within a context of multiple policy objectives. In particular, the emission cap is negotiated between regulators and emitters with the emitters' abatement costs as crucial bargaining variable. This public choice view yields striking implications for an optimal policy mix comprising RES supporting policies. Whereas the textbook model implies that the ETS alone provides sufficient climate protection, our analysis suggests that support for renewable energies (1) contributes to a more effective ETS design and (2) may even increase the overall efficiency of climate and energy policy if other externalities and policy objectives besides climate protection are considered. Thus, our analysis also shows that a public choice view not necessarily entails negative evaluations concerning efficiency and effectiveness of a policy mix.

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E. Gawel · P. Lehmann
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

S. Strunz (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: sebastian.strunz@ufz.de

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1 Introduction

The current mix of policies in European climate and energy policy consists most prominently of the EU Emissions Trading Scheme (ETS) on the European level and additional policies supporting renewable energy sources (RES) on the level of member states. Started in 2005 and entering its third trading period in 2013, the ETS sets an overall cap on CO_2 emissions in the EU. Following the economics textbook, the ETS corrects externalities from CO_2 emissions in a cost-effective manner as its trading mechanism minimizes the costs of emission reductions. On top of the ETS, the member states of the EU employ policies supporting RES. Since 2009, member states have legally binding targets concerning their national share of RES. Via these RES targets and policies, member states express different levels of ambition and different technology priorities. This policy mix of a European cap-and-trade system and national RES-support schemes draws harsh critique concerning efficiency and effectiveness of policy intervention.

Several mainstream economists argue that the ETS suffices for optimal climate and energy policy, whereas additional instruments only reduce overall efficiency (e.g., Sinn 2011). From this perspective, the ETS represents a first-best policy instrument which ensures that anthropogenic climate change is strictly limited to an optimal (or at least politically determined) level. Hence, there is no need for additional policy instruments, which interfere with the ETS in a detrimental way: for instance, subsidies for RES undermine the carbon price within the ETS, thereby distorting the trading mechanism's price signal (Fankhauser et al. 2010). Thus, pushing relatively costly RES technologies into the market increases the overall social cost of climate protection and reduces the efficiency of policy intervention. In this way, RES subsidies may also lower public acceptance of renewable energies (Frondel et al. 2012) and thus may reduce the political leeway for climate protection in general (Weimann 2008).

While mainstream economists find fault with the efficiency of the policy mix, others question the effectiveness of the policy mix due to regulatory capture. Helm (2010: 195) argues that "capture has, indeed, been the norm rather than the exception." In particular, the ETS abounds in loopholes and only simulates effective climate protection. So far, ETS-related effective emission reductions have not occurred and cannot be expected to occur in the future, since "the EU ETS avoids the politically difficult cases having to be addressed" (ibid.: 190). Similarly, Spash (2010: 169) suggests that emissions trading "is creating a distraction from the need for changing human behavior, institutions and infrastructure" and likens mainstream economists' approval of emissions trading to the drug "soma" in Aldous Huxley's novel "Brave New World." From this view, European climate and energy policy appears as another instance of "simulative politics" that only "sustains the unsustainable" without effectively addressing environmental problems (Blühdorn 2007).

Thus, there is the puzzling situation that European climate and energy policy is criticized from two different directions—both resulting in very negative assessments of the current policy mix. While the attacks on RES-support policies draw on *efficiency* arguments from the economics textbook, the critiques of the *effectiveness* of the ETS follow from a public choice perspective on regulation. In their extremes, however, both alternatives seem to be futile for practical policy advice: either one strives in vain for the attainment of ideal, textbook-like policies or one succumbs to a fatalist diagnosis of merely symbolic politics.

Other approaches in the literature, which employ a realistic public choice view on climate and energy policy without a fatalist stance, appear to be more useful: Brunner et al. (2012) provide specific policy recommendations on how to address the commitment problem of climate policy. Hanoteau (2005) establishes a political-economy model of emissions trading, which shows how stringency of regulation might be increased by free allocation of allowances.

Hence, the literature so far provides specific public choice analyses of stand-alone ETS on the one hand and general discussions of the policy mix on the other hand (e.g., Sijm 2005; Kemfert and Diekmann 2009; Lehmann and Gawel 2013). What is lacking from the literature, however, is a public choice analysis of how the current main instruments of European climate and energy policy interact. To fill this gap, we assess the impacts of additional RES-support policies on the ETS from a public choice perspective. In particular, we analyze the specific rationale for a policy mix when the ETS originates from a political bargaining game within a context of multiple policy objectives.

The analysis starts from a hypothetical reference case under which the ETS provides a sufficient first-best policy instrument. This case arises if (1) climate protection is the sole objective of energy policy intervention and (2) the design of the ETS corresponds to the idealized textbook model. The first assumption rests on the twofold premise that only market failures justify policy interventions and unregulated CO_2 emissions are the only relevant market failure related to energy provision. The second assumption implies an exogenously given, optimal emission cap perfectly implemented by efficient instrument design. However, we argue that policy objectives beyond climate protection, such as member states' RES targets or specific technology restrictions (e.g., Germany's nuclear phase out), must not be ignored. These objectives may be economically warranted—e.g., due to externalities arising from fossil-nuclear energy production (long-run risks of nuclear power, oil spills, security of supply)—or simply politically set. Furthermore, we point out that the design of the ETS should be conceptualized as the result from repeated bargaining games between regulators and interest groups which try to maximize their rents. Concluding that the real ETS cannot be expected to live up to the textbook's requirements, we examine what the relevant deviations imply for the design of climate and energy policy. We differentiate four possible cases which we address in turn (see Table 1).

We first replicate the reference case A (Chap. 2), where the ETS is efficiently designed and only meant to address climate change. In this case, additional RES policies are welfare-decreasing. We subsequently demonstrate that in case B (Chap. 3), where the emission cap results from continuous bargaining, RES-support schemes may increase the effectiveness of emissions trading. In particular, we argue

Table 1 Framework (own illustration)

		Objectives of regulation	
		Single objective: Climate protection	Multiple objectives/ externalities
ETS design	Corresponds to the textbook model	Case A (Chap. 2)	Case C (Chap. 4.1)
	Results from a political bargaining game	Case B (Chap. 3)	Case D (Chap. 4.2)

that the level of the politically set cap is not a function of the overall social costs of climate and energy policy; rather, the cap depends on the abatement costs of powerful ETS participants only. As the ETS abatement costs decrease with deployment of RES technologies, we expect RES policies to have a *positive* effect on the eventually politically feasible level of the ETS cap. This conclusion rests on the assumption that ETS participants (who benefit from lower allowance prices) are better able to influence political decisions than household electricity customers (who face higher retail electricity prices due to RES deployment). From this point of view, RES may help to attain more ambitious reduction targets. In case C (Chap. 4.1), we assume that the ETS is ideally designed yet multiple policy objectives need to be achieved. We point out that, following the classical Tinbergen rule, a policy mix is needed in this case to address multiple policy objectives at a least cost. Finally, we argue that in practice, climate and energy policy most likely operates in a context such as case D (Chap. 4.2), where the ETS needs to be continuously negotiated and multiple objectives are to be attained. This makes a strong case for additional instruments supporting RES. First, RES policies help to reduce the political costs of implementing emission reductions. Second, RES support may actually improve the overall efficiency of climate and energy policy as it helps to internalize other externalities than climate change if corresponding first-best policies are not enforceable.

2 Reference Case: Ideal Emissions Trading for Climate Protection

Under case A, optimal climate protection is the only regulatory goal that complements energy policy's main objective of providing efficient energy supply. Furthermore, the ETS is efficiently designed: the emission cap E is exogenously given and corresponds to the optimal level E* where marginal abatement costs exactly equal the marginal social damages from climate change. Under these circumstances, the ETS perfectly internalizes the climate change externality, and additional policies only undermine the Emissions Trading Scheme (Fankhauser et al. 2010; Frondel et al. 2008, 2010, 2012; Paltsev et al. 2009; Sinn 2011; Weimann 2008).

Let us restate this argument in more formal terms. With:

K—aggregate abatement costs of ETS-regulated sectors
D—difference costs of renewable compared to conventional energy sources ($D > 0$)
C—social costs of climate and energy policy ($C = K + D + S_1$)
$\bar{E}$—emission cap
θ—share of RES in the overall electricity mix, with $\theta \in [0;1]$
S_1— climate change-related damages

The social costs of climate and energy policy C depend on the share of RES in the following way:

$$\begin{aligned} &C(\theta) = K(\theta; \bar{E}^*) + D(\theta) + S_1(\bar{E}^*) \text{ with } \frac{dC}{d\theta} > 0 \text{ as} \\ &\frac{dK}{d\theta} < 0, \ \frac{dD}{d\theta} > 0, \ \frac{dS_1}{d\theta} = 0 \text{ and} \\ &\frac{dD}{d\theta} > \left|\frac{dK}{d\theta}\right|. \end{aligned} \tag{1}$$

In this setting, as the emission cap is fixed at the optimal level $\bar{E}^*$, the RES subsidies have no effect on the level of climate damages S_1. They only affect the ETS abatement costs K and the RES-related difference costs D. On the one hand, pushing RES into the energy market lowers the demand for emission permits and brings down permit prices. Thus, RES subsidies reduce abatement costs for ETS participants. On the other hand, the overall expenses for RES increase in θ since RES are currently more expensive than conventional energy sources. The first-order condition for static optimality would require that these effects are of equal size so that $\frac{dD}{d\theta} = -\frac{dK}{d\theta}$. However, the technology-oriented climate policy supporting RES in addition to the (optimal) cap $\bar{E}^*$ is very likely not to lead to a least-cost way of overall emission reductions. Hence, the specific policy mix and the share of RES ($\theta > 0$) are most likely inefficient and $\frac{dD}{d\theta} > \left|\frac{dK}{d\theta}\right|$.

Consequently, under case A, the social costs of climate and energy policy C increase in θ. RES do not lower the overall level of emissions. They only yield a distortion of the energy mix by inducing inefficient technology substitution. That is, emission reductions for climate protection cost more than necessary and the policy mix is inefficient.

3 Emissions Trading Under Political Bargaining for Climate Protection

3.1 The Public Choice Approach for Instrument Design

In this chapter, we relax the assumption that the ETS is ideally designed. Instead, we analyze how political bargaining affects the actual ETS if climate protection is the only policy objective (case B in Table 1). In particular, we ask how additional RES-support policies bear on the negotiation of the emission cap.

To that aim, standard assumptions of the public choice approach concerning the main actors involved in environmental policy making are assumed to hold. Commonly, three actor groups are identified: (1) voters, (2) politicians/regulators, and (3) regulated industries' interest groups.[1]

1. Voters are rational agents who cast their votes in accordance with their self-interest so as to maximize their expected utility (Downs 1957). While non-monetary interests such as environmental preferences may also form part of voters' self-interest, economic motives might often be of primary concern. For instance, Scruggs and Benegal (2012) show empirically that public opinion on the importance of climate protection crucially depends on the state of the economy—in particular, the financial and economic crisis in Europe starting in 2008 entailed a substantial decline in public concern about climate change.
2. Emitting industries and their interest groups aim at minimizing the burden of environmental regulation. Olson (1965) und Tullock (1967) propose the concepts of rent-seeking and regulatory capture to explain how small, well-organized interest groups are capable of affecting policy design in order to extort resources to the detriment of less organized interest groups and the wider public. Kirchgässner and Schneider (2003: 379) list several reasons why industry interest groups are "not only better organized than environmental interest groups but also better suited to achieve their self-interested goals."
3. Politicians act as transfer brokers who redistribute welfare from less organized groups within the society to well-organized groups (McCormick and Tollison 1981). Politicians' main motivation is to get (re-)elected. Yet, in a "politics without romance" view (Buchanan 1984), this does not lead to the naïve conclusion that politicians generally try to maximize social welfare. Rather, their brokering activities serve to foster support from the recipients of redistribution, be it local constituencies, interest groups, or specific parts of the electorate.

Assumptions (2) and (3) constitute the main theoretical background for the discussion below. Assumption (1) is implicitly included in assumption (3) as voters' preferences are at least one explanatory variable for politicians' choices.

Table 2 provides an overview of those parts of our argument which are based on these public choice assumptions. In addition, there can be found empirical confirmation for the hypotheses used. Therefore, Table 2 also contains the available empirical evidence that substantiates the different claims. The following sections unfold the respective arguments in detail.

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[1] Often public bureaucrats are included as a fourth actor group. Yet in this paper, we do not analyze the specific effects of bureaucrats' involvement in policy design. Note, however, that adding bureaucrats would only contribute to our argument that policy design should be assumed to be far from optimal.

Table 2 Overview of empirical evidence (own illustration)

Argument	Support	Sources
Interest group influence on ETS design (Sect. 3.2)	Strong empirical evidence	Markussen and Svendsen (2005), Anger et al. (2008), Skodvin et al. (2010)
Interest group influence on RES policies (Sect. 3.3)	Strong empirical evidence	Jenner et al. (2012), Dagger (2009)
Lower abatement costs make tighter cap negotiable (Sect. 3.3)	Tentative empirical support	COM (2008a), COM (2008b)

3.2 ETS Design as a Result of Political Bargaining

Theoretical as well as empirical research suggests that the ETS's design is heavily influenced by industry lobbying. Lai (2008) derives analytical conditions for grandfathering of allowances to prevail in instrument design, and Hanoteau (2005) theoretically shows that the allocation mechanism should be particularly prone to lobbying. Indeed, the empirical findings fully corroborate this reasoning. Markussen and Svendsen (2005) demonstrate how interest groups successfully lobbied for a grandfathering of allowances during the introduction of the EU ETS in 2005. Also, the numerous exemptions from full auctioning during the scheme's revision in 2008 can be traced back to lobbying efforts (Skodvin et al. 2010). Anger et al.'s (2008: 17) empirical analysis of a cross-section of German firms shows the important effects of industry lobbying on the overall stringency of regulation:

> Our results suggest that those EU ETS sectors represented by more powerful interest groups have not only benefited from a preferential allocation of emissions allowances compared to other ETS sectors—they were also able to lower the abatement burden of the EU ETS as a whole at the expense of overall economic efficiency.

These results indicate that the emission cap cannot be assumed to correspond to some objective valuation process exogenous to the political process. A comparison of the current ETS allowance price and estimates for the marginal damages of emissions adds to that reasoning. In April 2013, the allowance price for 1 tonne of CO_2 fell below 3 euros. In contrast, Tol's meta-study (2012) estimates the average social cost of emitting 1 tonne of CO_2 between 5 and 76 euros, depending on the pure rate of time preference. In other words, only if the lowest estimates for climate damages are used as a reference, current allowance prices could be considered as optimal. It seems likely that an inefficiently lax cap contributes to the low allowance prices.

Therefore, the emission cap itself should be seen as a bargaining token—a variable that needs to be negotiated with affected parties. Section 3.2 addresses the question which independent variable(s) determine the emission cap in a more detailed, formal way. Empirically, the initial emission cap in the EU ETS was aligned to a business-as-usual emission scenario for affected industries (Heindl and Löschel 2012). That is, the initial trading period from 2005 to 2007 was intended to be a policy test phase, and only later trading periods are actually meant to effectively reduce emissions. The second trading period from 2008 to 2012 was also marked by significant over-allocation of emission allowances (Morris 2012). The third trading period from 2013 to 2020 introduces only an annually linear reduction of the cap by 1.74%. In other words, the task of negotiating effective emission reductions remains.

Thus, in the real-world context of Europe's climate and energy policy, the negotiation over the stringency of regulation is no one-shot game. Instead, regulators and interest groups will repeatedly debate the ETS cap: in order to attain the aims of the EU's Roadmap 2050, that is, almost full decarbonization of Europe within the next 40 years, the ETS would have to be extended and the cap significantly reduced. The declared prospect of both extension of the scheme and tightening of the cap increases the challenges for successful regulation. Helm (2010: 189) argues that "the political price of widening the scheme will inevitably be dilution." Thus, the argument that a dynamic perspective does not alleviate the challenges for a textbook-like design of the ETS is straightforward: a continuous tightening of the cap would have to overcome equally rising resistance of affected interest groups. Thus, the EU's commitment to climate protection suffers from regulatory uncertainty and a lack of credibility (Brunner et al. 2012). This commitment problem, in turn, reduces investment incentives (Dixit 1989, 1992) and leads to a dynamically inefficient ETS.

3.3 Bargained ETS and RES Support: Effectiveness and Efficiency of the Policy Mix

Assuming that the emission cap is no longer fixed but has to be negotiated, the decisive question becomes: which variable(s) determine the cap's stringency? In standard economic literature, it is suggested that a stricter cap becomes politically more feasible when the overall costs of climate and energy policy decrease (Weimann 2008: 56). Translating this view in the above notation, $\bar{E}$ is no longer fixed at $\bar{E}^*$ but a function $\bar{E}(C)$, with the emission cap increasing in the overall costs C, which in turn increase in the share of RES, θ. Thus, the standard argument yields:

$$\bar{E} = \bar{E}(C(\theta)) \quad \text{with} \quad \frac{d\bar{E}}{d\theta} = \frac{d\bar{E}}{dC}\frac{dC}{d\theta} > 0, \text{since}$$

$$\frac{d\bar{E}}{dC} > 0, \quad \text{assuming that} \quad \frac{dC}{d\vartheta} > 0 \tag{2}$$

In other words, the emission cap becomes more lenient if expensive RES technologies crowd out cheaper abatement possibilities. Not only does RES support make climate protection more expensive, but it also leads to *less* overall climate protection! In short, the standard argument contends that the more expensive actual emission reductions get, the less emission reductions are politically implementable.

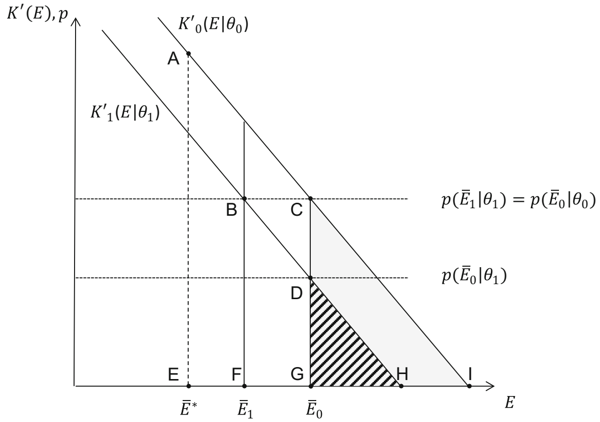
The main weakness of the argument that $\bar{E} = \bar{E}(C)$, even though describing a political interaction, is its lack of plausibility from a public choice point of view. If regulators were maximizing social welfare, they would jointly determine the share of RES and the emission cap so as to minimize the overall costs C of climate and energy policy. From a public choice perspective, however, both the emission cap and the share of RES should be considered as heavily influenced by lobbying. Thus, rather the abatement burden of regulated industries K should be seen as the politically decisive variable. In the above notation, the emission cap then depends on the abatement costs within the ETS, or $\bar{E} = \bar{E}(K)$. This claim builds on the organizational advantages of powerful industry interest groups as compared to the wider public (see assumption (2) above). Regulators must "sell" the emission regulation to a well-organized lobby. One way to achieve this consists in transferring part of the abatement burden *outside* the ETS. It turns out that RES-support policies—by lowering the ETS abatement costs—exactly fulfill this transfer function:

$$\bar{E} = \bar{E}\left(K(\theta)\right) \text{ with } \frac{d\bar{E}}{d\theta} = \frac{d\bar{E}}{dK}\frac{dK}{d\theta} < 0, \quad \text{since} \frac{d\bar{E}}{dK} > 0 \text{ and } \frac{dK}{d\theta} < 0. \tag{3}$$

In other words, supporting RES makes a stricter emission cap feasible because it lowers the abatement burden of affected industries. Figure 1 illustrates this point.

Without RES deployment (i.e., $\theta_0 = 0$), emitting industries' demand for allowances is given by their aggregated marginal abatement cost curve K'_0. In this situation, the initially bargained emission cap $\bar{E}_0$ ($>\bar{E}^*$) leads to abatement costs represented by the gray triangle CGI. Climate policy misses effective and efficient cap design since in that case the burden AEI is politically not feasible. Introducing RES deployment (i.e., implementing θ_1) shifts the emitting industries' marginal abatement cost curve to the left: RES crowd out electricity production by fossil

Fig. 1 Interaction between ETS abatement costs and RES (own illustration)



fuels, which decreases the demand for emission allowances.[2] This, in turn, means lower allowance prices and reduced abatement costs (shaded triangle DGH). Yet this also involves space for bargaining and tightening the cap: compared to the initial situation with $\bar{E}_0$ and θ_0, emitting industries now would be better off at any $\bar{E}_1 < \bar{E} < \bar{E}_0$ because tightening the cap to $\bar{E}_1$ would just keep the industry's abatement burden constant (BFH = CGI). Thus, regulators' bargaining position improves and some $\bar{E}_1 < \bar{E} < \bar{E}_0$ should become negotiable. Furthermore, Fig. 1 implies that if the optimal emission cap $\bar{E}^*$ is stricter than $\bar{E}_1$, increased RES deployment contributes to a more efficient cap. While $\bar{E}^*$ might not be politically feasible (or not exactly known at all), RES deployment may at least help to shift the emission level in the right direction. Since $\bar{E}^*$ is politically not available, the policy mix including RES supporting policy has to be compared with the situation given in $\bar{E}_0$ which is neither effective nor efficient.

The additional costs of RES policies, in turn, are primarily borne by electricity customers as subsidies are funded from a surcharge on the retail electricity price. It is eventually primarily households and small and medium enterprises (SME) who pay for RES policies because large industry customers are often widely exempted from the surcharge, as in Germany, for example. In fact, the latter may actually benefit from declining wholesale electricity prices which (also) result from decreasing CO_2 allowance prices. Thus, RES policies redistribute some of the costs of climate protection from emitting industries to the wider public (see assumption (3) above). Furthermore, RES-support policies act as a kind of stakeholder support (Bennear und Stavins 2007) for advocates of stricter emission caps and the transition to a renewable system. The higher the share of RES, the more convincing the position of environmental groups calling for more climate protection. In sum, RES-support policies could be interpreted as the "political price" to pay for stricter emission caps. Obviously, the level of RES support may also be influenced by lobbying activities of producers of RES technologies (Jenner et al. 2012; Dagger 2009). In the above terminology, the difference costs D are in this case not only technically determined (price difference of RES and conventional energy sources) but also resulting from a bargaining process between green industries and the regulator. That is, the more successful green industries' lobbying efforts are, the higher the level of remunerations and the higher D.

What does assumption (3) imply for the efficiency of the policy mix? The overall costs of climate and energy policy, using Eq. (3), read:

$$C(\theta) = K(\bar{E}(K(\theta)); \theta) + D(\theta) + S_1(\bar{E}(K(\theta))) \tag{4}$$

First observe that θ is the only independent variable here because $\bar{E}$ just mediates the indirect effects of θ on K and S_1. An analytical solution of (4) for the optimal θ

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[2] For instance, Weigt et al. (2012) show that between 2006 and 2010, German RES production reduced CO_2 emissions from the German electricity sector by 10–16% compared to a scenario without RES.

would require balancing all the direct and indirect effects of θ, which is mathematically not straightforward.[3] However, some hypothetical static equilibrium choice of θ is irrelevant here and would miss the point: we are asking whether, under condition (3), RES deployment necessarily decreases overall welfare. This is not the case as the sign of $\frac{\mathrm{dC}}{\mathrm{d}\theta}$ is indetermined:

$$\frac{\mathrm{dC}}{\mathrm{d}\theta}=\frac{\partial K}{\partial \bar{\mathrm{E}}}\frac{\mathrm{d}\bar{\mathrm{E}}}{\mathrm{dK}}\frac{\mathrm{dK}}{\mathrm{d}\theta}+\frac{\partial K}{\partial \theta}+\frac{\mathrm{dD}}{\mathrm{d}\theta}+\frac{\mathrm{dS}_1}{\mathrm{d}\bar{\mathrm{E}}}\frac{\mathrm{d}\bar{\mathrm{E}}}{\mathrm{dK}}\frac{\mathrm{dK}}{\mathrm{d}\theta}>< 0 \tag{5}$$

The direct and indirect effects of θ may balance (5) in either way: the first term on the right-hand side, the indirect effects of RES on the abatement costs via making a tighter emission cap politically feasible, is positive. The second term, the direct effect of RES on the abatement costs through a lower demand for emission allowances, is negative. The third term, the increase in difference costs from a rise in RES, is positive, and the fourth term, the indirect effect of RES on climate damages through a tighter emission cap, is negative. In sum, the combined effects of RES on overall welfare are unclear if the impacts of RES on the ETS cap are taken into account.

4 Emissions Trading Under Multiple Policy Objectives

4.1 Ideal Policy Design: Case C

Under case C, a textbook-like ETS faces a regulatory system consisting of multiple policy objectives, e.g., several energy-related externalities to be addressed at the same time. Since Tinbergen (1952), it is an established result that there must be at least one policy instrument for each independent policy objective. To be effective, the number of instruments must exactly match the number of objectives. The context of climate and energy policy is no exception in that respect (see, e.g., Jensen and Skytte 2003; Knudson 2009). Thus, even an ideally designed ETS cannot attain a system of multiple policy objectives.

There are two different ways to make sense of the multitude of policy objectives, such as RES targets, efficiency targets, or technology-specific targets. On the one hand, it might be argued that the numerous goals in European climate and energy policy lead to unnecessary distortion of energy markets. In this view, all objectives besides climate protection are to be neglected. On the other hand, the objectives could be interpreted as a legitimate representation of citizens' preferences (e.g., regarding the desired technology mix) or a second-best attempt at internalizing non-climate externalities (e.g., RES targets as one way of limiting the scale of damages generated during production and transport of fossil fuels if direct first-

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[3] In Eq. (4), the first term on the right hand side contains a problematic circularity in that K depends on $\bar{\mathrm{E}}$, which in turn depends on K.

best regulation is politically not feasible). This would imply that the objectives are not devoid of economic logic. Sure enough, this question is a topic of its own and cannot be addressed here in detail (see for a discussion Gawel et al. 2013). However, it seems fair to say that a realistic representation of climate and energy policy in Europe cannot content itself with climate protection: while on the EU level politicians struggle to establish a common climate policy, on the national level member states pursue a broad set of openly diverging objectives, especially within the field of energy policy.

In the following, it is assumed that there are other externalities besides climate change (say, oil spill and nuclear risks) that justify additional environmental objectives next to climate protection. How does the introduction of RES-support policies affect overall costs of climate and energy policy when an ideally designed ETS is already in place? To answer this question, add a new damage term S_2 to Eq. (1), which gives Eq. (6). S_2 represents non-climate change-related damages of fossil-nuclear energy production, such as oil spills or radiation damages from nuclear power:

$$\begin{aligned} & \mathrm{C}(\theta) = \mathrm{K}\left(\theta; \bar{\mathrm{E}}^*\right) + \mathrm{D}(\theta) + \mathrm{S}_1\left(\bar{\mathrm{E}}^*\right) + \mathrm{S}_2(\theta) \\ & \text{with } \frac{\mathrm{dC}}{\mathrm{d}\theta} >< 0 \quad \text{since} \\ & \frac{\mathrm{dK}}{\mathrm{d}\theta} < 0, \ \ \frac{\mathrm{dD}}{\mathrm{d}\theta} > 0, \ \ \frac{\mathrm{dS}_1}{\mathrm{d}\theta} = 0 \quad \text{and} \quad \frac{\mathrm{dS}_2}{\mathrm{d}\theta} < 0 \end{aligned} \tag{6}$$

Thus, a new, positive effect of increased RES deployment on the social cost of climate and energy policy enters the picture. In consequence, the sign of $\frac{\mathrm{dC}}{\mathrm{d}\theta}$ is indetermined. As long as the difference costs for RES are higher than their benefit in terms of reduced S_2 damages and reduced ETS abatement costs, the social cost of policy intervention increases. If the reduction in S_2 and ETS abatement costs outweighs the deployment costs, RES lower the social cost of climate and energy policy. As the cap is fixed, climate protection remains optimal, whatever the level of RES expenditures.

4.2 Political Bargaining: Case D

Under case D, the ETS design results from negotiations with affected parties, and a regulatory system consisting of multiple policy objectives is in place. Arguably, case D represents the most realistic setting, as it neither assumes ideal policy design nor reduces all externalities to climate protection. This setting reinforces the argument for a policy mix that includes other instruments beyond emissions trading.

In order to account for the political genesis of the ETS, assume that $\bar{\mathrm{E}} = \bar{\mathrm{E}}(\mathrm{K})$. Furthermore, consider additional non-climate damages S_2. Introducing RES-support policies in this setting, the social cost of climate and energy policy reads:

$$\mathrm{C}(\theta) = \mathrm{K}(\bar{\mathrm{E}}(\mathrm{K}(\theta)); \theta) + \mathrm{D}(\theta) + \mathrm{S}_1(\bar{\mathrm{E}}(\mathrm{K}(\theta))) + \mathrm{S}_2(\theta) \tag{7}$$

with $\frac{\mathrm{dC}}{\mathrm{d}\theta} >< 0$ since

$\frac{\partial K}{\partial \bar{\mathrm{E}}} \frac{\mathrm{d}\bar{\mathrm{E}}}{\mathrm{dK}} \frac{\mathrm{dK}}{\mathrm{d}\theta} > 0$ (i) indirect effect on abatement costs
$\frac{\partial K}{\partial \theta} < 0$ (ii) direct effect on abatement costs
$\frac{\mathrm{dD}}{\mathrm{d}\theta} > 0$ (iii) difference costs
$\frac{\mathrm{dS}_1}{\mathrm{d}\bar{\mathrm{E}}} \frac{\mathrm{d}\bar{\mathrm{E}}}{\mathrm{dK}} \frac{\mathrm{dK}}{\mathrm{d}\theta} < 0$ (iv) indirect effect on climate damages
$\frac{\mathrm{dS}_2}{\mathrm{d}\theta} < 0$ (v) direct effect on non-climate damages

Again, solving (7) for static equilibrium values of θ would face a circularity problem (within the indirect effect on abatement costs), but hypothetical optimal choices are irrelevant for our public choice argument. Instead, the relevant question is whether θ necessarily decreases overall welfare. In Eq. (7), this claim can be refuted: subsidized RES deployment reduces overall social costs via three terms—the direct effect on ETS abatement (ii), the indirect effect on climate damages (iv), and the direct effect on non-climate damages (v). In contrast, subsidized RES deployment increases overall social costs via two channels—the indirect effect on abatement costs (i) and the difference costs (iii). Thus, the sign of $\frac{dC}{d\theta}$ is a priori indetermined and depends on the relative weight of positive and negative terms. It is clear, however, that under case D, the argument for RES-support policies is stronger and the argument for ETS as a single instrument is weaker than under all other cases A–C.

Moreover, it may be noted that some authors argue for a long-term perspective on $\frac{\mathrm{dD}}{\mathrm{d}\theta}$ with increasing costs of fossil energy carriers and decreasing costs of RES (Nitsch et al. 2012). Hence, in the long run $\frac{\mathrm{dD}}{\mathrm{d}\theta} < 0$ might become more likely, and this prospect increases the probability of $\frac{\mathrm{dC}}{\mathrm{d}\theta} < 0$. Furthermore, energy systems have been optimized for producing and transporting energy from fossil fuels. In other words, they are characterized by a very high degree of path dependency (Goldthau and Sovacool 2011), also termed "carbon lock-in" (Unruh 2000). Considering the long-term cost scenarios, it may, therefore, be beneficial to subsidize current RES deployment in order to overcome the path dependency in energy systems (Lehmann et al. 2012; Lehmann and Gawel 2013).

5 Discussion and Outlook

An evaluation of the policy mix in European climate and energy policy critically depends on the perspective applied to policy objectives and instrument design. A narrow focus on textbook-like emissions trading and climate protection yields a fundamentally different assessment than a public choice perspective applied to a setting of diverse policy objectives and multiple externalities. Table 3 summarizes the results of the differentiated analysis carried out in this paper. Evidently, the mainstream argument on the harmful consequences of RES-support policies to the detriment of the ETS as a first-best policy instrument only holds under the restrictive assumptions of case A. In the other cases B, C, and D, the effect of RES-support policies on the overall social cost of policy intervention is not that clear as often argued. In particular in case D, where not only climate externalities are considered and the ETS must be negotiated with vested interests, the deployment of RES may even have positive effects on the efficiency of the policy mix. In sum, RES-support policies do not necessarily decrease the efficiency of climate and energy policy, and they are not necessarily irrelevant for the overall GHG emissions.

Besides efficiency of the policy mix, the effectiveness of the deployed instruments is of main concern. Here, our analysis provides a strong argument for including RES-support policies in the policy mix because RES subsidies could improve the effectiveness of the ETS. By lowering the allowance price and abatement costs, RES subsidies make a tighter emission cap negotiable. This relation holds if the emission cap derives from a bargaining process between regulators and emitters. In conclusion, RES subsidies might be interpreted as the "political price" to pay for introducing and tightening an emission cap.

These results rely on stylized model assumptions, which raises the question of their empirical plausibility (see Table 2). Since our argument "RES-subsidies make a tighter emission cap negotiable" points to a possibility, rather than claiming an inevitable development, it is not possible to instantly refute or confirm it on an empirical basis. However, a closer look at the current status of and the prospects for the EU ETS highlights some critical issues.

First, our argument may be supported from the fact that the EU, within its "20/20/20" package, simultaneously established goals for emission reductions and RES buildup. That is, RES projections were included when devising the ETS targets (COM 2008a, b). Yet ex ante RES production can only be estimated, and actual RES

Table 3 Overview of results (own illustration)

		Objectives of regulation	
		Single objective: climate protection	Multiple objectives
ETS design	Corresponds to the textbook model	Cap: $\bar{E} = \bar{E}^*$ Externalities: S_1 $d\bar{E}/d\theta = 0$ $dC/d\theta > 0$ **Case A**	Cap: $\bar{E} = \bar{E}^*$ Externalities: S_1, S_2 $d\bar{E}/d\theta = 0$ $dC/d\theta ? 0$ **Case C**
	Results from a political bargaining game	Cap: $\bar{E}(K(\theta))$ Externalities: S_1 $d\bar{E}/d\theta < 0$ $dC/d\theta ? 0$ **Case B**	Cap: $\bar{E}(K(\theta))$ Externalities: S_1, S_2 $d\bar{E}/d\theta < 0$ $dC/d\theta ? 0$ **Case D**

production might turn out higher (smaller) than expected, as has been the case in Germany, for instance.

Second, however, iteratively tightening the cap ex post, depending on prior RES progress, is not unproblematic. Changing the cap retrospectively "could possibly also entail counterproductive effects" (Matthes 2010: 34) because it increases uncertainty for affected industries which in turn might further erode the dynamic efficiency of the ETS. Also, the current discussion about "backloading" some of the allowances for trading period III indicates the resistance that each proposal to tighten the cap will be met with. Thus, even low allowance prices and correspondingly low ETS abatement costs do by no means guarantee a stricter emission cap.

Finally, the proposed mechanism may become more relevant the longer the time horizon. So far, the ETS has been closely aligned to the emitters' business-as-usual (Heindl and Löschel 2012). Until 2020, the EU has set a linear cap reduction factor of -1.74% annually (basis year 2010). It is clear that extrapolating this trend will not provide for the ambitious goal of an almost carbon-free economy in 2050. In other words, the really hard ETS negotiations are still to come—and the further cap stringency will have to deviate from business as usual, the more important (ceteris paribus) the level of RES diffusion.

As the influence of powerful interest groups on policy making cannot be assumed away—in the real world, that is—the question is how to deal with this influence when giving policy advice. Two diametrically opposed reactions exist. First, it is suggested that economists should engage in "lobbying for efficiency" (Anthoff and Hahn 2010), thereby providing a counterweight to special interests in order to increase overall efficiency. In a similar vein, Helm (2010: 194) advises politicians to reap the "premium on simplicity" by implementing simple policy schemes which are "harder to capture" than complex schemes. However, this appears almost tautologically considering that it is the very influence of organized interests that causes the complexity of policy regimes. Second, Spash (2010: 192) suggests that we abandon all hope that ineffective instruments like the ETS could be saved from dilution and capture: "After all, the reason for emissions trading is that corporations and the technostructure proved too powerful for the political process to establish a tax or direct regulation in the first place." Consequently, in a rather pessimistic outlook, Spash (ibid.) estimates that only fundamental (and unlikely) changes in "economic structure, institutions and behaviour" could remedy the situation.

Yet we believe that viable policy advice can neither build on combating the influence of organized interests nor on visionary social change. Instead of treating vested interests as a lamentable characteristic of politics, we propose to accept the interest-driven process of policy design and implementation as a necessary background for policy advice. Thus, political feasibility should be a main criterion when evaluating current policies and drafting recommendations (Gawel et al. 2012).

From this perspective, we argue that the interaction of EU ETS and national RES policies may be quite useful: making the ETS more effective by tightening the cap is probably one of the top priorities in current European climate and energy policy. Here our analysis provides an additional, hitherto overlooked justification for RES-support policies: by transferring some of the abatement burden outside the

ETS sectors, RES policies strengthen the EU's bargaining position toward emitting industries. Moreover, addressing non-climate externalities by second-best technology-oriented policies (nuclear phase out, RES support) might be considered a pragmatic satisficing policy approach if first-best policies are not available or create prohibitive political cost. Thus, supporting RES in general (albeit deficiencies in detail) might be in a sense a well-nigh clever contribution in practice to the aims of least-cost and effective energy and climate policy under real-world conditions.

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Between Energy Transition and Internal Market Agenda: The Impact of the EU Commission as a Distinct Energy Policy Actor

Sebastian Strunz, Erik Gawel, and Paul Lehmann

Abstract The EU Commission has newly evolved into a leading energy policy actor. At the same time, the Commission's proclamation of an "Energy Union" depicts a visionary future rather than the current reality: the internal energy market still awaits full integration and the transition towards a sustainable energy system is taking place largely on the national level (e.g., the *Energiewende* in Germany). To shed some light on this muddled situation, we analyse the Commission's promotion of the internal market and policy harmonisation/centralisation from an economic perspective along two dimensions. First, on the *content* dimension, we investigate whether the double challenge of decarbonising the energy system and finalising the internal market exhibits trade-offs. Second, on the *form* dimension, we outline the benefits of (de)centralising energy policies. For both dimensions, we build on the theory of fiscal federalism to elucidate the normative aspects of the discussion and the Public Choice approach to positively explain the emergence of the current situation. Overall, we find that the normative policy evaluation indeed differs in some respects from the Commission's positions, while the latter can be well explained via the Public Choice approach.

1 Introduction

The European Union (EU), as a descendant of the *European Coal and Steel Community* of the 1950s, displays a long history of debate on the energy sector. This "long energy journey" (Buchan and Keay 2016) is still continuing—with a

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S. Strunz (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: sebastian.strunz@ufz.de

E. Gawel · P. Lehmann
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

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number of related but distinguishable issues currently driving the discussion. First, this concerns the preferable course of energy policies with respect to the double challenge of tackling climate change and fully integrating the internal market. Second, this concerns the issue of how (de)centralised energy policy should be. Within these problem areas, different disciplines have also chosen different analytical foci. From a legal perspective, the development of EU law and its impact on national energy policies has been at the centre of attention (e.g., Callies and Hey 2013; von Unger 2014). The political science literature has analysed, amongst other issues, the interactions between actors, interests and institutions on different levels of governance (e.g., Knodt 2010; Ohlhorst 2016). The economic discussion has most heatedly debated whether (and, if so, which) renewable energy support policies are effective and efficient climate policy instruments (e.g., Lehmann and Gawel 2013; Stavins 2014). However, a comprehensive politico-economic analysis of the double challenge of tackling climate change and fully integrating the internal market is lacking.

The overlap of competences between the national and the EU level further complicates the issue. Prior to the Lisbon treaty, energy policy had not been a formal competency of the EU. So it was only in 2009 when the Lisbon treaty entered into force, that energy policy was established as a co-responsibility of the EU—thereby strengthening the Commission's position. Then again, Member States explicitly stipulated their sovereignty over national energy mixes (Art. 194 TFEU). As a result, frictions remain inevitable—this concerns both substantial differences on how to square climate policy and the internal market agenda, as well as struggles over competences.

The analytical starting point of this paper, then, is that in order to clarify the discussion, two dimensions should be distinguished. First, the *content* dimension (*what is the vision for the energy system?*) revolves around the double challenge of decarbonisation and market integration. Second, the *form* dimension (*who decides upon energy policy?*), pertains to the issue of the appropriate degree of (de) centralisation. Certainly, these dimensions appear often mixed within the discussion: For instance, it is often argued that, based on the supposed overall cost savings from coordinated deployment of renewables, support for renewables should be organised in a more centralised way (e.g., Bigerna et al. 2016). What is more, the EU Commission, as a pivotal actor within EU energy policy debates (e.g., Thaler 2016; cf. Steinebach and Knill 2017), makes the case for connecting both dimensions in practice: the "Energy Union" is said to meet all challenges and suit all regional and national interests (e.g., energy security) best. Specifically, the EU Commission (2015) seems to provide two answers to the above questions. With respect to the *content* dimension, the Commission contends that the internal market is broadly compatible with the sustainability transformation of the energy system. Procedurally, the internal market principle dominates other interests such as the climate challenge in the sense that the burden of proof always lies with those who argue that a deviation from the market principle is unavoidable. With respect to the *form* dimension, the Commission argues that, in line with the internal market agenda, decision-making should move towards more centralisation and towards harmonised policies.

In this paper, we aim to scrutinise the Commission's position critically. First, we review whether the Commission's positions rest on economically sensible grounds, i.e. we take a normative economic perspective. We condense this normative discussion into two propositions:

1. There is a trade-off between the goals of finalizing the internal market and the sustainable transformation of the energy system.
2. In order to manage this trade-off efficiently, a mix of centralisation and decentralisation is advisable.

Second, we analyse how the Commission's positions in terms of policy content and form are to be explained: How can the Commissions' efforts to centralise energy policies be accounted for theoretically, and how are the Commission's existing "co-governance" opportunities to be explained, given that member states still have the last word? By addressing these questions, we provide a positive analysis of the Commission's stance. For the purpose of this analysis, we adopt the public choice approach. This approach assumes that the self-interest of actors involved in the political process (voters, politicians, bureaucrats and interest groups) is the main explanatory criterion to understand policy outcomes (seminal Tullock 1967; see Kirchgässner and Schneider 2003 for an introduction). This perspective leads to a "politics without romance" (Buchanan 1984) view that does not expect policies to be welfare-maximizing, that is, efficient from a normative economic perspective. Rather, politicians act as brokers (McCormick and Tollison 1981), balancing different stakeholder interests so as to maximise their own special interest, which consists mainly in getting (re-)elected. Likewise, bureaucrats (Niskanen 1971) and interest groups (Olson 1971; Stigler 1971) aim to influence the political process in their favour—that is, they engage in "rent-seeking".

Based on this economic policy perspective, we derive and defend two hypotheses regarding the Commission's positions on *content* and *form* of energy policy:

1. *Content:* The Commission frames the internal market as the overarching principle, because this is where it has its legal competences.
2. *Form:* The Commission pushes for centralisation and harmonisation as this strengthens its position.

Based on the analysis of these hypotheses, it should become clearer why and in what way the Commission's positions deviate from our normative propositions as outlined above.

Meanwhile, in the political context of national energy policies, the Commission is exercising considerable impact. We illustrate the Commission's influence via the example of the guidelines on state aid for environmental protection and energy (EU Commission 2014) and their influence on Germany's renewable support. The 2014 reform of Germany's support scheme for renewable energies (the so-called RES Act) provides an illustrative case where the different issues discussed so far intersect: competing visions for the future of the energy system left their mark, and so did the debate on the appropriate governance level for energy policy.

The remainder of this paper is structured as follows: in the next section, the normative analysis, we sketch the potential trade-offs between the goals of decarbonizing the energy system and finalizing the internal market. Subsequently, in the positive analysis, we investigate how the Commission's positions and its influence on actual energy policies are to be accounted for theoretically and empirically. On that basis, we outline the Commission's impact on Germany's revision of the RES Act. Finally, we discuss and conclude our findings.

2 Normative Analysis: Does the Internal Market Guarantee Sustainability?

2.1 Content Dimension: Trade-Offs Between the Goals of Finalizing the Internal Market and the Sustainable Transformation of the Energy System

The official narrative put forward by the EU Commission, for instance in its Energy Union package (2015), reads that market integration and the sustainable transformation of the energy system are complementary goals; by implication, failure to move forward on the internal market front would endanger the EU's climate mitigation pledges: "the unavoidable challenge of moving towards a low-carbon economy will be made harder by the economic, social and environmental costs of having fragmented national energy markets" (EU Commission 2015: 3). To be sure, the Commission's case is partly well-founded: The main instrument of the EU's climate mitigation efforts is the emissions trading Scheme (EU ETS) and the latter's struggles to become an effective trigger for decarbonisation are also rooted in nationally fragmented perspectives on energy policy. In order to foster market-based emission regulation, the reduction of overlapping regulations and the gradual expansion of the scheme to hitherto non-ETS sectors has been advised (Böhringer 2014). This would be well in line with and contribute to the full integration of the internal market.

However, when looking beyond ETS functioning, several points of friction between the internal market vision and sustainability transformation policies begin to appear. To start with, Buchan and Keay (2016: 84) analyse "the tensions between two of the EU's main goals: a freely operating market and a secure low-carbon energy system." They trace these frictions back to two risks: First, interventions in favour of (or against) particular technologies undercut the idea of a single, common market area; second, such interventions render electricity price signals ineffective, thereby undermining the basis of liberalisation. In consequence, a "clash" between liberalisation and intervention is diagnosed: climate externalities warrant government interventions on an "unprecedented scale", yet "unless they are carried out on a consistent basis across the EU, [they] could threaten the whole basis of the single market in energy" (Buchan and Keay 2016: 13 f.).

Now the sustainability transformation of the energy system is more than decarbonisation, and other components need to be acknowledged as well: for instance, ecological sustainability concerns further externalities from conventional electricity production such as nuclear risks. Yet if the Commission's (2015: 2) vision of "an integrated continent-wide energy system where energy flows freely across borders, based on competition and the best possible use of resources" were realised, the decisions to phase out nuclear energy in Germany and Belgium[1] were somewhat subverted. Again, this points to an important tension at the heart of the integration project: While the internal market constitutes a main pillar of the EU, Article 194 (2) TFEU preserves the member states' rights to decide upon their national energy mix. Clearly, this contradiction can only be solved in one of two ways—either the free flow of energy across borders diminishes national control over the energy mix (e.g., substituting national nuclear production with imports of nuclear energy), or technological decisions on the national level limit the degree of overall integration of electricity markets.

Even more fundamental trade-offs emerge when sustainability is not reduced to the internalisation of environmental externalities but understood in the encompassing sense of intra- and intergenerational justice. Specific conceptions about a just societal organisation of energy systems may then clash with idea of a common market on the EU level. Critics of market-based policies have for a long time opposed the Commission's "neoliberal" course on energy policy (Lauber and Schenner 2011). Consider the Commission's push towards tender schemes in renewable energy support. Tender schemes are regularly criticised for endangering bottom-up transformation initiatives by decentralised actors such as communal energy cooperatives (Tews 2015; Michalena and Hills 2016). Furthermore, some include municipal ownership of utilities and distribution grids as an essential pillar in their vision of the sustainability transformation, which is consistently framed as a "decentralised energy revolution" (e.g., Burger and Weinmann 2013). Yet, local efforts to re-communalise (or to prevent privatisation of) distribution grids for gas and electricity have been inhibited by EU procurement law: for instance, as the German Federal Court of Justice decided in 2013 (Case No. KZR 65/12 und 66/12), municipalities cannot just refer to the principle of subsidiarity and local self-government when intending to attain or regain control over communal grids. Instead, they need to comply with EU procurement law and carry out transparent tender procedures where corporate bidders may naturally apply as well. In other words, the visions of "decentralised energy revolution" and "internal market" do not necessarily match.

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[1] While Germany is the focus of many pro/contra nuclear energy discussions, one should not forget other countries that have committed themselves to not using nuclear energy a long time ago, such as Italy or Austria, or non-Member States that will phase out nuclear energy, such as Switzerland.

What is more, empirical research shows that the deregulation of electricity markets has led to a decline in public renewable energy R&D (Smith and Urpelainen 2013; Grafström et al. 2017). The reason is that stronger competition yields lower profit margins and less room for investments in long-term energy technology innovation. But, due to the public good character of knowledge stocks, public R&D efforts form an essential part of long-term climate mitigation pledges. So here as well, the internal market agenda seems to work against the climate policy agenda.

The above discussion yields two implications: first, there is a clear role (economic rationale) for the state to intervene in energy markets in order to correct market failures. Second, the optimal degree of state intervention, which depends on value judgments varies according to the plurality of judgments: If preferences are heterogeneous, efficiency requires that the degree of state intervention be equally heterogeneous. This argument also underlies the discussion in the next subsection.

2.2 *Form Dimension: A Mix of Centralisation and Decentralisation to Manage the Trade-Offs Between Internal Market Agenda and Sustainability Transformation Efficiently*

Generally, there are reasonable arguments for and against centralisation of decision-making as well as for and against homogenisation of policies (for more extended discussions of these arguments, see Gawel et al. 2014a; Strunz et al. 2015 as well as chapter "Policy Convergence as a Multi-faceted Concept: The Case of Renewable Energy Policies in the EU" of this volume). In other words, there is a trade-off which implies that not all the benefits of both decentralisation and homogenisation can be reached at the same time.

The traditional argument for centralisation of decision-making highlights potential economies of scale and scope. Economies of scale arise when the centralised provision of public goods brings about lower average costs than decentralised provision. Economies of scope arise when centralised production of several outputs leads to lower costs than decentralised production. For instance, a centralised EU-wide deployment of RES could be more cost-efficient than national deployment because of lower administrative costs and optimised geographical allocation of RES capacities (assuming, for the moment, that local externalities are appropriately taken into account). In general, centralisation of decision-making is a means of addressing spillover effects (or positive and negative externalities) between smaller units.

In contrast, Oates' (1972, 1999) theory of Fiscal Federalism points to the beneficial role of decentralised government in tailoring the output of public goods according to local and regional preferences: if local preferences are heterogeneous, a differentiated provision of public goods is welfare-increasing. The second main argument against centralisation of decision-making points to the experimental function of decentralised problem-solving. In this "laboratory federalism" (Oates 1999; Ania and Wagener 2014) view, decentralisation provides the opportunities for trial-and-error problem solving on small scales. Compared to a centralised approach, a higher number of alternative policy options can be tested which raises the chances of finding better solutions: different policy options compete and their respective (dis) advantages can be assessed. Thus, lock-in effects might be avoided. Finally, discussions about the above trade-offs also should consider that centralisation and homogenisation need not necessarily align: in particular, homogeneous policies may arise without centralisation but via decentralised, bottom-up processes of convergence (see Kitzing et al. 2012 as well as Chapter "Policy convergence as a multi-faceted concept: the case of renewable energy policies in the EU" of this volume).

With regard to the trade-off between internal market agenda and sustainability transformation, it is impossible to objectively derive an optimal solution to the trade-off. Ideological commitments on the market vs. state debate inescapably affect the evaluation here. That said, the following general conclusions seem to be broadly supportable: First, since climate change represents a global challenge, a centrally coordinated climate policy approach, as manifested in the EU's emissions reduction goals and the Emissions Trading Scheme, is indeed recommendable. Second, with heterogeneous visions about the future energy system (e.g, which mix of technologies?), a fully centralised and uniform approach towards the sustainability transformation is not optimal. Third, even if we assume a very market-oriented stance (e.g., no preference for communal ownership over corporate ownership with respect to grids), the "laboratory federalism" argument recalls the merits of decentralised policy experiments.

In the next chapter, we investigate which factors (besides ideological reasons) lie behind the Commission's strong promotion of the internal market agenda.

3 Positive Analysis: The Agenda of the EU Commission from a Public Choice Perspective

3.1 Theoretical Background: The Public Choice Approach

The public choice perspective is based on the assumption that political decisions are predominantly determined by the self-interest of all actors involved in the political process, that is, voters, interest groups, politicians and bureaucrats. Traditionally, the lobbying efforts of interest groups are placed at the centre of the Puclic Choice approach: various interest groups compete in their aim to extract rents by steering regulation in their respective favor (Stigler 1971; Tullock 1967). For instance, with regard to the energy system, incumbent conventional industries try to defend their position against new RES producers. Within the quest for "regulatory capture" [see Dal Bó (2006) for a review], environmental concerns of voters and environmental interest groups are often considered less powerful than conventional industry interests (Olson 1971; Kirchgässner and Schneider 2003). That said, the RES sector in Germany has also become a powerful lobby (Sühlsen and Hisschemöller 2014).

The role of politicians has been described as transfer brokers between these competing interests (McCormick and Tollison 1981): they redistribute welfare between different stakeholders so as to secure public support and maximise their chances of electoral success. On the one hand, politicians may aim to influence electoral outcomes directly by addressing the interests of the median voter (Downs 1957). On the other hand, they may also strive to satisfy interest groups which may indirectly affect electoral success by launching (or not) public campaigns. Finally, bureaucracy constitutes an important element within the process of policy formation and implementation (Niskanen 1971): administrative officials aim at maximizing their discretionary power and their departments' budgets. This concerns all levels of government. While we will explore the EU Commission's incentive to centralise decision-making power on the EU level in more detail, analogous incentives prevail on lower governance levels: national governments aim at preserving Member States' decision-making-power, regional administrations oppose uniform policies (on EU and national level) and aim for regional specifications at their discretion.

In sum, one might speak of a layered system of political markets (cf. Keohane et al. 1998), where politicians try to balance supply of and demand for regulation. The best organised interests succeed in framing the demand for regulation. Importantly, this perspective does not neglect ideological motivations: Early on, public choice theory acknowledged the influence of politicians' own ideological motivations on the supply of regulation (Peltzman 1976). Thus, a comprehensive theoretical framework relies on the interplay of interests, ideas and institutions (cf. May and Jochim 2013). The crucial point here is that interest-based and ideologically motivated behaviour are not mutually exclusive categories of action. Rather, they are constantly interacting, leaving an institutional imprint, which, in turn, feeds back into motives and interests. Furthermore, some specific argument may be both interest-based and ideologically motivated: in particular, rent-seeking might be framed (cynically: disguised) as promoting the public interest.

3.2 Content Dimension: The Internal Market Agenda and the Commission's Legal Competences

The EU Commission traditionally defends a liberal vision of the internal market. It is part of a discursive issue network that upholds a strong market-orientation, coupled with continued support for market-based instruments—critics prefer to frame the Commission's stance as support for "neoliberal instruments" (Lauber and Schenner 2011), thereby evoking the negative connotations of the fuzzy term neoliberal. We will address the Commission's preference for specific policy instruments below, in Sect. 4. Here, we are concerned with the more general stance the Commission adopts by promoting the internal market.

In April 2014, the Commission proposed new guidelines concerning state aid for environmental protection and energy. While guidelines may sound harmless enough, state aid law provides a powerful lever the Commission has at its disposal to influence national energy policies. State aid law, therefore, also illustrates our proposition that ideological and formal/legal competences are tightly linked. Member States need to notify the EU Commission when they intend to implement a state aid (Article 108(3), TFEU); the Commission, in turn, investigates whether the state aid in question complies with its guidelines. The first two paragraphs of the 2014 guidelines (EU Commission 2014: 2) make the resulting power differential very explicit: "(1) In order to prevent State aid from distorting competition in the internal market and affecting trade between Member States in a way which is contrary to the common interest, ... State aid is prohibited. (2) ...the Commission may consider compatible market State aid to facilitate the development of certain economic activities within the EU, where such aid does not adversely affect trading conditions to an extent contrary to the common interest". Thus, whether national state aid can be considered as opposed to or in line with the EU's common interest, lies completely within the Commission's discretion. In view of this pivotal position, it has been argued that the Commission possesses "almost unrestricted veto power" over national state aid (Knauff 2017: 64).

The crux, of course, is: what makes a given legal measure state aid? Observe that the regulatory impact of a given measure will be the same, whether it legally counts as state aid that has been approved or whether it counts as regulation not pertinent to state aid law. From the Commission's perspective, however, the difference could not be bigger: in the first case, the Commission may actively influence the process of drafting national regulation via its veto power. In the second case, the Commission sees itself relegated to the role of spectator. Consequently, it is in the Commission's interest to frame national measures as state aid, the numerous exemptions from the general prohibition of state aid notwithstanding (Article 107(2,3) TFEU).

In practice, the Commission clearly tends to treat national measures as state aid requiring notification and approval. While Member States may decide to disagree, this may be a risky strategy for boundary cases. A negotiated compromise with the Commission to attain approval of some measure as state aid provides legal clarity, whereas the alternative may consist in prolonged legal uncertainty: the Commission may still decide to investigate and sue Member States at the EU Court of Justice for measures that have not been notified. Crucially, the standstill requirement (Article 88 TFEU) forces Member States to immediately suspend those provisions under investigation until a solution has been reached.

Indeed, Member States often fold under this pressure, Germany being case in point. The German government finally notified its support scheme for RES as state aid, and it did so against its explicit conviction that the German RES Act constitutes state aid in the sense of EU law (Knauff 2017). In the scientific debate, the Commission's judgment has been questioned as well (von Unger 2014; Gawel and Strunz 2014); even more interestingly though, seems the fact that legal precedents also point in the other direction. In 1998, the German *Stromeinspeisungsgesetz*, the antecedent of the RES Act, which was only introduced in 2000, had been challenged as inappropriate state aid. The ECJ gave its judgment in 2001, arguing that the RES

Act's antecedent did not count as state aid since it lacks the involvement of state financial resources.[2] At the time, the Commission conceded that the German renewable support system does not involve state aid. In order to motivate its renewed investigation of Germany's support scheme, the Commission (2013: 74) referred to revisions of the RES Act: "However, since the initial decision, the EEG-Act has been amended substantially. *Given that the amendments introduced by the EEG-Act 2012 were not notified* to the Commission, the aid has to be considered as unlawful new aid. [. . .] The Commission believes that the system at stake differs considerably from the PreussenElektra case" (emphasis added). The Commission did not deny that, in principle, support of renewables may be compatible with the internal market, it rather focused on the specifics of the financing mechanism of the RES Act. The resulting negotiating process between the Commission and the German government will be outlined in Sect. 4 below. For now, it is noteworthy that Germany's non-notification triggered the Commission's investigation, and that the Commission succeeded in making notify-as-state-aid the default option.

Quite probably it would not make sense to try to discern the respective shares of "ideology" and "quest for competences" in the Commission's internal market agenda. Instead, we would like to highlight the mutually supporting role of the internal market vision and state aid law for the Commission's standing (both in terms of legal competences and in terms of soft agenda-setting power). On the one hand, the Commission uses state aid law as "a compulsive lever to enforce regulatory harmonisation" (cf. Tews 2015: 11); on the other hand, the more energy market regulations are harmonised on the EU level, the stronger the legal and political standing of the Commission.

In conclusion, the lead hypothesis (i.e., the Commission frames the internal market as the overarching principle, because this is where it has its legal competences) is not meant as an exclusive identification of causal relationships. Rather, the implication of a Public Choice approach here reads that official motives, such as the one that only the internal market will deliver "clean energy for all" (EU Commission 2016), may deflect from the self-interest that contributes to shaping the agenda.

3.3 Form Dimension: Centralisation and Harmonisation Benefit the Commission

Generally, the Commission attempts to centralise decision-making and harmonise energy policies on the EU level. This does not mean that the Commission claims that each and every decision on energy policy matters should be made in Brussels and Strasbourg—the principle of subsidiarity, as a founding principle of the EU, is duly respected. However, the Commission emphasises that "the majority of energy challenges facing the Union cannot be met through uncoordinated national action" (EU Commission 2016: 4). Furthermore, it highlights the "EU added value" for

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[2] Case C-379/98 PreussenElektra AG v Schleswag AG.

Member States, who would benefit from efficiency gains arising from streamlined procedures and coordinated governance processes. So the Commission's framing is that it should be in the Member States own best interest to follow the road towards supranational integration.

In practice the Commission has not always succeeded in steering the Member States in the desired direction. For instance, since the 1990s the Commission has unsuccessfully aimed at harmonizing national support schemes for RES within the EU (Lauber and Schenner 2011; Jacobs 2012: 25ff.). Moreover, even though the 2009 Lisbon treaty for the first time grants the Commission explicit competences in energy policy, the Member States have preserved their formal sovereignty in this respect: Any measures taken by the EU "shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply" (Article 194(2) TFEU). The resulting overlap of competences has been described as a "governance dilemma" at the heart of energy policy-making in the EU (see also Hildingsson et al. 2011): since the Commission's desired mode of governance (top-down harmonisation) is not routinely available, it resorts to competition law to indirectly steer Member States in the desired direction (Tews 2015).

So it is understandable that the Commission presents its case in terms of benefits for the Member States. Yet the Public Choice perspective advises us to focus on the self-interest of actors (see above, seminal are Niskanen 1971; Peltzman 1976). In the context at hand, the underlying motives, that is, the Commission's incentive to increase (i) formal legislative competences and (ii) informal agenda-setting power, seem obvious. First, whenever legislative competences are transferred to the EU level, the Commission gains far-reaching influence on the respective matter due to its central position in the legislative process: following the EU treaties, only the Commission can initiate new legislation (Art. 17(2) TFEU). The Council and the Parliament may push for changes and amendments but if the Commission sees the general line of its proposal in danger, it can simply withdraw the proposal. Hence, the initiative monopoly translates into veto power in terms of secondary law (Knauff 2017). Second, even when legislative competences formally remain with the Member States, the Commission benefits from a "Europeanisation" of the discussion. Consider the so-called "open method of coordination", a voluntary process of communication and cooperation between the Member States (Borrás and Jacobsson 2004; Kerber and Eckardt 2007); in this process, the Commission acts as a moderator and agenda-setter, which brings along considerable informal influence on national policy-making (see also Callies and Hey 2013).

Naturally, and in line with the presumptions of Public Choice theory, national bureaucracies and politicians oppose any transfer of decision-making power to the EU level. This follows not only from the implied direct loss of legislative power but also from the expected indirect consequences of "Europeanised" climate and energy policy. Consider the effect of purely production-cost based allocation of energy infrastructure around the EU (i.e., the main goal of the proponents of an EU-wide approach towards RES, cf. Stavins 2014): the "free" allocation of energy infrastructure and technology choice implies a major redistribution of rents, which may lead to potentially disruptive change in national industry structures, such as the relocation of solar power from Central to Southern Europe or the accelerated dismantling of coal power in Eastern Europe. So, beyond the mere ability to decide, decision-making power over energy policy is coveted as discretion over rents, which Member States would rather continue to allocate themselves in order to serve domestic rent-seeking pressure groups (cf. Gawel et al. 2014b; Strunz et al. 2015).

In sum, the Commission's levers of top-down harmonisation of energy policy remain limited. At the same time, national differences are too strong for Member States to set the tone for EU energy policy themselves. The commission expertly exploits this "governance dilemma" in its favour: under the guise of eliminating possible obstacles towards the common market, the Commission relies on state aid law to guide national energy policy-making. Overall, the Commission's position vis-á-vis the Member States and the EU Council becomes stronger, the higher the degree of centralisation (both with respect to formal procedures and informal discussion). Thus, the Public Choice well explains the Commission's preference for increasing supranational integration.

4 The EU Commission and the 2014 Revision of Germany's RES Act

In the following, we illustrate how the Commission's influence unfolds in practice via the reform process of Germany's RES Act in 2014. Traditionally, the main mechanism of the Germany's RES Act consisted of a feed-in tariff that guarantees fixed remuneration for every kWh of renewable electricity produced. To fund the scheme, a levy on electricity retail prices is to be paid by consumers. The success of the feed-in tariff in pushing the share of RES in Germany also meant that RES were leaving their former status as niche technologies (cf. Jacobsson and Lauber 2006). In consequence, a scientific and political debate on market and system integration of RES has come up (e.g., Kopp et al. 2012; Winkler and Altmann 2012). Specific discussions on how to reform the RES Act, therefore, also revolve around the question of how to facilitate the integration of RES, cutting deployment costs along the way.

Against the background of these debates, the EU Commission affected the 2014 reform process via two related channels. First, the EU Commission in 2013 opened in-depth proceedings against the refunding mechanism of the RES Act. More specifically, the Commission questioned the exemption scheme: energy-intensive industries only pay a fraction of the levy on electricity prices (consequently, the levy for the remaining industry-, business- and household-consumers increases). The Commission argued that this reduction of the levy for some consumers distorts competition in a way that negatively affects trade between Member States. This assessment also implied a considerable threat because, if legally affirmed by the ECJ, the German government would have had to immediately suspend the exemption schedule *and* demand that exemptions already granted be paid back in full. In other words, competition law enabled the Commission to threaten heavy de-facto industry fines amounting to several billion euros. The Commission's official reasoning does not necessarily stand up to scrutiny because the distortion introduced by the exemption schedule concerns relative competitiveness and the distribution of the cost burden for RES deployment *within* Germany rather than between Member States (for a more detailed discussion, see Gawel and Strunz 2014). However, from the German government's point of view, even though it objected to the Commission's reasoning, the political risk of the looming industry back-payments was considerable—hence the government started to negotiate with the Commission on how to adapt the RES Act in ways acceptable to both sides (Tews 2015; Strunz et al. 2016).

Second, this is where the EU Commission's 2014 guidelines on state aid for environmental protection and energy (2014/C 200/01) enter the negotiation stage. The guidelines aim at exposing RES to market pressure by leading Member States away from feed-in tariffs towards premium schemes and tenders. Specifically, the Commission (§127 ff.) requires that from 2017 on, support for new renewable energy installations "is granted in a competitive bidding process". While the Commission acknowledges that there shall be no retroactive changes to existing support commitments, the Commission's intention of a complete alignment in the medium term is very clear: during a transitional phase in 2015 and 2016 Member States should prepare by setting up competitive bidding processes and distributing "aid for at least 5% of the planned new electricity capacity from renewable energy sources". Furthermore, in order to "incentivise the market integration" of renewables, producers should sell their electricity from 2016 on directly on the market (§125). In other words, the Commission wants Member States to have aligned their support schemes by the end of the decade so that all renewable energy is directly marketed by producers and only the most competitive bidders receive support. Again, the Commission's legal reasoning could be questioned—the RES support scheme may not fall under the official definition of state aid (public budgets are involved or the state directly controls financial flows) in the first place: public budgets are neither directly nor indirectly affected by the scheme; the state only sets minimum prices for renewable electricity so as to ensure that producers of renewable energy are remunerated their previously guaranteed amounts of money per kWh.

Nevertheless, given the Commission's proceedings against the RES Act, the German government notified the RES Act as state aid with the Commission. As a result of the negotiations between Commission and the federal government, the 2014 reform introduced prototype tenders for large photovoltaic installations in Germany. Therefore, reform has been called "a hasty government's adaptation to supranational pressure" (Tews 2015: 280). From this point of view, Germany's reform is akin to preemptive obedience with the not yet existing guidelines. Indeed, this seems to be a remarkable case of "horse-trading" (Strunz et al. 2016: 39): in return for Germany's compliance with the forthcoming guidelines, the Commission rested its case against the exemption scheme. To be sure, the exemption scheme was also reorganised but, if anything, the exemptions have become even more generous over time (cf. Gawel and Klassert 2013; Gawel and Lehmann 2014). So the relevant concession from the German side seems to have been the introduction of prototype tenders. The subsequent reform of the RES Act in 2016 confirmed that a shift of the support scheme from feed-in tariffs to tender schemes (by implication, a shift from price regulation to quantity regulation) is on the way: from 2017 on, onshore-wind, offshore-wind, large photovoltaic and biomass capacities will be remunerated following a tender procedure. Certainly, a number of details in the latest RES Act (technology-specific tenders, special treatment for small installations) may lead to the assessment that the shift is step-wise (Purkus et al. 2015; Gawel and Purkus 2016), but the general direction is very well in line with the Commission's preferences.

5 Discussion and Conclusion

This paper proposed that trade-offs between the goals of finalizing the internal market and the sustainable transformation of the energy system may exist (e.g., unrestricted flow of electricity vs. heterogeneous technological preferences); in order to manage these trade-offs, a mix of centralisation and decentralisation of policy-making is advisable from an economic point of view. By comparison, the EU Commission suggests that the internal market also constitutes the best way to achieve sustainable energy supply. While it acknowledges the principle of subsidiarity, the Commission emphasises the merits of more centralisation and harmonisation—merits that supposedly arise even from the Member States' perspective.

In principle, the Commission's focus on the internal market is legitimate. After all, who defends the common interest, who seeks to overcome coordination dilemmas if not a supranational institution as the Commission? That said, this paper emphasised the main insight of the Public Choice approach, that is, the self-interest of all political actors as a crucial driver of politics. Notably, the Commission's internal market agenda also promotes its own standing relative to the EU Council and the Member States. Thus, legal competences and ideological position merge in a mutually beneficial way. Even more obviously, the Commission's promotion of harmonised regulation and governance procedures—as advertised in the 2016 package "Clean energy for all"—caters to its own relative power position.

The 2014 state aid guidelines provided a prime example of how the Commission may gain ground on both the ideological and the competency agenda at the same time. Still, when criticising the Commission, one should clearly differentiate between *content* and *form*: does one refer to the Commission's efforts to direct Member States as such, or does one refer to the shift towards tender instruments? We will address both issues in turn:

Form: The Commission's guidelines implicitly suggest that a solution to the "market integration problem" has already been found and decentralised policy experimentation is needed no more. In contrast to that, one might also argue that the issue of how to integrate renewables into conventional electricity markets still merits trial-and-error competition for the best solution. For instance, it could be argued that rather than renewables having to adjust to the conventional energy-only market, it is the conventional market structure itself that has to fundamentally change so as to accommodate the specific characteristics of renewables (volatility, marginal costs of zero). Hence, a decentralised process of problem-solving might lead to even better solutions to the market-integration problem. What is more, the highly detailed proposal of the guidelines contradicts the broad scope for state aid as laid down in Article 107 TFEU, which only precludes aid that is incompatible with the internal market. In consequence, the commission possibly overstretches its mandate of Art. 108 TFEU in that it intends to prescribe specific policy solutions for Member States still falling within Member States' genuine competences.

Content: The guidelines compel Member States to align their renewable support schemes to "competitive bidding processes". While such an instrument could be readily justified from a theoretical economic point of view, practical experiences with tender schemes have been mixed (e.g., Lipp 2014). Furthermore, competitive tender schemes will increase uncertainty for potential investors in renewable energies; accordingly, risk premia will rise, and fulfillment of the overall expansion goals might be less certain than under feed-in tariff schemes. In general, tender schemes are not necessarily the best or the only instrument that can be implemented to integrate renewable energies into electricity markets. Recall that Article 107(3)(c) TFEU provides sufficient scope to justify very different schemes and corresponding financing mechanisms as aids to "facilitate the development of certain economic activities" as long as they do not adversely affect trading conditions "to an extent contrary to the common interest".

In sum, the EU Commission presents itself as a rational actor who pursues a specific policy agenda (i.e., market integration), which, in turn, also caters to its own interest of increasing competences. This should not come as a surprise, given that the Member States lack a common vision on how to advance energy policy on the EU level—even the cooperation mechanisms provided by the RES directive have, so far, mostly been neglected (Klinge Jacobsen et al. 2014). The Commission eagerly fills this void to foster both its own standing and to advance the internal market agenda. From a legal perspective one can conclude that the Commission stretches its influence via the state aid guidelines very far (e.g., von Unger 2014). Furthermore, as regards the trade-offs between sustainability transition and market integration, the Commission's positions appear biased towards the efficiency assumptions of the internal market agenda, possibly neglecting the requirements of sustainability as a partly decentralised bottom-up project. Therefore, while an active role of the Commission is to be welcomed, a more balanced approach that does not overstep its competences and acknowledges the above outlined trade-offs would be even better.

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Part V

The Spatial Dimension of the Energy Transition

Cross-Border Electricity Interconnectors in the EU: The Status Quo

Gert Brunekreeft and Roland Meyer

Abstract An important goal of the European Commission is the promotion of the internal energy market (here specifically electricity), which requires sufficient and adequate cross-border interconnector capacity. However, cross-border interconnector capacity is scarce and, more importantly, the progress of interconnector capacity expansion is too slow. As a result, the Commission has proposed several policy measures to accelerate interconnector investment. This paper provides an overview of the policy debate on interconnector expansion and studies two particular points. First, the effects of network regulation on interconnector investment and the policy proposals to improve the investment incentives, and more specifically, how to deal with risks. Second, we study the policies and effects of capacity remuneration mechanisms (CRMs) on the use of and need for cross-border interconnector capacity.

1 Introduction

Electric cross-border interconnector capacity is key to the internal energy market, promoting supply security, sustainability and affordability. For historical reasons, dating back to pre-EU times, cross-border interconnector capacity is scarce and expansion is slow. This paper discusses selected current EU policy issues concerning the use of and need for cross-border interconnector capacity.

The European Commission is actively pursuing the EU's policy to promote and accelerate the expansion of interconnector capacity, as current progress is considered to be too slow. The so-called TEN-E Regulation 2013 addresses several hurdles.

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G. Brunekreeft (✉) · R. Meyer
Jacobs University Bremen, Bremen, Germany
e-mail: g.brunekreeft@jacobs-university.de

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Two reasons for the delays stand out: first, permitting issues—the main hurdle to expanding interconnector capacity—and second, regulatory issues. In this paper, we concentrate on the latter. The worry is that the regulatory framework for interconnectors may impede adequate investment in interconnectors. We discuss two specific challenges. First, the cross-border cost-allocation (CBCA) rule to internalize cross-border spillover effects of interconnector expansion. Second, the regulatory treatment of investment risk. The risk associated with investment in interconnectors is perceived to be higher than that of business-as-usual investments. The TEN-E Regulation outlines additional regulatory incentives to deal with the higher risk.

There is widespread concern that the energy-only markets which have so far dominated the European day-ahead markets will not provide sufficient incentives for adequate generation capacity and hence may endanger security of supply. Instead, market design may be changed to include capacity remuneration mechanisms (CRM). The debate as such goes back a long way, but the discussion has intensified recently, due to the surge in renewable energy sources and the question: How do we produce electricity in times without sun or wind? Currently, there is no common European policy; the member states decide unilaterally whether and how to implement CRMs. At the moment, anything goes. One of the more challenging issues regarding CRMs is how we should take account of interconnector capacity; this is a two-way relationship. First, when assessing the generation capacity of a given country, we should consider the possibility of relying on the generation capacity of its neighbouring countries; this, however, is restricted by interconnector capacity. Second, the design of CRMs in neighbouring member states affects the use of and incentives to expand interconnectors. We discuss the current state of the debate.

Section 2 presents the state of affairs in European policy regarding cross-border interconnector capacity. Section 3 discusses regulatory hurdles to efficient interconnector investment, focussing on the treatment of risk. Section 4 discusses the relation between CRMs and the role of cross-border interconnectors. Section 5 presents concluding remarks.

2 Cross-Border Interconnectors: Background and Overview

Achieving adequate cross-border interconnection between the energy systems of different member states is one of the pillars of the energy policy of the European Commission.[1] Wikipedia defines an electrical interconnector as: “a high power AC or DC connection, typically across national borders or between different electrical grids. They can be formed of submarine power cables or underground power cables

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[1] This concerns electricity and gas. However, as this paper focusses solely on electricity, we will ignore gas interconnectors here.

or overhead power lines."[2] Historically, the energy systems of the individual member states were developed quite independently from one another. But the increased trade associated with market liberalization and the surge of renewable energies soon led to the realization that cross-border links between the energy systems were far too weak and needed to be strengthened.

In 2013, the European Commission adopted the energy infrastructure package, stressing the importance of the internal energy market. Following the background report of Booz & Company (2013), the Commission notes (EC 2014b, p. 4): "the net economic benefits from completion of the internal market to be in the range of 16–40 billion euros per year." If we compare this to investments in additional interconnector capacity in the range of 200 billion euros (see details below), with a lifespan of over 40 years, it is immediately clear that these benefits are significant.[3]

The European Commission uses the term *energy triangle* to highlight the three main advantages of the internal market and therefore of interconnector capacity (EC 2014b, Sect. 2): sustainability, affordability, and security of supply. More interconnector capacity allows investment in renewables where they yield the highest efficiency (i.e. solar in the south and onshore and offshore wind along the coastlines) and then traded and transmitted to the area where the load is. In fact, the European Commission is actively promoting cross-border renewable energy support Schemes (EC 2016d). More interconnector capacity increases energy security. Concerning electricity, interconnectors allow the member states to share reserve capacities. Many countries are implementing some kind of capacity mechanism to deal with generation scarcity due to the so-called missing-money problem.[4] More interconnection relieves some of this pressure and can facilitate more efficient capacity mechanisms and reduce overall reserve capacity. Lastly, more interconnector capacity allows for more trade and will likely increase competition and thus lower electricity prices.

The European Commission has set targets for interconnector capacity. EC (2015, p. 2) states the goal of interconnection of at least 10% of their installed electricity production capacity for all member states by 2020 and 15% by 2030 (EC 2015, p. 15). These goals are rather controversial and should largely be seen as political compromises or better, minimum requirements. Both technically and economically, different member states will have different interconnector requirements, although the target is a one-size-fits-all approach. Yet, the good news is that there is a target at all, which gives transmission system operators (TSOs) and investors a guideline for preparing their network development plans.

The need for new interconnector capacity is high and the development is slow. In 2011, the European Commission commissioned a study on the progress of interconnector capacity to Roland Berger Strategy Consultants. As illustrated nicely

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[2] AC refers to alternating current, DC to direct current.

[3] To be precise, in the numbers presented by the European Commission for the *net* economic benefits, the investment costs are already subtracted.

[4] See Sect. 4 of this paper for more detail.

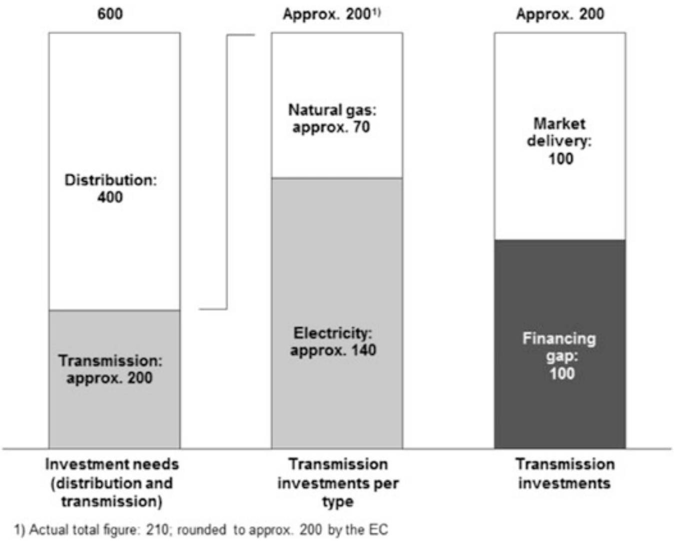

Fig. 1 The investment financing gap. Source: Roland Berger (2011a, Fig. 2, p. 18)

in Fig. 1, the investment costs for electricity transmission (up to 2020) is ca. 140 billion euros. This is a very substantial sum but given the size of the overall EU electricity market nothing out of proportion. More importantly though, Roland Berger (2011a) identifies a "financing gap" amounting to half of the investment requirement: half of the required investment will be delivered by the market, but it is unclear where the other half will come from. The reasons for this financing gap were studied by Roland Berger (2011a, b) and have been addressed in various policy measures by the European Commission since then.

The study conducted by Roland Berger (2011a) identifies the following causes for the financing gap, with varying severity.

- Permitting issues. This is *the* big hurdle to new interconnector capacity and, as will be discussed later, still the main cause for delays. In fact, this issue is so significant that it was treated in a separate study by Roland Berger (2011b) for the European Commission. Permitting issues can be assigned to two main categories: (1) bureaucracy (especially misaligned cross-border rules) and (2) the not-in-my-backyard (NIMBY) problem, i.e. public opposition to the building of new lines. Despite its importance in practice, the issue of permitting is not the focus of this paper and so we will not go into detail here.
- Financing issues and financing conditions. Roland Berger treated these as two different aspects, but one could summarize these as one: given that the study was in 2010 and in the middle of the financial crisis, the worry was that the markets would not provide the necessary capital to the investors. This concern was unfounded.

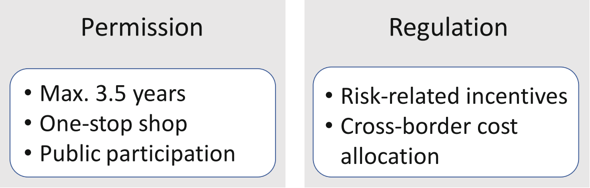

Fig. 2 Two main instruments of the TEN-E Regulation. Source: based on ENTSO-E (2016)

- Operator capabilities. Some TSOs are considered to be too small or otherwise constrained in their capabilities to make the interconnector investments. Overall though, this is not a major hurdle, and it does not concern the majority of TSOs.
- Specific types of projects. These mainly concern projects which aim to contribute to security of supply. At least partly, security of supply is a public good for which the market will not pay fully. Moreover, interconnectors typically affect different countries: what happens if an interconnector in country A derives benefits for country B, while country B does not contribute to the cost? This is an important point, which has been addressed by the European Commission with the cross-border cost-allocation rule (CBCA), which will be discussed in more detail below.
- Regulatory issues. Most interconnectors are regulated, and the worry is that the regulatory framework itself hinders efficient investment. One particularly important issue is how the *risk* of investing in interconnectors is addressed in the regulation. We will deal with this in more detail below.

The European Commission has responded with the so-called "TEN-E Regulation", Regulation No. 347/2013 (EC 2013). The TEN-E Regulation specifies details for PCIs, which stands for "projects of common interest". The main purpose of the TEN-E Regulation is to promote cross-border interconnector investment. The two, for our purpose most important, instruments of the TEN-E Regulation are summarized in Fig. 2.

Figure 2 shows two blocks of measures covered by the TEN-E Regulation:

- Permitting. As mentioned above, permitting is a major issue. Two major improvements under the TEN-E Regulation are, first, that the member states have committed to the goal that permitting procedures for PCI projects should not be longer than 3.5 years [compared to the current average of 10–13 years (EC 2015, p. 10)] and, second, member states have committed to create one-stop-shops for the necessary permits for PCI projects.
- Regulation. Two specific points have been addressed. First, the internalization of cross-border effects of interconnector investment with the so-called *cross-border cost allocation* rule (CBCA): if country A invests in an interconnector which benefits country B it can request a cost contribution from country B. Economically this sounds good, but politically this is a bit awkward if country B is not actively involved in the investment decision. Second, the appropriate

Fig. 3 Map of interconnection levels in 2020 after implementation of current electricity PCIs. Source: EC (2015, p. 9)

remuneration of the *risk* of interconnector investment is addressed explicitly. We will delve into this in more detail in Sect. 3.[5]

What is the current state of interconnector investment? Figure 3 indicates that, after implementing the first round of PCIs up to 2020, many of the heartland European countries, notably Germany and France, will have between 10% and 15% interconnection. Hence, the 10% interconnection target will be met, but further investment is needed to achieve the 15% interconnection target by 2030.

The group of European Network of Transmission System Operators for Electricity (ENTSO-E) must prepare a detailed Ten-Year Network Development Plan (TYNDP) every second year. ENTSO-E (2016, p. 4) writes: "ENTSO-E's TYNDP 2016 identifies the need for up to 150 billion euros investment in electricity infrastructure only, of which 70–80 billion for mid-term and long-term projects (committed in national plans and to be commissioned by 2030)" and: "In its Progress Monitoring Report, ACER estimates the investment costs for electricity transmission Projects of Common Interest (PCIs) reported by project promoters to reach 49.3 billion euros." To summarize, up to 2030, an investment of ca. 150 billion euros needs to be made of which roughly 50 billion euros has PCI status.

Both ENTSO-E (2016, p. 1) and the European Agency for the Cooperation of Energy Regulators (ACER 2016, p. 35 ff.) study the progress of these projects and come to a similar conclusion that roughly one-third of the projects are delayed. Delays and re-scheduling can take up to 4 years.

Figure 4 indicates that the main reason for the delays is, once again, permitting issues, here accounting for 58%. It should be noted, however, that the majority of the

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[5] To be precise, there is a third line of measures. Investors can request *regulatory exemptions*, especially on third party access. This leads to the option of merchant investments. As this is not the focus of this paper we will further ignore this.

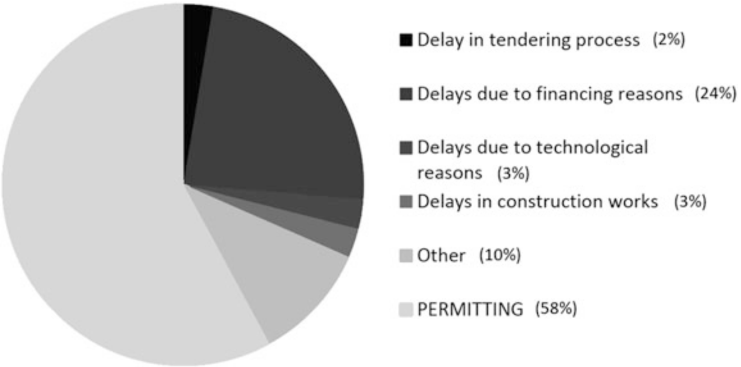

Fig. 4 Reasons mentioned for the delays. Source: ACER (2015a, p. 40)

projects are in a very early stage, mostly in the planning or study stage. Hence, some of the other hurdles are by definition not yet relevant, but may become more relevant later.

3 Regulatory Policy to Accelerate Cross-Border Interconnector Investment: How to Address Risk?

As mentioned in Sect. 2, the TEN-E Regulation 2013 specifies permitting and regulation as two major blocks of measures, and within these, specifically CBCA and the treatment of risk. In this section, we deal with the third point: regulatory issues, focussing especially on the treatment of risk.

3.1 CBCA

Art 12 of the TEN-E Regulation 2013 under the heading "Enabling investments with cross-border impacts" provides for cross-border cost allocation (CBCA). To be precise, "Regulation (EU) No 347/2013 facilitates investments in PCIs by envisaging decisions by National Regulatory Authorities (NRAs) or by ACER on the allocation of the costs of such projects across borders if project promoters submit an investment request, including a request for a cross-border cost allocation (CBCA)" (ACER 2015b, p. 2). Three points are to be noted. First, the CBCA rules only concern PCIs. Second, the NRAs or ACER decide on the CBCA. Third, the project promoter has to request that the CBCA be applied; the rule is not applied automatically.

The key idea is that interconnectors typically have cross-border benefits for parties who do not incur costs. If investing parties do not consider these external benefits, the partial cost-benefit analysis may turn out to be negative, whereas the overall net benefit may actually be positive. For example, say country A considers investing in a line with a cost of 100 and a benefit for country A of 90; assume the line has a cross-border benefit in country B of 20. Although the overall net benefit is positive (10), the line will not be built if country A pays all the costs, because the net benefit of country A alone is negative (−10). The CBCA rule aims to internalize this externality by making country B contribute to the costs (between 10 and 20).

To facilitate the investment request (including the CBCA request), ACER (2015b) prepared a guideline document setting out the required information. Two important elements stand out. First, requests can only be made for projects that have reached sufficient maturity (ACER 2015b, p. 3). This is a problem: if the initial investment decision is made before the CBCA request, the investment decision is in fact highly uncertain. In other words, theoretically, it may be the case that some potentially positive projects never actually make it to a CBCA request. Clearly, it should be possible to make a CBCA request at a very early stage. Second, the project promoter has the burden of proof and must submit a detailed cost-benefit analysis, showing and specifying the spillover benefits (ACER 2015b, p. 6). This is notoriously difficult and an endless source of debate. Alternatively, a specification of cross-border benefits of interconnectors as a standard procedure in ENTSO-E's network development plan would address both problems mentioned above.

What experience has been had with CBCA requests so far? ACER (2016) states that by the end of 2015, out of a total of 100 projects, only 5 projects submitted an investment request. This is quite poor. Apparently, somewhat surprised itself, ACER (2016, p. 71) notes: "the low rate of submitted investment requests could be explained to some extent by the legal requirement that a project has to reach a sufficient level of maturity before the project promoter(s) can submit an investment request." A further explanation might be that the project promoters might be the wrong party to initiate the CBCA request. Usually, the TSOs will be remunerated by the national regulation anyhow, and therefore their incentives to prepare a CBCA request will be quite low: whereas the bureaucracy cost of making the request are substantial, the benefits for the TSOs may be quite low. Alternatively, the NRAs or the ministry of the host member states could be the party to initiate the request.

3.2 Risk Treatment

Section 2 mentioned the report by Roland Berger (2011a), which identifies hurdles to market financing of interconnector investment, including regulatory issues. *Inter alia*, Roland Berger (2011a, pp. 50 ff.) claims as a regulatory issue that projects with a higher risk receive the same regulated rate-of-return as other projects. Consequently, Roland Berger (2011a, pp. 70 ff.) recommends making investments more attractive by introducing "priority premiums"; in other words, regulators should consider adjusting the risk premium for investments with a demonstrated higher

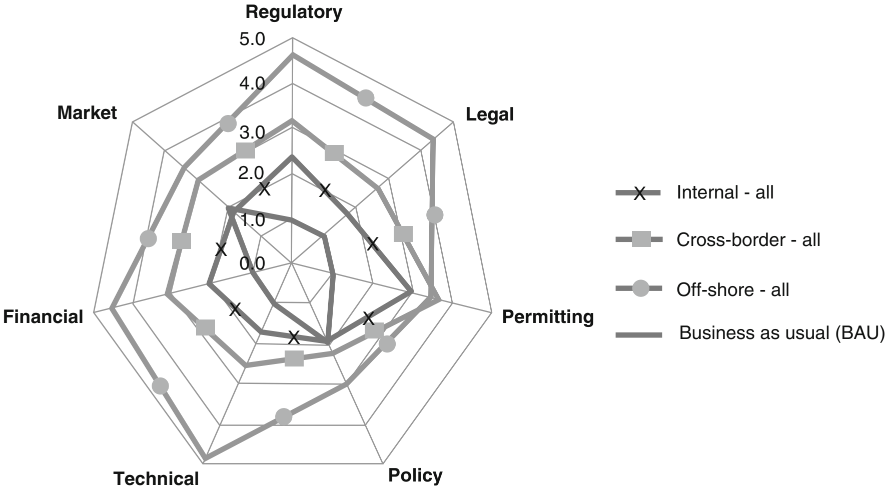

Fig. 5 Which sources of risk matter? Source: AF-Mercados EMI and REF-E (2014, p. 22)

level of risk.[6] Arguably, this will increase the investment incentives, however, this is easier said than done.

What are the risks? Figure 5 depicts the main risks as perceived by project promoters and makes two main points. First, cross-border interconnectors and especially offshore lines are risky vis-à-vis business as usual (i.e. non-TYNDP).[7] Second, regulation is one of the frequently mentioned sources of perceived risk.

The key question then is whether the higher risk is reflected in a risk-adjusted regulated rate of return. Typically, this is not the case. Usually, regulation of network revenues knows only one-and-the-same rate of return on all assets and there is no distinction between different investments. This is precisely what a "priority premium" tries to achieve: it raises the regulated rate of return for a risky PCI above the usual level of the regulated rate of return. This should improve incentives to make the investment in the PCI.

Art 13 of the TEN-E Regulation 2013 aims to improve incentives for PCIs with higher risk with *inter alia* precisely such priority premiums. The priority premium should be requested by the project promoter at the NRA. ACER (2014) developed a 7-step procedure for these requests, where the burden of proof is on the project promoter:

– Step 1: Availability of information on project risks
– Step 2: Identification of the nature of the risk from a regulatory point of view

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[6] Note that "priority premiums" are also known as "rate-of-return adders" or "top-ups".

[7] To be precise, TYNDP projects are projects of pan-European significance; these can be national projects, with cross-border effects. Consequently, non-TYNDP projects are national projects without any significant cross-border effects (cf. ENTSO-E 2014).

  (a) The risk of cost overruns
  (b) The risk of time overruns
  (c) The risk of stranded assets
  (d) Risks related to the identification of efficiently incurred costs
  (e) Liquidity risk

- Step 3: Risk-mitigation measures by the project promoters
- Step 4: Assessment of systematic risk and definition of cost of capital
- Step 5: Risk-mitigation measures already applied by NRAs
- Step 6: Risk quantification
- Step 7: Comparable project

Much can be said about this procedure, but for the scope of this paper, we will concentrate on three points only. First, the project promoter has to show and quantify the risk. This is challenging. Presumably, it might be better if ACER were to develop a more general framework, specifying the type of investments to which the priority premiums automatically apply. Second, as specified in step 4, the assessment of systematic risk and the definition of the cost of capital. This too is a challenge. Typically, the regulators rely on the CAPM approach[8] to determine the risk-adjusted regulated rate of return on capital. As is well-known, the CAPM approach relies on the risk-beta to estimate the risk-adjustment. Basically, step 4 requires showing that the normal risk-beta does not properly reflect the higher risk of the project for which the request is made. Moreover, the NRA are required to examine whether the project risk is systematic or non-systematic, such that it can be diversified. Third, the guidelines set many restrictions for the application of the priority premiums. Many of these are sources of endless discussion and will likely discourage project promoters from trying.

What are the experiences with requests for priority premiums so far? Very few requests have actually been made: only 4 out of 100 projects (ACER 2016, p. 73). As a possible explanation for this low number, ACER (2016, p. 73) writes: “With regard to the very low number of applications and plans to apply for specific incentives, while no investigation on the underlying reasons have been carried out, it seems that PCIs in general do not face higher risks compared to comparable infrastructure projects or that the existing regulatory frameworks already provide sufficient measures to tackle risks and therefore, already incentivise the necessary investments.” That may be a bit too easy. In contrast, the European Commission seems to think that regulation itself may be a hurdle: “NRAs have faced challenges in applying the TEN-E Regulation.” (EC 2015, p. 12).

There may be an alternative explanation: the question is whether project promoters really need the risk premium. In many cases, the risks (e.g. for outages of offshore lines) are insured (Umar 2017). If an investor can insure the higher risk and if the insurance premium is part of the regulated cost base, then the higher risk is

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[8] CAPM stands for Capital Asset Pricing Model and is a standard method to determine the rate of return of a company or an industry. For an explanation, see e.g. Brealey et al. (2016).

translated into higher revenues and supposedly the problem is gone. Or, put differently, step 5 in the 7-step ACER procedure would be fulfilled: through the backdoor, the regulation would already take account of the higher risk. As a side-remark, for the end-user it would be the same as with a higher rate of return; it is just a matter of who bears the risk, but at the end of the day the end-user pays for the risk.

4 Capacity Remuneration Mechanisms and Their Effect on Interconnectors

The European Commission’s target model for the internal electricity market is primarily based on a functioning energy-only market, where remuneration for generation and interconnection is solely based on electricity prices. In the absence of market failures, electricity prices should provide efficient signals for both short-term trade and long-term investments. Increasing *prices* in one market incentivise generation investment, while increasing *price differences* between interconnected markets lead to an increase in congestion rents and thereby trigger interconnector investments.

In many European markets, however, concerns have been raised that electricity prices (especially in scarcity situations) may not be high enough to create adequate investment incentives. Large-scale integration of renewables may reduce scarcity revenues and thereby suppress efficient price signals for capacity investments needed to back up intermittent supply from renewables. The underlying discussion on generation adequacy is neither new nor is it limited to renewables. Subsumed under the term “missing money” (Cramton and Stoft 2006) electricity markets in the US started to change their market designs already more than a decade ago. Different forms of *capacity remuneration mechanisms* (CRMs) have been developed to address the potential risk of underinvestment. CRMs aim to restore efficient investment incentives by providing revenues for available capacity in addition to the market revenues for produced electricity. Several European countries have recently implemented (or discuss the implementation of) CRMs. Although the European Commission acknowledges the potential need for CRMs in justified cases, it raises concerns about market distortions and cross-border effects CRMs may cause (EC 2016c). Most importantly: what impacts do CRMs have on market integration and interconnector investment?

4.1 Capacity Remuneration Mechanisms in Europe

Various forms of CRMs are implemented or planned in EU member states. Figure 6 gives an overview.

From the European Commission’s point of view, the most critical form of CRMs are *capacity payments*, where capacity providers are paid an administratively fixed price for available capacity in addition to the revenues they receive for selling

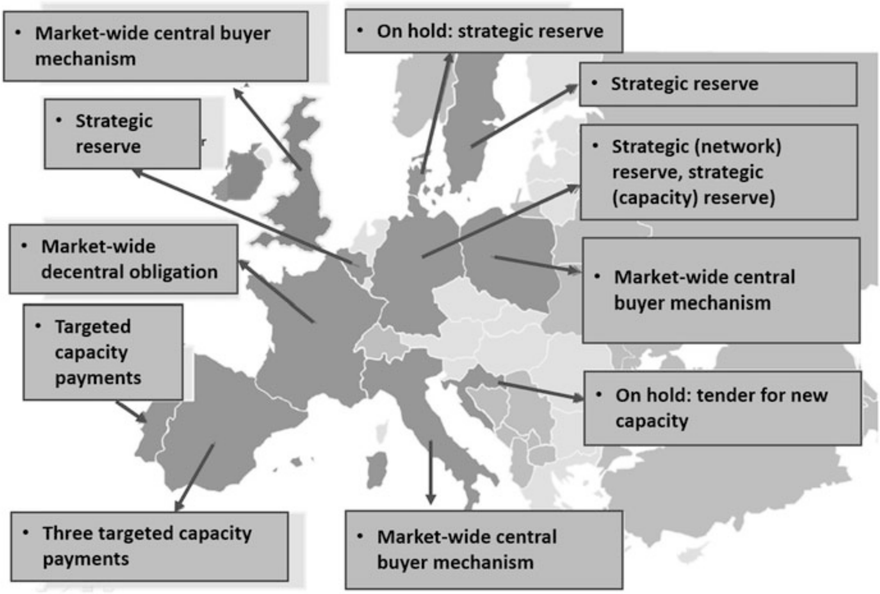

Fig. 6 Existing and planned CRMs in EU member states. Source: adapted and updated from EC (2016a, p. 55)

electricity to the regular market. Such a mechanism, as for instance established in Spain, is called price-based, because the capacity price is fixed, while the quantity is determined by the market via individual investment decisions. The drawback of price-based CRMs is the risk of over- or underinvestment, as small errors in determining the capacity price may have large effects on the investment equilibrium (Brunekreeft et al. 2011).[9] Moreover, capacity payments tend to distort technology choice and are potentially seen as discriminatory state aid by the European Commission (EC 2014a). Hence, the European Commission concludes that “Administrative capacity payments are unlikely to be appropriate, regardless of the specific issues facing a Member State, because the lack of a competitive process means a high risk of failing to achieve the capacity objective or of over-compensating” (EC 2016b, p. 18).

Volume-based CRMs are considered more effective in achieving a target level of generation adequacy, as they directly control for the quantity of capacity, while leaving price setting to the market. The procedure is that a predetermined volume of capacity is acquired through regular capacity auctions; the auction price then sets the remuneration for capacity providers. The two most common forms of CRMs are the *strategic reserve* and full *capacity markets.*

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[9] For a general analysis concerning the control of prices vs. quantities, see the seminal paper of Weitzman (1974)

A strategic reserve is considered a targeted CRM, as it only provides capacity revenues for a certain amount of (reserve) capacity. Hence, the major part of the market remains energy-only. Strategic reserves are for instance established in Sweden and Finland. Both markets have a high share of hydro power which exposes them to the risk of capacity scarcity in dry winter periods. The common belief of a strategic reserve is that an energy-only market will bring about sufficient investments in all but exceptional scarcity situations. To take account of such extreme cases, a certain reserve is acquired by a central authority; often this is the TSO. The reserve is withdrawn from the market and will only be dispatched centrally in cases of extreme scarcity, i.e. when the market is not able to provide sufficient capacity.

Full capacity markets require a more fundamental change in market design. Capacity markets address the whole market and turn capacity into a separate, tradable product in addition to energy. Capacity markets can be organized as centralized *capacity auctions* or decentralized *capacity obligations*, depending on who is in charge of providing capacity: a central authority or the supply companies. In both models, the target volume of market capacity is fixed at expected peak demand plus a reserve margin. The supply side is formed by generators or demand response, who receive the capacity auction price in return for holding the tendered amount of capacity available.

The UK introduced a centralized capacity auction model in 2014, which is operated by the British TSO National Grid (DECC 2012). The system consists of two auctions per year. One auction (T-4) is 4 years ahead, with the first auction held in December 2014 for the delivery period 2018/2019. Another 1-year-ahead auction (T-1) covers the remaining amount of capacity based on an update of demand forecasts. The amount of capacity acquired was 82 GW, thereby significantly exceeding the 2014 peak demand of 56 GW (Baker et al. 2015). France opted for a decentralized market, where supply companies are required to buy capacity certificates for their served customers. These certificates can be traded bilaterally and on the EPEX spot market. The French transmission operator RTE determines parameters for the required capacity obligations 4 years ahead of delivery and organizes the certification process in which all generators on French territory must participate (RTE 2014).

4.2 Cross-Border Effects of CRMs

As the European Commission's main focus is on an efficient energy-only market, the question is whether and how a CRM interacts with the energy market and cross-border trade. Two sources of cross-border effects can be identified that seem to be the focus of discussion (Meyer and Gore 2015):

1. *Capacity effects*: CRMs may lead to overcapacities in a market which reduces cross-border trade and imposes excessive costs on consumers.
2. *Price effects*: CRMs may cause (or cover existing) price distortions in the energy-only market, which may hamper efficient market integration.

Capacity effects result from a CRM design that causes investment distortions. One concern of the European Commission relates to potential state aid. Most notably, member states might use CRMs to subsidize old coal power plants, counteracting not only the European goals of free electricity markets but also environmental ambitions. In its so-called "Winter Package" of proposed measures for the European energy markets, the Commission therefore proposes to exclude power plants emitting high levels of CO_2 from capacity markets, while Poland, in particular, is pushing towards a capacity market to keep their coal plants online (EC 2017).

Another major concern of the European Commission is that CRMs may incentivize excess capacity investments, especially as the contribution of imports to available capacity is often underestimated. This may be due to political preference for national self-sufficiency over import dependency (Hawker et al. 2017). Consider a high-price country like the UK that used to import electricity from abroad. If the CRM does not account for imports, it will induce domestic excess capacity that replaces imports by reducing (peak) prices. This tends to lower the price difference to neighbouring markets and thereby undermines the business case for interconnectors. Hence, "Ignoring interconnectors risks a self-fulfilling but expensive policy of autarky" (Newbery 2016, p. 407). Accordingly, the lack of cross-border participation in CRMs is a major issue for the European Commission: "The current guidelines require that individual capacity mechanisms facilitate cross-border participation in order to maintain and promote market-wide efficiency. Thus far, however, cross-border participation is not observed in most capacity mechanisms" (EC 2016c, p. 31).

In the case of the UK, the first capacity auction carried out for the capacity market in the UK seems to confirm this concern: "Although the detailed assessment carried out by National Grid recognised that interconnection would likely contribute to security at times of peak demand, the amount of generation capacity to be procured for delivery in 2018/19 is based on the assumption of a zero net contribution from neighbouring systems" (Baker et al. 2015, p. 12). For the following auctions, however, cross-border contribution has been included. Similarly, the French capacity market was only opened stepwise to neighbouring market capacity. The European Commission finally approved the French CRM after some revisions which allowed capacity from abroad to participate in the capacity market (EC 2016e).

The second source of cross-border effects as mentioned above relates to "price effects". CRMs may either cause price distortions themselves, or they cover distortions in the energy market which are already there. In both cases, market integration will be hampered as inefficiencies spill over to neighbouring markets. A typical form of price distortion is the capping of electricity prices. If a country implements a CRM, which reduces scarcity prices in return for additional capacity payments, this will have effects on the exchange with neighbouring energy-only markets. If revenues for exports and interconnection are reduced, the missing-money problem is partly "exported" from the CRM market to the neighbouring energy-only market (Meyer and Gore 2015). Two examples:

- A strategic reserve may have a price-capping effect, if the reserve is activated whenever domestic energy prices reach a certain price level. If this price cap is set below the price of electricity imports, it will lead to a crowding out of imports, leaving generators in the neighbouring market with lower revenues. The strategic reserves currently in place in the Scandinavian markets, however, avoid such crowding-out effects by limiting the activation of reserves to situations when neither domestic nor imported market capacity can release the scarcity.
- A more important case of price effects applies to full capacity markets, if generators under the CRM change their bidding behaviour in the energy market. As generators are remunerated for capacity, they do not depend on high scarcity prices to recover their fixed costs. Hence, the two-part tariff (consisting of energy and capacity price) may lead to lower energy bids and thereby reduce scarcity prices. This in turn will affect remuneration of imported electricity from neighbouring energy-only markets, thus creating a missing-money problem on the other side of the border (Meyer and Gore 2015).

Even if capacity markets themselves are not the cause of market distortions, a CRM may still cover market distortions already present in the energy market. If missing money is caused by market-design flaws in the energy-only market—like price caps—a capacity market will be the wrong instrument to solve the investment problem: market distortions will spill over to the neighbouring market and create a missing-money problem there. This explains why the European Commission is cautious about the implementation of CRMs without a well-founded reasoning: the priority should always be an undistorted energy-only market design (EC 2016b).[10] An additional CRM should only be considered if an efficient energy-only market design alone does not solve the missing-money problem. The main challenge for adequate CRM design is how to cope with the cross-border effects analysed above. The key term is cross-border participation.

4.3 Cross-Border Participation in Capacity Markets

Given that a CRM is considered the right solution to address the missing-money problem, some form of cross-border participation is essential to avoid market distortions. But what should this look like? The Commission (2016c) distinguished between *implicit participation* and *explicit participation*.

Implicit participation means that the CRM applies only to domestic capacity providers, but the import contribution from neighbouring markets is considered when calculating the amount of national capacity needs. This is regarded as the minimum requirement for CRMs. It avoids the growth of national overcapacities at the expense of cross-border trade—the above-mentioned “capacity effect”.

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[10] In its State aid inquiry, the Commission already defined requirements which should be fulfilled when implementing a CRM (EC 2014a). Above all, clear evidence must be provided that the establishment of a CRM is at all necessary to ensure capacity adequacy.

However, this form of participation does not prevent “price effects” leading to a spillover of the missing-money problem to neighbouring markets. The problem is that domestic capacity will compensate for the missing money through capacity remuneration, but the general shortfall in energy market revenues remains. Since neither foreign capacity nor interconnection providers receive capacity payments, the missing-money problem is “exported” to interconnected markets (EC 2016c).

Therefore, *explicit participation* of cross-border capacity is considered a more efficient solution. EC (2016c) distinguishes between two options. *Direct participation* allows cross-border resources to directly bid into the neighbouring capacity market. This is considered the preferred option, but it is also the most difficult one to implement. One of the challenges is to ensure availability of generation or demand resources and measure their respective contribution to generation adequacy—especially if they participate in more than one capacity market. To account for the probabilities of simultaneous stress events, a regional rather than a national analysis and forecast of the interconnected electricity system is required (EC 2016c). Furthermore, there is the question of how to ensure availability of the interconnection capacity required to back up cross-border participation. As known from electricity markets, there are two forms of auctions for interconnection capacity. *Implicit auctions* would assign interconnection providers a congestion rent based on the capacity price difference between markets—similar to electricity prices differences in energy-only markets. Implicit auctions are known to be more efficient than explicit auctions, because the markets for energy and transmission capacity are cleared simultaneously. But it is unclear how implicit auctions can be implemented for decentralised capacity market models (EC 2016c). On the other hand, separate, *explicit auctions* increase the risk for energy providers given the uncertain outcome of future interconnection auctions. This may reduce capacity bids and lead to lower expected rents for interconnection owners (EC 2016c).

A second form of explicit participation *indirect participation*. This means that interconnection capacity (instead of cross-border energy capacity) would participate in a capacity market. In other words, capacity remuneration directly applies to interconnection providers, incentivizing them to invest in cross-border network capacity. Foreign production capacity would only benefit indirectly. This mechanism appears to be easier to implement, also for decentralized capacity markets, as it limits the number of counterparties involved in cross-border arrangements: typically, only the TSOs would participate.

5 Conclusions

Cross-border interconnector capacity is key to the internal energy market. Yet, capacity is scarce, and expansion is slow. The European Commission is actively pursuing a policy to use interconnector capacity efficiently and develop interconnector capacity more effectively. In this paper, we have discussed selected issues relating to the EU energy policy affecting cross-border interconnector capacity. In particular, we have focussed on two issues. First, reasons for delays in the expansion of interconnector capacity and policy measures to accelerate the expansion. Second, the developments towards capacity remuneration mechanisms (CRMs) and their effects on cross-border interconnectors.

Expansion of interconnector capacity is too slow; delays are still substantial. Apart from permitting issues, regulatory issues are often mentioned as a hurdle for efficient interconnector capacity. Cross-border spillover effects of interconnectors and the higher risk of interconnector investment seem to be especially important. The TEN-E Regulation addresses these issues: the first with the cross-border cost-allocation (CBCA) rule and the second with additional investment incentives, most notably with the priority premium which reflects the higher risk. First experiences with these two policy measures indicate that they are not effective: the number of requests by project promoters is very low. It is not clear what the precise reason is. Upon theoretical reflection, however, we can draw two conclusions. First, in the CBCA rule the TSO needs to make the request; this may be the wrong party because the TSO will be remunerated for the investment by national regulation anyhow, and thus the incentives to initiate a CBCA request may be low. It might be better that the NRA or the competent ministry, as a consumer representative, initiates the CBCA request. Second, to the extent that risks of interconnector investment are insured and the risk premium is part of the regulatory cost base, the risk is in fact already internalized. We have to examine carefully, how the company or the regulation implicitly deals with the risk of the investment.

The debate on interconnector investments is also related to the implementation of CRMs in a growing number of European markets. CRMs should address the potential missing-money problem for generators in energy-only markets by raising investments through capacity-based revenues. However, this may negatively affect cross-border trade and interconnection revenues. If CRMs do not allow for explicit cross-border participation, only domestic capacity is compensated for the shortfall of energy market revenues, but imported capacity is not. This reduces incentives for trade and revenues for interconnection providers. The problem intensifies, if CRMs do not even consider the contribution of imports to domestic capacity and thereby induce overcapacities. As for now, only the weak form of implicit participation constitutes the minimum requirement for approval of a CRM by the European Commission: import contributions should be subtracted from national capacity requirements to avoid a movement towards costly autarky. The preferred solution is explicit participation of either foreign capacity or interconnection in CRMs, which is more difficult to implement.

The debate has just begun, and we will have to await further developments. The following problems seem particularly important as starting points for further research. First, the low rate of regulatory requests is puzzling. It is crucial to determine why this is: whether there is no need for additional incentives or whether the policy measures are ineffective makes a difference. This is not well understood. Second, how should interconnection capacity be included in the CRMs, which currently differ strongly in design? Will further harmonization of CRMs be necessary to foster European market integration?

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The Electricity Transmission Line Planning Process at European Level: Legal Framework and Need for Reforms

Jana Bovet

Abstract This chapter presents the legal framework for the electricity transmission line planning process at European level and highlights where there is need for reform. The legal competence for 'energy policy' (Article 194 TFEU) was only introduced in 2009. It is not an original EU competence detached from national planning competences, but rather the Union 'shall contribute to the establishment and development of trans-European networks'. Consequently, although the two European legal instruments 'Projects of Common Interest (PCI)' and the 'Ten-Year Network Development Plan (TYNDP)' fulfil the tasks of achieving transparency and coordination within the European planning groups, they do not empower the EU to enforce its energy policy interests against the interests of the member state concerned. Whilst the methodological approach for the TYNDP is well-organised in that scenario planning and monitoring are used, there is still need for improvement in the integration of the public into the planning process, the overarching coordination, and the legal enforcement tools.

1 Introduction

Up until 2009, the responsibility for ascertaining the demand for expansion and the planning of electricity networks was assigned to the national planning authorities of the member states and a decision which network operators had to take within the legal framework of the respective member state. It was only through the Treaty of Lisbon and Article 194 TFEU that a European competence for energy policy was created. European regulations relating to energy from the period prior to that are based on the competence to establish the internal market and trans-European networks. Thus, as early as the mid-1990s, the guidelines on trans-European networks for energy (TEN-E) for the cross-border expansion of the network, where the subject

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J. Bovet (✉)
Department of Environmental and Planning Law, Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany
e-mail: Jana.bovet@ufz.de

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of planning trans-European electricity lines was addressed for the first time, could be adopted. Those guidelines have meanwhile been replaced by the regulation on guidelines for trans-European energy infrastructure, which is applied directly in the member states. This strengthened regulation is accompanied by the establishment of institutions such as ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators for Electricity).

This chapter examines how the current legal framework for the planning of electricity transmission lines is structured at the European level and which reform deliberations should be made in this regard. First, the European competences and regulations in the energy sector will be outlined (see Sects. 2 and 3). In the next two sections, the control options and limitations of Projects of Common Interest (PCI) and the Ten-Year Network Development Plan will be illustrated (see Sects. 4 and 5).

This contribution is a revised chapter from a recently published study for the German Federal Environment Agency. The aim of the study was to systematically analyse the instrument of demand planning and to come up with proposals as to how the requirements assessment can be legally structured to allow the best possible integration of environmental protection. The planning of electricity networks at European level was one form of demand planning examined in this context (Köck et al. 2017, p. 191ff.).

2 European Competences in the Energy Sector

According to the principle of conferral laid down in Article 5(2) of the Treaty on European Union (TEU), the EU can only act in the policy areas in which it has been given competence to do so by the member states (Calliess and Hey 2013, p. 89). Before the entry into force on 1 December 2009 of the Treaty on the Functioning of the European Union (TFEU), which replaced the EU Treaty, the Union had no competence to regulate the energy sector. At that time, EU legislation in the energy sector took place primarily on the basis of its ‘energy-neutral’ competence to harmonise the internal energy market (ex Article 95 EC), environmental competence (ex Article 175 EC) and competence with regard to trans-European networks (ex Article 156 EC).

Then, with the creation of Article 194 TFEU in 2009, an autonomous legal basis for energy policy was established for the first time. It defines the four core objectives of EU energy policy as follows:

(a) To ensure the functioning of the energy market
(b) To ensure security of energy supply in the Union
(c) To promote energy efficiency and energy saving and the development of new and renewable forms of energy
(d) To promote the interconnection of energy networks

The newly created regulation of Article 194 TFEU is *lex specialis* for the principles of energy policy and replaces other unspecific competence norms (sceptical, Calliess and Hey 2013, p. 95; affirmative, Posser and Faßbender 2013, p. 7; Schmitz and Uibeleisen 2016, p. 23). According to Article 4(2)(i) TFEU, it belongs to the category of shared competences, so that member states can only exercise their competence 'to the extent that the Union has not exercised its competence' second sentence of Article 2(2) TFEU), whereby in the case of the expansion of the electricity networks, we are clearly dealing with a complementary competence, since the objective is not for the Union to assume full responsibility for the expansion of the energy infrastructure networks. As a corrective measure, so to speak, Article 194(1) TFEU appeals that 'Union policy on energy shall aim, in a spirit of solidarity between Member States'. The objective is, first, that member states are enjoined from taking any action in the name of national interest that would interfere with achievements of energy policy goals of common interest and, second, that member states may be obligated to provide assistance to other states that are facing an energy policy emergency (Calliess and Hey 2013, p. 102).

Moreover, Articles 170–172 TFEU confer competence for the development and expansion of trans-European energy infrastructure networks and for the issuing of (planning) guidelines for the harmonisation of technical norms and for financial support. According to Article 4(2)(h) TFEU, this too is an area of shared competence between the Union and its member states. That means that it is not an original competence for European infrastructure policy and planning that is detached from national planning, rather the Union 'shall contribute to the establishment and development of trans-European networks' (Article 170(1) TFEU). In doing so, it 'shall take account in particular of the need to link island, landlocked and peripheral regions with the central regions of the Union' (Article 170 (2) TFEU). In order to achieve these objectives Article 171 states that the Union shall establish a series of guidelines covering the objectives, priorities and broad lines of measures envisaged in the sphere of trans-European networks and shall implement any measures necessary to ensure the interoperability of the networks, in particular in the field of technical standardisation. The competence to establish guidelines includes the possibility to establish directly enforceable guidelines, whereby the planning authority of member states shall not be restricted too much by detailed specifications. The coordination provision of Article 171 (2) TFEU is limited to the creation of a harmonised planning process including a needs assessment, but does not go so far as to allow the Union to make provisions on the methods, procedures and the implementation of the plans, since the member states remain in control of the relevant planning process (Calliess and Hey 2013, p. 88; Peters 2018; Posser and Faßbender 2013, p. 9ff; Strunz et al. 2015, p. 147).

3 The Third Energy Package of the EU from the Year 2009 and Regulation No. 347/2013 on Guidelines for Trans-European Energy Infrastructure

Since the mid-1990s there have been attempts at the level of the European Union to influence the development and planning of transnationally significant electricity networks as it was recognised that transmission network expansion is not a task that is limited to the national level but one that would require stronger interaction at European level. In 1996, a list of projects deemed especially worthy of support was drawn up for the first time in the so-called TEN-E guidelines,[1] and, in 2007, financial aid[2] for these projects was secured. The legal nature of the TEN-E guidelines is controversial, whereby the *effet utile* and the fact that the guidelines were published in the Official Journal of the European Union would suggest that they are binding (Posser and Faßbender 2013, p. 54). In practice, the guidelines have not proven effective, which can be mainly attributed to their low normative steering effect and their very limited financial contribution to projects of common interest (Calliess and Hey 2013, p. 121). Then, in 2009, the European Union's so-called Third Energy Package was adopted to further liberalise the electricity and gas markets in the EU and to strengthen consumer rights.[3] For this purpose, a series of new instruments and governance approaches were introduced which aimed to improve and speed up the realisation of interconnectors (Calliess and Hey 2013, p. 122). The regulations of the energy package also resulted in the establishment of the Agency for the Cooperation of Energy Regulators (ACER) and the European Network of Transmission System Operators for Electricity (ENTSO-E) (Calliess and Hey 2013, p. 120f.). ACER is a panel of experts which advises the Commission on energy sector issues and works towards the completion of the single EU energy market for electricity. The Agency coordinates regional and cross-regional initiatives and monitors the work of European networks of transmission system operators and the functioning of gas

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[1] Followed by Decision No 1229/2003/EC of the European Parliament and of the Council of 26 June 2003 laying down a series of guidelines for trans-European energy networks and repealing Decision No 1254/96/EC and Decision No 1364/2006/EC of the European Parliament and of the Council of 6 September 2006 laying down guidelines for trans-European energy networks and repealing Decision 96/391/EC and Decision No 1229/2003/EC.

[2] Regulation (EC) No 680/2007 of the European Parliament and of the Council of 20 June 2007 laying down general rules for the granting of Community financial aid in the field of the trans-European transport and energy networks.

[3] The Third Energy Package consists of two Directives and three Regulations: Directive 2009/72/EC concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, Directive 2009/73/EC concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC, Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003, Regulation (EC) No 715/2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005 and Regulation (EC) No 713/2009 of the European Parliament and of the Council of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators.

and electricity markets in general. Its tasks are primarily of an advisory and observational nature; it does not have any final decision-making competence. The European Network of Transmission System Operators for Electricity (ENTSO-E), on the other hand, is a purely organisational alliance of 43 transmission system operators from 36 European countries working on the Ten-Year Network Development Plan (TYNDP), including the drafting of a summary of the projects deemed necessary for the expansion of the transmission networks (see Sect. 5).

The energy package obligated the transmission system operators to submit a Ten-Year Network Development Plan (TYNDP) every year to their national regulatory authority. This meant that infrastructure investment planning was highlighted for the first time as having a relevant role in the existing energy legislation (del Guayo and Pielow 2012). However, these legal acts still lacked the stringency and enforcement instruments needed to achieve ‘security of supply, competitiveness and sustainability’—the target triad of energy policy valid, at the latest, since 2007.[4] So, although the member states were required to ‘work towards implementation of the guidelines’, the requirement was not further specified and was therefore not suitable to promote the plan in a targeted manner. The decisive malalignment was that the binding effect of the guideline does not refer to the concrete realisation and enforcement of plans, but rather only addresses the efforts of the member states. Consequently, the guidelines were action-oriented but not success-oriented (Glachant et al. 2017, p. 60; Kment 2014, p. 394; Posser and Faßbender 2013, pp. 55 and 73 f.).

In 2013, efforts were made to remedy this shortcoming with the TEN-E Regulation on guidelines for trans-European energy infrastructure,[5] which is still in force today. It was adopted as a regulation on the basis of Article 172 TFEU, and therefore, in accordance with the second sentence of Article 288(2) TFEU, it applies directly in all member states, even if it is intrinsically not fully enforceable in parts, for example, because it contains concretisation possibilities for the national authorisation procedures (Article 8 TEN-E Regulation) (Fest and Operhalsky 2014, p. 1191; Peters 2018, p. 356). The aim of the TEN-E Regulation is to no longer only declare individual connections worthy of support but to ensure that central expansion projects for the interoperability of the trans-European electricity network are actually moved forward by defining infrastructure priorities and regulations to support more rapid and transparent national authorisation procedures as well as providing for the development of a cost-benefit analysis.[6] Out of a total of nine electricity, gas and

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[4] Communication from the Commission to the European Council and the European Parliament—an energy policy for Europe SEC(2007) 12/COM(2007) 1 final.

[5] Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009.

[6] Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009, recital (43).

mineral oil corridors mentioned in Annex I, four affect the electricity grid and, accordingly, the following four regional groups were set up[7]:

1. Northern Seas offshore grid ('NSOG')
2. North-South electricity interconnections in Western Europe ('NSI West Electricity')
3. North-South electricity interconnections in Central Eastern and South Eastern Europe ('NSI East Electricity')
4. Baltic Energy Market Interconnection Plan in Electricity ('BEMIP Electricity')

These regional groups are made up of representatives of the member states, the national regulatory authorities, the transmission system operators as well as the Commission, the agency ACER and the ENTSO for electricity (Annex III.1 (1) TEN-E Regulation), whereby according to the third sentence of Article 3(1) of the TEN-E Regulation, only the member states and the Commission are eligible to vote and have decision-making powers. It will have to prove whether this is sufficient to ensure a regular Europe-wide balancing (Buus 2018, p. 123). The relationship between the groups, or whether and how cooperation or harmonisation should take place, is unregulated. So, for example, up to 2016 the modelling methods used in the groups for the TYNDP were not coordinated so that it is not easy to compare the results (Umpfenbach et al. 2015, p. 12). The ENTSOE has meanwhile rectified this situation, and, as of 2016, a uniform cost-benefit analysis is used (see Sect. 4).

Like in the TEN-E guidelines, the implementation instruments in the TEN-E Regulation are only weakly defined. Article 10(2) of the TEN-E Regulation merely provides that—in the case that the national permit granting process takes more than three-and-a-half years—the national authority responsible for the construction of the electricity transmission line shall inform the group concerned and present measures to be taken so that the authorisation procedure can be completed with the least possible delay. Therefore it is purely a reporting obligation; it does not provide for sanctioning instruments.

4 Projects of Common Interest (PCI)

For the planning of transmission networks, projects of common interest (PCI) shall be identified in the priority corridors (Article 1(1) in conjunction with Annex I and Article 3 TEN-E Regulation). These are projects that are necessary in order to implement the energy infrastructure priority corridors and in which at least two member states must be involved (Article 2(4) TEN-E Regulation). Member states are 'involved' in a project even when the transmission line is located on the sovereign

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[7] In addition, three priority thematic areas that relate to all Member States were defined—smart grids, electricity highways and carbon dioxide networks.

territory of only one member state but has significant cross-border impacts. To meet this criterion, it is sufficient that the project increases the grid transfer capacity, or the capacity available for commercial flows, at the border of that member state with one or several other member states, or at any other relevant cross-section of the same transmission corridor having the effect of increasing this cross-border grid transfer capacity, by at least 500 megawatt compared to the situation without commissioning of the project (see Annex IV.1 TEN-E Regulation).

The selection of the PCI projects takes place in several steps (Dross and Bovet 2014, p. 433; Posser and Faßbender 2013, p. 59; Stracke 2016, p. 328): As a first step, the promoters of projects that might be considered PCI, and for which the status of project of common interest is being sought, submit an application to the relevant regional group responsible for the energy infrastructure corridors and areas (Annex III.2.1 TEN-E Regulation). The groups assess and evaluate the submitted project proposals and rank them in order of importance (Article 3(1) and (3) in conjunction with Annex III.2 and Article 4 TEN-E Regulation). In the process, they check in particular whether the proposed projects meet the selection criteria—the target triad 'security of supply, competitiveness and sustainability' [Article 4.2.a) i–iii of the TEN-E Regulation], the European climate and energy targets[8] as well as the 10% electricity interconnection target[9] [see also recitals (2), (3) and (7)]—and whether they have cross-border significance within the meaning of the regulation.

For a harmonised energy system-wide cost-benefit analysis of the PCI, the ENTSO-E with participation of the member states, the Commission and ACER is developing a uniform method in accordance with the principles set out in Annex V (cf. Article 11 TEN-E Regulation), which is the basis for TYNDP, PCI selection and cost allocation decisions. With this, an element of forecasting and evaluation for energy infrastructure projects at EU level was introduced for the first time (Posser

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[8] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy 2020—A strategy for competitive, sustainable and secure energy (COM(2010) 639 final of 10.11.2010): Currently, the so-called '20-20-20' targets set in 2009 are still valid: Greenhouse gas emissions are to be reduced by 20%, or by 30% if other industrial countries adopt comparable targets; the use of renewable energies is to be increased to 20% of final energy consumption; energy efficiency is to be increased by 20% by comparison with a development without further efforts to improve energy efficiency. For the targets up to 2030, so far the European Council has merely adopted a framework in October 2014: Inside the EU, greenhouse gas emissions are to be cut by at least 40% compared with 1990 levels, whilst the use of renewable energies is to be increased to 27% of final energy consumption (this minimum target is binding at the EU level, but will not be translated into binding targets at the national level. Instead the Member States will commit themselves to achieving targets in the context of the integrated national energy and climate protection plans); energy efficiency is to be increased by 27% by comparison with a development without further efforts to improve energy efficiency and with the option of raising that target to 30% following a review of the period up to 2020.

[9] See, e.g. the Communication from the Commission to the European Parliament and the Council: Achieving the 10% electricity interconnection target–Making Europe's electricity grid fit for 2020 / * COM(2015) 82 final.

and Faßbender 2013, p. 64). This was preceded by the CBA 1.0 methodology,[10] which was adopted in February 2015 and used in the TYNDP 2014 (partially) and in the TYNDP 2016 (fully) project assessments. Based on the experience gained from these two exercises and the feedback received from the stakeholders, including the European Commission, ACER and public consultation, ENTSO-E revised the CBA 1.0. methodology.[11] For the upcoming TYNDP 2018, the new CBA 2.0 will be used. One of the bigger changes involved in the transition from CBA 1.0 to CBA 2.0 is that ENTSO-E now groups the indicators into only three categories (benefits, cost and residual indicators) to offer more clarity to the reader. As a consequence, the title of Annex 9 has changed from 'Environmental and social impact' to 'Residual environmental and social impact'.

According to Annex III.1.5 to the TEN-E Regulation, each group shall hear the organisations representing relevant stakeholders, including producers, distribution system operators, suppliers, consumers and environmental protection organisations in the context of the PCI evaluation process. In the future, the intention is that the regional groups will allow some external stakeholders to attend their consultations (Dross and Bovet 2014, p. 434). This certainly makes sense because at present public involvement is still weak, as a direct consultation takes place only if deemed necessary by the group. An enforceable claim to 'be heard' does not exist. The Commission then draws up a Union-wide list of projects (Article 3(4) TEN-E Regulation), whereby it must take into account the opinions of ACER and the member states whilst also ensuring that the criteria of cross-regional consistency are met and the total number of PCIs remains manageable (Article 3(5) TEN-E Regulation). The PCI list is updated every 2 years in a kind of rolling procedure. Starting with the second Union list, all PCIs to be selected must have been included in the latest available TYNDP (Annex III.2.3 TEN-E Regulation). For this reason, the first TYNDP played an important role as it represents a preselection of sorts (Strobel 2014, p. 302).

As a consequence of qualifying as a PCI, the network expansion projects are to enjoy priority status, whereby this is observed primarily in the procedural requirements for the national permit granting process and less so in the preceding Union-wide demand planning. This is because, pursuant to Article 7 of the TEN-E Regulation, the adoption of the PCIs in the Union list justifies their necessity from an energy-economics perspective in the national federal demand plans. (For more on the requirements of the individual national permit granting processes, see Erbguth and Schubert (2014), Guckelberger (2015) and Leidinger (2015).) Whereas under Article 5(8) of the TEN-E Regulation, a PCI can be removed from the Union list if its inclusion in that list was based on incorrect information which was a determining factor for that inclusion, or the project does not comply with Union law, its

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[10] Guideline for Cost Benefit Analysis of Grid Development Projects FINAL. Approved by the European Commission on 5 February 2015

[11] ENTSO-E: Going from CBA 1.0 to CBA 2.0. Main improvements and why did ENTSO-E do this. 8 July 2016

retroactive deletion from a national demand plan violates the TEN-E Regulation (Fest and Operhalsky 2014, p. 1196). However, owing to the selection procedure, a European expansion project will, as a rule, already be an element of the national demand plan—although the case of the *Gleichstrompassage Süd-Ost* (a high-voltage direct-current transmission line from Saxony-Anhalt to Bavaria) shows that federal states, too, may fight against a decision of the member states. [For examples, see Strobel (2014, p. 303).] If a project is not adopted as a PCI, the way remains open to the project promoters to bring an action for annulment under Article 263 TFEU. Also the EU legislator likely anticipated that negotiation difficulties could arise and provided in Article 6 of the TEN-E Regulation that 'where a project of common interest encounters significant implementation difficulties, the Commission may designate, in agreement with the Member States concerned, a European coordinator for a period of up to one year renewable twice'. However, the European coordinator is primarily equipped to provide support and advice and has no pronounced powers to act (Article 6(2) TEN-E Regulation).

The question of cross-border cost allocation (CBCA) is regulated in Article 12 of the TEN-E Regulation. The background to this regulation is that the investment costs of the PCI are borne by the national transmission system operators, for whom the project has a net positive effect. If a PCI has net positive effects on another member state, a cross-border cost allocation will be considered for this project. The conditions are that the project promoters submit a joint application for cost allocation to the national regulatory authorities concerned, the project is sufficiently mature and the transmission system operators of the member states have been consulted with a net positive effect. On the basis of such a cost allocation decision, projects are eligible for CEF funding under Article 14(2) of the TEN-E Regulation.

In summary, it can be said that the determination of PCIs is not an automated planning regime. Because the electricity list in fact feeds out from selected network expansion projects of the national network development plans, the PCIs represent a selection of network expansion plans already approved by the member states. So far, the Commission does not have any power to enforce expansion plans it considers important, e.g. to increase the low level of electricity interconnection[12] of Cyprus, Malta or Spain[13] against the interests of the member state (Strobel 2014, p. 302). Because the member states have the right to veto under Article 3(3)(a) of the TEN-E Regulation, needs-oriented energy planning is not possible.

A differentiated assessment of the CBA cannot take place at this point. However it is clear that a close interlinking of the assessment methods, Union lists, TYNDP and sanctioning instruments (Article 5(7) TEN-E Regulation) is needed in order to arrive at an independent European demand-oriented energy planning system. A

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[12] The interconnection level describes the capacity of the cross-border electricity transmission lines to other member states in relation to domestic electricity generation capacity.

[13] Communication from the Commission to the European Parliament and the Council: Achieving the 10% electricity interconnection target Making Europe's electricity grid fit for 2020 /* COM (2015) 82 final, p. 5 ff., 9.

study conducted by the Helmholtz Centre for Environmental Research and the University of Leipzig (Köck et al. 2017) describes the steps towards such an environmentally compatible needs assessment as follows: After the (energy-specific) needs and objectives have been determined, concept alternatives for a more environmentally friendly fulfilment of the identified needs must be worked out and the impacts of potential developments evaluated by means of a needs forecast. By taking concept alternatives into account, a programmatic and, due to the orientation to normative targets, evaluative decision would then be available, which should serve as a basis for planning decisions (Köck et al. 2017, p. 81f.). The capacity to enforce such a course of action at European level is lacking because under Article 3(3)a of the TEN-E Regulation, the member states have veto rights with which the endorsement requirement laid out in Article 172(2) of the TFEU is taken into account.

5 The Ten-Year Network Development Plan (TYNDP)

The central steering instrument for energy planning at the European level is the European Network Development Plan (TYNDP), a non-binding Union-wide grid development plan which is adopted every 2 years pursuant to Article 8(3)b) of the TEN-E Regulation. The TYNDP is drawn up by the ENTSO-E using scenarios which are evaluated with the aid of market and network studies (Posser and Faßbender 2013, p. 76). The first pilot TYNDP was released in 2010 and every 2 years thereafter; TYNDP 2018 is currently in preparation. The TYNDP has three main functions: It is meant to ensure greater transparency regarding the European transmission network, support the decision-making process at regional and at European level and form the basis for the selection of PCIs. However, these projects merely represent a summary of the expansion requirements identified at the national level, and the TYNDP has no legal effect because it does not bind the transmission system operators to expand the transmission lines contained in it (see Sect. 4). Hence, the aim of drafting the 10-year plan is to obtain a consolidated overview of electricity network planning and therewith to provide some transparency—not only for the interested public, the European Commission and the regulatory authorities but also for neighbouring transmission system operators. The TYNDP nevertheless represents a big step forward as it suddenly and considerably increases the transparency and uniformity of Europe-wide network planning.

The System Development Committee of ENTSO-E, which is responsible for developing the TYNDP, is made up of six regional groups: North Sea, Baltic Sea, Continental Central East, Continental South East, Continental Central South and Continental South West. There are several steps to preparing the TYNDP. First, a uniform network is modelled. ACER then gives its opinion of the TYNDP and the national development plans and assesses the consistency between the TYNDP and the national development plans. However, ACER does not have any decision or veto right with regard to the TYNDP, because its opinions have no binding effect and no legal consequences. The public is increasingly involved in this process. For this purpose, ENTSO-E makes information available to the public via the Internet and has opened a consultation phase during which stakeholders can express their views. Moreover, ENTSO-E organises regional and Europe-wide workshops. Besides organising events to which members of the public were invited, a long-term Network Development Stakeholder Group was established. It includes representatives of, among others, ACER, the Directorate-General for Energy of the European Commission and various associations (including, among others, the Renewable Grid Initiative, Greenpeace, Eurelectric, EWEA, Friends of the Supergrid and Europacable) and is aimed at improving communication between stakeholders.

Whilst the first TYNDPs covered a 10-year period only, as of 2014, in addition to the year 2020, the plans also consider the period up to 2030. The first TYNDP already worked with scenarios. But over time the specific design was refined (Overview see: Glachant et al. 2017, p. 61ff.). At first there were only two basic scenarios ('conservative estimate' and 'best estimate'), which were developed in the context of a bottom-up approach only. In 2012, in addition to the bottom-up approach to scenario development, a top-down approach was also used. The 'Scenario EU 2020' was based on the European 20-20-20 objectives and the National Renewable Energy Action Plan (NREAP) data provided by the member states. Four scenarios were developed for the TYNDP 2014: Vision 1 'Slow Progress', Vision 2 'Money Rules', Vision 3 'Green Transition' and Vision 4 'Green Revolution'. All of these scenarios include significant developments in renewable energies (40–60% of the annual total demand) and also assume a 40–80% reduction of CO_2 emissions compared to 1990 levels. They differ from one another mainly in the following points: the trajectory of the path to the Energy Roadmap 2050 target—Visions 3 and 4 assume a regular and consistent pace up to 2050, whereas Visions 1 and 2 assume a slower start followed by an acceleration after 2030. These four scenarios were complemented in 2016 by a fifth, 'Expected Progress', with a time horizon only up to the year 2020. For the TYNDP 2018, five new scenarios with a 2040 time horizon were developed.[14] Since 2016, the scenarios are being evaluated by means of a CBA (see Sect. 4). Changes have also been made in the area of stakeholder involvement. Whereas simple consultations with selected stakeholders took place in 2010 and 2012, since 2014, interactions are taking place in every phase of development. Monitoring is also essential to good planning. In this area, too, it makes sense to set targets—and also interim targets—because only they make it possible to identify whether the actual developments are consistent with those envisaged. This applies especially to energy infrastructures as considerable timeframes are required to adjust them and the lifespan of such systems is long.[15] For this purpose, the ENTSO-E 2012 introduced an annual monitoring programme: the Mid-term

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[14] https://consultations.entsoe.eu/system-development/joint-electricity-and-gas-consultation-build-the-e/user_uploads/160509_energy-scenarios-2040.pdf

[15] High-voltage transmission lines have a lifespan ranging from 80 to 100 years.

Adequacy Forecast (MAF)[16] is a pan-European assessment. It involves an assessment of the TYNDP scenarios in relation to Regulation 714/2009 and an analysis of the evaluation of the relationship between supply and demand in the ENTSO-E network system in respect of medium- and long-term timeframes. The shaping of this planning process was accelerated and guided by the Energy Union Package adopted in February 2015,[17] with which a further step towards stronger cooperation was taken. To ensure that energy policy measures taken at European and member state level contribute to the objectives of the Energy Union in a coherent fashion, a reliable, transparent and integrated system of governance for the Energy Union is to be established. What shape this should take is merely indicated by the Commission in that it points out that the current energy and climate policy planning and reporting procedures need to be streamlined and unnecessary administrative burdens avoided when it comes to monitoring. At the same time, the governance process should strengthen cooperation between the member states and with the Commission.

To sum up, the following can be concluded: The fact that ENTSO-E is working with scenarios for the preparation of the TYNDP is to be welcomed. Scenarios are not forecasts, but rather plausible future (extreme) states, which showcase a wide range of possible alternatives. With them, various developments can be illustrated, and they facilitate decision-finding in complex, unpredictable situations. In terms of methodology, it is important that scenarios be fixed to targets. Of course, the more concrete these targets are, the more realistic and helpful the scenarios will be (Calliess and Hey 2013, p. 125). In this respect, it is important that binding, quantified energy targets exist at the EU level and that they are accompanied by a legal requirement to observe them when plans are being prepared. Targets are also important for the monitoring programme established at EU level, which, with its annual reporting, is ambitiously designed. The public—in the form of stakeholders and associations—will increasingly be involved in this process; for the public at large, so far, there is little opportunity to do so (Schweizer and Bovet 2016). However, this process is also to be improved, and the TYNDP 2018 pursues added stakeholder and external interaction in the definition of scenarios (Glachant et al. 2017, p. 70).

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[16] ENTSO-E, Mid-term Adequacy Forecast @ a glance 2016. Prior to 2016 this report was called the Scenario Outlook & Adequacy Forecast (SOAF).

[17] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy /* COM(2015) 80 final.

6 Conclusion

Overall, the European energy planning process with PCIs and the TYNDP is meanwhile relatively consistent and well positioned in terms of methodology: Scenarios are being developed, and public participation and monitoring are taking place. However, the system is flawed by unclear objectives and a lack of enforcement powers and because, ultimately, the list of projects considered necessary to expand the transmission networks is merely a reflection of national plans and it is not based on a European needs assessment.

Accordingly, the EU has no power to enforce or impose expansion projects against the will of the member states. The coordinator, who may be consulted when conflicts arise, has not been vested with powers to act so he must rely on his negotiation skills alone. If there is a delay in the permit granting process at the national level, a notification is simply sent to the group concerned; here, too, there is a lack of sanctioning options. Authorities, businesses and associations are increasingly involved in the planning process. It would be difficult, however, to involve the public at large in these processes because the discussions are frequently very technical and citizens would find it hard to reconcile their local interests with European ones; nevertheless, efforts to improve this situation should continue. Another area that needs to be improved is coordination and cooperation between the regional groups. Whilst participation and coordination deficiencies could be remedied through changes in procedure, the basic problem—the lack of regulatory options—can be traced back to the EU's lack of competence in the energy sector.

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The Spatiality of Germany's Energy Transition: Spatial Aspects of a Reconfiguration of an Energy System

Ludger Gailing

Abstract While the technological, political and institutional aspects of Germany's energy transition are widely featured in political and scientific debates, the spatial dimensions tend to be overlooked. Nevertheless, the interpretation of Germany's energy transition as a spatial reconfiguration is an important one, because it is critical to understanding the opportunities and conflicts involved in implementing the German *Energiewende* on different scales (local, regional, national and supranational). To this end, the paper first presents different crucial aspects of the spatial reconfiguration of the energy sector such as the trend towards decentralization, the spatial differentiation between regions and the constitution of new action arenas. Secondly, these dimensions of the German energy transition will be systematically addressed by conceptualizing their socio-spatial relations with the help of the TPSN framework (territory, place, scale and network) by Bob Jessop, Martin Jones and Neil Brenner.

1 Introduction: What Is so "Spatial" About Energy Transitions?

At first view, the German energy transition is not a spatial issue. It has been shaped mainly by federal law, especially the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, or EEG) with its prioritized "feed-in" of electricity from renewable resources. This law itself is blind to specific aspects of cities, regions and federal states in Germany. Behind this imagery of the German energy transition being a uniform transformation process, however, the implementation of the so-called *Energiewende* is by all means a highly contested and spatially uneven transformation process. Research on the national characteristics and Germany's way of turning

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L. Gailing (✉)
Research Department "Institutional Change and Regional Public Goods", Leibniz Institute for Research on Society and Space (IRS), Erkner, Germany
e-mail: ludger.gailing@leibniz-irs.de

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its policies and institutions towards a full nuclear phase-out and the rapid acceleration of electricity and heat generation from renewable sources, however, tended to narrow the scientific discourses related to spatial aspects of the *Energiewende* to comparisons between national policies (e.g. Mitchell 2008), or to the German energy transition as a special path (e.g. Hennicke and Welfens 2012) within a European energy transition. Surely, the national perspective and the discussion of the role of different pathways within the European Energy Union can be considered as an important spatial perspective. But the “spatial turn in energy research” (Bridge 2017: 2) finds its expression in many more and diverse fields of research related to the spatial embeddedness (Dahlmann et al. 2017) of energy transitions.

In general (Gailing and Moss 2016), transitions research has been widely criticized for its “geographical naivety” (Lawhon and Murphy 2012: 355). It has been accused of failing to explain how different spatial contexts matter, treating places either as homogeneous actors of transition or merely as the locations where transitions happen (Hodson and Marvin 2010). This has been taken up by scholars arguing for a “geography of sustainability transitions” (Truffer and Coenen 2012). The complex relations between energy and a space and the multiple ways in which a space (e.g. a city) and its energy infrastructure constitute each other (Bulkeley et al. 2011) are indicative of the value to be derived from conceiving energy transitions as a “set of processes, practices and policies which come together differently and are differently interpreted, translated, experienced and grounded, at particular moments in specific places” (Rutherford and Coutard 2014: 1355). Thus, research on energy transitions requires sensitivity to spatial as well as scalar interactions between the global and the local or between the national and the regional and so on. There is a new attentiveness to the way relationships between energy and society take different forms across scales and spaces and to the dynamics of uneven and contested spatial development of energy systems (Bridge 2017).

In the same way, the German energy transition cannot be fully grasped without appreciating its spatial impacts and implications. Interpreting Germany’s energy transition as a spatial reconfiguration is an important one, because it is critical to understanding the opportunities and conflicts involved on different scales. The *Energiewende* is at the same time a local, a regional, a national and a European project. To this end, the paper first presents different crucial aspects of the spatial reconfiguration of the energy sector: the trend towards decentralization, the spatial differentiation between regions and the constitution of new action arenas in cities and regions. Secondly, these dimensions of the German energy transition will be addressed by conceptualizing their socio-spatial relations with the help of the TPSN framework (territory, place, scale and network) by the British scholars Bob Jessop, Martin Jones and Neil Brenner (Jessop et al. 2008). The paper is based on the (preliminary) results and publications of two collaborative research projects at the Leibniz Institute for Research on Society and Space: “Public Goods and the Spatial Dimensions of Energy Transitions: Between Materiality and Power” (Gailing and Moss 2016) and “New energy spaces—Dimensions of socio-spatial relations in regional energy transitions”.

2 German Energy Transition: A Spatial Reconfiguration of an Energy System

The German energy transition is not only a technological, institutional and political transformation process, but at the same time a spatial reconfiguration of an energy system having a wide-ranging impact on the spatial structures and governance of the energy sector. In the face of changes in the spatial structure of the energy system (Beckmann et al. 2013) the technological transition leads to a reorganization of the relationship of energy and space and to the formation of new energy spaces (Monstadt 2007). Important aspects of the spatial reconfiguration of the energy system are the trend towards a more decentralized system of electricity generation, the modified spatial differentiation between regions and the constitution of new action arenas (Gailing and Röhring 2016).

In general, the energy transition in Germany has induced a trend towards a more decentralized system of electricity generation (Burger and Weinmann 2012). This emanates from the nature of wind, solar and bio-energy as relatively ubiquitous energy resources and the push for small-scale renewable energy technologies like photovoltaic systems, onshore wind farms and biogas plants. Individual and collective investors, municipalities and regions are competing for renewable energy projects—regardless of how well designed or located they are—as more projects means more jobs, more profits, more local tax revenues and more exported electricity from renewable energy sources. This is also true for the 16 federal states in Germany who pursue regional economic goals and are sometimes explicitly heading for the role of being an energy exporter (Monstadt and Scheiner 2016). In this context, the development of renewable energies is often driven far more by physical factors and economic incentives than by the spatial location of energy demand (Gailing and Röhring 2015). The main pillars of EU energy policy in recent years, such as the EU climate change and energy package and internal energy market regulations, have provided an important institutional context for the German energy transition, but were under no circumstances its main driver. Nevertheless, the market paradigm of liberalization and privatization has prompted institutional changes in the organizational structure of Germany's energy system, in which economic integration, territorial monopolies and central government regulation were once predominant features. This has ultimately been favorable for the German energy transition, creating opportunities for new market entrants in the field of renewable energy production and supply (Canzler et al. 2016).

Local and regional initiatives (such as energy cooperatives or municipal power utilities) in a highly diversified actor constellation have gained in importance in generating electricity from renewable sources. Many different stakeholders on the local and regional level have taken up the role as active driving forces in the energy system with very different spatial perspectives and specific interests. Additionally, the EEG has created a new type of key actor in the energy system: the individual "prosumer". The term "prosumer" characterizes private households and farmers who are at the same time producers and consumers of energy. Radtke (2016) has shown that the breadth, variety and diversity of engagement in energy projects is very large. In Germany, more than 800 energy cooperatives have been established, mostly by citizens, having a high impact on the decentralized spreading of energy generation based on renewable energies over the country (Klagge et al. 2016). However, the growth of community energy has recently declined as a result of amendments to the EEG.

Against the background of the privatization of municipal power utilities since 1998 and the phase-out of concessional contracts, a number of municipalities have attempted to remunicipalize energy production and distribution networks to advance public interests in climate protection and reassert their economic standing, even if they can only meet part of the local energy demand. Municipalities, their public utilities and their publicly owned housing companies are also front runners in the field of energy conservation, which is—contrary to the thrust of national energy policy—one of the main concerns of energy transition at the local scale (Riechel 2016). Some local rural energy initiatives, such as "bioenergy villages", are able to cover their full energy needs for electricity and heat (Becker et al. 2013). A small number of them are even aspiring to achieve local autonomy in energy supply, raising questions about the challenges this can pose to the solidarity principle in energy systems.

The spatial differentiation between regions within Germany is another important aspect of the spatial reconfiguration of the energy system. The German energy transition is altering the spatial configuration of the production, supply and use of energy. The roles of certain German regions in the energy sector and their relationships have changed in the course of the transition process. In the northern and northeastern states, huge generation capacities in wind power have been built up, whereas some regions in the south or west of Germany have lost their importance in electricity generation after the shutdown of some nuclear power plants or coal-fired power stations. Thus, in general, the north of Germany has become a new space of renewable energy production, central German states are sites for new transmission lines and the contestation they bring, whilst the west and south of Germany is increasingly a space of renewable energy consumption. The planned expansion of offshore wind power generation in the North Sea and Baltic will exacerbate this spatial differentiation unless the stakeholders in southern and western states continue to invest in generating energy closer to consumption hotspots. Indeed, some of these states are trying to redress the geographical imbalances of electricity production and to secure their own energy supply by expanding renewable electricity generation locally. For some of the local actors in the energy system in the south and west of Germany, fostering the decentralization of the energy system thus means avoiding the controversial grid development (Weber and Kühne 2016). In the end, this debate within Germany had effects on the electricity grids of neighboring countries in Europe due to the fact that they play a role in transmitting electricity from the north of Germany to the south.

The varied roles of rural and urban areas in the energy transition are another example for the importance of the aspect of the spatial differentiation. It should be emphasized that the German energy transition is primarily not an urban but a rural phenomenon. Although cities are in many cases an important laboratory for new technologies and socio-technical innovations in the energy sector (Bulkeley and Kern 2006), rural areas are becoming increasingly significant as energy suppliers for cities and urban agglomerations (Gailing and Röhring 2015). The availability of space for photovoltaic, biomass or wind power systems is elevating the importance of rural areas, which are not only delivering the principal achievements of the German energy transition but also bearing the brunt of the landscape interventions and political conflicts it is prompting (Bosch and Peyke 2011).

An additional important socio-spatial trend is the constitution of new action arenas. Whilst some regions are reacting passively to the opportunities of localized energy systems, others are taking the initiative and forging their own regional alliances. The constitution of energy regions as action arenas, such as "Bioenergy Regions" and "100 per cent Renewable Energy Sources Communities", was supported by programmes of the federal government aimed at facilitating collective action at the regional level and increasing acceptance as well as economic participation. Some of the federal states like Brandenburg took the initiative for developing their own funding opportunities for energy regions and an energy management at the level of the planning regions. The emergent regional networks in many parts of Germany involved a diversity of public and private actors. These activities at the local and regional scale are indicative of a complex rescaling of energy politics and the energy system as a whole. At the same time, these new modes of local and regional energy governance are, in most parts of Germany, only peripheral to the overarching activities of the national legislature on feed-in tariffs and national grid expansion plans. Despite the multiple initiatives at local and regional scales, it is clear that large-scale power generation will, provisionally at least, remain important and the distribution grids will still be called on to provide more long-distance coverage to compensate for weather-dependent fluctuations in power generation.

3 Conceptualizing the Spatiality of Energy Transitions: Territory, Place, Scale and Network

In order to address the spatial aspects of the German energy transition in a systematic way, this section introduces Jessop et al.'s (2008) Territory, Place, Space and Network (TPSN) framework. This interdisciplinary approach has been influential for human geographers, sociologists and experts in urban and regional studies as well as in other social sciences related to spatial issues and their governance. It represents a comprehensive approach to grasp the different spatial dimensions of a given strategic field of action. The main proposition of the authors is that each of the four dimensions of spatiality (territory, place, scale and network) should be "viewed as mutually constitutive and relationally intertwined" (Jessop et al. 2008: 389) instead of focusing on only one dimension. Their approach is based on a critique of methodological one-dimensionalisms: Territorialisms are subsuming all aspects of socio-spatial relation under the rubric of territories, especially when it comes to the role of the nation state. Place-centrism treats places as discrete, more or less self-contained and self-identical locations without taking into consideration the ways they are socially constructed in interaction with other places, with scales or with networks. Scale-centrism treats scale as the primary basis around which other dimensions of spatial relations are organized. And finally, network-centrism entails a one-sided focus on networks as the most important aspect of spaces without taking into consideration existing territories or materialities (Jessop et al. 2008: 391). In sum, Jessop et al. stress that territory, place, scale and network should be researched in combinations. No one spatial dimension should be accorded a priori preference; equally, not every dimension may be relevant to a particular empirical phenomenon (Beveridge et al. 2017).

"Territory" is conceived in terms of processes of bordering, bounding, parcelization and enclosure resulting in inside/outside divides. The nation state as a power container defined by its boundaries and frontiers is the characteristic and classical example of a territory (Jessop 2016: 24). In the case of energy, the territorialization of electricity at the scale of the nation—the development of a national grid and a national energy legislation—has historically been a major political project in all European countries (Bridge et al. 2013: 336). The German energy transition can be interpreted as an example of this territorial fix of energy policy. The institutionally and geographically nested nature of national energy politics and policy-making has overridden many aspects of the process of Europeanization in the energy domain (Dahlmann et al. 2017). The *Energiewende* is a national project rather than a European one: This may be "based on the German self-perception of being a leader in energy and climate policy, whose good example the other Europeans will eventually follow—either by making ambitious decisions on the EU level or by imitating at some later point in time" (Geden and Fischer 2014).

But understanding the German energy transition from a simple territorial perspective would miss many of its important aspects: Firstly (and as stated above), the German electricity grid is part of a European one, so that spatial networks play an important role. Secondly, the German policy for the development of renewable energy is always embedded in the European frameworks and policies related to climate protection targets, energy market aspects and so on. And thirdly, the nation state is not the only territory relevant to the German energy transition due to the fact that the federal states provide their own energy strategies and legislative frameworks for regional and land-use planning relating to transmission grids and windfarm development. Furthermore, the case of the recently emerged "energy regions" with its distinctive territorial form and geographical characteristics (Gailing and Röhring 2016) may illustrate how territorial differentiation shapes the specific manifestations of the German energy transition on the sub-national level (Bridge 2017).

The latter example demonstrates how the issues of territorialization and place-making are intertwined. The social construction of new regional action arenas is always a combination of territorialization (demarcating the borders of a bioenergy region) and place-making (strategies to improve the social acceptance of renewable energies and the participation, e.g. by combining renewable energy development with other regional issues like tourism, regional value creation or agriculture). "Place" can be understood in terms of proximity, spatial identity and areal differentiations. Place is a fundamental dimension given that place characteristics are fundamental for all constructions of energy spaces. The energy transition in Germany has its specific local and regional constellations. This is true for material conditions such as lignite deposits, existing power stations and grids, wind and solar conditions, but at the same time it is true when it comes to the specific local and regional actor constellations related to energy issues who often play an important role in preserving or changing the material conditions. Protecting places against new windfarms and other infrastructures of the energy transition has become one of the most conflictual issues in regional planning and regional development in many rural parts of Germany. At the same time local citizens' energy groups and cooperatives, institutional investors, farmers as producers of energy, project investors and prosumers often advocate for specific place-based ways of organizing the energy transition.

As a result of the rescaling of energy policy, the development of new more or less "informal" territories on the basis of existing territories and new actor networks may take a variety of forms: the remunicipalization of public utilities, the establishment of local or regional energy co-operatives and the institutionalization of new action arenas for regional renewable energy development (such as bioenergy regions and smart regions) or for the transformation of lignite mining areas (innovation regions heading for a preventive transformation of these old energy regions). Thus, an energy transition is always a nexus between place-making, territorialization and scaling. "Scale" refers to scalar connections and divisions, resulting in differentiations between dominant and marginal scales in policy-making and collective action. The re-scaling of the governance of energy transitions as well as the upscaling of local place-based projects, experiences and practices are important strategies of individual actors and organizations in the energy sector.

The decentralization of energy supply as discussed above potentially increases the importance of the regional and local scale (Becker and Naumann 2017). Paying attention to the scalar aspects of energy transitions helps to avoid the simple equation of place-related aspects with the local and particular (Bridge 2017). In this sense, local sites like forests and villages in lignite mining areas threatened by open-cast mining are not only places of localist discourses and conflicts, but at the same time "battlegrounds" of national and European climate policy. Stakeholders in these debates sometimes use the strategy to rescale political conflicts on the European and national level related to the reduction of greenhouse gas emissions to local conflicts—and vice versa. The same is true for many conflicts around the development of new wind farms or open field photovoltaic plants.

Upscaling these kinds of local or regional conflicts related to lignite mining or to new wind farms to the policy sphere of the states or even the federal state entails building new networks with policy-makers on different levels of the political system. Thus, networking is an additional and supporting strategy in order to achieve the objectives of place-making, territorialization and scaling. "Network" in the sense of the TPSN framework means the establishment of, or exclusion from, nodal connectivity and the interdependencies which thereby emerge. The first type of networks relevant to energy transitions are networks of key players and other stakeholders. Prominent examples are networking activities of the renewable energy industries (networks within 100% Renewable-Energy-Regions, networks lobbying the planning policy of the states or the energy policy of the federal government and so on), anti-wind networking activities or networking of traditional energy suppliers in order to maintain good conditions for coal-fired generation. These actor networks are directly embedded in the second type of networks: the much more fundamental socio-material networks of resources, infrastructures etc.

4 Conclusions for Further Research

This paper discussed emblematic issues related to the spatiality of the German energy transition and introduced the TPSN framework of Jessop et al. (2008) as a way of comprehensively conceptualizing space in energy transitions. The German energy transition has brought about changes to different aspects of spatiality and at the same time it poses a challenge for the spatial aspects of energy policy on different levels (local, regional, national and European). The development of "new energy spaces" through government, administration, businesses and civil society is an often neglected aspect of energy governance in Europe, in Germany, in its federal states as well as in the regions, cities and villages. This is an important area for future research due to the fact that energy policies on the different levels of society are always intertwined with socio-material networks of infrastructures and installations with its particular spatial patterns.

The TPSN framework focuses on the complexity of socio-spatial relations. Therefore, it may help to systematize the existing and future complexities and problems of energy transitions—in Germany and in Europe. It helps to analyze the different ways in which spatial structures of energy transitions are coproduced with a wide range of social, cultural and economic relations in place-specific geographies and territorial settings. Furthermore, it may increase the understanding of the scalar governance of energy transitions as a mode of structuration but also as a medium of power relations and network-based forms of governance, as illustrated by the role of national or EU legislation in local energy policy or the interconnectivity of regional modes of governance with global energy markets (Gailing and Moss 2016).

One important issue of further research is to investigate new energy spaces as expressions and vehicles of the energy transition, using empirical analyses in different emblematic case studies. Examples may refer to the creation of new action arenas related to renewable energies on the regional scale, on the tensions between "old" and "new" energy regions (especially in lignite mining districts), spaces of experimental energy governance in cities and spaces of conflict concerning the development of renewable energies in rural landscapes. These cases and other different typical constellations of energy transitions should be brought to light from the theory-based perspective of the TPSN framework. One important outcome of this kind of research would be to systematize the interdependencies between territory, place, scale and network for the German energy transition and to compare the typical patterns of the emblematic constellations. In any of the case studies it would be important to take a closer look on their embeddedness in a supranational European constellation of energy policy. Conducting socio-spatial research with regard to energy transitions in Europe always means bearing in mind that the German energy transition as well as a European energy transition is not a holistic process. The territorialization of energy policies within a federal state (like Germany) or within the European Union does not necessarily lead to "policy convergence" (Strunz et al. 2017). There are specific places and spaces of energy systems with their respective actor constellations, institutions and geographical characteristics so that analyzing energy transitions—especially in a supranational perspective—is always about taking seriously the subnational contexts of EU-driven or national legislations and policies.

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The Spatial Dimension of the Energy Transition: European Renewable Energy Sources—Local Resources and International Exchange

Christoph Kost and Sven Längle

Abstract A single renewable energy power plant relies strongly on the availability of specific resources such as wind, solar, water, biomass and geothermal energy. Connected to the grid, however, the generation of all renewables in a certain area is summed up and the availability of a single resource is less important. Because cost-efficient systems benefit from using different resources which are distributed throughout Europe, recent studies have focused on analyzing the spatial dimension of resources. Renewable energy, however, is sourced and distributed locally. Decisions on investments in renewables and new power plants are therefore more decentralized and made by local investors. Grid integration and grid connection of each individual power plant is a basic requirement. On the other hand, exchanging electricity over longer distances via the energy grid requires action at national and international level (e.g. new transmission lines). With an increasing share of renewable energy in the electricity system, international electricity exchanges are increasing and this leads to more coordination between grid operators and utilities. Therefore, local resources can only be used efficiently if they are integrated into European electricity systems and exchanged between European countries. This paper discusses the interaction between local electricity generation from renewables and the international coordination required to allow renewable electricity to flow to consumers across Europe.

1 Introduction

The spatial dimension of future electricity systems is an important new aspect to be considered in the rapidly changing energy sector. This applies above all to the electricity sector, which is transitioning from a system with a small number of large electricity generators (nuclear, coal or gas power plants) to a system with

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C. Kost (✉) · S. Längle
Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany
e-mail: christoph.kost@ise.fraunhofer.de

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thousands or even millions of single electricity generators (such as a wind power plants or photovoltaic (PV) systems). Europe is rich in renewable resources such as wind, solar radiation, water, biomass and geothermal energy (Resch et al. 2008; de Vries et al. 2007). In Europe, especially, with its high population density and low share of unused land, renewable energy cannot be exploited at some few locations in huge renewable energy power plants, but has to be geographically distributed and deployed in smaller entities. Furthermore, the complementarity of weather conditions at different locations makes it necessary to distribute the new generators in a system (Haller et al. 2012). Of course, this development does not depend on or stop at national borders. Weather conditions and topographical constraints are similar within regions and therefore may be similar in neighboring countries, e.g. water potentials in Austria and Switzerland due to the topography of the Alps. This opens up the European perspective on the spatial dimension of the future energy system. European electricity strategies will be based on European weather conditions and potential land-use for the construction of power plants. Locally generated electricity from renewables will be used in the European electricity system (Patt et al. 2011). The first large developments of expanded regional renewable energy capacity with effects on the national or international electricity system can be seen already today, e.g. in Northern Germany and Denmark, with a high onshore wind penetration compared to energy demand in this joint region. Offshore power plants are installed in the North Sea between the UK, Germany and Denmark. PV plants have been expanded in Southern Germany, Italy and Greece and they have a larger influence on the surrounding electricity system. But also hydropower plants installed in Switzerland and Austria, or even those in Norway, have an impact on a larger area around their specific location. Certainly, new European regions with high penetrations of renewables or with a specific focus on a certain renewable energy technologies will be developed over time. Therefore, the need to exchange electricity between regions and countries is increasing and will continue to increase in the future (Schaber et al. 2012; Rodríguez et al. 2014). At certain times, region A will generate surplus electricity and supply its neighboring region B with electricity. Just a few hours later, the situation may change and region B can supply region A. Certainly, there are also regions like region C which might not have the potential to install renewables and will depend completely on region A and B. Certainly, metropolitan areas do not have high potential for renewables, but a high energy demand and may represent a region C. This paper will discuss how renewables across Europe will interact due to their spatial distribution, how electricity is generated in the different European regions and how electricity from renewables will be exchanged between European countries.

This paper is structured as follows. First, an outline of current developments in renewables and their integration into the European electricity system are given, with a particular focus on spatial aspects. The next section presents an evaluation of the resources and availability of renewables in Europe to demonstrate potential locations and distribution options. In a next step, the impact on international (but also national) electricity exchange and the European electricity network is assessed. The paper ends with an outlook on challenges and barriers to the energy transition in relation to the spatial dimension of renewables expansion.

2 Renewable Electricity Generation in Decentralized Locations

All renewable energy technologies use natural resources that are locally produced or locally available to generate electricity. There is a direct link between these natural resources and the space required to utilize that resource, e.g. the use of sunlight is linked to a certain area on which it is received or the use of the flow of water at a certain geographical point due to its topography and water availability such as rainfall. The following section will explain how these resources and availabilities are distributed and how their complementary use can be supported by different technologies. However, this special dimension of the resource for renewables has a direct impact on the use of the technologies, their application to collect the resources, and finally the operation to generate electricity based on these resources.

Wind power plants use the wind resources available at sites with good wind conditions (often given as average annual wind speeds). Grouped together to wind farms, power plants can reach capacities ranging from a few megawatts, when using only a few wind turbines of 1–5 MW each, up to several hundred megawatts. However, due to the high population density in Western and Central Europe, even the largest wind farms do not exceed values of hundreds of MW, although technically a wind farm of gigawatt size could be realized. Onshore wind plants are often installed at particularly exposed and highly visible sites to capture high wind speeds, frequently in flat areas, close to the coast or on hills. This explains the distribution of power plants in certain areas, as sufficient locations are rare or have a very high impact on the environment. Because the resource (wind speed) has such a high impact on the cost of generation (this also applies to other renewables as the resource is directly linked to the output), good site selection is crucial and sites with poor conditions should be avoided. In Europe, offshore wind power plants are often installed far away from where the electricity is needed, i.e. mainly in the North Sea and Atlantic Ocean. Offshore wind farms normally exceed onshore wind farms in terms of size as they use larger free areas in the open sea, are not subject to land restrictions, and use larger transmission links to the mainland.

Photovoltaics can be installed as roof-top systems, while ground-mounted power plants can be scaled in size from a few kilowatts to megawatts. As a result, PV systems vary in size more than all other electricity generation technologies. As solar radiation does not change significantly from one location to another (if the system is not moved to the south by more than one hundred kilometers), the exact position is not really important. These facts lead to installations of different sizes but also by grid connection to different grid levels. As the system size of many roof-top installations is often negligibly small, active operation management or monitoring with a smart meter is often not carried out.

Electricity generation from other renewable sources such as biomass, geothermal energy or hydropower is distributed geographically based on the availability of naturally distributed resources. Similar to wind, they can also be scaled from small units to larger power plants, but their capacity is always limited by economic, technical or resource-related factors.

For environmental, economic, technical and social reasons, therefore, renewable energy is always spatially distributed. Furthermore, site selection is a key factor for investment decisions as a site is always connected with a local natural resource. And this resource directly influences the economics of the specific plant.

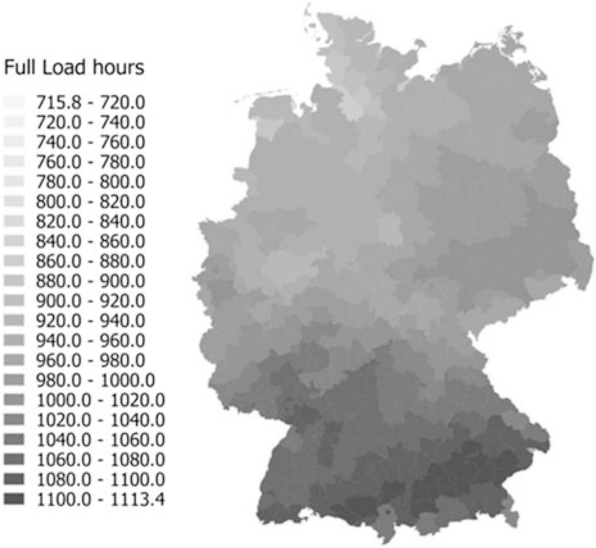
3 The European Perspective: Resources and Land Availability

Resources and the availability of land for renewables vary from region to region around the world. Due to weather conditions, some regions have greater potential for a certain technology than others. Fortunately, regions often have different advantages that are complementary and most regions are not optimal for all technology options. Generally, northern locations have less potential for solar applications than southern locations as, in Europe, radiation increases with decreasing longitude (Ban et al. 2013). Wind speeds are often higher at coastal locations as the temperature degradant is high to create flows of air between the different temperature levels. Therefore, in Northern Europe, especially around the North Sea, wind conditions are better than in southern areas around the Mediterranean Sea where, normally, relatively low wind speeds are found. Biomass resources are linked with land use (e.g. forests) as well as agricultural conditions. Of course, competition with other agricultural goods is a key limitation for biomass (Monforti et al. 2013). Water availability is another key factor for the amount of biomass. Hydropower plants are directly dependent on the amount of water available in rivers or lakes to generate electricity from differences in height. The resulting force of the water flow and its speed influence the turbine output. Hydropower is therefore limited to large rivers or great lakes with the potential to create electricity through the movement of water from a higher level to a lower level. Due to the economics of hydropower, only large resources can be used. Geothermal energy resources for electricity generation are very limited. As only very high temperature levels can be used to generate power, the sites available in Europe are concentrated mainly in Italy, where the topographical conditions make electricity generation economically viable.

To show the spatial distribution of PV systems in Germany, the following map contains all large-scale ground-mounted PV power plants (Fig. 1). The spatial distribution to some extent matches the distribution of solar radiation (Fig. 2). However, other factors such as land availability (e.g. in the eastern part of Germany where solar radiation is low compared to the huge amount of plants in this area) also influence investment decisions, which may be more profitable with lower solar radiation compared to sites with maximum conditions.

Fig. 1 Map of ground mounted PV > 1 MW in Germany (own figure)

Fig. 2 Full load hours for PV in Germany (own figure)



Wind and solar resources far exceed what is needed for the electricity system. The question is: How much can be used for electricity generation, economically and technically, when environmental and social constraints are taken into consideration?

Analyses of renewables potentials are being carried out throughout Europe to assess the available land to build PV and wind power plants. The following table shows the potential suitable land area in Western and Central European countries for a range of acceptable resource either solar radiation in kWh per m^2 or wind speed in m/s (Table 1). Suitable areas exist in all countries with better or worse conditions for renewables depending on local weather conditions. The available and suitable area varies strongly with the assumptions made during the calculations. The suitable area should therefore not be taken as a hard number, but as a rough estimation of what is possible. The potential analyses can help to create a better understanding of the available land and its characteristics.

However, the best locations cannot always be used for electricity generation, be it solar, wind or another renewable technology. Often, a trade-off exists between the use of good resources versus a location which is accessible and not too far from electricity demand or infrastructure. On the European level, some countries and also some national regions have much better resources than others. But this does not mean that local wind or solar resources should not be used. Two important outcomes of the decentralized expansion of renewables are the *complementary availability* of wind and solar from one region to another region and the *electricity grid* which is required to connect the decentralized and intermittent electricity generation with the demand.

Complementary electricity generation at a specific site compared to another is an important basic requirement for renewables expansion. If all solar power plants were located at the best site, a single cloud could easily interrupt electricity generation. However, if the PV power plants are distributed over hundreds of kilometers, cloud coverage has only a stochastic impact on the total system. The generation curve depends on general weather conditions rather than local conditions.

4 Complementary Analysis of Solar and Wind at Different Locations in Europe

The energy generated by wind and PV depends on the time and location of the power plant and the predominant weather situation (Heide et al. 2010). That points to irregular power generation for a single location. Multiple locations with different weather situations have different power in-feeds that can result in more regular power production (Grams et al. 2017). Figure 3 shows the correlation between the power in-feed from wind power plants in Austria, Belgium, Spain, Italy and Norway with the wind power in-feed from Germany in the year 2016, based on data provided by Pfenninger and Staffell (2016a, b). The highest correlation is with Belgium which is near the north of Germany where most the wind power is installed. Austria and Norway are about the same distance from northern Germany, but the wind in

Table 1 Potentials of wind and solar in specific European countries (Kost et al. 2015)

Rooftop PV		
Area	Range[a] (kWh/m^2/a)	Suitable area (km^2)
Belgium (30)	1074.0–1170.0	60.83
Netherlands (31)	1078.5–1176.5	49.14
Luxembourg (32)	1127.0–1184.0	2.30
Switzerland (34)	1174.0–1640.0	26.21
Italy (35)	1214.0–2025.0	138.87
Austria (36)	1146.0–1779.0	39.56
Czech (37)	1095.0–1265.0	48.27
Poland (38)	1119.0–1230.0	121.12
Denmark (39)	1085.5–1174.0	30.95
Norway (40)	861.0–1054.5	25.12
Sweden (41)	1026.0–1168.0	61.39
Germany	1065.5–1482.0	287.91
Greece	1457.0–1961.0	26.92
Ground mounted PV		
Area	Range[a] (kWh/m^2/a)	Suitable area (km^2)
Belgium (30)	1074.0–1178.0	101.86
Netherlands (31)	1075.0–1180.0	169.99
Luxembourg (32)	1125.0–1178.0	6.16
Switzerland (34)	1130.0–1810.0	20.12
Italy (35)	1319.0–2039.0	1373.57
Austria (36)	1090.0–1730.0	194.81
Czech (37)	1105.0–1266.0	352.47
Poland (38)	1117.0–1248.0	1479.58
Denmark (39)	1076.0–1178.0	249.76
Norway (40)	804.0–1158.0	1271.31
Sweden (41)	920.0–1166.0	432.32
Germany	1065.0–1619.0	1632.67
Greece	1465.0–1961.0	346.03
Wind		
Area	Range[b] (m/s/a)	Suitable area (km^2)
Belgium (30)	4.43–8.31	948.39
Netherlands (31)	5.12–12.01	4289.01
Luxembourg (32)	4.26–6.72	118.85
Switzerland (34)	2.34–4.84	2038.27
Italy (35)	2.17–8.98	31926.59
Austria (36)	2.25–6.60	4837.73

(continued)

Table 1 (continued)

Wind		
Area	Range[b] (m/s/a)	Suitable area (km^2)
Czech (37)	3.80–6.64	7589.20
Poland (38)	3.11–9.01	40958.73
Denmark (39)	6.04–11.87	29857.96
Norway (40)	2.01–12.04	50248.70
Sweden (41)	2.56–13.14	38574.27
Germany	2.65–11.54	32227.37
Greece	3.13–11.35	21804.39

[a] Yearly average radiation on optimally-inclined photovoltaic modules

[b] Yearly average wind speed at 100 m hub height

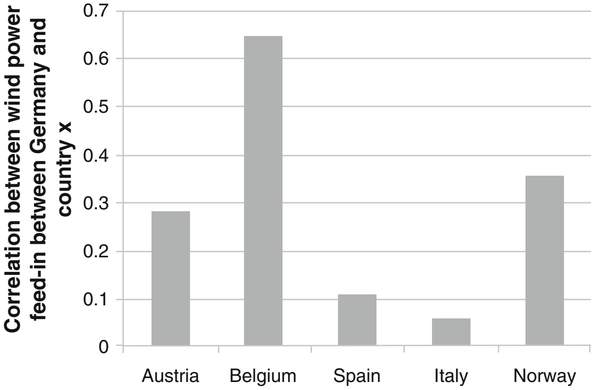


Fig. 3 Correlation of the nominal wind power in-feed from Germany with other European countries, based on data from Pfenninger and Staffell (2016a, b)

Norway has a higher correlation than that in Austria. Norway is also located at the North Sea, while Austria has no coastline. Italy and Spain are even further away from Germany and are also located at different at different oceans than Germany.

Figure 4 evaluates the standard deviation for the wind power in-feed for different European countries. Smaller countries like Austria and Belgium show a higher standard deviation than the other four larger countries. The standard deviation for the weighted mean of all six countries is even smaller. This shows that large well connected power systems could weaken the intermittency from the power in-feed of renewable power sources.

Figure 5 provides an analysis of the normalized wind in-feed for one week of August in the year 2016 in Austria, Belgium, Germany and Spain compared to the weighted mean of those for countries. The wind in-feed in the power systems of Austria and Belgium is more volatile than in the larger countries Spain and Germany. There are two reasons for this: first, Austria and Belgium have far less installed capacity and, second, the smaller spatial extent of those countries. Germany and Spain can distribute their generation over a much larger area than Austria or Belgium. The mean in-feed of all countries also shows that a larger area and installed capacity reduces the erratic behavior of the wind in-feed. This observation does not

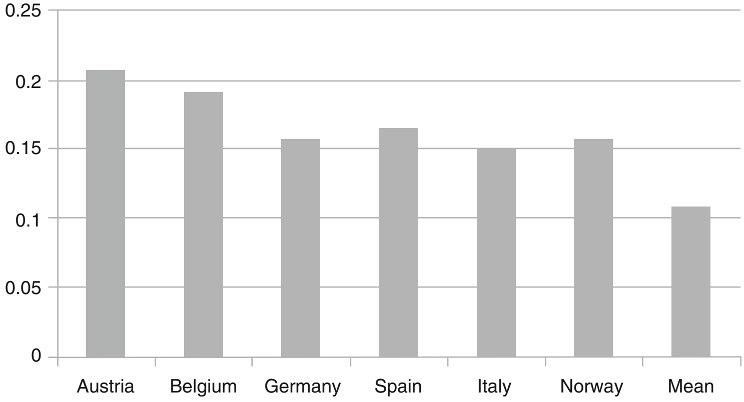


Fig. 4 Standard deviation for European countries and the weighted mean value of those countries, based on data from (Pfenninger and Staffell 2016a, b)

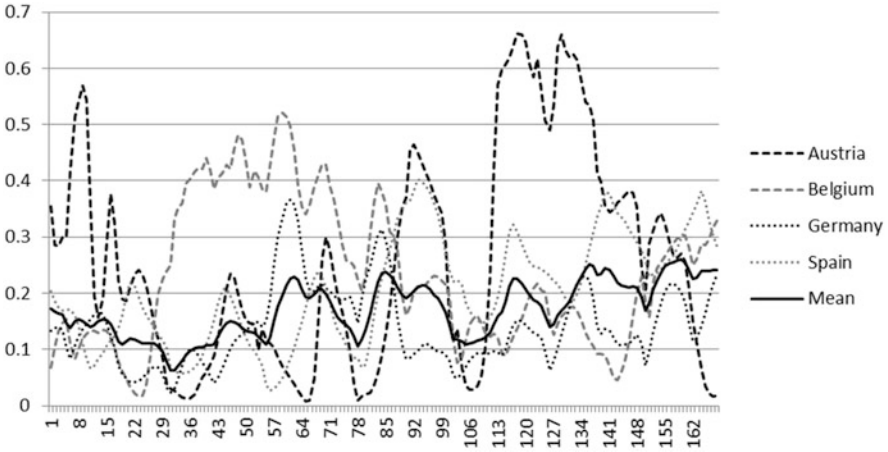


Fig. 5 Normalized wind in-feed in Austria, Belgium, Germany and Spain and the weighted mean value, based on data from Pfenninger and Staffell (2016a, b)

consider the grid limitations between those regions and countries. But it shows that a strong regional, countrywide and Europe-wide electricity grid could help to stabilize the in-feed from different RES generators such as wind and solar, but also from hydropower or biomass. Geothermal power generation is normally very continuous due its constant availability.

In terms of planning and support the renewable expansion, much more effort and support should be put on achieving an optimal distribution of power instead of targeting always the lowest price per kWh if grid integration costs are not included in the remuneration scheme or curtailment is not efficiently considered in the planning process. This means that renewable energy (mainly PV and wind onshore) should be located at points in the grid where grid access is available, congestion to demand centers is low, complementary to local resources and other renewable technologies is high as well as complementary resource to other power plants of the similar technology within an network area is high. By achieving a good distribution, the overall system cost for integration are calculated to be lower compared to a high penetration of a certain technology only in a specific area of a country (compare (Kost et al. 2016)).

5 Electricity Grid: Local and International Electricity Exchanges

Every renewable energy power plant has an output of electricity which depends on the local availability of its natural resources such as wind, solar, biomass, geothermal energy or hydropower. Connected to the electricity network (high, medium or low voltage level), the electricity generation of all renewable energy plants in a certain area or region is summed up. In that case, the availability and occurrence of a single resource does not have a strong direct impact on the overall system. Consequently, access to the grid, connections between important grid points (such as high demand centers or areas with high renewable penetration) and trade in electricity between larger areas has to be enabled from a technical, economic and regulatory point of view. In Europe, the situation can differ in the various network areas. However, the transmission grid is playing an increasingly important role in the European electricity system on its transformation path towards renewables. The reasons for this are as follows:

- Connection of renewables is being realized at all voltage levels (from distribution to transmission grid).
- Decentralized generation is taking place at many widely distributed locations in the electricity network.
- Large distances exist between electricity generation from renewable energy sources with good natural resources and demand centers (where there is only low renewables potential).
- Intermittent feed-in and complementarity of resources increase the change of electricity flows in terms of volume and direction frequently.
- Lower full load hours of renewable power plants can reduce the utilization rate of existing and new transmission lines. This can lead higher costs for transmission operations and expansion.
- Different electricity strategies in terms of renewables expansion create a wider use of the technology portfolio than in the past.
- Over-investments at specific locations require an improved grid operation strategy and curtailment.
- Delayed grid expansion requires more efficient and flexible use of the existing grid structure.

These effects can be detected in the European electricity system already today. Therefore, several activities and improvements are underway to maintain the speed of renewables deployment. Market coupling of electricity markets is continuously improving on the day-ahead level, but also on intra-day and reserve markets. To improve the price coupling of regions (PCR), the CWE electricity region (Central Western Europe with Germany, France, Belgium and the Netherlands) changed from the available transfer capacity (ATC) system to a flow based market coupling (FBMC) system. With this change, the available transmission capacity is more adequately calculated to take the whole electric network into account, compared to single lines. On the intra-day level, the cross-border intra-day market (XBIM) is another initiative to create larger common markets.

In the North Sea, the transmission grid is being expanded using high-voltage direct current transmission lines between Norway, Denmark, Germany, Sweden, the UK and the Netherlands. Projects such as NordLink (between Norway and Germany), NorNed (between Norway and the Netherlands) or BritNed (between the UK and the Netherlands) increase the transmission capacity in the North Sea area. This area shows the largest wind power expansion in Europe, with both offshore and onshore applications. The TYNDP (Ten-Year Network Development Plan) by ENTSO-E indicates expansion of interconnections at almost all potential routes in the North Sea, but also extends existing connections on a GW scale. Compared to the national network expansions which are focused mainly on the larger countries—Germany, Italy and Spain—interconnections on the mainland in Central and Western Europe have to take place everywhere (Fig. 6).

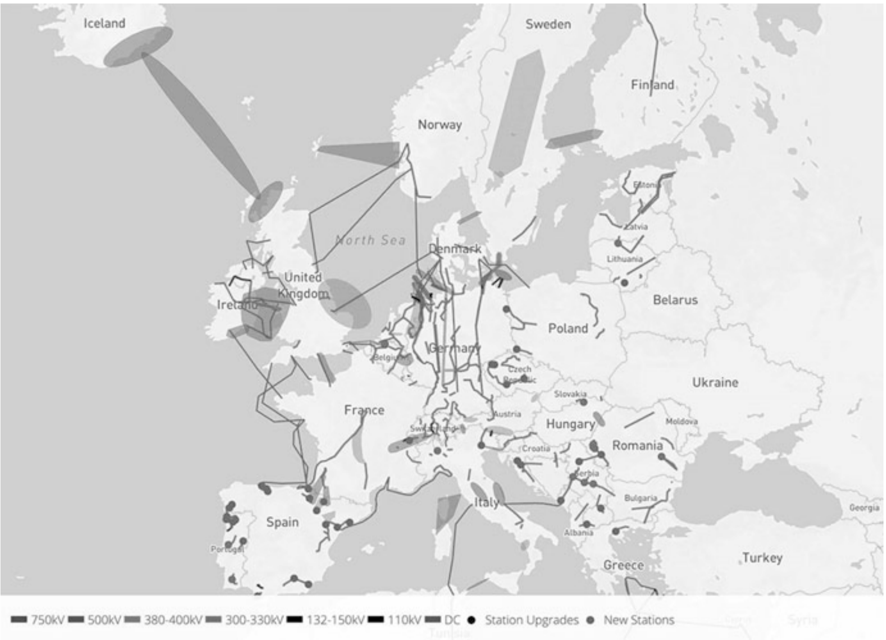


Fig. 6 ENTSO-E's Ten-Year Network Development Plan, version 2016 (ENTSOE 2016)

However, based on the current grid operation and power generation events, it is unclear whether the integration of renewables is possible with the ongoing activities. To meet the decarbonization and CO_2 targets of the European countries, expansion of renewables has to be further increased. In some countries, renewables development has only just started while in others, such as Germany, a full decarbonization of all energy sectors would require an expansion of renewables to a level three to five times higher than the current installed renewable energy capacity. This huge expansion can only be achieved cost-efficiently if neighboring countries' resources are used too. The framework conditions for the market integration of renewables as well as market mechanisms for the joint use of renewable electricity resources still require further development. In particular, the use of complementary resources or complementary technologies between neighboring countries should be promoted. In this respect, the buying and selling of renewable electricity to and from other countries will be a central part of future electricity systems. Remuneration schemes and European framework conditions have to take these aspects into account. These developments will show that national plans to expand renewables and their decentralized and local installation are more easily realized with international electricity exchanges over large distances.

6 Challenges and Barriers

The spatial distribution of renewables presents challenges for and barriers to future developments in Europe's electricity systems. With its goal of achieving an integrated European energy market as well as a joint decarbonization objective by 2050, the EU has created the first European and international activities which take the wide distribution of renewables and their decentralized and locally generated electricity into account. However, some big challenges remain and they should be further analyzed in order to reduce them. Certainly, any inefficient allocation of support for inflexible conventional power generation which stands in the way of distributed and intermittent electricity generation from renewables must be avoided. Decommissioning of conventional power plants should also be taken into consideration in the search for new sites and locations for renewable power plants, as the electricity network is historically relatively strong at these sites.

The next major challenge is to connect the national development plans for renewables with a European perspective to create benefits for an optimal spatial distribution of renewable energy sources. In the process, inefficient national allocation of support or markets for renewables can be avoided if the best locations and resources are used. Of course, it is not only the national support schemes for renewables that should be improved in this context; rather, the creation of a European renewables deployment mechanism might be necessary. Certainly, the tools for assessing the value of renewable energy power plants using local resources for the European and national electricity system still have to be developed. These tools, along with the mechanism, can then help to foster spatial distribution, to explore the complementary value of the technology to the system, and to improve the robustness of the system in terms of energy security. This framework could improve not only the coordination of renewables deployment between countries, but also network integration and expansion under a joint European program, as already initiated with the TYNDP developed by ENTSO-E.

7 Conclusions

Renewable energy sources are a naturally widely distributed source of electricity generation. The spatial distribution of all renewable technologies has to be increased to create a robust renewables-based electricity supply for Europe. This creates many new challenges for the management of electricity generation, but also for the operation of the network. This paper has highlighted the key ongoing activities in the European electricity market related to decentralized renewables expansion, mainly in terms of onshore wind power and PV deployment. These recent developments have shown that, in terms of spatial distribution, huge efforts are required to expand the national and international electricity network in Europe. International electricity generation and exchange of energy from renewables has to be successfully coordinated before locally-generated green electricity from each individual PV, biomass or wind power plant can be used to decarbonize the energy system and empower the European economy efficiently.

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Part VI

The Energy Transition Beyond the Electricity Sector

Road Transport and Its Potential Inclusion in the EU ETS

Martin Achtnicht, Kathrine von Graevenitz, Simon Koesler, Andreas Löschel, Beaumont Schoeman, and Miguel Angel Tovar Reaños

Abstract Road transport accounts for about one fifth of the EU's CO_2 emissions and its share is growing. One of the key policy tools for achieving CO_2 emissions reductions in road transport is the implementation of emission performance standards for passenger cars and light commercial vehicles (LCV). However, regulation through emission standards has a number of drawbacks. In this article, we focus on an alternative or complementary policy option for the CO_2 regulation of passenger cars and LCV in the EU, namely the inclusion of road transport in the EU Emissions Trading System (ETS). We discuss whether to incorporate the road sector directly into the existing EU ETS or to create a gateway solution. We present advantages and disadvantages of making fuel providers, car manufacturers, or consumers the regulated entity. We also look at how the emission allowances should be allocated and how the cap should be set.

1 Introduction

The transportation sector is responsible for some 21% of the EU's CO_2 emissions, where road transport is the predominant contributor, with growing emissions in the past 10–20 years. Accordingly, this sector features prominently in the climate policy of the EU and its member states. With the aim of reducing CO_2 emissions in road

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M. Achtnicht (✉)
Leibniz Institute of Ecological Urban and Regional Development (IOER), Dresden, Germany
e-mail: m.achtnicht@ioer.de

K. von Graevenitz · M. A. Tovar Reaños
Centre for European Economic Research (ZEW), Mannheim, Germany

S. Koesler
University of Strathclyde, Glasgow, UK

A. Löschel
University of Münster, Münster, Germany

B. Schoeman
University of Basel, Basel, Switzerland

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transport, binding emission performance standards for new passenger cars and LCV were introduced in 2009 and 2011 at the EU level. Although this regulation may have helped to improve the fuel efficiency of new vehicles sold in Europe, it has been increasingly criticized for several inherent drawbacks.

A general concern and well-known result from economic theory is that emission standards usually fail to meet the environmental target at minimum cost (i.e. to be cost-effective). This is basically due to the fact that virtually all car manufacturers have to fulfill the prescribed standard, no matter what their marginal abatement costs are, while other abatement options remain unaddressed. The standards focus only on the new car fleet, but provide no incentive for used car drivers to change their driving behavior. Moreover, fuel economy standards may lead to what is referred to as "used car leakage": higher costs of new cars result in postponed scrapping of older vehicles, reducing the expected fuel savings (Jacobsen and van Benthem 2015). To make matters worse, drivers of new, fuel-efficient cars are incentivized to use their car for more and longer trips, as driving becomes relatively cheaper. Such "rebound effects" can substantially reduce the abatement that was originally intended by the introduction of the standards (Frondel et al. 2008). There is also some empirical evidence that car manufacturers have adapted to the standard as it is currently designed by making their car models heavier, which may lead to other unintended consequences such as more serious injuries in car accidents (Ito and Sallee 2018). Additional problems are associated with measurement of emissions through performance tests and potential distortions in the technology used to produce better test performance rather than reduce real world emissions.

Against this background, the important question arises whether there are other, better alternatives available to regulate the CO_2 emissions of road transport. This article discusses the policy option of regulating the sector's CO_2 emissions within a cap-and-trade system, in particular the inclusion of road transport in the existing EU Emissions Trading System (ETS).

The advantages of including the transportation sector in the EU ETS are many. An ETS equalizes abatement costs across sectors and ensures that the emissions abatement takes place where it is cheapest. As abatement costs for individual sectors are imperfectly observed by regulators, this implies that abatement may take place in sectors and ways that are unexpected to the regulator (Convery et al. 2008). However, by setting a cap and issuing allowances for emissions corresponding to the cap, the ETS ensures that the emission reduction target is achieved. The cost of achieving the target is revealed through the price of emissions allowances and in principle allow a policy response if the costs become too high or too low relative to society's marginal valuation of emission reductions. In effect, the ETS puts a price on CO_2 emissions, which will provide incentives to reduce emissions across the economy. Compared to emission standards, a market-based ETS provides stronger incentives for innovation and technology diffusion (e.g., Downing and White 1986; Milliman and Prince 1989; Jaffe and Stavins 1995), although this may depend on the market structure (Montero 2002; Requate 2005).

This article, which is an abridged and updated version of a project report published in 2015 (Achtnicht et al. 2015), discusses three specific design issues for including road transport into the EU ETS. The focus is on passenger cars and light duty vehicles, and freight will not be touched upon. Section 2 discusses whether to incorporate the road sector directly into the existing EU ETS or to create a separate ETS for the road transport sector and link it through gateways to the remaining ETS. Section 3 focuses on the advantages and disadvantages of making fuel providers, car manufacturers, or consumers the regulated entity. Section 4 discusses how emission allowances should be allocated among the parties in the road transport sector and takes a look at how the cap should be set. The conclusion summarizes the discussion with recommendations for policy makers.

2 Inclusion in the Open ETS Versus a Closed ETS for Road Transport

The EU introduced its emissions trading scheme in 2005 thereby becoming the first multinational cap-and-trade scheme for greenhouse gases. The EU ETS remains the largest carbon market and covers Iceland, Lichtenstein and Norway in addition to 28 EU member states. More than 11,000 power stations and other installations are currently covered by the ETS. The latest addition to the scheme is aviation, which entered the EU ETS in 2012. The EU ETS is currently in its third phase running from 2013 to 2020. It covers approximately 45% of the EU's greenhouse gas emissions. Sectors currently not covered by the ETS include buildings (e.g. heating), agriculture, and road and maritime transport. In recent years the EU ETS has been much criticized due to the currently low allowance price and the accumulated surplus of allowances in the market. In its carbon market report 2012, the Commission discusses different options for improving the functioning of the EU ETS and reducing the number of surplus allowances accumulated during the financial crisis (European Commission 2012). Among the options discussed is an expansion of the ETS to cover sectors currently outside the carbon market. In the conclusions from the council meeting of 23/24 October 2014 the EU Council has noted that under existing legislation member states can opt to include transport in the ETS (European Council 2014). Such an expansion requires consideration of each of the design features of the enlarged EU ETS.

The impact of an ETS in terms of cost-effectiveness, distributional effects and efficacy depends on its design. The market must be large enough for regular trading to take place, and single traders should not hold considerable market power such that the carbon market can be used strategically. Likewise, the more sectors an ETS covers, the more potential abatement opportunities exist within the carbon market. As an ETS ensures that abatement takes place where the cost is lowest, this implies that some sectors may not experience much reduction in their emissions. The damages from CO_2 emissions do not depend on the source of the CO_2, therefore there is no reason why emission reductions should necessarily occur in specific sectors. Including new sectors can affect the price of emissions allowances depending on how the expansion is designed. In this section, advantages and disadvantages of a full integration of road transport into the ETS are discussed versus a more limited integration or the setting up of a separate ETS where only emissions from road transport are traded.

2.1 The Closed Road Transport ETS

Creating an ETS in parallel to the existing EU ETS focusing solely on road transport would ensure that emission reductions set as a cap for the system are achieved within the road transport sector. In addition, a separate ETS for road transport could take into account any legal or organizational issues specific to that sector, which may be less easily accounted for in full integration. Regulation through an ETS is more flexible than standards as the emission reductions may occur through the use of other abatement measures than improving fuel efficiency. Potentially, the price on carbon emissions in the transport sector could provide incentives to reduce driving, reduce the carbon content of fuel, and influence purchase of relatively fuel efficient vehicles (both used and new). The exact impact may depend on the choice of regulated entity, which is the subject of Sect. 3. A disadvantage to this approach would be that the abatement measures used are likely to be more costly than abatement measures available in the sectors covered by the existing EU ETS. Prohibiting the use of these cheaper abatement measures to achieve the needed emission reductions for the economy as a whole would imply a higher overall cost of GHG emission reduction than in an integrated system. While the cost of achieving the target set for road transport would likely be lower with the possibility of trading emission allowances than the cost of using emission standards, the closed system overall is less efficient than a system which allows for more integration with the full EU ETS and in consequence has more abatement opportunities available.

A closed transportation ETS also runs the risk of strategic considerations affecting trading in emission allowances due to the limited number of actors in the market. The magnitude of this risk depends on who the regulated entity is. If car manufacturers are regulated (e.g. required to hold emission allowances corresponding to the estimated emissions of their sold vehicles), the structure of the market with few large players could imply that some actors have an interest in driving the price of emissions allowances up. The more participants there are in a market, the lower is the risk of such strategic behavior.

2.2 Improving Efficiency Through a Gateway

When aviation was included into the EU ETS there were concerns of how this might be accomplished while taking into account that aviation was not covered by the Kyoto Protocol. As such, emission reductions in aviation could not contribute to complying with the targets set out in the Kyoto Protocol. For this reason, a separate, but linked ETS was set up for aviation in which trade occurs between operators and owners of aircraft, but with a gateway to the full EU ETS. The gateway provides the opportunity for operators in the aviation sector to purchase allowances in the EU ETS, but allowances from aviation emission reductions cannot be used by industries in the EU ETS to cover their emissions (Directive 2008/101/EC).

The effect of having a semi-open system implies that the price of emission allowances cannot deviate too much between the two systems. For example, if the price of allowances within the aviation sector roses much above the price of an EU allowance from the EU ETS, aviation operators have an incentive to purchase allowances in the EU ETS until prices are equalized. In this way abatement costs across sectors in the two ETS are equalized and emission reductions have been achieved at less expense than in the fully closed system. At the same time, the gateway insulates the EU ETS from periods in which the price of an allowance in the aviation sector is much lower than the price in the EU ETS. In this case, as no allowances can flow out of the aviation sector, a price difference can be maintained.

A gateway may be useful in the early stages of expanding an ETS if the impact of the expansion on allowance prices is very uncertain (for instance if there is very little knowledge about an appropriate cap after the inclusion of a new sector) in the sense that it could prevent a price collapse. Alternatively, if a sector experiences much larger fluctuations in activity through the business cycle than the other sectors, a semi-integrated system can limit the impact of these fluctuations on other sectors by limiting the impact on the quota price.

If no limits are put on trade through the gateway, i.e. if all allowances are tradeable in both markets, then it is in effect a fully integrated ETS with one carbon price. In this sense it is possible to set different caps for the different ETS, but since the allowances can be traded freely between them, there is no control over where abatement occurs and in practice it would function as an integrated ETS with a cap equal to the sum of the caps set for each scheme.

2.3 Full Integration

Full integration of road transport into the existing EU ETS has significant advantages. The institutional base is already available as a working system with reporting mechanisms and trading institutions. Enlarging the coverage of the existing ETS also offers several economic advantages for its operation. First, a correspondingly enlarged EU ETS has a larger number of abatement options and thus can improve cost efficiency of mitigation. Second, it is expected that larger schemes have lower volatility of trading and hence certificate prices. This is due to the fact that individual trading activities only have a small impact on the market price and liquidity due to the greater volume of trades in a single large trading scheme.

While the cap set for the integrated EU ETS would guarantee that no more emissions take place than those for which allowances exist, it could be the case that none or only very little of the abatement takes place in the road transport sector. The allocation of abatement efforts across sectors depends on the relative marginal abatement costs. The cheapest abatement opportunities will be realized before the more expensive alternatives are taken up. This is exactly the point of using an ETS.

When it comes to GHG emissions, it should not play a role which sector reduces emissions, as the damage caused by one additional ton of emitted CO_2 equivalent is the same regardless where it came from. Burden sharing among sectors is easily achieved in an ETS by ensuring that no sector covered by the regime avoids paying the market price for its emissions. The market price in this sense is determined by the marginal abatement cost curve and the cap for the integrated system.

2.4 Impact on Allowance Price and Distributional Concerns in the Case of Full Integration

The inclusion of road transport into the EU ETS with a single common cap could redistribute resources between sectors by reducing compliance costs for climate policy goals for the road sector while raising compliance costs for other sectors. Sectors such as manufacturing are already covered by the EU ETS and are exposed to competition in the global market. For such sectors a substantial increase in allowance prices could have a negative impact on their international competitiveness and might lead to carbon leakage as carbon-intensive production relocates outside the EU ETS area.[1] Whether the inclusion of road transport into the ETS will have a large impact on the allowance price and hence potentially on the global competitiveness of other sectors depends on the setting of the cap and the marginal abatement cost curve for the enlarged EU ETS.

Flachsland et al. (2011) illustrate the effect of integrating road transport into the EU ETS in a stylized graph repeated here in Fig. 1. The horizontal axis depicts the total volume of abatement in both transport and the existing ETS as implied by the reduction target or cap. From the left hand side, the marginal abatement cost curve (MACC) of the existing ETS is shown to be rising from left to right as abatement volume in the ETS sectors increases (ETS MACC). From the right hand side, the MACC for transport is illustrated rising from right to left as abatement within the transport sector increases. The point on the horizontal axis marked by Q_{set} shows the allowance price in two separate emission trading schemes where the existing ETS and the transport sector have to reduce emissions corresponding to the distance from the origin to Q_{set}. This distribution of required abatement efforts results in the allowance prices P_{ETS} and P_{trans} in the ETS and the transport sector, respectively. Due to the steeper MACC in the transport sector, the allowance price in the isolated transport emissions trading scheme is higher than the allowance price in the ETS. The intersection of the two curves at (Q^*, P^*) illustrates the distribution of abatement efforts in the integrated ETS. Here, P^* is the emission allowance price in the integrated system. It is slightly higher than in the isolated ETS, but lower than in the isolated transport emissions trading scheme. The figure thus illustrates the effect of integrating the two systems and how it depends on the relative steepness of the

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[1] For a survey of empirical evidence of adverse effects on firm performance and competitiveness in the existing EU ETS, see Martin et al. (2016).

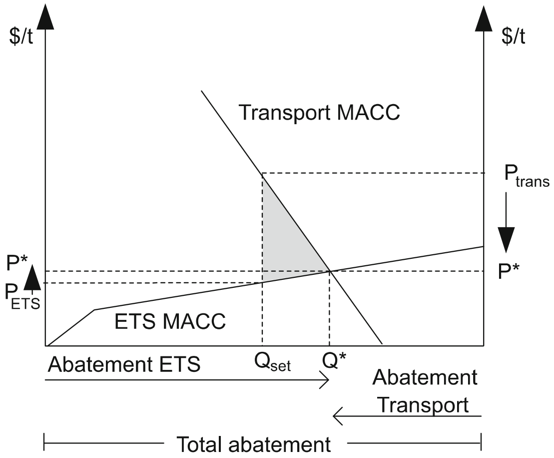

Fig. 1 Allowance price effects of including transport. Source: Fig. 5 in Flachsland et al. (2011), reprinted with permission from Elsevier

respective marginal abatement cost curves and the total quantity of abatement necessary.

While there is some uncertainty as to the steepness of the actual MACC, a series of modeling exercises have been carried out with different assumptions to shed light on how the EU allowance price might be affected. The general sentiment is that the marginal abatement cost curve for the road transport sector is steeper than for the remaining EU ETS (Blom et al. 2007; Cambridge Econometrics 2014; Heinrichs et al. 2014). However, indications of a steep marginal abatement cost curve for road transport does not imply that allowance prices would rise steeply with the inclusion of road transport into the ETS (Flachsland et al. 2011), although it does strongly suggest that the cost-effectiveness of the regulation for CO_2 reduction would be improved. In a recent CGE analysis, Paltsev et al. (2018) find substantial welfare gains from using the ETS rather than emission standards for private cars to achieve the same carbon reductions. Annual cost savings of 24–63 billion € in 2025 are found, depending on the stringency of the emission standard.

3 Regulated Entity: Upstream, Midstream or Downstream Regulation

Regulating the road transport sector at any level along the fuel chain creates the same macroeconomic incentives, in the form of a price effect that increases the marginal cost of driving, for the actors involved (Ewringmann et al. 2005). The important caveat to this result is that all abatement options must be incentivized, all emissions along the fuel chain in the road transport sector must be accounted for, and the transaction costs must be passed through to consumers (Flachsland et al. 2011). This section discusses at which point along the fuel chain transaction costs are minimized, but also touches upon possible difficulties with incentivizing abatement options along the fuel chain.

The fuel chain is divided into three levels: downstream, midstream, and upstream, which represent consumers of fuel, car manufacturers, and fuel suppliers, respectively. It is assumed throughout that the additional costs incurred by actors further up the fuel chain are fully passed through to consumers at the downstream level.

3.1 Downstream Regulation

Consumers are responsible for the CO_2 emissions from personal car fuel consumption through the use of their vehicles. Regulating the actual consumption-related emissions of CO_2 at the source incentivizes adjustments in behavior and in consumer demand for vehicles and carbon content of fuels. It therefore does provide incentives for entities further up the fuel chain to abate, as consumers presumably have a willingness to pay to reduce their carbon emissions related to driving. Flachsland et al. (2011) point out however, that the transaction costs involved in regulating such a large number of units are non-trivial. Regulation of the road transport sector at the consumer level (downstream) would involve over 243 million passenger cars and over 512 million potential car users in the EU (NFF 2014). In addition, consumers are highly dispersed (Brunner et al. 2009) and mobile (Raux and Marlot 2005), both of which contribute to the relatively high transaction costs involved in regulating the road transport sector at the downstream level. Flachsland et al. (2011) go as far as to say that the level of transaction costs prohibits downstream regulation.

The transaction costs involved in regulating consumers in the road transport sector include the cost of implementing and administrating the EU ETS trading infrastructure, and the cost of information campaigns (Raux and Marlot 2005). Decomposing transaction costs into these components provides a detailed picture of where the specific costs arise.

The cost of implementing the trading infrastructure of the EU ETS contributes significantly to the transaction costs of regulation at the consumer level. Raux and Marlot (2005) suggest a system for trading where consumers are equipped with chip cards loaded with a specific number of CO_2 permits. These can then be used at the point of fuel purchase to surrender the required amount of CO_2 permits. In addition, the trading of permits could be possible using ATMs at gasoline stations or banks, as well as over the internet. Desbarats (2009) proposes a similar system where carbon credits for the fuel combusted by the consumer will be deducted at the point of purchase. Such a design would imply frequent trade but with very small trade volumes. Jochem (2009) estimates that the cost of implementing a system as described above would cost around 140 million € in Germany alone.

Administration costs must be added to the pure implementation costs and include the monitoring, verification, and reporting of emissions, which, in the case of downstream regulation, would apply to over 243 million entities (NFF 2014). As most of these are relatively small emitters, in some cases requiring less than one EUA per year, increased efficiency gains through trading larger volumes of EUAs at an upstream level are foregone (UK Department for Transport, n.d.). The cost of managing the permit exchange market further adds to the above administration costs (Raux and Marlot 2005).

The third major component of overall transaction costs for regulation at the consumer level is the cost of informing consumers about the EU ETS and how the exchange mechanism functions. Raux and Marlot (2005) acknowledge that the cost of information campaigns cannot be ignored and Abrell (2010) suggests that this cost alone is sufficient reason not to regulate the road transport sector at the downstream level.

3.2 Midstream Regulation

At the midstream level, car manufacturers represent a significantly smaller pool of regulated entities (36 brands) compared to consumers (NFF 2014). As such, the transaction costs of regulation at this level (midstream) are lower than at the consumer level. In particular, the cost of implementing EU ETS trading infrastructure and information campaigns as described by Raux and Marlot (2005) for downstream regulation is significantly reduced. However, it is less clear how to implement an ETS at this level and simultaneously provide incentives for fuel suppliers and consumers to abate. Difficulties in incentivizing abatement further along the fuel chain make this option less likely to be cost-effective in practice.

Accounting for the level of CO_2 emissions that require coverage at the car manufacturer level is a major factor in the calculation of the administration costs involved with regulating the road transport sector at this level. The literature advocates an approach where car manufacturers have to surrender sufficient EUAs at the time of sale to cover the lifetime emissions of new cars (Desbarats 2009). The UK Department for Transport (n.d.) suggests that these estimates should be calculated by multiplying tailpipe gCO_2/km (grams of CO_2 emitted per kilometer travelled) by the projected lifetime distance travelled for each car. Abrell (2010) finds that covering lifetime emissions for cars is in line with the EU ETS carbon accounting, which makes it preferable to trading specific emission rights for gCO_2/km among car manufacturers alone.

Flachsland et al. (2011) argue that defining uniform emission factors for heterogeneous cars and fuels is cumbersome and inefficient. They also raise the issue that the trading infrastructure of the EU ETS would require modification, for example, multi-year trading periods, to allow car manufacturers to surrender allowances for car emissions several years into the future. Abrell (2010) likewise points out the fact that current EU ETS trading periods may be too short compared to the average car life cycle, which would necessitate a change in the EU ETS trading period setup.

NFF (2014) adds that changes in the carbon content of fuel and, therefore, actual future tailpipe emissions, cannot be reliably forecast. This suggests that in practice, it may be difficult with a midstream design to incentivize fuel providers to lower the carbon content of their fuel. Similarly, regulation of lifetime expected emissions of a vehicle does not take heterogeneity of consumers into account. Therefore, it would be difficult in practice to give consumers incentive to reduce driving or drive more efficiently if car manufacturers are the regulated entity.

3.3 Upstream Regulation

Fuel suppliers are responsible for the sale of fuel to passenger car users via service stations. According to the ADAC (2017), there are over 14,000 service stations in Germany alone. However, a few large companies cover the majority of the market with 6 brands accounting for almost 75% of the market in Germany. Similarly in the UK, regulating fuel producers covers 99% of the market with just 20 firms (UK Department for Transport, n.d.). The large fuel producers are typically vertically integrated and cover everything from drilling for oil to selling fuel to consumers. Regulating at the fuel supplier or producer level concerns a much smaller number of regulated entities than regulating at the consumer level. An added advantage derives from the fact that fuel is already taxed in all EU countries. UK Department for Transport (n.d.) emphasize that the point at the supply chain at which these fuel taxes are collected provides an excellent basis for regulation of carbon content and additional administrative costs would be low. As fuel sales are already recorded for tax purposes, these records could provide the basis for monitoring CO_2 emissions as well as for initial allocation of allowances unless auctioning is used. In a fully integrated ETS, for example, fuel producers would then need to hold EUAs to cover the total amount of CO_2 emissions resulting from the fuel they sell. As many fuel producers are already covered by the EU ETS due to oil refinery activities, they are already familiar with the functioning of the system.

Depending on whether road transport is integrated completely into the existing ETS or whether a separate road transport ETS is established, the small number of actors in the upstream fuel supplier market may give cause for concern about strategic trading. The basic idea would be that firms could hold excess carbon allowances in order to raise the allowance price and put competitors under pressure. A gateway similar to the one implemented for aviation could mitigate such issues, whereas full integration into the existing ETS would likely make such concerns redundant due to the larger number of market participants.

In terms of incentivizing abatement along the fuel chain, regulating fuel suppliers is also attractive. Fuel producers have two options for responding to inclusion into the ETS. They can lower the carbon content of their fuels and they can pass on the cost of emissions allowances to consumers through higher fuel prices. An increase in fuel prices experienced by passing on allowance costs to consumers is unlikely to be very high, but of course would depend on the effect on the allowance price of including road transport into the ETS. Taking the carbon content of a liter of gasoline or diesel delivers a carbon-related fee of approximately 0.025 €/l for an allowance price of 10 €. Current fuel taxes are at least an order of magnitude larger in all EU countries.

4 Cap Setting and Allocation Mechanism

Two important design features of the ETS concern setting of the cap and how the allowances are initially allocated to market participants. The setting of the cap determines the stringency of the environmental policy and the emission reductions attained through the ETS. The allowance allocation mechanism has implications mainly for distribution of the scarcity rents that the cap creates and can be designed with the aim to reduce impacts on global competitiveness. In this section, we briefly touch upon each of these issues and how they relate to an expansion of the EU ETS to cover the road transport sector.

4.1 Setting the Cap and Reduction Paths for the Cap

Setting the cap has important implications for achieving environmental goals and sending the right signals for innovation and adoption of new technologies. During Phase I of the EU ETS the emission permits were issued for 2080 $MtCO_2$, while the actual emissions were around 2020 $MtCO_2$. This mismatch prompted a dramatic fall in the allowance prices (Brunner et al. 2009). Alternatively, setting the cap too tight may increase the EU allowance price to levels at which competitiveness of European firms is seriously affected. Additionally, efficient regulation of the CO_2 externality requires that the marginal abatement cost is equalized across sectors. Since not all sectors are currently covered by the EU ETS, adjustments to the cap and the distribution of abatement efforts across sectors should keep the criterion of equal marginal abatement costs in mind (Böhringer et al. 2009).

The EU ETS covers around 50% of EU CO_2 emissions and approximately 45% of total EU GHG emissions in Phase III (2013–2020). Light-duty vehicles account for around 15% of the total EU CO_2 emissions. There are separate emission reduction goals defined for both the existing ETS and the transportation sector. As a result, an overall cap and reduction path to achieve these goals can be calculated. The calculation of a new cap for the integrated system could follow the principle illustrated in Fig. 1 in Sect. 2, where the integration of two systems is displayed.

Setting the cap and its adjustment is a dynamic process that depends on the inclusion or exclusion of sectors, countries, entities, economic growth, emissions and stringency of the economy-wide cap. In phase III of the ETS the cap will be adjusted downwards by an annual rate of 1.74% of the average total emissions in the period 2008–2012 to reach emission levels 21% below 2005 levels in 2020 (European Commission 2015). To reach the target of a reduction of emissions of 43% below 2005 levels by 2030, the reduction rate will increase to 2.2% after 2020. In setting the reduction rate it is important to incorporate expected growth rates in the economy and interactions with other policies as well as the rate of technological change.

4.2 Allocation Mechanism

Once the cap has been set, allowances can be issued equalizing the total number of permits to the cap. The allocation mechanism has an impact on the distributional effects of including the transport sector into the EU ETS. Who receives the scarcity rent created by capping emissions will be established by defining whether permits are sold (e.g. through auction) or allocated for free (Brunner et al. 2009). The considerations involved in choosing an allocation mechanism are also concerned with the risk of carbon leakage, the effects on early movers (i.e. entities with above average environmental performance), the possibility of windfall profits for regulated entities, and the potential need to garner revenue for redistribution or other policy instruments such as subsidies. There are basically four options for allocation of emission allowances to the road transport sector upon inclusion into the EU ETS. The first two options—grandfathering and benchmarking—assume that some new emission allowances are allocated for free upon expansion of the EU ETS. The third and fourth options require emission allowances to be bought on the market. They could be auctioned by the authorities directly, or the authorities could opt not to allocate any additional allowances for road transport, essentially leaving the cap as it is, and requiring the road transport sector to purchase existing allowances from other regulated installations.

4.2.1 Free Allocation

With the allocation mechanism known as grandfathering emission allowances are allocated for free in proportion to past emission levels. In this scheme, a one-off allocation can be fixed for the current emission levels or there can be regular updates based on new emission data. One of the main drawbacks of this allocation mechanism is that it may not provide much incentive to reduce emissions. Depending on how the baseline is adjusted over time, this may encourage agents to invest in dirty technologies or not to invest at all in order to keep their emission levels high and get more free allowances. There is empirical evidence from the first two phases of the EU ETS that free allocation is likely to have led to fewer innovation activities related to climate-friendly innovations (Martin et al. 2012). Grandfathering allowances also runs the risk of punishing early movers in terms of environmental technology whose emissions are relatively low within a sector. Since they would be awarded a lower number of allowances based on their past emissions than less efficient competitors, they would not be able to benefit from their investments. Grandfathering can also lead to an increased lobbying of powerful groups to get more allocations for free.

When allowances are allocated for free, but based on a benchmarking scheme, there is more incentive to reduce emissions. Depending on how the benchmark is determined, early movers can retain an advantage of their investments. Benchmarking requires data to determine what an appropriate benchmark is, which may in some cases be difficult to obtain.

One of the main problems with free allocation mechanisms is that they may present barriers to market entry or exit. For instance, if allowances are allocated for free to incumbents while entrants need to pay for them, this may discourage entry and reduce competition. Moreover, in order to keep allowances and profit from their monetary value, agents may delay shutting down inefficient plants. For this reason, additional allowances are typically set aside for new entrants.

A major lesson learned from the early stages of the EU ETS was that some recipients of grandfathered allowances were able to pass on the opportunity cost of the allowances to final consumers. This led to windfall gains for the regulated entity and was especially observed in the power sector (Ellerman et al. 2010; Woerdman et al. 2009). As demand for electricity is rather inelastic and immobile, the price of electricity increased to reflect the emission allowance price, despite utilities not having paid for their allowances in the first place. Cars also need to refuel where they are used suggesting that windfall gains might be large if allowances are given away for free to this sector.

4.2.2 Auctioning

According to Brunner et al. (2009), auctioning offers several advantages over free allocation. It follows a polluter-pays principle that can lead to more efficient investment decisions. In addition, the revenue generated by auctioning can be used by governments to outweigh the regressive effect generated when income is transferred from poorer households (i.e. drivers with high income shares of fuel expenditure) to higher income groups (i.e. shareholders) via pass-through of the cost of the allowances. While in free allocation there is an incentive for sellers to keep permit prices high, in this scheme all are buyers, so there is an inverse incentive to keep prices low which can be achieved by investing in clean technologies. It is recommended to carry out small and frequent auctions to limit the market power of large bidders that can also affect competition.

If no new allowances are allocated upon expansion of the EU ETS to cover road transport, then the regulated entities in the road transport sector will be required to purchase allowances from the existing ETS. Including the sector without increasing allowances could potentially remove a large share of the current excess supply of allowances. In this case the transport sector would literally be paying for emission reductions in other sectors by purchasing allowances from them directly. In terms of distributional impacts within the ETS, this is a question of whether the price of allowances would increase enough to impact on global competitiveness of other ETS sectors once excess allowances are taken by the transport sector. Potential windfall gains would not accrue to fuel suppliers since they would be required to purchase allowances in the market.

There is a New Entrants Reserve (NER) that contains allowances for new installations or airlines, as well as expansion (under certain conditions) of existing installations and airlines after 2013. The rationale behind the NER is based on principles of equity and securing competition in the markets affected. The NER holds allowances amounting to 5% of the cap (for aviation 3% of the cap). The allocations from the reserve to new entrants should mirror the allocations to corresponding existing installations. Road transport would not need to be treated differently than other sectors under the ETS in this respect.

5 Conclusion

Compared to emission performance standards, including road transport in the EU ETS has a number of advantages. First and foremost, in a cap-and-trade system the marginal abatement costs are equalized within and across the regulated sectors, resulting in overall cost efficiency. By setting the cap the total amount of emissions allowed in the system is constrained, creating a scarcity and market price of (tradeable) emission allowances, and thus incentivizing emissions reductions. Entities with abatement costs below the allowance price will undertake the abatement activities and sell surplus allowances, while entities with higher abatement costs will buy additional allowances instead of implementing costly abatement measures. This trade is beneficiary for both entities and ensures that the emissions abatement takes place where it is cheapest. The larger the ETS and the more sectors included, the more abatement options are available and the higher the efficiency and welfare gains. Although it would be feasible to construct a separate ETS for road transport only—perhaps amended with a gateway to the existing ETS—the most cost-efficient means of regulation would therefore be to integrate the road transport sector fully into the existing ETS. Recent analysis as cited in this article has shown that the potential savings from regulating the road transport sector in the ETS rather than through standards are large.

Of course, the trade mechanism implies that the actual emission reductions may vary significantly across the regulated sectors. If private transport is included in the EU ETS, then it can be assumed that this sector will be a net buyer of allowances, while more emission reductions are expected to occur in electricity production and energy intensive sectors. However, in terms of climate change mitigation the only thing that matters is achieving the overall CO_2 emission reduction target, not the specific source of reduction. And that is ensured by the cap—the other big advantage of a cap-and-trade system.

When including the road transport sector in the EU ETS, regulation at the upstream level of the fuel suppliers seems to be most feasible. Fuel suppliers are able to pass through costs and thus incentivize actors along the whole fuel value chain to undertake abatement efforts. The transaction costs associated with the ETS (e.g., monitoring and reporting) are minimized at the upstream level, since the number of fuel suppliers is limited and most of them are already experienced with the EU ETS through their refinery activities. Strategic trading behavior to manipulate the EUA market is most unlikely to occur due to the mere size of the market.

In order to avoid windfall gains and not to adversely affect previous abatement efforts, emission allowances should be allocated through auctioning, instead of any form of free allocation. Auctioning also generates revenues that can be used to reduce distortionary taxes elsewhere in the economy. The increased demand for EUAs by the entities from the road transport sector will stabilize the market price. Given the current oversupply of EUAs, the short term price effects are likely to be small, while the long term effects will depend on how the cap of the integrated ETS is adjusted. Most EU ETS stakeholders would welcome a higher allowance price that provides stronger incentives for CO_2 abatement and innovation of clean technologies. However, an increased EUA price may raise concerns about reduced competitiveness of Europe's economy and carbon leakage effects. To date, competitiveness concerns are not supported by available empirical evidence from the EU ETS, but further research in this area is needed.

In summary, the inclusion of road transport in the EU ETS is a feasible and promising way to address the climate externalities of car driving in the future. Unlike the emission performance standards, the cap-and-trade approach ensures to achieve a given overall emission reduction target at minimum cost. The market price of tradeable emission allowances provides technology-neutral incentives for abatement activities within the regulated sectors. Fuel suppliers are likely to pass through costs to car drivers by raising fuel prices, strengthening incentives for fuel-efficient cars and driving. Nevertheless, in the presence of other externalities and path dependencies in the road transport sector, further policy measures may be required to complement an integrated EU ETS. Subsidies for R&D activities and the expansion of fueling infrastructure, for example, may help to overcome R&D spillovers and network externalities, fostering technological change. When thinking about such vehicle technology policies, however, policymakers should take possible interactions with an integrated EU ETS into consideration, e.g. adjusting the cap reduction path accordingly.

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Energy Transition and Electromobility: A Review

Jan Lepoutre, Yannick Perez, and Marc Petit

Abstract Nowadays electromobility is more and more becoming a cross-sectorial innovation. Electromobility is the convergence of technical innovations in battery technologies and charging systems, on Internet of things and finally on new business model developed by classical original equipment manufacturers and innovative newcomers. This developing phenomenon is really challenging for the ecosystem made of car manufacturers, electricity industry, local and national public actors dealing with clean energy transition. We review these challenges and highlight the most promising way of future researches in each of these dimensions for the EU actors.

1 Introduction

Electromobility is a key challenge for many actors dealing with energy transition. This phenomenon is caused by the convergence of multiple decisions in international negotiations on climate change (COP 21), on regional regulation towards the reduction of CO_2 emissions, on proactive national public policies to foster decarbonization of the personal road transport and on more general development of Internet of Things (Donada and Perez 2015, 2016, 2018).

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J. Lepoutre
ESSEC Business School, Cergy-Pontoise, France

Y. Perez (✉)
LGI, CentraleSupélec, RITM Université Paris-Sud and VEDECOM Institute, Gif-Sur-Yvette, France
e-mail: yannick.perez@u-psud.fr

M. Petit
GeePs, CNRS UMR 8507 CentraleSupélec, UPSud and UPMC, Gif-sur-Yvette, France

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At the European level, electromobility is also a challenge. For instance, EU Commission's proposal for a recast Renewable Energy Directive, with targets for an annual minimum share of RES-based transport fuels including renewable electricity (Article 25), is a proof of the potential impact of electromobility at the EU level.

Electrification of vehicles (from micro-hybrid technology to full electric vehicles) is assumed to result in a reduction in greenhouse gas emissions. In case of electric vehicles, these reductions depend critically on the technology used to produce the electricity and the components of the vehicle itself. If most of the electricity can be produced using sources of renewable energy (solar, wind, etc.), reductions in greenhouse gases will be high (Hoarau and Perez 2018), but if the dominant technologies are coal and oil, the reduction will not happen (Eurelectric 2015). A further advantage of the electric vehicle is that it should lead to an improvement in city air quality (as electricity generating plants are typically located some distance away) and noise levels.

Despite the potential benefits of electric cars, they do not represent an unambiguous remedy to individual mobility. One explanation for the gradual introduction of electric vehicles is the obstacles this technology faces compared to Internal Combustion Engine (ICE) vehicles. The two main obstacles of massive diffusion of electromobility solutions are purchasing cost and the limited range (due to a low energy density of batteries and the lack of recharging infrastructure). Although the total costs of electric vehicles are not as great as those of ICE vehicles (Kempton et al. 2014), the upfront cost of acquisition remains higher because of the price of the cell battery pack. Ensuring a competitive purchase price will, therefore, largely depend on the evolution of battery costs. Predictions of battery costs vary from company to company, but seem to provide for a significant reduction in the coming years, which should facilitate their competitiveness (IEA 2016). From $1000 per kWh in 2008 to 100 € in 2020, a major breakthrough is taking place in this technology taking for 50% of the actual cost of the car.

However, for the time being, the cost of the battery still remains one of the main obstacles to the adoption of the electric vehicle, so much so that some companies are beginning to spread the cost of the battery, which is being granted under lease or by creating sharing EV services. This cost of acquisition has led to public sector intervention through subsidies for the purchase of such vehicles and to R&D support to reduce battery costs conception and manufacturing.

The second issue could be overcome with the rollout of infrastructure for recharging. Although in some cities (such as London, Rome, Berlin, etc.) small networks exist for recharging vehicles, the spread of such national, or international, networks is rather slow. Charging points installed in private houses are low power but relatively inexpensive (around $300), while faster charging requires an investment of several thousand euros. The relative slow development of adapted recharging networks can induce "range anxiety" in vehicle owners, that is, the fear of not reaching a charging point before the battery becomes empty. This fear is a significant barrier to the introduction of the electric vehicle. Moreover, the

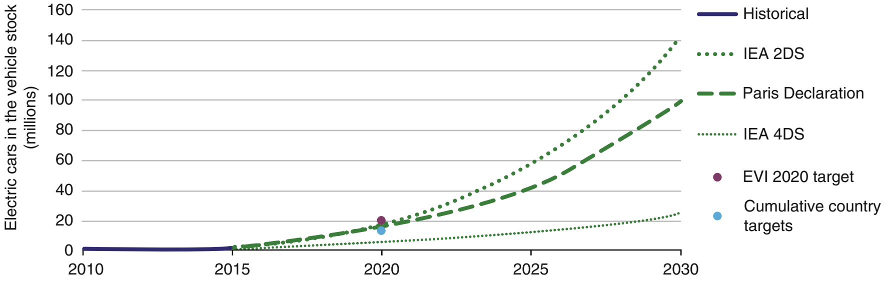

Fig. 1 Historical and projected EV market. Sources: Donada and Perez (2018)

interoperability of charging systems is essential for the diffusion of electric vehicles, and there is an obvious role for public regulation and standard definition.

Obviously, these two obstacles are linked and create a "chicken and egg dilemma" (hereafter C&E Dilemma): without the massive deployment of EVs, there is no need for charging infrastructures; but without charging infrastructures, the sales of EVs are hindered by the lack of charging solutions and the actual limited range of EVs or will be limited to the second car of the family or to commercial fleets.

To solve this dilemma, multiple solutions are possible and some of them are tested. In this paper, we review the innovative solutions applied first by policymakers at the national and local levels; second, we will explore how stakeholders change their business model to address this issue. We will see that electromobility induces two main possible responses by companies: a first solution is vertical integration strategies towards battery manufacturing and charging infrastructures, and a second solution is to reduce the total cost of ownership of the EV by adding new streams of resources in the smart use of their batteries. This solution consists in the creation of new services offered by EV fleets on energy markets and bringing accordingly new possession revenues to the EV owner.[1]

Of course, as the relatively low numbers of sales indicate (see Fig. 1 hereafter), all these partial solutions seem to be insufficient to ensure the substitution of thermal cars by electric ones in the short run. Some additional changes are needed to provide an efficient environment for the development of electromobility. This paper seeks to explore the most promising ways to solve this problem.

The paper is structured as follow: Section 1 will present the different public policies to address this issue at the national and/or local level. In the second section we will show how innovation from companies tries to address this "chicken and egg dilemma".

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[1] Also called vehicle to grid (VtoG), vehicle to build (VtoB) and vehicle to home (VtoH) technologies. The sum of all options is called VtoX.

2 Section 1: Public Policies

The sections that follow break down the measures applied by the public authorities as they seek to address the main barriers and to promote the development of electric vehicles markets (Kempton et al. 2014; Leurent and Windisch 2011; Perdiguero and Jiménez 2012). Despite some progress, this development is not as fast as some governments expect it in the past years as Figs. 1 and 2 recalls.

In order to present the solutions explored by different policymakers for battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), we will present first the nationwide policies (1.1.) and after the local public policies (1.2) to overcome the "electromobility chicken and egg dilemma".

2.1 *Member State*

Public policies are multi-faced decisions towards electromobility pledge by non-evaluated and captured positive externalities like reduced local emission, noise reduction or healthcare protection's contribution. Public policy actions at the national level are technical standards validation, public definition of the efficient level of public investment in the charging infrastructure and direct and indirect actions to foster EV demand. One of the rationales for public intervention would be to reduce the total cost of ownership of an EV to include the efficient level of positive externalities.

2.1.1 Standards and Investment Decisions

The first action towards standards is clearly set around emission standard of CO_2 per regions. As Fig. 1 shows, these emission standards are creating a continuous threat on the automotive industry. This action set regulatory constraint of the new cars and push towards electrification of the producers' fleets. As reported in the Transport and Environment document (2009a), obliging an industry average CO_2-exhaust levels

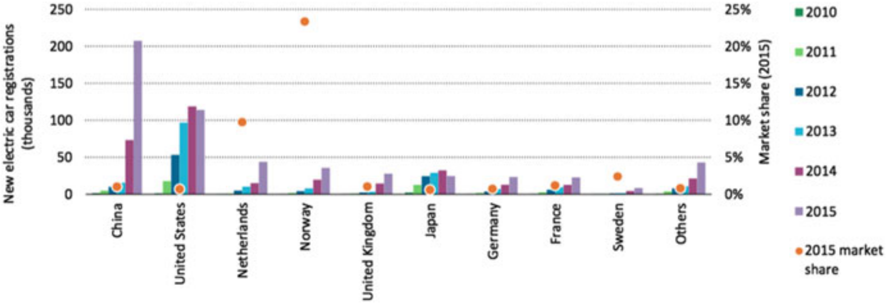

Fig. 2 EV sales and market share. Sources: Donada and Perez (2018)

for ICE vehicles at 80 g CO_2/km by 2020 and at 60 g CO_2/km by 2025, accompanied by increases in gasoline taxes, would result in a competitive upgrading for electric vehicles, thus increasing market penetration.

The second action that should be taken is on standardization of recharging systems, at least on the same continent. This point is one of the key issues of the public policy to allow economic of scale and scope to take place in the recharging infrastructure development. The main features that would need to be standardized are (1) plug types, (2) electrical recharging protocols, (3) communication protocols between cars and recharging systems, (4) safety regulations for public recharging, (5) battery recycling standards and regulations and (6) storage and rules for charging and discharging electricity into electrical grids.

This public action is not yet achieved at the European level where multiple standards are existing and competing. Following Codani (2016), we can distinguish four main types of recharge systems: first, slow recharging points or Mode 1 points, located primarily in homes, residential buildings or in public spaces close to residences. It is thought that car owners will use these stations essentially to recharge their vehicles overnight, that is, when traditional household electricity consumption is low. However, workplace parking lots or shopping centres are also potential sites for these points, inducing vehicle recharging by consumers during the day, during peak periods of electricity demand. Second, there are the rapid charging or Mode 2 points, located primarily in shopping centres, supermarket car parks or gyms, which will also be used during the day.[2] Third, the fast or Mode 3 charging points require a specific charging station (or so-called wall box) to enable high-level communication and high power. The vehicle and the wall box communicate by means of pilot lines.[3] Lastly Mode 4 is dedicated to direct current (DC) charging, meaning that there is a direct connection between the battery bus and the electric vehicle supply equipment (EVSE, also called charging stations) which is responsible for performing the AC/DC conversion. This mode enables very fast charging (>50 kW and up to 350 kW). This last solution is pushed by a convenience challenge, and the goal is to recharge the battery at 80% of its capacity as fast as the conventional petrol station allows it for ICE (6 min).

Rough estimations of the cost of such infrastructure are between 1000 and 2000 dollars per vehicle for Level 1 charging station at home. For Level 2 points designed for private use (located in private homes or garages), the cost ranges between 500 and 2500 dollars. If the point of recharge (Level 2) is publicly accessible (located in public garages or on the street), the cost rises to between 2000 and 8000 dollars. Finally, for Level 3 points (located along highways and requiring a maximum of 30 min to recharge a vehicle), the cost ranges from 40,000 to 75,000

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[2] Mode 2 charging is very similar to mode 1, but enables advanced communication, in particular regarding earth presence detection, residual current and over-temperature protection. The charging cable requires an additional box to deal with these communication steps. The maximum current level drawn by the vehicle is 32A.

[3] In particular, as specified in the IEC 61851 standard, the EVSE may use the control pilot line to send a signal indicating the maximum charging current allowed.

dollars. Level 4 are prototypes yet, and the costs are not yet disclosed in the public domain.

But, what are the features and elements that need to be taken into account when developing an efficient charging network? Who is supposed to make the investments to develop the needed net of charging stations?

To date, governments, automotive industry and EVSE development partners have yet to reach an agreement on who should cover these investment costs and how they might be recovered through the charging of fees. It is clear that a major investment in charging infrastructure is required and those national, regional and local authorities will have a significant role to play in coordination with private investors.

The main form of public policy to encourage the development of a network charging points is the implementation of direct subsidies, especially for slow recharge points. But the risk associated is that without ad hoc coordination, charging infrastructure will probably develop in an inefficient manner, having too much or not enough fast charging solutions over the country.[4] To mitigate that risk, GPS technology and mobile telephony can be useful. They would reduce driver uncertainty and stress, enhancing the usage of electric vehicles and reducing the number of charging points and guide investment where needed. Some start-ups in Europe are helping this potential coordination providing real-time mapping charging options.[5]

Some specific issues will remain to develop slow charging point in residential areas. In collective buildings garage areas are common properties where any charging point installation decision requires the authorization of all the owners. Things are easier when a lessor who can decide in investing in charging points manages the building. The French smart grid project BienVEnu[6] is probably the only one that is dedicated to this concern.

2.2 *Boosting Demand for Electric Vehicles*

A first option for stimulating demand is to promote the use of public vehicle fleets, courier companies and the like. Kley et al. (2011) report that various delivery companies have introduced electric vehicles into their fleets. UPS has started to use electric vehicles for postal services in the Washington area. Similar programmes are also being introduced in Europe, where companies such as DHL or TNT are using electric vehicles in cities such as Hannover, Barcelona and Lyon. In the United States, the Strategic Sustainability Performance Plan promotes the use of low-emission vehicles in almost all states. In fact, it is mandatory to use alternative

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[4] As for mobile 4G developments, some places in the country would not be equipped because the density of population will be too low.

[5] See, for instance, www.chargemap.org.

[6] See www.bienvenu-idf.fr/en.

vehicles in federal vehicles. In France, the public postal service is one of the leading actors in the EV market. The French postal company “La Poste” has created a new business unit called Greenovia to manage its 23,000 EV fleet. Nowadays, Greenovia is proposing its skills in EV fleet management to other fleet managers like urban communities, large companies, etc.

Many countries that have implemented direct and indirect purchase subsidies intended to reduce the upfront cost of electric vehicles and/or its total cost of ownership. In fact, while the direct purchase public subsidy is the most implemented measure in order to increase demand for electric vehicles, it is not the only one.

According to Perdiguero and Jiménez (2012), most OECD governments have implemented various subsidies policies to enhance the purchase of electric vehicles. These policies can be grouped in four mains options. The first one exempts registration tax for electric vehicles.[7] For example, electric vehicle owners pay minimum tax in Finland. The second subsidy policy takes the form of a road tax exemption.[8] The third kind of public intervention in stimulating EV adoption, and probably the most widespread form, is to subsidy final consumers to buy a new electric vehicle. This policy has been implemented in the United States and various European countries, but with different levels.[9] Finally, some governments also subsidy other expenses in income tax reductions.[10]

The following graph (Fig. 3) describes in a comparative way the total cost of ownership of two cars (Renault Zoé and Clio) in Norway, France and Germany. The sum of the public policies is compared in terms of cost for the buyer over 4 years of usage. This comparison of TCO helped by public policies seems to have an impact on the EV adoption in each country as Fig. 1 recall.

If national policies seem to be one of the key levels of intervention taken by policymakers, they can be reinforced by local policies, at the regional or city level.

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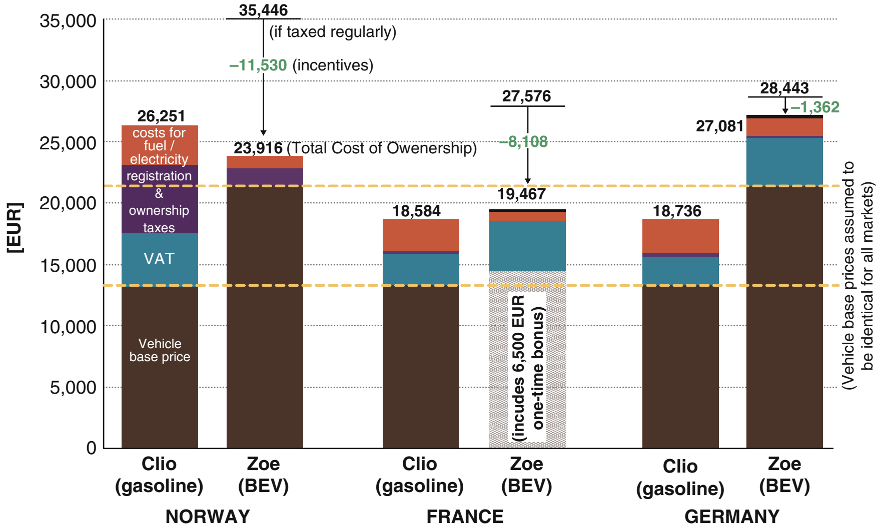
[7] It is applied in Austria, Belgium (in some regions), Denmark, Ireland, the Netherlands, Norway, Portugal and Romania.

[8] Which has been established in Denmark (cars with weight less than 2000kgs), Germany (only in the first 5 years), Italy (first 5 years and then a 75% reduction), the Netherlands, Norway, Portugal, Sweden and the United Kingdom.

[9] Austria fund in the range 1400–3000€; a 15% discount is granted in Belgium, with a maximum pay of 4640€; the subsidy range in France is from 2000€ to 10,000€; 1500–5000€ in Ireland; in Luxembourg, the subsidy is up to 5000€; from 2000 to 6000€ in Spain, depending on regional policies in this sense; up to 40,000 SEK in Sweden; and finally from 5000 to 8000£ in the United Kingdom.

[10] As in Belgium (deductible expenses for domestic consumers are 30% in income tax, up to 9190€), the Netherlands (deductible expenses for firms), Norway (50% discount in corporate tax), Sweden (deductible expenses for domestic consumers are 40% in income tax) and the United Kingdom (deductible expenses for firms). In Portugal, it was established a scrappage programme which gives up to 1500€ for older vehicles to purchase electric one.



Total Cost of Ownership includes vehicle purchase and registration costs,
as well as ownership taxes and fuel / electricity costs for 4 years. All data estimates for tax year 2013.

Fig. 3 TCO comparison. Sources: http://www.avem.fr/actualite-voiture-electrique-une-etude-confirme-le-role-cle-des-politiques-fiscales-5009.html

2.3 Regional or Municipal Actions

In terms of local public policies, mention should be made of some local initiatives taken in California (The Zero Emission Vehicle Program, Reichmuth and Anair (2016)) or in cities like London, Amsterdam, Shanghai, Oslo, Paris, etc. In the case of London, the mayor offers discounts on the city's congestion charges[11] and encourages the uptake of electric vehicles via car clubs. The city of London plans to establish a network of recharging stations throughout the metropolitan area.

In the case of Amsterdam, the City Council Electric Transport subsidy programme has a fund of EUR 3 million and covers up to 50% of the additional costs incurred in buying an electric vehicle. In 2011 in Paris, the mayor and Bolloré company have created a new EV-shared mobility solution called Autolib. It is an EV car sharing solution with more than 4000 charging points and 3000 EVs funded via a private public partnership and customers. Originally created in Paris, this new solution has been deployed also in Bordeaux and Lyon. Now this innovative solution is under deployment in other cities around the world (London, Cincinnati, Milan, Rio de Janero, Los Angeles, etc.).

As we have seen in this section, the vast majority of the measures that have been implemented are public investments or subsidies, which can be a significant cost to the government or municipality. Equally noteworthy is that these public grants have

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[11] Worth up to 1700 pounds a year.

focused on the installation of slow charge points for private use and not only in the creation of a network of fast charging that can alleviate potential problems of “range anxiety” that can undergo electric vehicles.

3 Section 2: Private Initiatives

A common statement in the automotive sector is that the sector will undergo more changes in the coming decade than in the previous century. Due to increasingly ambitious targets of CO_2 emissions, car manufacturers (or original equipment manufacturer (OEM)) have to adapt their product line to this new challenge. There are several possible ways to reduce the CO_2 emissions of a vehicle: reducing its weight, improving its engine’s efficiency, reducing the ground and air frictions when driving, improving the mechanical and thermal energy recovery, using low-consumption electric equipment, etc. Among these available solutions, a very promising one consists in electrifying part of or the entire powertrain with hybrid technologies (from micro-hybrid to full hybrid) or with full electric vehicles.

If they choose the latter solution, they have to define the new design of the car and to determine if they have to build expensive cars with 100 kWh batteries allowing for 500 km of autonomy like Tesla Model S or 24–40 kWh ones allowing for 150–300 km like Renault Zoe or Nissan Leaf. If they choose the latter, the EV purchasing costs are reduced, the need for charging infrastructure capacity is limited, but the low range of the car scares the buyer. The second challenge is to find innovative solutions to reduce the total cost of ownership of the car. Among other options like sharing autonomous car (Attias 2017), the most promising one seems to be the development of VtoX technologies allowing EV fleets to sell their storage spar capacity for flexibility provision to different actors in electricity markets.

3.1 Emergence of a New Dominant Design

In the conventional automotive industry, the value chain consists in a pyramid relationship between car manufacturers as original equipment manufacturer (hereafter OEMs) and suppliers that provide the different parts or modules such as gearboxes and auxiliary batteries to OEMs, the main role of OEMs being to assemble the parts and design core components such as motors and vehicle bodies. Energy utilities then act as an independent industry that offers the services to fill the car with fuel during its lifetime as shown in Fig. 4a. A typical OEM in-house production share of car components is around 25% of a total vehicle (Huth et al. 2013). This position of the OEM in the value network as an integrator has allowed OEMs to maintain control and margin in ways that other industries have not been able to maintain (Jacobides and MacDuffie 2013).

In the EV industry, most OEMs closely involved in the EV market choose to follow their established value configuration routine, i.e. they tend to use their existing production infrastructure, capabilities and supplier network (Chen et al. 2016).

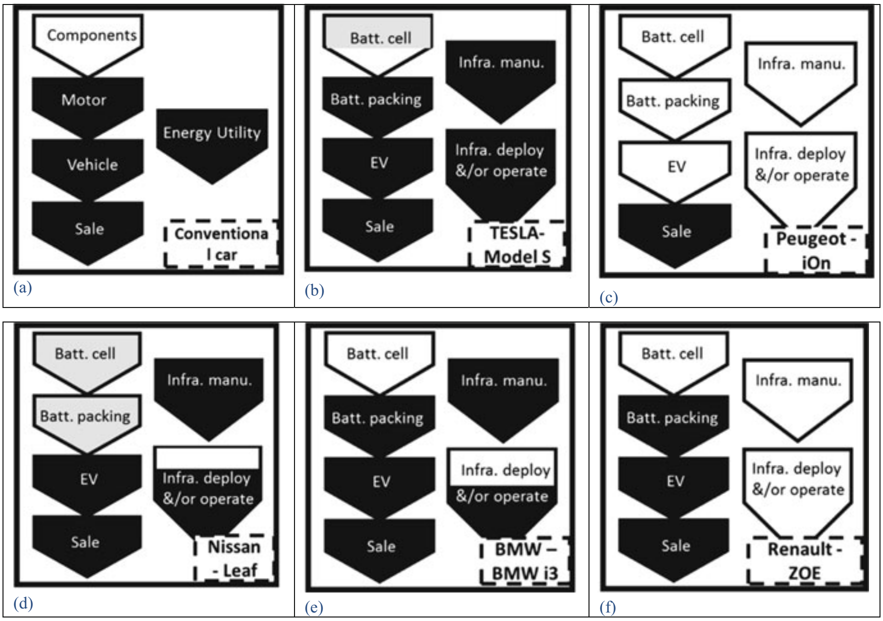

Fig. 4 Value configurations of Tesla and other OEMs (black, outsource from supplier/other utility; grey, joint venture; white, vertical integration by OEM). Source: Chen and Perez (2018)

This is known as integration-as-usual. In this type of value chain, when OEMs treat batteries as a module for outsourcing as before, it could be due to limited technology knowledge or the transaction cost involved.

BMW i3 and Renault Zoe are examples as shown in Fig. 4e, f, respectively. A more involved choice could be the OEM and battery supplier form a joint venture company, as is the case for Nissan leaf (Fig. 4d). On the other hand, in terms of recharging network deployment, most OEMs wait for action from the recharging operation company or other stakeholders, such as national or local government. Renault and BMW have followed this strategy, and their EVs can access the chargepoint and chargemaster recharging networks in the United States and United Kingdom. Furthermore, BMW started to invest in a fast recharging infrastructure network with partners in late 2014 (Fig. 4e, f). Nissan started developing a quick charging network in 2012, earlier and more aggressively than BMW, but still through a partnership with a utility provider (Fig. 4d). At the same time, companies that are less engaged in the EV market yet wish to keep EV in their product portfolio may choose to be less integrated in their value chain and purchase EVs from another OEM. Citroën C-Zero and Peugeot iOn by PSA are examples for this type of value configuration: the company purchases i-MiEVs from Mitsubishi and resells them in Europe under the brand names Citroën and Peugeot. As a result, PSA only occupies a sales position in the EV value chain (Fig. 4c).

In contrast, Tesla shows a considerably different value configuration compared to other OEMs, ranging from a high level of outsourcing to in-house manufacturing. During the delivery period of the Tesla Roadster, most components, including battery cell manufacturing and vehicle design, were outsourced to suppliers, mainly due to the company's initial stage, lack of knowledge and requirement for fast market response; however, the packing and assembly of battery cells and the energy management were conducted by Tesla. When the commercial delivery of Tesla Model S began, Tesla began to show a high level of vertical integration along its value chain: body design, battery packing and recharging systems, as well as recent move towards improved cell manufacturing, such as the Gigafactory with Panasonic which opened in 2017 (Fig. 4b).

Following this analysis, several lessons can be drawn that will merit the attention of the more conventional OEMs if Tesla's disruptive choices succeed in challenging the dominant design. Tesla implements a product strategy of entering from the high-end market and moving to the mass-market customer segment. At the same time, as an entrepreneurial firm, it employs a high level of innovation adaptation and flexibility in learning by doing. Second, Tesla is implementing an ambitious plan to solve the range anxiety issue associated with EVs. The company focuses its efforts on both high-capacity battery packs and highly efficient supercharger stations (Table 1).

Table 1 Business model of Tesla from a value-related perspective

	Innovations on vehicle	Innovations on battery pack	Innovations towards infrastructure system
Value proposition	High performance regarding range and vehicle performance; innovative connective and intelligent services	Innovative management of battery packs enables high capacity and low cost; connective service enables user interaction; new product aimed at stationary battery market	High-performance recharging station with highly developed recharging station network; connective service enables user interaction
Customer segments	Innovatively starting at high-end market moving to mass market		
Distribution channel	Innovative multi-channel model, involving high integration of IT; vertical integration for sales	Sold with vehicle, replacement possible	Public network deployed by Tesla only
Value configuration	Innovatively possesses high level of vertical integration		
Revenue model	Ownership-as-usual; government loan	Purchase with vehicle or separate purchase when updated	Free to Tesla users
	Sales of powertrain and battery packs to other EV manufacturers		
	Market share		

Source: Chen and Perez (2018)

With the upcoming decrease in battery costs, the increase of energy density per unit and the deployment of charging stations, EV or plug-in hybrids sales are expected to increase within the next few years.

One of Tesla's most important long-term strategies is its high-performance supercharger station network and its aggressive expansion along main intercity highways in the United States, China and Europe. Furthermore, the strategic choice of bigger batteries provides it with driving ranges much higher than that available from other OEMs. All of these aspects contribute to reducing the range anxiety of Tesla users and enable high performance in the value proposition of its business model. Third is that Tesla shows a very high level of integrating information technology into many aspects of its EV business model. Tesla has innovatively increased connectivity between users and the environment, such as charging stations and batteries. Furthermore, a high share of information technology is involved in the company's online and retail outlet distribution channels. Fourth, Tesla presents a new value configuration that involves an innovative level of vertical integration towards batteries and recharging networks.

This vertical integration strategy in the automotive industry will reduce in the case of EV's coordination costs between OEMs and their suppliers and consequently diminish the risk caused by a lack of supporting infrastructure. However, it also involves high investments and risks arising from the uncertainty of the EV industry. EV is a relatively new industry at an emerging stage, and OEMs need to weigh up the trade-off and transaction costs for their value configuration and business organization.

3.2 *VtoX: Cooperation or Disruption?*

VtoX is mainly known as vehicle-to-grid (VtoG). VtoG has been intensively studied since its first definition and introduction in the end of the 1990s by the seminal work of Kempton and Letendre (1997). Finally, EVs entail a demand for innovation and new energy services, either at the level of households (VtoH), buildings (VtoB) or the grid (VtoG). The technical and economical aspects of this solution have already been studied at length in existing scientific literature, and a number of experiments concerning VtoG have already been implemented in the United States (California and Delaware), in Europe (Denmark, the Netherlands, the United Kingdom) and in Asia (South Korea) (Codani 2016). In this approach, the idea is that new economic actors called aggregators manage these new services offered by EV fleets to different economic actors on the energy markets. As market intermediaries, they have to manage the risks and the resources in order to provide needed electrical services and to get paid for that provision. In exchange, the EV owner must receive a share of this value creation and be incentivized to plug and play in this new markets for flexibility provision.

By doing so, EVs challenge the development strategies implemented by electric network operators who invest in Smart Grid environments. Traditionally, the owners and administrators of power grids benefited from a de facto exclusivity in the development and technical management of electric grid infrastructures for a demand that was both known and predictable. But with the development of EV fleets (cars, buses, bikes, etc.), these grids now have to face three new demands (Codani et al. 2016a, b). The issues raised by the integration of vehicles within the network do not only concern engineers. They also call for decisions to be made in terms of product innovation, which involve automotive manufacturers and grid operators in very specific cooperative strategies[12] (Borne et al. 2017).

The first demand is for energy because electromobility is a source of additional electrical consumption, although this does not yet represent a significant volume due to the limited driving distances (partially due to the limited size of the battery). Typically, one million of EVs (intermediate target in 2025 for France) with a mean trip of 24 km per day (250 days per year) will require 1.2 TWh (0.3% of the total French demand). A second demand is a need for power delivery capabilities (amount of energy per hour that can be delivered by the grid to the EV), which is more complex to address because it depends on the grid sizing and topology. If electricity is available almost everywhere in developed countries, power level can be limited by the local grid characteristics. It will then impact the connection of charging stations (in number and in power). Thus, rolling out the charging station may induce reinforcement costs for the grid operators. Moreover, simultaneous charging at a large scale may generate additional peak power that would require investments in peak generation. Finally, either for global balancing or for local constraints, smart charging strategies will become mandatory to support the EV development. The third demand is related to the ability for using the EV batteries (and their associated storage capabilities) for improving the electric power system operation, particularly in the context of more variable energy resources.

Therefore, among the many possible services, which EVs could offer to grids on a competitive basis, Kempton and Tomić (2005) demonstrate that the best-suited solutions, both from an economic and technical viewpoint, are spinning reserves (primary and secondary) in order to regulate instantaneous frequency variations in the transmission grid. VtoH solutions are also tested in Japan and in remote areas to secure energy provision in case of blackouts or local energy shortages. Finally VtoB tests are deployed in most of the smart grid projects tested in developed countries to reduce the energy connexion fees or the overall peak consumption of the buildings.

If the rules of electric grid operators would be open and adapted to this new situation (Codani et al. 2016a, b), the fleets of EVs could then actively participate in the operation of electrical transmission and distribution networks. It will turn to be an innovative solution to reducing the total cost of ownership (TCO) of an EV that will use its spare storage capacity to help the management of the electrical grids.[13] EVs remuneration for participating in the frequency control are displayed in the following table (Table 2).

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[12] In case of non-cooperative strategies, VtoG will not be implemented. VtoB and VtoH solutions are in that case the most probable way of using the spare capacities of the EVs in a profitable way.

[13] Note that, theoretically, EVs can be connected to the network in order to charge for up to 95% of the time, which is more than sufficient for a 30 kWh battery.

Table 2 EVs remuneration for participating in the frequency control

Sources	Analysed region	Participated market	Net profit €/month/vehicle	Regulation power
Kempton and Tomic (2005)	USA	Regulation up and down	112–165	10–15 kW
Tomic and Kempton (2007)	USA, Four different control areas	Regulation up and down	4.3–43 (Th!nk City) 6–64 (Toyota RAV4)	6.6 kW
Andersson et al. (2010)	Germany	Control energy market	30–80 (Germany, coal fired power plants)	3.5 kW
Borne et al. (2018)	France	Regulation up and down	2–45	3 kW, 7 kW, 23 kW, 43 kW

Of course, in order for them to be mobilized by the grid operators, grid-integrated vehicles must have specific communication means and variable charging regimes, and they must also be able to reinject energy into the grid, the house or the building and get paid to do it (Table 2).

Additionally, the increasing penetration of renewable energy sources (RES) like wind and solar PV generations creates new opportunities for decentralized complementarities with EV fleets. These two innovations bring up concerns regarding their impacts on the electrical grid investment needs and challenge operational security: on the one hand, renewable energy sources (RES) are asynchronous and intermittent by nature and distributed mostly at the distribution grid level. They could trigger local congestion, and voltage-related problems, as well as system wide balancing and frequency issues (Eftekharnejad et al. 2013; O'Sullivan et al. 2014); on the other hand, if these innovation are not managed properly, the massive introduction of plug-in vehicles could jeopardize grid security (Clement-Nyns et al. 2011; Darabi and Ferdowsi 2011; Green et al. 2011). We find that most of the literature either considers the balance between RES production and EV charging at the system-wide scale (Budischak et al. 2013; Hu et al. 2013; Kempton and Tomić 2005) or in islanded systems watching over frequency deviations (Rocha Almeida et al. 2011; Marrero et al. 2015).

Nevertheless, EVs have a good charging flexibility. In France, a vehicle is used in average 6 hours a week, for a daily commuting trip of 24 km (CGDD 2011), what would lead to an approximate daily energy consumption of 4.2 kWh. Moreover, when considering a fleet of EVs, the share of EVs being parked never falls below 75% (Pearre et al. 2011). As a consequence, using EVs as buffer storage units to level the production of RES appears as a promising innovative solution. The coupling of RES and EVs would require to synchronize EV charging periods with RES production periods and—if vehicle-to-grid (V2G) capabilities are available—to discharge EVs in case of substantial RES production shortfall. This solution could increase the maximum penetration level of RES, as well as the "green charging" ratio of EVs.

Despite its potential contributions, VtoX are still in demonstration phases in most countries. Rules and regulations in place in most countries are efficient for centralized provision of flexibility. They generally still need to be upgraded to allow decentralize storage facilities to deliver desired flexibility (Codani et al. 2016a, b; Eid et al. 2016; Borne et al. 2017).

4 Conclusion

Electromobility is one of the major innovations that will take place in the coming years in the mobility, energy and automotive industries. Electromobility issues are at the convergence of different social, economic and scientific domains which have to provide the analytical frameworks to deal with this major disruptive change in the personal mobility sector.

In this paper, we assume that if coordination between policymakers and the new eco-system we have described is at least weakly complementary, this new mobility paradigm will certainly emerge. At the EU level, electromobility is a game changer in the relations between OEMs, the electricity actors, the member states, the regions and the EU commission. Options for solving the chicken and egg issue in Europe will create a new set of experiments and innovations all around Europe. Taking into account the best practices and helping them to diffuse across countries would be a great opportunity and a great academic source of cases studies.

In the meantime, it is clear that more academic works coming from different social sciences and engineering studies will be required to contribute to the definition of the optimal technical solutions at the lowest cost in the best analytical framework to solve the chicken and egg dilemma of electromobility in every specific condition it may take place.

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The Role of a Renewable Energy Target for the Transport Sector Beyond 2020: Lessons Learned from EU Biofuel Policy

Alexandra Purkus, Erik Gawel, and Daniela Thrän

Abstract To date, biofuels remain the main option for addressing the European Union Renewable Energy Directive's 10% transport sector target for renewable energy sources. At EU level and at the level of the member states, political support for biofuels has been motivated by expected contributions to the aims of greenhouse gas (GHG) mitigation, security of energy supply, rural development and employment creation. However, the diffusion of mainly agricultural crop-based biofuels has been accompanied by a critical debate on a range of sustainability issues such as land use change impacts or impacts on resource competition. Moreover, biofuels' cost-effectiveness as a GHG mitigation option has been called into question. Between the two poles of high expectations and multi-faceted criticism, EU biofuel policy has proven a very dynamic policy field, with no small amount of policy uncertainty for market actors. Against the background of negotiations on a recast Renewable Energy Directive, this contribution discusses from an economic theory perspective whether there is a case for continuing a target which supports the use of biofuels and other low-carbon options in the transport sector; and if so, what lessons can be derived from EU biofuel policy so far for its design.

A. Purkus (✉)
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany
e-mail: alexandra.purkus@thuenen.de

E. Gawel
Department of Economics, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

D. Thrän
Institute for Infrastructure and Resources Management, Leipzig University, Leipzig, Germany

Department of Bioenergy, Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

DBFZ Deutsches Biomasseforschungszentrum, Leipzig, Germany

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1 Introduction: The Changeable Climate of EU Biofuel Policy

Progress towards the decarbonisation of the European transport sector, which is responsible for almost a quarter of the EU's greenhouse gas (GHG) emissions, has been slow—despite a decrease between 2008 and 2013, emissions in 2015 were 23% higher than 1990 levels (EEA 2017a, b). To promote the diffusion of innovative, low-carbon technologies, the EU's 2009 Renewable Energy Directive (RED) set not only a 20% target for the share of renewable energy sources (RES) in the community's final energy consumption, which was broken down into binding national targets, but also a 10% target for the RES share in the transport sector which should be met by each member state (Directive 2009/28/EC). While the EU is on track to meet its overall RES target, progress towards the transport sector target is considered insufficient, with RES accounting for a share of 7.1% in 2016 (Eurostat 2018a; EEA 2017b). Similarly, few member states are close to fulfilling their targets (with notable exceptions, such as Sweden or Austria, see Fig. 1).

Biofuels play a crucial role in the implementation of the transport sector target: in 2015, biodiesel and bioethanol accounted for 88% of renewable energy used in the transport sector at EU-28 level, with renewable electricity contributing most of the remainder (EC 2017). The biofuel market continues to be dominated by first-generation biofuels based on food and feed crops. The share of second-generation biofuels derived from residues, wastes, lignocellulosic and non-food cellulosic material in the European biofuel mix increased from 1% in 2009 to 23% in 2015, but this can mainly be attributed to the utilisation of used cooking oil (EC 2017).

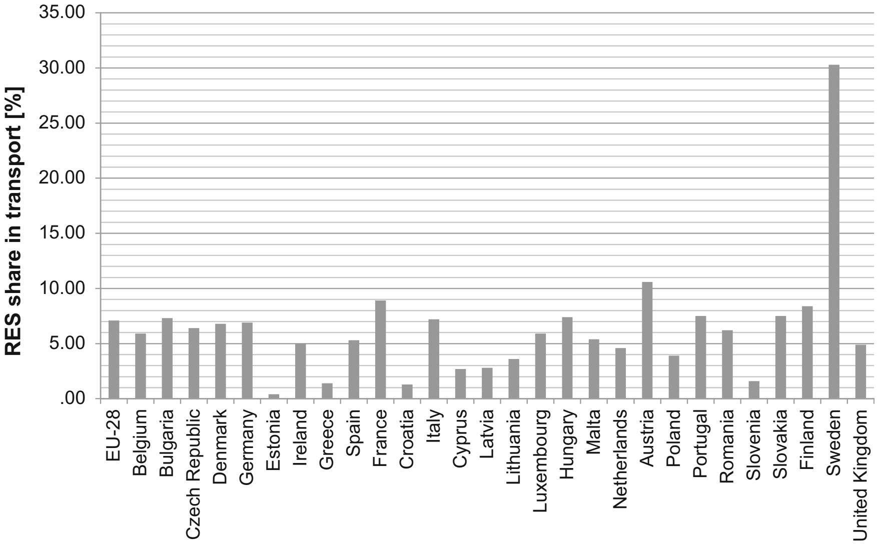

Fig. 1 RES share in the transport sector in 2016, EU-28. Source: own illustration based on Eurostat (2018a). Note: In 2015, Finland's RES share in the transport sector amounted to 22%

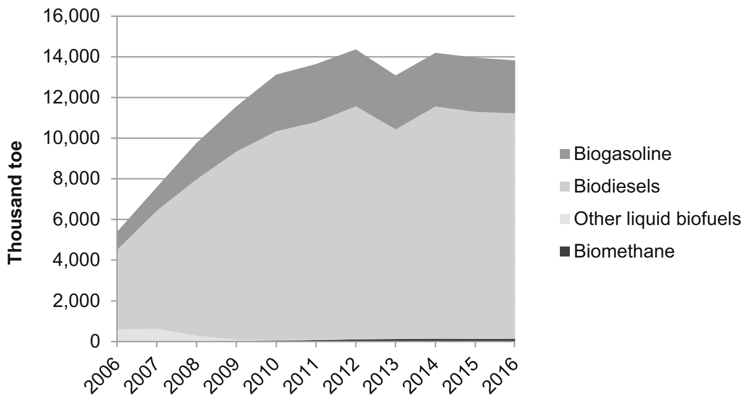

Fig. 2 Development of liquid biofuels and biomethane use in the transport sector; EU-28, final energy consumption in transport in thousand tonnes of oil equivalent (toe). Source: own illustration based on Eurostat (2018b)

Overall, biofuel use has been stagnating in recent years (see Fig. 2). Besides cost issues, regulatory uncertainty is seen as a major contributing factor to this development (EC 2017; REN21 2017).

Initially, the European Commission (EC) and member states such as Germany regarded biofuels as a promising means not only to reduce GHG emissions but also to increase security of energy supply in the mineral oil-dependent transport sector and promote rural development and employment (e.g. EC 2005; BMU and BMELV 2009). The emphasis placed on different aims shifted over time (Londo and Deurwaarder 2007)—while early national-level biofuel promotion policies in the 1990s were dominated by agricultural policy considerations, the EC's 2000 Green Paper "Towards a European strategy for the security of energy supply" (EC 2000) shifted the focus to biofuels' role as a strategic substitute for mineral oil (given OPEC restrictions on oil exports and price increases at the time). The 2003 Biofuels Directive (Directive 2003/30/EC), which required member states to set indicative targets for market shares of biofuels and other renewable fuels, stressed the role of biofuels in reducing dependence on imported energy but also highlighted contributions to GHG mitigation and rural development. The EC's "Biomass Action Plan" (EC 2005) and the "EU Strategy for Biofuels" (EC 2006) further pursued this approach of stressing contributions to all three aims (Londo and Deurwaarder 2007). With the mainstreaming of biofuel policies, concerns about actual GHG mitigation performance and wider sustainability impacts gained weight in the debate, leading to the implementation of binding GHG reduction and sustainability certification requirements in 2009, with the adoption of the RED and Fuel Quality Directive (FQD, Directive 2009/30/EC). Overall, the opportunity to bundle environmental, energy security and agricultural aims plays an important role in explaining biofuels' attractiveness from a political viewpoint, same as their comparative commercial maturity (Kaup and Selbmann 2013; Hunsberger et al. 2017). Also, compatibility with existing infrastructures and consumer behaviour is high, unlike with electromobility (see Perez 2019). Accordingly, many member states adopted technology-specific support schemes such as biofuel quotas or tax incentives (RES Legal 2017), contributing to an overall increase in liquid biofuel use in transport in the EU-28 from 5.38 million tonnes of oil equivalent (Mtoe) in 2006 to 13.69 Mtoe in 2015 (measured as final energy consumption, Eurostat (2018b), see Fig. 2).

This development has been accompanied by a critical debate regarding the economic, environmental and social sustainability of first-generation biofuels in particular. For one, biofuels' cost-effectiveness as a GHG mitigation option has been called into question, given comparatively high GHG mitigation costs (SRU 2007; WBA 2007; Henke and Klepper 2006; Frondel and Peters 2007). For example, GHG mitigation costs of biodiesel are estimated to range from 100 to 330 €/ tCO_2-eq.; for sugar- and straw-based bioethanol, the range is estimated to be 100–200 €/tCO_2-eq. (Joint Research Centre 2015).[1] Moreover, by increasing competition for agricultural commodities and land, the promotion of crop-based biofuels can exacerbate environmental and social problems in the agricultural sector, e.g. by incentivising the conversion of natural land or inhibiting access to land (see Goetz et al. 2017 for an overview). Land use changes in particular can negate biofuels' GHG mitigation advantages compared to fossil fuels (e.g. Fargione et al. 2008; Gibbs et al. 2008; Edwards et al. 2010; Plevin et al. 2010). The RED implemented binding sustainability criteria to make sure that biofuels are not obtained from land with high biodiversity value or high carbon stock or peat lands and defined minimum GHG emission-saving requirements (Directive 2009/28/EC, Article 17). However, as long as the majority of agricultural production is not subject to sustainability certification requirements, indirect land use changes (ILUC) remain problematic; these occur when biofuels displace the production of other (uncertified) agricultural commodities to formerly uncultivated land (EC 2010; Van Stappen et al. 2011; van Dam et al. 2010). Also, voluntary certification systems which can be used to prove compliance with the RED's sustainability criteria differ considerably in whether and how they cover social impacts (e.g. on local food security, land rights) or additional environmental impacts (e.g. on water or soil quality) (de Man and German 2017; Mohr and Bausch 2013; Schlamann et al. 2013). Certification systems with a comprehensive scope and rigorous compliance verification tend to suffer from low uptake in the biofuels market (de Man and German 2017).

Largely in response to ILUC concerns, an amendment of the RED was adopted in 2015 after lengthy negotiations (Directive (EU) 2015/1513), establishing a maximum 7% cap on the contribution of agricultural crop-based biofuels to the 10% transport sector target. Other provisions included more stringent GHG emission reduction requirements for biofuels, ILUC reporting requirements and the call on member states to set nonbinding national targets for advanced, i.e. nonagricultural crop-based biofuels with a low ILUC impact.[2] Concerns about the GHG mitigation performance of biofuels have also triggered adjustments in member state-level

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[1] In both cases, emissions from indirect land use changes are not included in the estimates.

[2] "Advanced" biofuels encompass not only second-generation but also third-generation biofuels made from algae, see Directive (EU) 2015/1513.

policies, such as Germany's change from an energy content-based to a GHG emission reduction-based biofuel quota. Moreover, in the debate on decarbonising the transport sector, increasing emphasis is put on electromobility and renewable electricity-based fuels (see, e.g. BMUB 2016). In Germany, the biofuel quota was opened for contributions from hydrogen and methane produced from renewable electricity of non-biogenic origin in 2017 (37. BImSchV). In 2018, an ordinance followed which also allows upstream emission reductions in mineral oil-based fuel production to count towards quota obligations from 2020 (*Upstream-Emissionsminderungs-Verordnung*—UERV), further dampening demand prospects for biofuels.

In the light of these developments, the future design of EU biofuel policy beyond 2020 has remained uncertain. In the context of the EU's 2030 climate and energy policy framework, the recast RED which is currently (as of winter 2017/2018) being negotiated will be particularly relevant. So far, the design of transport sector RES targets has proven a particularly contentious topic, with significant changes being implemented between the EC's proposal which was released in November 2016 (EC 2016a, b), a compromise proposed by the Presidency of the Council of the European Union in October 2017 (Council of the European Union 2017a, b) and the European Parliament's resolution on the proposal put forward in January 2018 (European Parliament 2018). At the same time, from an economic perspective, the question remains whether RES targets and policies supporting the diffusion of RES are even necessary or merely result in efficiency losses compared to policies focussing on cost-effective GHG mitigation only (as argued, e.g. by Stavins 2014; Weimann 2012; Frondel et al. 2010; see Lehmann et al. 2019 in this volume for a discussion). Based on a short overview of the proposed design of the transport sector target beyond 2020 (Sect. 2), this contribution examines whether from an economic theory perspective, there may be a case for continuing a target which supports the use of biofuels and other low-carbon options in the transport sector (Sect. 3). As an outlook, implications are derived for its design (Sect. 4).

2 The RED's Transport Sector RES Target Beyond 2020: Cornerstones of Recent Reform Proposals

The EU's 2030 climate and energy policy framework, which was adopted in 2014, turns away from binding member state-level targets for RES expansion. Instead it combines collective 2030 targets for RES (at least 27% RES share in the community's final energy consumption), GHG mitigation (reduction of GHG emissions by at least 40% compared to 1990) and energy efficiency (increase by at least 27%) with member state-level targets for GHG emission reductions (EC 2014). In the proposal for a recast RED, existing RES targets for 2020 are now merely considered as baseline levels below which member states should not fall (EC 2016a, Article 3 (3)). Moving away from national-level RES targets was intended to improve the cost-effectiveness of GHG mitigation and strengthen the integration of the European internal energy market but also reflected individual member states' concerns about retaining competence to determine the composition of their energy mix (Council of the European Union 2014; EC 2014).[3]

Similarly, the EC intends to discontinue sectoral targets for reducing the GHG intensity of fuels, which are currently implemented by the FQD (EC 2014). The 2009 version of the FQD obligates fuel suppliers to gradually reduce road transport fuels' GHG intensity by up to 10% per unit of energy supplied by 2020. An extension beyond 2020 has not been proposed (EPRS 2017). However, despite the absence of national RES targets, the EC's proposal for a recast RED includes a target for the minimum share of RES in the transport sector.[4]

According to the EC's 2016 proposal, member states shall require fuel suppliers to provide a minimum share of energy from low-emission and renewable fuels in the amount of transport fuels supplied, starting at 1.5% in 2021 and increasing to 6.8% in 2030 (EC 2016a, Article 25 (1)). To meet this obligation, suppliers can use advanced biofuels as well as other liquid and gaseous biofuels which are not produced from food or feed crops but from feedstock listed in the proposal's Annex IX (see EC 2016b), renewable liquid and gaseous transport fuels of non-biological origin (e.g. hydrogen fuel), waste-based fossil fuels and renewable electricity. To promote advanced biofuels and biomethane from selected feedstock (as defined in Annex IX Part A), separate minimum shares are defined (increasing from 0.5% in 2021 to 3.6% in 2030) (EC 2016a, Article 25 (1); EC 2016b). While the original RED allowed advanced biofuels to be double counted (i.e. with twice their energy content), the 2016 proposal discontinues this practice (EC 2016b, Annex IX). However, fuels supplied in aviation and maritime transport can be counted as 1.2 times their energy content (EC 2016a, Article 25 (1)).

At the same time, the proposal envisions a gradual reduction in the use of food and feed crop-based first-generation biofuels, to address ILUC concerns. To this end, their contribution to the calculation of a member states' final energy consumption from RES (which counts towards the EU-level RES target) is limited to 7% of that member state's final energy consumption in road and rail transport in 2021, decreasing to 3.8% in 2030 (EC 2016a, Article 7 (1)). Member states are free to set lower limits (which also can apply only to selected food or feed crop-based biofuels).

Furthermore, sustainability and GHG emissions-saving criteria are further developed (EC 2016a, Article 26). Among other provisions, biofuels from new plants would have to provide a GHG emissions saving of at least 70% from 2021. For existing installations, requirements of the existing RED would continue to apply (at least 50% GHG emissions saving for plants in operation before 5 October 2015

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[3] Meanwhile, the European Parliament's resolution on a recast RED criticises this approach, arguing for a more ambitious EU-level RES target of at least 35% by 2030 and its translation into national targets (European Parliament 2018).

[4] Also, for the heating and cooling sector, an annual increase in RES share by 1% is envisioned, but in the Council's 2017 proposal, this is included as an indicative trajectory only (Council of the European Union 2017a, Article 23).

and at least 60% for newer plants). Also, a new sustainability criterion is introduced for forest biomass.

The Council's 2017 compromise approach places much greater emphasis on maintaining investment security for past investments in first-generation biofuels, stating that this would be "a sine qua non for securing adequate *future* investment in advanced biofuels" (Council of the European Union 2017a, p. 2). Accordingly, the proposal extends the current RED's approach and proposes a 15% minimum RES share that each member state's transport sector should meet by 2030 (Council of the European Union 2017a, Article 25 (1)). First-generation biofuels could continue to contribute to this target, up to the 7% ceiling adopted in 2015. "Low indirect land-use change-risk biofuels and bioliquids" would be exempted from this restriction (Council of the European Union 2017a, p. 105). Nonetheless, member states would still be free to set lower limits or distinguish between different food and feed crop-based biofuels according to perceived ILUC effects. For second-generation biofuels from selected (i.e. Annex IX Part A feedstocks, see Council of the European Union 2017b), a sub-target of at least 0.3% would apply (with a footnote indicating that the possibility of double counting is still on the table, see Council of the European Union 2017a, Article 25 (1)). To promote electromobility, a multiplier of five is proposed for the use of renewable electricity in road transport. Moreover, member states would be able to choose whether or not to include recycled carbon fuels from fossil waste streams in obligations on fuel suppliers.

As to GHG emissions-saving criteria, the 2017 proposal specifies that the requirements outlined above apply not only to biofuels and bioliquids but also to biomethane consumed in transport (Council of the European Union 2017a, Article 26 (7)). For recycled carbon fuels and renewable liquid and gaseous transport fuels of non-biological origin, an emissions-saving criteria of 70% from 2021 onward is proposed (Council of the European Union 2017a, Article 25 (1)).

Compared to the Council's position, the European Parliament takes a more critical stance on food or feed crop-based biofuels, proposing that their contribution to a member state's transport sector RES target should be frozen at 2017 levels, with a maximum share of 7% in gross final energy consumption in road and rail transport (European Parliament 2018, Article 7 (1)). Moreover, from 2021 a 0% contribution for palm oil-based biofuels and bioliquids is proposed. As a minimum transport sector RES share for 2030, 12% is suggested (European Parliament 2018, Article 3 (1a)). Additionally, the European Parliament follows the EC's proposal of requiring an increasing minimum share of advanced biofuels (as defined by Annex IX) and other low-emission and renewable fuels (including recycled carbon fuels and renewable electricity). For the trajectory, a starting minimum share of 1.5% in 2021 is proposed, increasing up to 10% in 2030 (European Parliament 2018, Article 25 (1)). Also, the EC's proposal for separate minimum shares for advanced biofuels and biomethane from feedstocks listed in Annex IX Part A is endorsed. Compared to the EC's proposal, the European Parliament's resolution emphasises that it should be possible to remove feedstocks from Annex IX following an evaluation in 2025, even though exceptions would apply for existing biofuel production installations (European Parliament 2018, Article 7 (5)).

3 Is There an Economic Rationale for a Transport Sector-Specific RES Target?

The proposed continuation of a transport sector RES target which would need to be implemented in every member state is not without surprise—after all, moving away from binding member state-level targets for the overall share of RES in final energy consumption was motivated by the argument that GHG emission reductions should be achieved at least cost, besides concerns about national sovereignty concerning the energy mix. From a static cost-effectiveness perspective, a transport sector-specific RES target distorts search processes for least-cost GHG mitigation options even more than an overall RES target, as the comparatively high GHG mitigation costs of biofuels illustrate. This gives rise to the question whether, from an economic perspective, there is a rationale for continuing the target. In the following, two potential rationales shall be discussed: the interaction between GHG mitigation externalities and knowledge and learning spillovers on the one hand, and GHG mitigation externalities and other politically relevant aims on the other hand.

3.1 Interaction Between GHG Mitigation Externalities and Knowledge and Learning Spillovers

A climate policy which is geared only towards the static minimisation of GHG mitigation costs neglects positive knowledge and learning externalities associated with the diffusion of innovative but presently more costly low-carbon technologies. To support low-carbon innovation, it can therefore be advisable to combine policies which internalise the costs of GHG emissions not only with R&D support but also with support for the diffusion of innovative technologies (Jaffe et al. 2005; Gallagher et al. 2012; Lehmann et al. 2019; Smith et al. 2019). In this way, learning effects can be promoted for a portfolio of technologies, lowering the costs of achieving GHG mitigation targets over time. RES targets—including sectoral RES targets—can be an important framework condition for member states to implement such diffusion support.

Importantly, implementing member state-level RES targets in the RED can provide additional planning security for investments in innovative technologies whose profitability depends on the continued existence of policy incentives, given a lack of commercial maturity. Indeed, the RED states that “the main purpose of mandatory national targets is to provide certainty for investors and to encourage continuous development of technologies which generate energy from all types of renewable sources” (Directive 2009/28/EC, L 140/17). Of course, in order for RES targets to act as safeguards against a discontinuation of policy incentives, they need to be stable and credible, and the same holds true for member states’ willingness to comply with targets. Nonetheless, especially for biofuels which can be easily traded, the existence of transport sector RES targets in various member states significantly lowers dependence on individual states’ policies. Meanwhile, the design of policies and the role of specific RES in the fulfilment of targets may still change, depending on how technology-open targets are formulated. Specific sub-quotas for specific technologies (e.g. advanced biofuels) increase planning security, but they can also distort investment decisions and increase the costs of target achievement.

Whether the interaction between GHG mitigation externalities and knowledge and learning spillovers can provide a rationale for the continuation of the transport sector RES target, specifically, depends on the innovativeness and potential for learning effects of the technologies in question. Even if only biofuels are considered, there are large differences between technologies. First-generation biofuels are based on comparatively mature technologies, whereas for advanced biofuels, a higher scope for learning effects is expected (Sims et al. 2010; Carriquiry et al. 2011; Eggert and Greaker 2013). Learning associated with the diffusion of first-generation biofuels does not necessarily spill over to more innovative but more expensive second- or third-generation pathways (Eggert and Greaker 2013; Berndes et al. 2010). Given that so far, primarily first-generation biofuels have been used to meet the transport sector RES target, a stronger focusing of the target on innovative low-carbon transport options seems advisable.

3.2 Interaction Between GHG Mitigation Externalities and Other Policy Aims

For the transport sector, security of supply has a particular relevance as a RES policy aim, given its high dependence on imported mineral oil from geopolitically unstable regions (Directive 2009/28/EC, L 140/16; Tänzler et al. 2007). This is reflected by the importance the EC’s 2000 Green Paper on security of energy supply had for the subsequent development of EU biofuel policy (see Sect. 1). The interaction between GHG mitigation externalities and security of supply can therefore be another rationale for continuing the transport sector RES target. However, particularly in the case of biofuels, significant conflicts can arise between the two aims, making a prioritisation necessary (SRU 2007; WBA 2007; WBGU 2008; German et al. 2017; Hunsberger et al. 2017). Especially once indirect land use change impacts are taken into account, there is a clear limit to the contribution first-generation biofuels can make to security of supply while also delivering GHG mitigation benefits and not exceeding sustainable biomass production potentials. Advanced biofuels promise higher GHG mitigation potentials, but their large-scale use can also lead to distortions in resource markets (including markets for waste streams) and sustainability challenges (e.g. in the case of agricultural or forestry residues) (Giuntoli et al. 2014; Thrän et al. 2011). Feedstock cost developments are likely to play a major role in determining the future costs not only of first-generation biofuels but also of advanced biofuels (Millinger et al. 2017). Nonetheless, they could prove an important future option for transport segments with few alternatives for decarbonisation or mineral oil substitution—an important example is aviation with its reliance on energy-dense and easily storable energy carriers (Köhler et al. 2014).

Rural development and employment is another important aim of biofuel support and RES support in general (Directive 2009/28/EC, L 140/16). However, from an economic perspective, the use of biofuel policy as a support measure for rural value creation and employment has been heavily criticised, due to its high distortionary impacts (Henke and Klepper 2006; Isermeyer and Zimmer 2006; WBA 2007; Hermeling and Wölfing 2011). Net impacts on rural employment tend to be highly uncertain, as energy crop production displaces other agricultural production activities (Joint Research Centre 2015; Nusser et al. 2007; Isermeyer and Zimmer 2006). Even if jobs in biofuel processing or transport are taken into account, net effects may be neutral, due to the displacement of jobs in mineral oil-based value chains or the depressive economic effect of price increases for transport fuels (Joint Research Centre 2015). Also, by limiting incentives to search for competitive land use options, structural change processes in the agricultural sector may be inhibited, creating a long-term dependence on policy support. Using rural development and employment as a rationale for transport sector RES targets can therefore not be recommended, even if positive impacts may emerge as co-benefits of RES policies.

4 Implications for the Design of Transport Sector RES Targets

In sum, an economic rationale for a RES transport sector target can be derived if it serves to promote the diffusion of innovative RES technologies with a high GHG mitigation potential as well as scope for learning effects which would reduce GHG mitigation costs in the long term. Positive effects on security of supply provide a further rationale, but given the challenge of decarbonising the transport sector, security of supply benefits of RES should not come at the expense of GHG mitigation.

If the RES target is defined in a technology-neutral fashion, as is the case in the current version of the RED, it will promote the adoption of the lowest-cost RES options. This can be observed in the development so far, with first-generation biofuels continuing to be the dominant option for target fulfilment, whereas the relevance of more innovative options such as advanced biofuels, renewable electricity-based fuels and electromobility remains limited (EC 2017). Against this background, the EC’s 2016 proposal which focusses transport sector targets more strongly on innovative technologies seems more promising than the continuation of an overall transport sector target proposed by the Council. In the latter case, it is to be expected that the permissible 7% share of first-generation biofuels will continue to be utilised for target fulfilment, despite limited scope for innovation and learning spillovers as well as sustainability concerns. In all proposals, the role of waste-based fossil fuels needs to be critically examined—if their use is comparatively low cost, the target’s effect on the promotion of innovative RES options may likewise be diminished.

The EC's proposal is based on the assessment that the future role of food crop-based biofuels is limited "due to the concern about their real contribution to the decarbonisation of the transport sector" (EC 2016a, p. 17). The Council's 2017 proposal does not counter this assessment but stresses planning security for investors as the main argument for maintaining a transport sector target towards which first-generation biofuels can contribute to a significant extent. However, re-examining the support for innovative technologies based on policy outcomes is a vital component of technology-specific innovation policies. Finding a balance between investor security and policy learning is an exceedingly difficult task (Finon and Perez 2007; Rodrik 2014; Purkus et al. 2017), but it can be questioned whether in the case of the Council's proposal, the balance is not tipped too far in favour of the former. Moreover, it is not necessarily given that foregoing a fundamental reassessment of first-generation biofuels will result in higher planning security for investments in advanced biofuels. The downside of technology-specific sub-targets, such as those proposed for advanced biofuels, is that they imply high information requirements on the side of policymakers. Accordingly, there is a possibility of steering errors, as market actors' search processes may be led down avenues which turn out to be inefficient (Hayek 1968/2002). Given uncertainties about technology and cost developments, a reassessment of targets may well become necessary in the future to limit costs of errors. The more specific targets are, the more difficult it could become to establish credible commitment that they will not be changed in the light of new information. This problem also applies to the European Parliament's proposal, whose attempt to balance investor security with sustainability concerns adds a layer of complexity to the target structure.[5] In effect, planning security for advanced biofuels and other innovative RES technologies may benefit more from a credible, long-term decarbonisation perspective for the transport sector. For example, effective GHG mitigation incentives for aviation would indicate the existence of a long-term market for investors in biofuel value chains with high GHG mitigation potentials.

Lastly, RES targets do not address a major barrier in transport sector decarbonisation, namely, the increasing demand for personal- and trade-related transport which has contributed significantly to the increase in sectoral GHG emissions over time (EEA 2017a). In 2015, EU-28 GHG emissions from international aviation were 105% above 1990 levels, whereas international shipping emissions were 22% and road transportation emissions 19% above 1990 levels (EEA 2017a). For effective emission reductions, stronger efforts are necessary not only in the expansion of low-carbon transport options but also in the fields of efficiency improvements and absolute reductions in energy consumption. To implement this, a broad mix of policy measures beyond RES support is necessary, including instruments which increase the costs of fossil fuel-based transport technologies. To support transition processes in the transport sector, combining a

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[5] In sum, the European Parliament's proposal combines an overall minimum transport sector RES share (12% by 2030) with a non-decreasing cap on food or feed crop-based biofuels (max. 7% contribution), an increasing minimum share of advanced biofuels and other low-emission and renewable fuels (10% by 2030) and a separate increasing minimum share for selected advanced biofuels and biomethane (3.6% by 2030).

comparatively cautious and therefore error-friendly RES transport sector target which focusses clearly on innovative technologies with a sectoral GHG emission reduction target might be a worthwhile option for further discussion. A starting point for this could be the EC's strategic White Paper goal to reduce transport sector GHG emissions by 60% by 2050 compared to 1990 levels (EC 2011).[6] However, the greater challenge lies in the adoption of effective policy initiatives in support of this target, as the example of the withdrawn reform proposal of the Energy Taxation Directive illustrates (EC 2016c).

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Biomethane: Local Energy Carrier or European Commodity?

Thomas Horschig, Eric Billig, Stefan Majer, and Daniela Thrän

Abstract In most European Union member states, natural gas plays an important and increasing role in energy provision to meet the demand for heat, electricity and transport. Nevertheless natural gas is a fossil energy carrier and various countries have started the stepwise transition from a fossil resource base towards a renewable energy-based energy system due to concerns regarding greenhouse gas emissions, energy security and conservation of finite resources. A biogenic substitute for natural gas is biomethane, defined as methane produced from biomass with properties similar to natural gas. It is a promising fuel to support the transition from fossil fuels to renewables and to support the greenhouse gas emissions reduction targets of the different European Union member states. Biomethane can be produced by upgrading biogas (biochemical conversion) or as so-called bio-SNG (biogenic synthetic natural gas) by thermo-chemical conversion of lignocellulosic biomass or other forms of lignin-rich biomass. Biomethane production via biochemical conversion is a widely applied technology. Bio-SNG via thermochemical conversion is currently barely applied in the respective market. At present, there is hardly any cross-border trade in biomethane in the EU. During the phase of implementation of the biogas and biogas upgrading industry, each member state started to develop its own regulations, standardisations and certifications. For a working European-wide biomethane trade, unified framework conditions like standardisations and certifications have to be established. This chapter gives a brief introduction to biomethane followed by an overview of biomethane use in several European countries. Afterwards, certification, which is a precondition for biomethane trade, is introduced and possible schemes enabling biomethane trade are presented, followed by an outlook.

T. Horschig (✉) · S. Majer
DBFZ - Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany
e-mail: thomas.horschig@dbfz.de

E. Billig
Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

D. Thrän
DBFZ - Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Leipzig, Germany

Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany

Department Bioenergy Systems, University of Leipzig, Leipzig, Germany

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1 Introduction

1.1 Gaseous Energy Carriers

In most European Union member states, natural gas plays an import and increasing role in energy provision to meet the demand for heat, electricity and transport fuels. Natural gas is an important energy carrier with an already well-developed infrastructure in some countries encompassing gas grids, filling stations, road transport via heavy duty vehicles or marine transport via tanker (compressed natural gas or liquefied natural gas). Nevertheless natural gas is a fossil energy carrier and various countries have started the stepwise transition from a fossil resource base towards a renewable energy-based energy system due to concerns regarding greenhouse gas emissions, energy security and conservation of finite resources.

In Germany, there was a demand for natural gas of ~99,000 ktoe (~96 billion m^3) in 2016, with an increasing tendency, too (*Bundesamt für Wirtschaft und Ausfuhrkontrolle* 2017). Of those ~99,000 ktoe roughly 94% were imported (*Bundesamt für Wirtschaft und Ausfuhrkontrolle* 2017). In Germany, as in many other industrialised countries, natural gas is mainly used for the supply of heat in industrial processes and in residential buildings. Besides that, natural gas is used for the production of power, with a share of 9.1% in Germany in 2015 (*AG Energiebilanzen e.V.* 2016). An even smaller market is the transport sector. About 100,000 natural gas vehicles are in operation in Germany. In addition to its use for energy production, natural gas is also used in the chemical industry for the fabrication of hydrogen, propene and synthesis gas for the production of methanol or ammonia, products which are themselves important starting materials for the production of plastics.

The use of natural gas in Europe is increasing. In 2016, gross inland consumption of natural gas in the EU-28 increased by 7.0% in comparison to 2015, to reach 17,903 thousand terajoules (610,860 ktoe) (Eurostat—Natural gas consumption statistics 2016). The use of natural gas in the EU-28 is comparable to the use of natural gas in Germany. The overwhelming part is used for heating purposes in the industry and in residential buildings. Besides, natural gas is used for power production, chemical processes and as fuel in the transport sector.

In recent years the domestic production of natural gas in the EU-28 has declined (Eurostat—Natural gas consumption statistics 2016). For example, most European Union countries with limited domestic production (except for Denmark, the United Kingdom and the Netherlands) have been forced to increase their imports and thus increase their energy dependency. The most important suppliers to the European natural gas market are Russia, the Middle East, Canada, Norway and North Africa (European Commission 2014). To reduce this energy dependency and to decarbonise the natural gas utilisation pathways, the substitution of natural gas with a biogenic alternative has been raised as an option.

1.2 Biomethane

A biogenic substitute for natural gas is biomethane, defined as methane produced from biomass with properties similar to natural gas. It is a promising fuel to support the transition from fossil fuels to renewables and to support the greenhouse gas emissions reduction targets of the different European Union member states. In principle, biomethane can be used for exactly the same applications as natural gas, if the final composition is in line with the different natural gas qualities in the respective grids. Therefore, it can be used as a substitute for transport fuels, for the combined production of heat and power (CHP), direct heat provision or serve as base product in the chemical industry. Biomethane can be fed-in and buffered in the existing gas grid and thus may be an option for the more important task of energy plants that can operate on a demand-driven basis. Currently, biomethane can be produced by upgrading biogas or as so called bio-SNG by thermo-chemical conversion of lignocellulosic biomass or other forms of lignin-rich biomass (Fig. 1).

A further use of biomethane is not unlimited; it is strictly limited by several factors. Besides economic restrictions, one of the main factors is the feedstock potential. For example, considering economic and environmental aspects, there is a reasonable potential of 10% for the installation of biogas upgrading plants in Germany at existing biogas plant locations which is about 300 MW_{el} (Scholwin et al. 2014). However, it is hard to determine a reasonable potential for a further use of

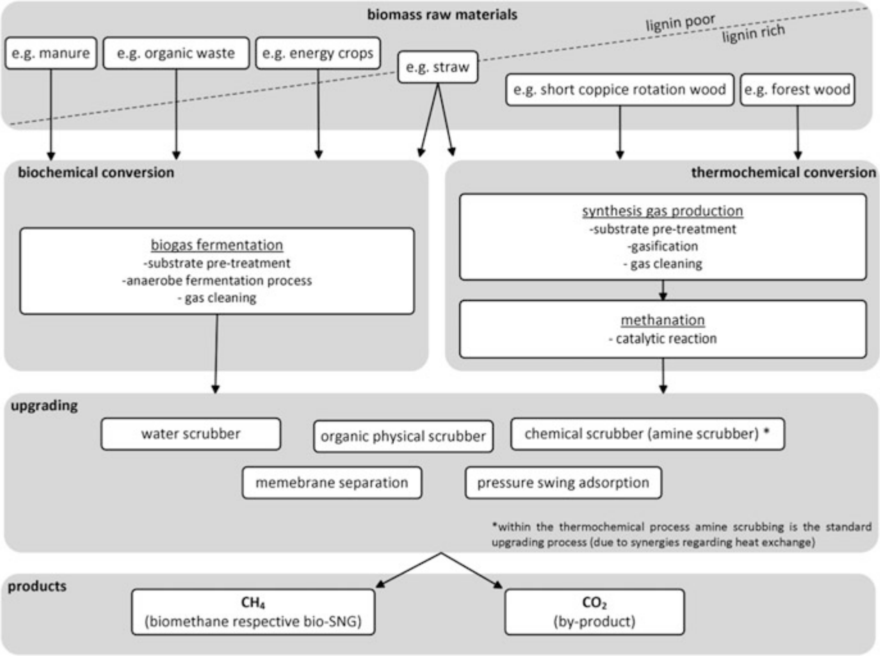

Fig. 1 Biomethane from different conversion processes (Source: own)

biomethane (Horschig et al. 2016a). Besides the legal framework, the use of a reasonable potential is highly dependent on the competitive situation between biomethane and natural gas, which is strongly influenced by the price difference.

Prices of biomethane produced from energy crops are usually about 7–8 euro cents per kWh and thus biomethane is 1–3 euro cents per kWh more expensive than biomethane produced from bio-waste and residual products (Dunkelberg et al. 2015; Billig and Thraen 2017). Besides the compensation from governmental support schemes and the direct marketing of the produced electricity, the sale of the arising process heat make a biomethane CHP project profitable. When used as fuel, biomethane usually has prices of about 4–6 euro cents per kWh. In the direct heat market biomethane as an additive product for natural gas has average prices of 13 euro cents per kWh and is usually more expensive than heat supply by pure natural gas. The sales in this market depend highly on green customers and their willingness to pay higher prices for green products (Horschig et al. 2016a, b).

The current discussion about the potential of sector coupling shows that flexibility is an important property of energy carriers and their production technologies. In the past decade a biomethane market was implemented that is able to provide a large amount of flexibility due to the possibilities of the natural gas infrastructure in Germany.

Even if the technical and logistical requirements for biomethane production are in principle available today and in some areas already implemented on a local level, uniform requirements for feeding biomethane into the gas grid (for transnational trade and transport) and its end use application are not yet in existence. Compared to natural gas, biomethane production and provision is associated with higher costs, at least in the short- and middle-term. To ensure a sustainable feedstock provision as well as a proper and transparent mass balance for the biomethane which is transported and traded via the natural gas grid, uniform and cross-border standards for biomethane composition and quality are needed.

The efficient use of biomethane in combined heat and power plants as well as the use of manure, agricultural residues and bio-waste are major advantages of biomethane when it comes to the reduction of greenhouse gas emissions. In 2015, 3.2 million tCO_{2eq} were saved through the use of biomethane in Germany, which corresponds to 2.1% of saved greenhouse gas emissions from all renewable energies (*Deutsche Energie-Agentur* DENA 2016). The environmental effects, meaning the amount of greenhouse gases that can be saved by substituting natural gas vary depending on the biomethane supply chain including the biomass/feedstock and the biogas technology, the upgrading process to biomethane and the scope of application where natural gas is substituted. More details on the most environmentally efficient ways of using biomethane can be found in (Horschig et al. 2016a).

1.2.1 Biomethane Via Biochemical Conversion

Biomethane production via biochemical conversion is a widely applied technology. The major process steps encompass (i) pretreatment of substrate (crushing, etc.), (ii) anaerobic digestion, (iii) raw biogas treatment and (iv) biogas upgrading (Horschig et al. 2016b). For the purpose of power and heat production, the first three steps (i–iii) have to be applied. For the purpose of producing biomethane, an additional upgrading step has to be applied. Five state-of-the-art upgrading technologies are currently in use: pressure swing adsorption (PSA), water scrubbing, chemical absorption with organic solvent, physical absorption with organic solvent, membrane separation and cryogenic approaches.

For upgrading biogas (produced by anaerobic digestion) to biomethane, it is necessary to remove carbon dioxide (to increase the level of CH_4) as well as H_2S, O_2, H_2O etc. Carbon dioxide removal can be done by several technologies. The most prevalent technologies for biomethane upgrading in Germany are chemical scrubber, water scrubber and pressure swing adsorption (Adler et al. 2014). Energy crops, especially maize, are the most prevalent biomass resource used for biomethane production. In large plants, manure is used only in combination with energy crops. In addition, organic waste is used as feedstock. Small-size manure digesting plants are also in operation with a maximum electric capacity of 75 kw. According to the data of the German Energy Agency (dena), the upgraded biomethane is predominantly used for combined heat and power generation funded by the Renewable Energy Sources Act (88%). Only 9% of the produced biomethane is used for heating purposes and 3% as transportation fuel (*Deutsche Energie-Agentur* DENA 2016).

1.2.2 Bio-SNG Via Thermochemical Conversion

Methane produced via the thermochemical conversion pathway is often called bio-SNG (biological synthetic natural gas). It is chemically identical to biomethane and natural gas. Biomethane or bio-SNG via thermochemical conversion is currently barely applied in the market. So far only a couple of commercial plants are in operation (Kopyscinski et al. 2010). The first commercial plant that started to operate in 2014 has a bio-SNG capacity of 20 MW and is located in Gothenburg (Sweden). All thermochemical conversion plants include the following process steps: (i) pretreatment of substrate (crushing, drying, . . .), (ii) gasification, (iii) raw syngas treatment, (iv) methanation and (v) raw SNG upgrading.

For the thermochemical conversion process mainly lignin-rich substrates like residual forest wood, short coppice rotation wood or straw are used. In a first step the substrates are pre-treated (crushed and dried) and in a second step converted via gasification to a synthesis gas. The synthesis gas consists of CO, CO_2, CH_4, H_2 and water (vapour), while their shares vary depending on substrate and gasification conditions (Kerdoncuff 2008; Kopyscinski et al. 2010). Due to impurities within the synthesis gas, the gas has to be cleaned, mainly to remove tar components and sulphur. After the cleaning process the methane content of the gas is enriched with the help of a catalyst by an exothermic reaction, the so-called methanation process. After this process the gas consists mainly of CH_4 and CO_2. In a last step the CH_4 and CO_2 are separated, usually via amine scrubbing, whereas the other upgrading processes (e.g. water scrubbing) are also technically feasible.

At present there is only one commercial-scale bio-SNG plant (20 $MW_{\text{bio-SNG}}$), which is located in Sweden. The only other existing plants are research and demonstration plants with a much lower capacity and they operate in test mode. The technology has not yet been implemented in the market or is not yet fully developed (Billig and Thraen 2017).

2 Biomethane in the European Union

In 2015 and 2016, the European biomethane market experienced steady growth with more than 92 new biomethane plants commissioned, an increase of 25% on prior years. Germany is still leading the European market, but significant growth was observed in other European countries like the UK with 43 new plants, France with 12, Switzerland with 11, and Denmark with 6. By the end of 2016, 459 plants produced biomethane in Europe, of which about 70% injected it into the gas grid (Fig. 2). The feedstock used for the production of biomethane varies considerably across Europe. Countries like Germany and Latvia use mainly energy crops and agricultural residues. A combination of sewage, bio-waste and industrial waste is used in countries like Finland, Sweden and the UK. Across Europe about 10% of the produced biomethane is used in the transport sector. Currently cross-border trade is limited to bilateral agreements (Switzerland-Germany, Denmark-Germany). An international trade in biomethane is mainly done through road transport as compressed or liquefied gas.

2.1 *Case Study Germany*

Natural gas is the second most important primary energy carrier in the German energy mix, after mineral oil. In 2016, its share in the primary energy consumption was 22.6%. Natural gas is expected to make a significant contribution to Germany's energy supply in the coming decades. At present, domestic gas production accounts for under 6% of gas consumption, decreasing slightly. The most important market for natural gas is the heating market. In addition, it is also used in the chemical industry and for electricity

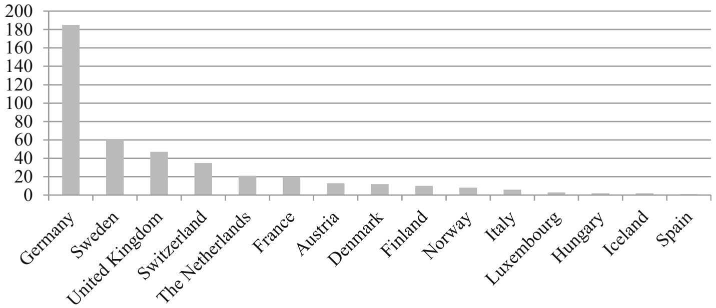

Fig. 2 European Distribution of biomethane plants (data from: European Biogas Association (2016a))

production. The German gas grid is well suited for the transport and storage of gas. Since 2006 biomethane is being produced in Germany for the tasks of decarbonizing the gas sector, improving security of supply and supporting the agricultural sector. By the end of 2016, 196 biomethane plants were injecting around 120,000 Nm^3/h into the national gas grid (*Deutsche Energie-Agentur* DENA 2016). The majority of those plants inject the produced biomethane directly into the gas grid and only a minority provide their biomethane as fuel at fuel stations. A minor portion is being traded. According to the data of the *Fachagentur Nachwachsende Rohstoffe e.V.*, biomethane accounts for only 26,000 tonnes of the 3.4 million tonnes of biofuels used in the transport sector (*Fachagentur Nachwachsende Rohstoffe e.V.* 2017). Despite the fact that currently only 3% of the total biomethane production is utilised as transport fuel in Germany, there is a number of economic incentives for distributing biomethane in the transport sector. When substituting natural gas with biomethane a mineral oil tax relief (§ 50 of the German Energy tax law) could be claimed until 2015, though a renewal is being discussed. In addition, credits for using biomethane can be received under the national biofuel quota (§37a of the Federal Imission Control Act, BImSchG 2013). Currently biomethane substitutes 1.3% of the German annual natural gas demand and helps to diversify the energy supply, foster rural development and decarbonise the gas sector.

2.2 Case Study France

Natural gas plays a vital role in the energy system of France. In 2015, it contributed 14% to France's primary energy production (*Ministere de l'Environment, de l'energie et de la mer* 2016). In the same year, the major sources of energy in France were nuclear power (44%) and crude oil (30%). Renewables accounted for 43.6 GW of installed capacity, representing 18.7% of final energy consumption. Solid biomass (39%) accounts for the biggest share of renewable energies followed by water (23.6%) and biofuels (11.6%). Currently, France is focusing on the development of offshore wind power and, in particular, on-sea power, where they want to expand their global leadership position. However, biogas and biomethane are not to be neglected since the various benefits provide decisive advantages. Thus, the declared objective of the government as well as of various stakeholders in this sector is to obtain biomethane using residual and waste materials. As an integral part of the French energy transition, the further development of the biogas and, in particular, the biomethane sector is firmly integrated in order to meet France's self-imposed energy system objectives. At present, biogas and biomethane (363 MW) still account for a small share of energy generation in France. However, the French expansion plans are increasing the importance of biogas and biomethane in order to make better use of the advantages of recycling, grid stabilisation and security of supply. For the purpose of decoupling production and consumption it is necessary to inject biomethane into the gas grid. In France, approximately 11 million natural gas consumers are connected to the distribution networks and thus represent potential end users in the direct heating market. For the purpose of using biomethane as transportation fuel, natural gas-selling fuel stations are vital. In

2015, 33 fuel stations offered natural gas. According to a report issued by the SER for the biomethane sector the energy input from biomethane amounts to 82 GWh/a, corresponding to 0.02% of the natural gas consumption (Syndicat des énergies renouvelables 2016). According to the French government, by 2030, 10% of gas consumption is supposed to be provided by biomethane, suggesting a reduction in gas consumption (−12.5%). Biomethane feed-in is supposed to increase to 30 TWh by 2030 according to the gas suppliers' plans. In addition, five TWhs are supposed to be generated from thermo-chemical conversion (see Sect. 1.2.2).

The development of the French biogas sector has been slow but steady. The promotion of the biogas sector is also aimed at offering income alternatives to the agricultural sector. By the end of 2015, about 17 biomethane plants fed biomethane into the French gas grid. Nearly half of the plants are agricultural plants, but represent less than 30% of the capacity. In contrast, more than 55% of the feed-in capacity comes from five waste plants. Within the framework of the European research programme GREEN GAS GRIDS, ADEME has estimated possible production capacities based on different feedstock potentials. One approach was more conservative with 500 biomethane plants and 12 TWh of biomethane, whereas the other was based on more optimistic estimates for a maximum raw material volume yielding 1400 plants with 30 TWh (GNT Biogaz 2014).

2.3 Case Study Italy

Italy's national energy strategy encompasses four main points, namely to: (i) significantly reduce the energy cost gap, (ii) outperform the environmental targets set by the European Union, (iii) improve the energy supply security, especially in the gas sector and (iv) enhance sustainable economic growth (Perrella und D'Innocenzo 2016). In 2015 Italy's gas demand was equal to 67.4 billion m^3, of which 90% was imported (Snam Rete Gas 2016). The import of natural gas will continue to be the primary source to satisfy Italy's gas demand. Italy's major supplier is Russia (51%) followed by Libya (13%) and Algeria (13%). To address points ii–iv of its national energy strategy, Italy decided to support the growth of a biomethane market through legislative support and by setting up a corresponding legal framework. Currently about 1555 biogas plants are operating in Italy (ISAAC 2016). As the feed-in tariff for green electricity was reduced, the use of biomethane in the transport sector is an alternative. In June 2017 seven biomethane plants of between 50 and 100 Nm^3/h in size were operating in total. Twenty new plants of between 250 and 2000 Nm^3/h in size were already authorised. The feedstock is mainly the organic fraction of municipal solid waste. Considering the biomethane capacity, which is still very low in comparison to other European countries, and the large potential of biomethane use in the transport sector the main reason for the delay can be seen in the lack of clarity of specific legislative references regarding grid injection techniques. However, Italy is considered the most advanced European country as regards the number of filling stations and use of methane (natural gas) as vehicle fuel. Currently about 970,000 NGVs (natural gas vehicles) are operating in Italy using 1100 CNG (compressed natural gas) and LNG (liquefied natural gas) fueling stations. This large amount of vehicles represents about 75% of the European NGV fleet. For the promotion of biomethane in the transport sector, Italy has already overcome two major barriers: putting the infrastructure in place and raising public awareness about using methane as vehicle fuel. The overcoming those barriers is associated with encouragement of owners of passenger cars and light commercial vehicles to convert their vehicles to NGVs.

2.4 Case Study Sweden

In comparison to most other European countries the Swedish natural gas market can be considered small, with a 3% share of the primary supply only (18 TWh). About two thirds are used for industry applications, one third for district heating purposes and minor parts in the transport sector. Sweden's energy demand is mainly fulfilled by renewables and nuclear power, oil is dominating the transport sector. As Sweden has no domestic gas production, 100% of Sweden's natural gas supply is imported from Denmark. For the purpose of decarbonising Sweden's transport sector, the government supports the use of renewable fuels. As a result, in the last 15 years, the Swedish market for biomethane as transport fuel has grown steadily, reaching a proportion of biomethane in NGVs of 73% in 2015 (European Biogas Association 2016b). With about 52,000 NGVs Sweden has a substantial market for biomethane as a transport fuel. Besides its use in the transport sector biomethane is used in large-scale CHP units. In Sweden, where the gas grid coverage is limited and restricted to only a part of the country, solutions other than the transport of biomethane via the gas grid have to be implemented. In 2015, only 11 of 53 biogas upgrading plants injected biomethane into the national gas grid (Backman und Rogulska 2016). As an alternative solution, biomethane can also be transported off-grid in its compressed or liquefied state. Reasons for the widespread use of biomethane as vehicle fuel are a surplus of gas from biogas plants and a comparably low electricity price. That's why biomethane producers are forced to look for markets other than the electricity market. As a result, biomethane and natural gas are seen as complementary fuels in the transport sector.

2.5 Case Study Denmark

Denmark aims to become a fossil-free society by 2050. Currently, electricity supply in Denmark comes primarily (53.4%) from renewable sources, mainly wind power. The overall share of renewable energy was 28.5% in 2014, according to the EU method of calculation. With regard to natural gas, Denmark can currently be considered self-sufficient. However, this situation is expected to last another 20 years (Ahrenfeldt et al. 2010). Like all other fossil energy carriers used in the Danish energy sector, natural gas has a diminished representation in the Danish energy consumption compared to previous years. This can be explained by the slow reduction in overall energy consumption in Denmark and the growing share of sustainable energy and energy from waste (Energi Styrelsen 2014). A side effect of the Danish natural gas situation is a widely dispersed and up-to-date grid. Biomethane is seen as an option for the decarbonisation of the natural gas grid and the maintenance of self-sufficiency in gas supply. By the end of 2016, 18 biomethane plants injected about 159 million Nm^3 per year into the Danish natural gas grid. In June 2017, The German Energy Agency (dena) and the Danish power and gas grid operator *Energinet* announced a closer cooperation. Both companies will conclude an agreement which provides for mutual recognition of biomethane certificates from both countries. The planned cooperation between dena and *Energinet* is supposed to simplify the bilateral transfer of biomethane (certificates and the product itself) until a European solution comes into existence.

2.6 Case Study UK

In the UK, natural gas, along with other energy sources like wind, solar and nuclear, plays a key role in the national energy mix. Currently about 80% of the UK's 25 million homes are powered by gas. Industry applications cover about a quarter of the country's natural gas demand. However, as the amount of gas from national production (North Sea) declines, UK increases its efforts to ensure a regular and reliable supply of gas to the UK. By the end of 2016 almost 90 biomethane plants were injecting into the gas grid in the UK, which is double the number compared to 2015 (ADBA 2016). Biomethane is currently used for heating of around 170,000 homes in the UK. The main governmental support is given via the Renewable Heat Incentive (RHI). There are currently only few NGVs in the UK, and infrastructure to supply biomethane via fuel stations is sparse, which is just one reason why biomethane is used hardly in the British transport sector.

3 Biomethane Certification and International Trade

Sustainability certification, which has become a precondition of any promotion mechanism related to national quota systems in the transport sector, is gaining significant importance as a market factor. For biomethane, sustainability certification can contribute to the removal of existing barriers totransnational trade. Due to harmonised criteria, biomethane sustainability certification allows producers to develop and exploit specific product characteristics (e.g. feedstock origin, GHG mitigation potential, etc.) but also harmonised mass balancing approaches and solutions for guarantees of origin approaches. In this sense, current efforts to establish a EU biomethane registry represent the next step towards developing an important precondition for a successful trade of biomethane in the EU (European

Biogas Association 2016b). This approach would reduce the administrative burden associated with the sustainability certification of the different stakeholders, but also solve existing problems related to the mass balancing of sustainable biomethane in the natural gas grid of the EU.

As a direct consequence of the intense debate of recent years about the sustainability of bioenergy, the European Commission has introduced a set of mandatory sustainability criteria for liquid and gaseous fuels in the European transport sector as part of the EU Renewable Energy Directive 2009/28/EC (EU RED). Furthermore, the current draft of the EU RED recast includes a proposal to expand these criteria to the heat and electricity production sectors. Mandatory sustainability criteria included in the EU RED cover GHG-mitigation threshold values, requirements for good agricultural practice and the definition of no-go-areas for biomass production.

Consequently, a number of voluntary schemes for sustainability certification have been developed to ensure compliance with the respective EU RED sustainability criteria. It is important to note that amongst the currently existing schemes under the EU RED framework huge differences exist regarding regional or feedstock-specific focus areas as well as regarding the general comprehension of the sustainability criteria addressed in the schemes. The diversity of the existing schemes includes ambitious and very comprehensive approaches (with criteria in all sustainability dimensions) resulting from multi-stakeholder processes (e.g. Roundtable on Sustainable Biofuels, International Sustainability and Carbon Certification, etc.) as well as a number of schemes addressing only the core criteria defined in the EU RED.

Proof that the EU RED criteria are met is verified with a certification process executed under the standard of one of the certification schemes recognised by the European Commission. While a couple of these voluntary schemes are dedicated solely to a specific feedstock (e.g. palm or sugar beet) or technology (e.g. bioethanol), interestingly, the specialties of biomethane are almost not or only partially addressed. This is especially relevant for the GHG-mitigation criteria. While the sustainability certification as well as the individual calculation or the use of standard values for the investigation of a biofuel's GHG-mitigation potential is now common practice for liquid biofuels such as biodiesel and bioethanol, calculations for biomethane are often associated with methodological and data-related uncertainties and fuzziness. Main issues in this regard relate to, for example, methane losses/leakage, the consideration and valorisation of the by-product digestate, the inclusion of GHG- mitigation effects in other agricultural sectors (e.g. avoidance of methane emissions from livestock production, etc.) or the potentially huge effort required to deal with inhomogeneous biomethane feedstocks if they are supplied by a huge number of producers.

The reason for these deficits can be attributed mostly to the fact that biomethane is currently only seldom used as a transportation fuel in the EU RED context. Thus, most of the certification activities in the EU RED context address liquid biofuels. However, since the current draft of the EU RED recast for the 2021–2030 timeframe is aiming at an extension of the sustainability criteria to sectors such as electricity and heat production from biomass, the pressure to solve the issues mentioned above will increase.

4 European Trade: Barriers and Possibilities

Due to the varying production, regulation and subsidisation conditions within the EU, sales opportunities for biomethane are not equal between countries. Cross-border biomethane trade could reduce this discrepancy. In addition, it could help several EU member states to achieve their envisaged climate protection goals by using biomethane whilst not being able to produce the required amount sustainably in their own country. However, biomethane production is at different stages in the different European countries (see study cases). During the establishment of the biogas and biogas upgrading industry in the different EU member states, each country started to develop its own regulations, standardisations and certifications. This resulted in a wide diversity of regulation parameters and thresholds for, e.g., methane content, hydrogen sulphide, water and oxygen (Wellinger 2013). At the end of 2016, there was still no uniform standardisation. In 2016, after comprehensive coordination, the EN 16723-1 and, in 2017, the EN 16723-2 were published and are being transposed into national regulations. The EN 16723-1 deals with the specifications for biomethane for injection into the natural gas network and EN 16723-2 with the specifications for biomethane as an automotive fuel. This uniform standardisation is a first step towards implementing Europe-wide biomethane trade.

In addition to standardisation, other framework conditions have to be established as well to ensure that Europe-wide biomethane trade is workable. These include the development and introduction of a certification system as well as biomethane registers for tracking biomethane amounts, properties and origin for later trade and possible state subsidies, as well as a system for monitoring the sustainability of the produced biomethane. As long as this cooperation is not in place, no harmonised trade market for biomethane will evolve.

Several options for trading of biomethane were identified by the European BIOSURF project, provided the preconditions mentioned above (harmonisation of rules) are fulfilled (Kovacs et al. 2017):

1. A blackboard
    - offers a very simple opportunity for buyers and sellers to arrange a deal;
    - small producers can use a blackboard as a market place like an online auction platform (like ebay) with very low participation efforts;
    - a major obstacle is the time-consuming bilateral negotiations between buyer and seller;
2. OTC (over-the-counter) platform
    - comprises of several trading companies, brokers, banks, suppliers, etc. able to offer bids and submit orders for harmonised biomethane volumes;
    - buyer and seller do “meet” each other, i.e. there is a direct exchange between seller and buyer;

3. Exchange trading option
    - a central place with clear and defined rules for all market participants
    - one advantage is anonymity, disadvantage is the cost side
    - exchanges do have clear trading products and times (security and continuousness)
    - more trust in trading partners
4. Blockchain
    - would significantly increase the flexibility of trading as various parties would have the option of participating
    - registration rules are at a minimum compared to OTC and exchange trading
    - increased trust and security in trading due to a high level of transparency

Some countries have already implemented biomethane registers (DE, AT, FR, CH, GB, DK, NL, SE, IT) (Thrän et al. 2014). Other countries, like Ireland, are currently in the process of certification development (IERE 2017). In 2013, six of the biomethane registers started to cooperate to enable the recognition and exchange of mutual certificates (DE, AT, FR, CH, GB, DK) (Brijde et al. 2014). In conclusion, it can be stated that the fact that standardisation and certification systems are still missing or incomplete has prevented extensive biomethane trade within the EU so far. Cooperation between the existing biomethane registers or the design of a new general binding register is one possible option.

To conclude, biomethane is on the way from being a local energy carrier to becoming a European commodity. At present, there are still barriers that need to be overcome. However, considering the advantages of biomethane presented here it is worthwhile investing effort in this process.

5 Outlook

In recent years, boundary conditions have been set up on the national and on the European level to foster a European biomethane market. Currently bi-national trade takes place and this is going to develop into a multi-lateral trade in biomethane within the European Union. This enables countries with lower biomethane production potential to substitute their natural gas consumption with renewable gas, namely biomethane. However, the future outcome of such a multi-lateral trade in biomethane within the European Union in terms of production capacity, natural gas substitution, end-use, land change and greenhouse gas emissions savings is highly uncertain and needs further research.

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The original version of Chapter 11 was inadvertently published with the incorrect city and country name appearing in the affiliation of the author Sebastian Busch. The affiliation 'Knowledge for the Energy Union Unit, European Commission, Joint Research Centre, Ispra, Italy' has been updated as 'Knowledge for the Energy Union Unit, European Commission, Joint Research Centre, Petten, The Netherlands.' Further, the original version of this chapter inadvertently did not contain the below disclaimer and now has been added as per author's request.

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