German Energiewende - quo vadis?

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Abstract Under the impression of the Fukushima events in 2011, the German Government decided to immediately close down the seven oldest German nuclear power plants (built before 1980) and one younger plant, which had been under scrutiny due to several incidents. To secure energy supply, a set of measures concerning renewable energy deployment and the increase in energy efficiency has been established, together with nuclear phase out, which are often referred to as the "Energiewende". After more than two years into this transition, the challenges and opportunities of the Energiewende become measurable. The contribution reports findings from the monitoring process. One focus of the contribution is the analysis of the economic effects of the Energiewende thus far and in the near future. With the help of a macro-econometric model, two different paths of development are compared with respect to their effects on GDP, employment, and investment and value-added in different economic sectors.

1 Introduction

Renewable energy and energy efficiency had been already high on the agenda in Germany, when the Government decided in the aftermath of the Fukushima events in 2011 to abandon its earlier plans from 2010 for nuclear as a bridging technology and return to the decisions to phase out nuclear, as agreed at the beginning of the 21st century. Moreover, the decision extended to an immediate shut down of the seven oldest nuclear power plants and one younger plant, which had come to attention by several irregularities and out of operation for most of the time anyway. Renewable energy and energy efficiency therefore play an important role in what the world has come to know as the German Energiewende, the transformation of the energy system towards a less polluting, safer and secure energy supply.

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This decision has received much attention from scholars and the public in Europe and around the world. Germany as one of the leading industrialized countries in terms of industrial production and exports has few resources and has to provide energy to an 80 million population and an industrial sector, coined by large energy consumers. The literature ranges from "Germany's gamble" (Buchanan 2012) to the question of "Green Revolution or Germany's Nightmare?" (DW 2013).

Part of the Energiewende is an evaluation and monitoring process. Three years into this process, ex post analysis becomes more and more reliable. This contribution is based on a study for the German Federal Ministry for Economic Affairs and Energy, which did a back cast and a forecast for the next years to evaluate the economic effects of the Energiewende.

To do so, we employed PANTA RHEI, a macro-econometric model for Germany and simulated the economic indicators for two scenarios: an Energiewende scenario, which shows what has been reached in the process thus far and what will be reached in the near future, and a counterfactual scenario to compare with. By this, we can show, which effects can be attributed to the Energiewende. The remainder of this chapter is organized as follows. Section 2 gives an overview of earlier efforts and measures, which set the path towards the Energiewende, and shows earlier evaluation results from the literature. Section 3 defines the modelling framework. It introduces the macro-econometric environmental model PANTA RHEI and reflects upon recent applications and results. Section 4 defines the relevant scenarios in detail. It identifies the drivers of the economic effects and shows the most important characteristics of the respective scenario in terms of investment, the energy mix, prices and energy demand and supply. Next to the differences between the two scenarios, the section also presents the common set of framework data for both scenarios. Section 5 describes the simulation results and puts it into perspective, Sect. 6 concludes.

2 Germany's Way to the Energiewende—Beyond the Nuclear Discussion

The Energiewende was decided against the background of already existing regulation regarding the efficient use of energy and the generation of heat and electricity from renewable energy sources. As far back as the 1970s in response to the first oil crises, Germany started regulating residential heat demand through ordinances on the buildings' heat required and on age, consumption and maintenance of the heating system. The first energy savings act dates back to 1976. Latest since 2002, the idea that regulation of the buildings' envelope and their heating systems are related gained ground and the two strands of regulation merged into the energy saving ordinance.

Compared to this, renewable energy support started rather late. The first "Law on Feeding Electricity from Renewable Energy Sources to the Public Grid"

(Stromeinspeisungsgesetz 1990) had been drafted by a conservative and a green member of parliament and was submitted by the conservative CDU/CSU parliamentary group. It passed parliament in 1991 and was the first step towards what became the EEG, the Renewable Energy Act in 2000. The support was available for systems with a maximum capacity of five MW and the then still monopolistic utility companies could add the paid support to the electricity bill for all consumers. The central elements of the 1990 law were the existence of tariffs and the obligation to buy all generated electricity. Even after the liberalization of the electricity market in consequence of the European Electricity Directive in 1998, the need to regulate access to the grid persisted. Therefore, the new EEG decreed that electricity from renewable energy source gained priority access.

The 1000-roofs program between 1991 and 1995 supported photovoltaic (PV) installations (GIZ 2012). The objective of this capital grant promotional program was the "evaluation of the already achieved level of technology" and "evaluation of the required development need for small grid connected installations". It supported grid connected PV installation with a capacity between one and five kWp on rooftops of residential homes. The grant covered 70 % of the investment and mounting costs and a quota regulated the number of permissible installation per federal state, partly since the federal states paid for a share of the grant. From 1999 until 2003, the 100,000-roofs program supported solar PV. The target was an installed capacity of 300 MW and the support consisted of soft loans on a reduced rate. The late nineties and early 2000s were a period of high interest rates on loans; therefore, a reduction by more than 60 % was an attractive incentive.

The individual efforts in energy conservation and renewable energy use were bundled into the integrated energy and climate package in 2007 (IEKP 2007). The measures range from combined heat and power (CHP) support to buildings' efficiency, increasing efficiency in industry, support of renewables to transport measures for the introduction of biofuels and increasing efficiency of vehicles. Lutz and Meyer (2008) estimate the economic effects of partial measures of the IEKP such as the efficiency program for buildings, and other measures and find slightly higher growth and a positive impact on employment.

Lehr et al. (2012a, b, c) report findings from two studies, with a focus on efficiency measures in different economic sectors and the other one on the impacts of renewable energy increases. Energy efficiency measures are modelled bottom-up for each sector, i.e. for transport, residential building, efficient appliances and households and in industry as well as cross sectional technologies. Only technologies with payback periods from energy savings smaller than the equipment's lifetime are included in the analysis, which is based on Ifeu, Fraunhofer ISI, Prognos, GWS et al. (2011). In addition, export increases for energy efficient appliances contribute to the overall positive economic effects. For renewable energy, a higher growth path and more additional employment also strongly depend on the export assumptions. Germany's economy relies heavily on its position on global markets, also its wind and solar industry does. The media coverage of the integrated energy and climate package supported Germany's role as a pioneer in climate change mitigation and the transition towards an energy system based on renewables. First mover advantages pay in terms of higher shares on global markets. Further studies support these findings: economic effects of efficiency measures are analyzed by Blazejczak et al. (2014a, b). They focus on the improvement of buildings' efficiency and assume twice as high an effort in this sector. This leads to investment between 7.4 billion EUR (2020) and 14 billion EUR (2050) and annual saved energy costs of 3.8 billion EUR (2020) and up to 32 billion EUR (2050). Economic effects from these measures are positive. Compared to a reference without the respective measures (see the next section on the definition of counter factual scenarios) GDP is up to 1 % higher and additional employment ranges at 340,000. Böhringer et al. (2012) analyze the economic effects of the renewable energy support mechanisms. Applying a general equilibrium model, they find positive employment effects for some parameter choices, depending on the design of the respective support mechanism. Frondel et al. (2009) have repeatedly doubted positive employment effects and pointed at the high costs of the renewable energy support mechanism. However, their calculations stop at the cumulated costs.

IHS Global Insights (Wiegert and Hounsell 2013) find negative impacts, assuming high prices for energy intensive sectors and a termination of the exemptions of the energy intensive industries from surcharges for renewables. In November 2014, the EU Commission has declared the exemptions to be almost completely in line with EU legislation. The EEG amendment in summer 2014 has already been drafted in close cooperation with the Commission to ensure further exemptions. The analysis by the German Economic Institute (DIW) shows positive effects of renewable energy expansion (Blazejczak et al. 2014a, b). Finally, an analysis of the energy and climate policy measures since 1995 shows positive effects, due to accumulated energy savings (Lehr et al. 2013). Accordingly, the macroeconomic effects throughout the 2010–2012 period turn out to be positive.

The IEKP was an important step towards a more sustainable economy. However, it fell short of providing a pathway for a transition of the energy system until 2050, which is compatible with international climate change targets.

Therefore, the German government developed the energy concept, which is a continuation of the IEKP with detailed targets until 2050. It is at the core of the Energiewende framework of 2011, ironically partly to underpin life time extension of nuclear power plants in 2010. Table 1 gives an overview of the respective targets. Detailed pathways show the transition from today's shares of renewables, in final energy consumption and in electricity generation, from today's GHG emissions to an 80 % reduction by 2050; primary energy use shall decrease by 50 % by 2050 and electricity consumption by 25 %. The latter represents a steeper increase in efficiency than it may seem at first glance, because the number of electric appliances will further grow in the future as will electro mobility.

The energy concept further suggests measures to reach these targets and provides a framework of monitoring the success in reaching the suggested targets. The analysis on the economic effects of the Energiewende presented below is a small building bloc in the first comprehensive progress report (BMWi 2014).

And nuclear? The so-called nuclear consensus from 2001 had set dates for the phase out of nuclear energy. Any nuclear power plant received a lifespan of

Table 1 Targets of the energy concept

		2011 (%)	2012 (%)	2020 (%)	2030 (%)	2040 (%)	2050 (%)
Renewable energy	GHG reduction	25.6	24.7	At least 40	At least 55	At least 70	At least 80
	In electricity	20.4	23.6	At least 35	At least 50	At least 65	At least 80
	In final energy	11.5	12.4	18	30	45	60
Efficiency	Primary energy	−5.4	−4.3	−20			−50
	Electricity	1.8	−10				−25
	Production	Increase in energy productivity (=output/energy input) by 2 % per annum					
	Buildings	2 % of buildings modernized each year = all buildings in 50 years					

Source BMWI, own table

32 years and the amount of electricity it could generate until its end of operation. Two nuclear power plants were switched off immediately; four more should have followed in 2010 and 2011. After a brief reconsideration of the phase out schedule by the German Government, the Fukushima events in March 2011 led to the current state, where nuclear will be phased out by 2021. Figure 1 shows the path as it is set in the Amendment to the Law on Atomic Energy of 2011 (AtG 2011). It also shows the electricity generation from nuclear power plants according to the nuclear consensus from 2002 and the Energiewende scenario from 2011. A major challenge will be the shutdown of the remaining nuclear power plants between 2020 and 2022.

A large decrease in capacity took place immediately after the decision to return to nuclear phase out in March 2011. Eight out of 17 operating nuclear power plants were switched off; the decrease in operating capacity was 8.8 GW. 12.7 GW remained in operation. The reduction of installed nuclear capacity by more than one third went without disruption of the electricity supply in Germany. Studies on price impacts show only small increases in electricity wholesale prices, partly due to current overcapacity on the electricity market and merit-order effects.[1]

The energy mix, investment in new power plants, operation of the existing power generation as well as the multitude of other factors related to the above outlined goals impact the economy. Apart from individual cost-benefit-assessments for instance in support of the decision for or against the installation of a solar home

[1]The electricity supply curve can be thought of as ordered according to power plants‘ generation costs. This is called the merit order. The more electricity from renewable energy enters the market, the more generation at zero generation costs is in the market and spot market prices drop.

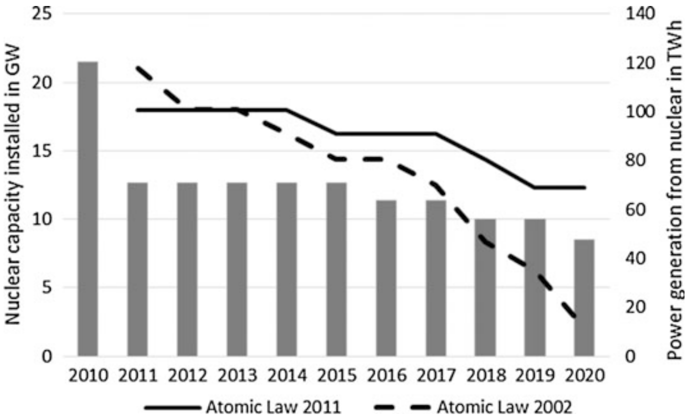

Fig. 1 Phase out path for nuclear energy as decided in the Law on Atomic Energy AtG 2011, 2010–2020, in GW. *Source* GWS, Prognos, EWI (2014), Sachverständigenrat Wirtschaft (2012)

system, the macro effects of the transition to a cleaner and safer energy system are important.

To determine the macroeconomic effects of the energy transition a macroeconomic model analysis can illustrate feedbacks between the energy system and the overall economy and determine gross effects at the macroeconomic and sectoral levels. Scenario analysis is the established technique to evaluate the effects of a political instrument or a bundle of instruments such as the Energiewende. Economic quantities from a scenario, which includes all the measures, are compared with the results of a scenario without the measures—the so-called counterfactual. The comparison shows in which scenario the economic performance will be better. Typical indicators are GDP, both level and growth rates, employment, consumption, the trade balance and others.

Figure 2 depicts the different steps of the evaluation. The scenarios describe possible specifications of the future energy system for Germany. Bottom-up models help to translate the scenarios into a set of monetary stimuli. Investment in energy efficiency or renewable energy technologies, price changes due to different heat and power generation costs or savings from reduced energy costs due to increased efficiency are the monetary effects of a change in the energy system. These monetary stimuli trigger many effects in the overall economy: relative price changes induce behavioral changes, investment leads to additional employment and demand for the respective goods in the short run and will increase depreciation in the longer term, energy savings shift demand to other goods than energy.

The comparison of the results becomes more difficult once different references, combinations of measures and design of the macroeconomic models are chosen. In this context, the key is the definition of the energy transition and a clear description of the measures that are necessary for its achievement compared to an appropriate reference trend.

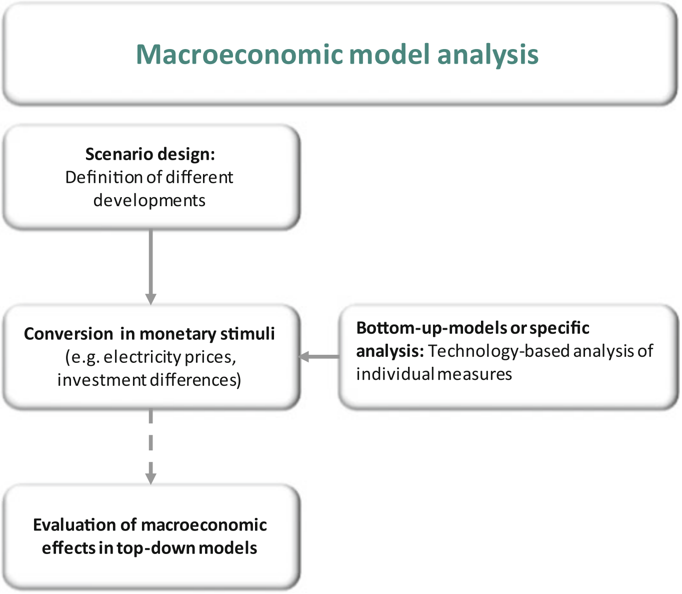

Fig. 2 Macroeconomic model analysis. *Source* GWS/Prognos/EWI (2014)

The next section briefly explores the modelling tool and explains the relevant links. We then turn to the scenarios and explain the main drivers for each of the two scenarios considered.

3 Model PANTA RHEI

The economic effects of the German Energiewende are determined using the environmental economic model PANTA RHEI. PANTA RHEI (Lutz et al. 2005; Lehr et al. 2008; Meyer et al. 2012) is an environmentally extended version of the econometric simulation and forecasting model INFORGE (Ahlert et al. 2009; Meyer et al. 2007). A detailed description of the economic part of the model is presented in Maier et al. (2013, 2015). For more details of the extended model, see Lutz (2011). PANTA RHEI has been used to answer several questions on the economic effects of environmental policy instruments. The support of energy efficiency and renewable energy, which has been outlined in Chapter “The EEC Commission and European Energy Policy: A Historical Appraisal”, has been evaluated with the help of PANTA RHEI. In 2010, economic effects of different energy scenarios were compared to each other, which were the basis for the German energy concept (Prognos, EWI, GWS (2010); Nagl et al. 2011). Recent applications include an evaluation of green ICT (Welfens and Lutz 2012), employment effects of the increase of renewable energy (Lehr et al. 2012a, b, c), and economic evaluation of climate protection measures in Germany (Lutz et al. 2014a, b). In a recent IEA (2014, p. 57) overview the model is classified as "input-output", but it is rather "econometric" plus "input-output", as parameters are econometrically estimated and input-output structures flexible (West 1995). The overall approach is based on the INFORUM philosophy (Almon 1991). More detail can be found in the chapter of Douglas Meade, who applies the US LIFT model to study the impact of shale gas in the US.

The behavioral equations reflect bounded rationality rather than optimizing behavior of agents. All parameters are estimated econometrically from time series data from 1991 to 2010. Producer prices are the result of mark-up calculations of firms. Output decisions follow observable historic developments, including observed inefficiencies rather than optimal choices. The use of econometrically estimated equations means that agents have only myopic expectations. They follow routines developed in the past. This implies in contrast to optimization models that markets will not necessarily be in an optimum and non-market (energy) policy interventions can have positive economic impacts.

The model is empirically evaluated: the parameters of the structural equations are econometrically estimated. In the model-specification stage various sets of competing theoretical hypotheses are empirically tested. As the resulting structure is characterized by highly nonlinear and interdependent dynamics the economic core of the model has furthermore been tested in dynamic ex-post simulations. The model is solved by an iterative procedure year by year.

Structural equations are modeled on the 59 sector level (according to the European 2 digit NACE classification of economic activities) of the input-output accounting framework of the official system of national accounts (SNA) and the corresponding macro variables are then endogenously calculated by explicit aggregation. In that sense the model has a bottom-up structure. The input-output part is consistently integrated into the SNA accounts, which fully reflect the circular flow of generation, distribution, redistribution and use of income.

The core of PANTA RHEI is the economic module, which calculates final demand (consumption, investment, exports) and intermediate demand (domestic and imported) for goods, capital stocks, and employment, wages, unit costs and producer as well as consumer prices in deep disaggregation of 59 industries. The disaggregated system also calculates taxes on goods and taxes on production. The corresponding equations are integrated into the balance equations of the input-output system.

Another important outcome of the macro SNA system is net savings and governmental debt as its stock. Both are important indicators for the evaluation of policies. The demand side of the labor market is modeled in deep industry disaggregation. Wages per head are explained using Philips curve specifications. The aggregate labor supply is driven by demographic developments.

The energy module describes the interrelations between economic developments, energy consumption and related emissions. The relations are interdependent. Economic activity such as gross production of industries or final consumer demand influence respective energy demand. Vice versa, the expenditures for energy consumption have a direct influence on economic variables.

The energy module contains the full energy balance with primary energy input, transformation and final energy consumption for 20 energy consumption sectors, 27 fossil energy carriers and the satellite balance for renewable energy (AGEB 2013). All together, the balances divide energy consumption into 30 energy carriers. Prices, also in Euros per energy unit, are modeled for different energy users such as industry, services and private households for all energy carriers. The energy module is fully integrated into the economic part of the model.

Final energy consumption of industries is explained by sector output, the relation of the aggregate energy price—an average of the different carrier prices weighted with their shares in the energy consumption of that sector—and the sector price and time trends, which mirror exogenous technological progress.

For services, the number of employees turned out to be a better proxy for economic activity than gross output. Average temperatures also play a role for the energy consumption of the service sector. For private households, consumption by purpose as heating or by fuels is already calculated in the economic part of the model in monetary terms. Additional information can be taken from stock models for transport and heating from the specific modules, as only new investments in cars, houses or appliances, or expensive insulation measures will gradually change average efficiency parameters over time.

Final demand of each energy carrier for industries can be calculated by definition, multiplying the share of the carrier with overall final energy demand of the sector. For the shares, the influence of relative prices, the price of the energy carrier in relation to the weighted price of all energy inputs of the sector, and of time trends are econometrically tested.

Energy carrier prices depend on exogenous world market prices for coal, oil and gas and specific other price components such as tax rates and margins. For electricity different cost components such as the assignment of the feed-in-tariff for electricity are explicitly modeled. For services, households and transport specific prices are calculated, as for example tax rates partly differ between end users.

For energy-related carbon emissions, fix carbon emission factors from the German reporting (Federal Environmental Agency 2013) to the United Nations Framework Convention on Climate Change (UNFCCC) are applied. Multiplication with final energy demand gives sector and energy carrier specific emissions. All detailed information in the energy balance for 30 energy carriers is consistently aggregated and linked to the corresponding four industries of the IO table.

4 Scenarios and Framework Conditions

The scenario definition centers on one principle: basic macroeconomic parameters, e.g., population, economic development and international energy prices, which are available either from historical values or from medium-term forecasts, are assumed the same in both scenarios. They correspond to the current Energy Reference Forecast (Prognos, EWI, GWS 2014, see Lutz et al. 2014a, b for an overview in English). The German government commissions an energy reference forecast in a 5 year frequency. It projects the most likely development, given the current policy framework. Projections for international energy prices and the global population development stem from or are closely related to the respective publications such as the IEA's World Energy Outlook. The projection of the global economic development, of the energy system in Europe and in Germany and of the German economic development result from the combination of several macro models, energy system models and electricity market models.

Three years after the Energiewende has been decided, it makes sense to ask, what has been reached thus far and what were the economic effects of the Energiewende until today? To answer these questions, the analysis in the next sections takes the energy system as we find it in 2013 and compares it with an ex-post counterfactual. For the ex-ante analysis, both, the counterfactual and the Energiewende scenario are forward projected.

4.1 Framework Data

Framework data, as mentioned above, are not in the realm of being affected by the energy transition, such as international energy prices for fossil fuels or the population development in Germany. The population is decreasing during the observation period from 80.3 million in 2009 to 79.4 million in 2020 (−1.1 %). This leads to a 1.5 % drop of labor force compared to 2009.

Real GDP has increased during the ex post period by an average of 2.1 % p.a. In the ex-ante period, the average growth rate is 1.2 % p.a. However, the scenarios change GDP growth rates and GDP will differ between the scenarios (see Sect. 5). Together with the population's decrease, this leads to an increase of average real per capita income by about 9 % by 2013 and 19 % by 2020.

Consumer prices for petroleum products, natural gas, and coal result from global market prices and exchange rates, as well as from associated taxes and fees. CO_2 prices will have an effect on relative prices of fossil fuels. The underlying assumption is that businesses not participating in emissions trading and private residences will pay a CO_2 surcharge in line with CO_2 certificate prices and the specific CO_2 content of the energy sources from 2020 onwards.

The price for natural gas for heating and other residential use has dropped in the ex-post period by 5 %; the price for light heating oil has risen by almost 50 % (Fig. 3). The projection for fossil fuel prices is based on Prognos, EWI, GWS (2014). In 2020, natural gas price will be 7 % higher than 2009 and heating oil will be 73 % compared to 2009. Although current price turmoil of crude oil seems to signal low prices, the analysis of the economic effects of the German Energiewende bases its price assumptions on the latest available IEA World Energy Outlook (IEA 2013). Brent oil prices will grow between 2011 and 2020 from 108 USD2011/bbl in

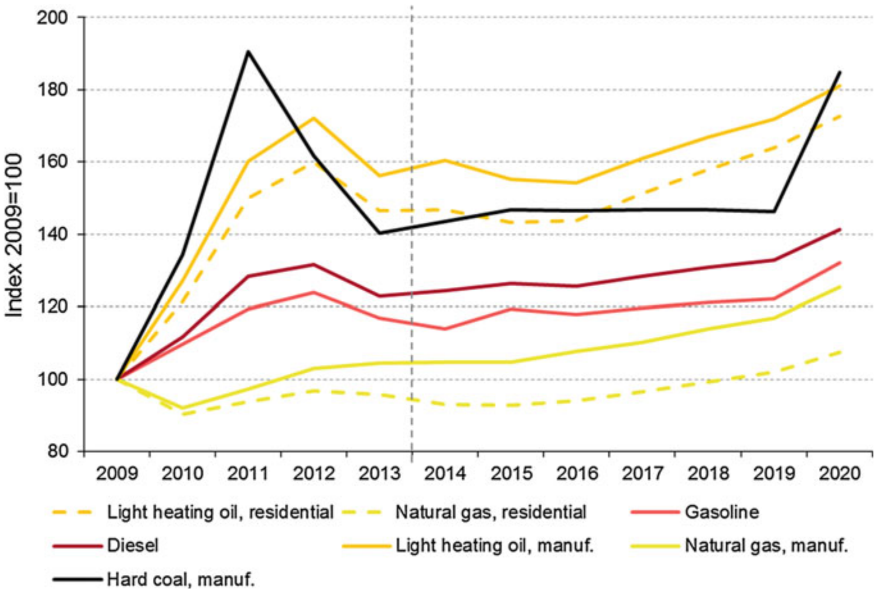

Fig. 3 Consumer prices for petroleum products and natural gas, household prices with VAT, manufacturing prices without VAT, 2009–2020, Index 2009 = 100. *Source* GWS/Prognos/EWI (2014)

2011 to 117 USD2011/bbl in 2020. As taxes and other charges for fossil fuels are assumed to remain constant until 2020, consumer price increases are driven by import price changes. In 2020, a CO_2 surcharge is introduced for all carbon emissions outside the EU-ETS. Industrial prices are assumed to show stronger increases.

The base year for the following analysis is 2009, because as has been pointed out above the Energiewende started in 2010 with the decisions laid down in the German energy concept. Therefore, the scenarios bifurcate in 2010 and 2009 is the last year with a shared data set.

Against this general framework, the Energiewende scenario and the counterfactual are developed. For the ex-post analysis, data for the Energiewende scenario are observable, the actual development of the energy mix, of prices and quantities supplied and demanded are contained in the most recent energy statistics. The counterfactual, however, is based on assumptions for the past development without the Energiewende policies. To stay consistent with the literature outlined above, we chose the development projected in Prognos, EWI, GWS (2010) as a proxy for the counterfactual, ex-post as well as ex ante.

4.2 The Energiewende Scenario

The Energiewende scenario, as mentioned above, contains the actual development prior to 2013. This can be seen as the implementation of the energy transition. For the years 2014–2020, the development follows the 2014 Energy Reference Forecast, because it reflects all measures from the Energiewende package. This does not necessarily mean that all Energiewende targets are met in this scenario. It rather describes the development under the Energiewende decisions from 2011, as they are described in Sect. 2.

Assumptions for exogenous variables such as international energy prices, carbon prices in the EU ETS or demographical development are taken from Prognos, EWI, GWS (2014). A brief overview in English can be found in Lutz et al. (2014a, b). For the electricity market, the Energiewende scenario draws fuel and CO_2 prices, the phase-out of nuclear power and the expansion of renewable energy from the 2014 Energy Reference Forecast.

Table 2 shows overall performance with regard to the targets of the energy concept for the year 2011 and 2012, and as expected in the Energiewende scenario (EW).

Table 2 Comparison of selected results of the EW scenario with targets of the German energy concept

	2011 (%)	2012 (%)	2020 (%)
Greenhouse gas emissions			
Greenhouse gas emissions compared to 1990	−25.6	−24.7	**−40**
Result ET-Scenario			−36
Efficiency			
Primary energy consumption compared to 2008	−5.4	−4.3	**−20**
Result ET-Scenario			−18
Energy productivity TFEC	1.7 (2008–2011)	1.1 (2008–2012)	**2.1** (2008–2050)
Result ET-Scenario			1.9 (2008–2020)
Gross electricity consumption compared to 2008	−1.8	−1.9	**−10**
Result ET-Scenario			−7
CHP			
CHP share in electricity generation	17.0	17.3	**25**
Result ET-Scenario			16
Renewable energy			
RE share in gross electricity consumption	20.4	23.6	**At least 35**
Result ET-Scenario			40.4
RE share in gross final energy consumption	11.5	12.4	**18**
Result ET-Scenario			21.8

Targets of the German Government in bold
Source GWS/Prognos/EWI (2014)

The Energiewende scenario fulfills the objectives of the Energy Concept with respect to renewable energy. The share of renewable energy in gross electricity consumption in 2020 will be 40.4 % (targeted value: 35–40 %). Lower coal prices would not change this increase, as a sensitivity analysis shows. The share of renewable energy in gross final energy consumption increased to 12.4 % in 2012. It will reach 21.8 % in 2020, exceeding the target of 18 %. Fossil fuels still provide the basis of energy supply with more than 75 % in 2020.

4.3 The Counterfactual Scenario

What is the counterfactual development to the Energiewende scenario? Although nuclear phase out received a lot of attention, it is *not* the main characteristic of the Energiewende implied changes in the system. On the contrary, as sketched in Sect. 2 nuclear phase out was mainly a reiteration of agreements from 10 years earlier. The core of the Energiewende scenario is in the perspective for a long-term transition of the energy system towards a cleaner and safer provision of energy. The definition of the counterfactual therefore contains the regulation and measures before 2010, without the long-term targets. The counterfactual scenario (CF) is based on a scenario developed before the Energiewende in 2010. It includes the assumptions of the reference scenario given in the “Energy Scenarios 2010” (Prognos, EWI, GWS 2010) and describes the development without the energy transition based on expectations from the beginning of 2010. The scenario assumptions are central to the macroeconomic effects of the thus defined energy transition.

4.4 Scenario Comparison

Differences in the economic results of the two simulation runs are driven by the differences in the two scenarios. Primary energy consumption is reduced in the Energiewende (EW) scenario by 2.5 % points more) than in the counterfactual (CF) scenario by 2020. Furthermore, the share of renewable energy in the EW scenario is higher than in the CF scenario. However, fossil fuels constitute the basis of energy supply (share >75 %).

In the EW scenario, primary energy consumption under increasing GDP shows a 1 % decrease by 2013 and a 13 % decrease by 2020 compared to 2009 values. In the CF scenario, the decrease is about 10 % by 2020. The additional savings of about 2.5 % points in the EW scenario correspond to a reduction of about 344 PJ. Figure 4 shows the relative changes in the energy mix.

Fossil fuels lose market shares but still dominate the energy mix in both scenarios in 2020, with shares of 76 % (EW scenario) and 79 % (CF scenario). Hard coal is used much less in the Energiewende scenario due to merit-order effects, the

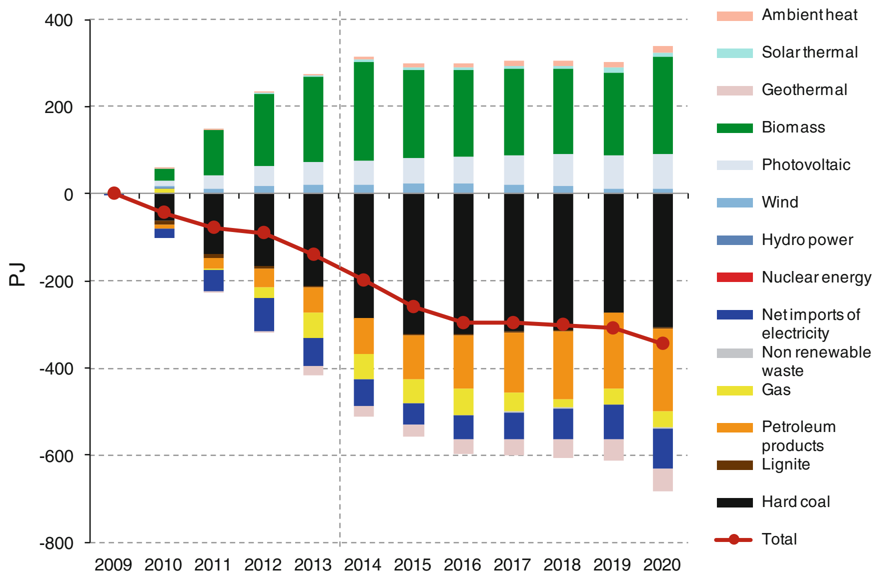

Fig. 4 Difference in primary energy consumption between the scenarios by energy source, 2009–2020, in PJ. *Source* GWS/Prognos/EWI (2014)

use of hard coal carries the largest part of the difference in fossil fuel use. Biomass and PV on the other hand carry the largest part of the additional increase in renewable energy. The increase in the contribution of renewables to primary energy demand in 2020 is 19 % for the EW scenario and 16 % for the CF scenario. Compared to the 9 % in 2011, renewables will be growing strongly. With a falling energy consumption, the need for RE growth is not as large as without it. The installed capacity of offshore wind energy will increase by the largest amount and more than quadruple compared to 2013. Onshore wind energy will mainly face replacement installation; PV will increase by 50 %.

Additional electricity generation from renewable energy in the EW scenario leads to lower electricity generation from hard coal- and gas-fired power stations than in the CF scenario (Fig. 5). Electricity exports in the EW scenario are significantly higher than in the CF scenario.

To balance volatile electricity production from renewables, fossil fuel based capacity is needed as back-up capacity. This leads to larger electricity exports when both capacities –back-up and renewables—feed into the grid. As can already be observed today, excess electricity production is exported to the European markets. However, European generation will also meet the respective targets and forecasts for generation from renewables will improve, so that imports and exports become more and more planned and lead to decreasing costs. Additional grid capacity and storage option improve this outcome. Renewable energy in Germany will contribute

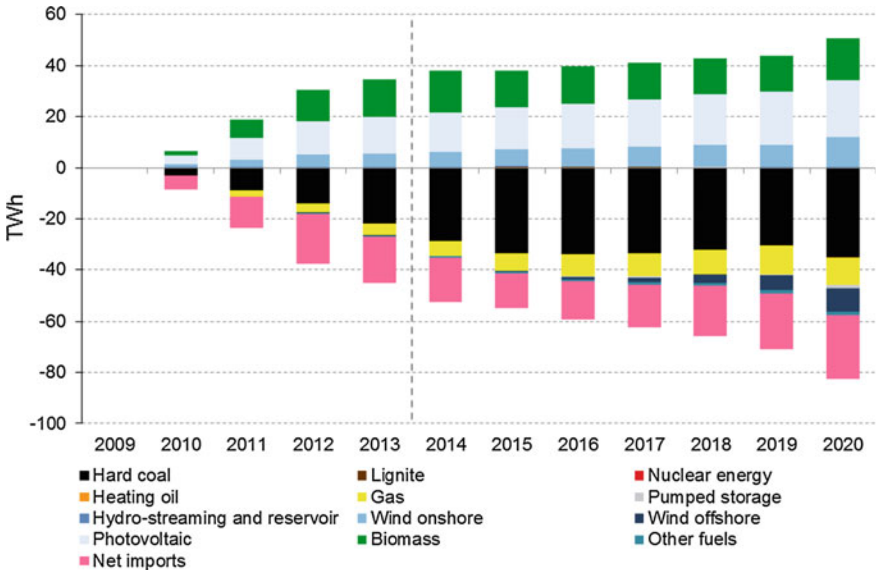

Fig. 5 Difference in gross electricity production between EW scenario and CF scenario by energy source, 2010–2020, in TWh. *Source* GWS/Prognos/EWI (2014)

40 % to electricity production by 2020 and thus meet the Energiewende target of a larger than 35 % share by far. The counterfactual scenario misses the target.

Renewable energy increase comes with large additional investment, which needs to be refinanced. The refinancing mechanism in Germany is based on the Renewable Energy Act as described in Sect. 2. Grid operators buy electricity from renewable generation at fixed tariffs and sell it at the power exchange at market price. If the difference between the turnover at the market and all tariffs paid is negative, this difference is added to the electricity bills of all consumers in a burden sharing process. Some large consumers are exempt. This burden sharing process has two flaws, which have been discussed in the literature and the public at great length in 2013/2014: firstly, the more renewables enter the market at the same time, the more the market prices fall, because renewables produce at zero generation costs. This is good news for all consumers buying their electricity at the market, but given the refinancing mechanism actually drives up additional costs for renewables, because falling market prices increase the gap between a fixed tariff and the market price. Secondly, though the exemption of additional costs for energy intensive industries, which compete on international markets, has just recently passed the European jurisdictions, which are critical towards favorable distortions, it decreases the denominator of the formula which determines the surcharge. This leads to unfavorable price increases for consumers that are not exempt. These price increases will cause negative effects in the economic model and in the economy.

The surcharge jumped with the large PV installations of more than 7 GW in 2010 and 2011 (Fig. 6). The increase in 2012 was at much lower cost, because the

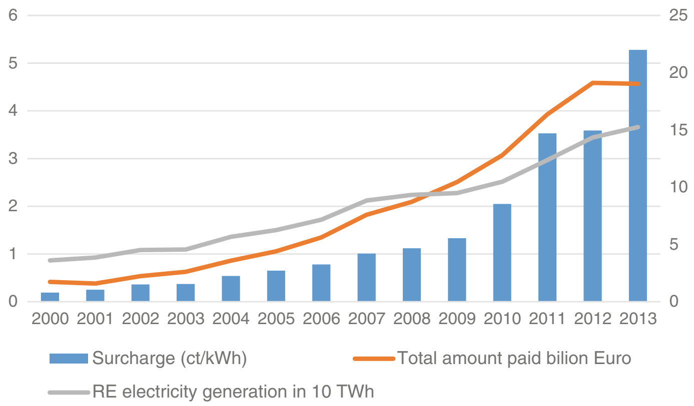

Fig. 6 Development of the surcharge, electricity generation from RE and total amount paid

price of PV modules in 2012 was less than 50 % of what it had been in 2010. The jump of the surcharge from 3.59 ct/kWh (2012) to 5.28 ct/kWh (2013) stems from a miscalculation of the surcharge and a deficit in 2012. In 2014, the surcharge again rose to 6.24 ct/kWh. The year 2015 will be the first year for the surcharge to slightly decrease to 6.17 ct/kWh.

The share of electricity to be exempt from paying the surcharge rose from 18.4 % in 2011 to 22.6 % in 2014 (Mayer and Burger 2014). The increase is due to business cycle activities of the respective industries and changes in the regulation for eligibility for the exemption. Electricity intensive industries have to apply for exemptions on the level of facilities. The design of the exemptions can be roughly compared to the carbon leakage list of the EU ETS, but does not focus on industry classifications, but on single facilities.

The EEG surcharge in the EW scenario has to be higher than in the CF scenario, because of higher shares of renewable energy. Households, trade and commerce as well as industrial customers face higher final consumption prices in the EW scenario. The wholesale price in the Energiewende scenario is slightly lower than in the CF scenario because of the merit-order effect. In brief, the merit-order effect shifts the marginal cost curve to the right, because electricity generation from renewable energy has priority access at zero marginal cost. Fossil fuel based price setting generation starts only to cover demand which has not been covered by renewables. Market prices decrease. Electricity prices for the energy-intensive industries also benefit from this effect, and are lower than those in the CF scenario due to the exemption from EEG surcharge and the lower wholesale price in the EW scenario.

For the other pillar of the Energiewende, i.e. for energy efficiency, the outlook is not quite as promising. Final energy consumption for instance, increased during the ex post period by about 2 % in the EW scenario and 3 % in the CF scenario. This is partly due to economic recovery and sinking energy prices compared to the 2008 price highs. The future development foresees a turnaround of this trend (Fig. 7).

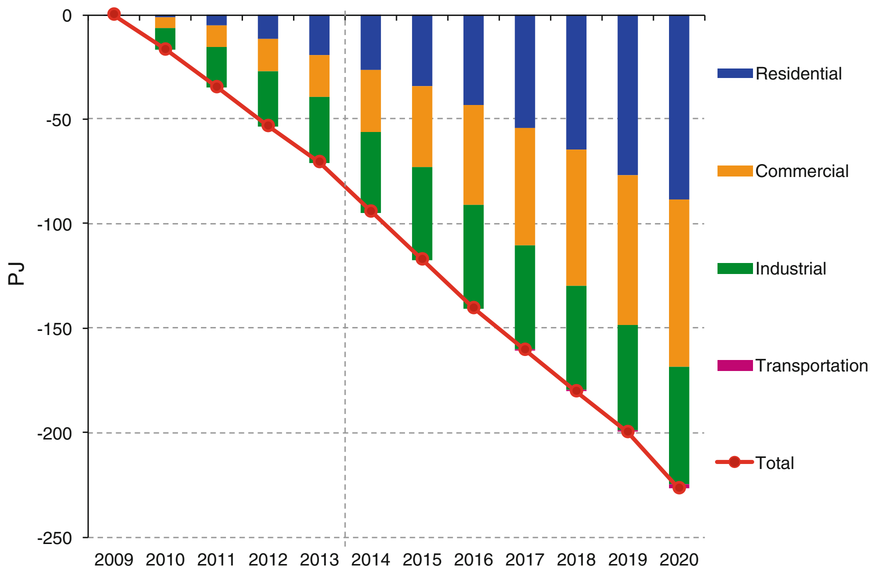

Fig. 7 Additional saved final energy in EW scenario by sector, 2009–2020, in PJ. *Source* GWS/Prognos/EWI (2014)

Already in the counterfactual final energy consumption declines by almost 6 % between 2013 and 2020, the EW scenario with its additional efforts to improve energy efficiency reaches a more than 8 % decline. All sectors contribute to this decline, but the industrial sector starts the increase of efficiency later than for instance the residential sector. However, from 2011 onwards, consumption also begins to decline in the industrial sector.

The additional reduction in the EW scenario seen in 2020 is due to a large extent to the residential (39 %) and commercial (35 %) sectors. The share of the industrial sector in additional savings is 25 %. The additional savings in the transportation sector are low (1 %). Apart from the increasing energy demand for process heat, cooling, ventilation and building automation, less total energy is required for all other purposes in 2020 compared to 2009. In the EW scenario, consumption by space heating and mechanical energy drops more significantly than in the CF scenario. The additional reduction is 82 PJ for space heating and 68 PJ for mechanical energy.

Energy efficiency has mostly positive economic effects, especially if it pays back the necessary investment during its lifetime or even before. The savings free money for other purposes and free the consumer from the dependence on fossil fuel price changes.

The Energiewende catalogue also contains emission targets for 2020 and beyond. Energy-related GHG emissions decrease between 2009 and 2020 by about 15 % in the EW scenario and 9 % in the CF scenario. The additional reduction in the EW scenario of about 45 million t CO_2 equivalents mainly stem from the trends in the energy sector. The transition towards more renewables decreases emissions.

Between 2009 and 2013, the energy-related GHG emissions rise in the EW scenario by about 2 % (CF scenario: +5.5 %). During the ex-ante period, emissions decrease in the EW scenario and in the CF scenario. In the EW scenario, the emissions in 2020 are about 15 % lower than in the base year 2009, the CF shows a reduction of nine percent.

The economic effect of this development hinges on the development of the carbon price mainly through the European emission trading system (ETS). In the ex-post analysis period, the price fell steadily and was between 4 and 7 Euro this year. To calculate avoided environmental damages from the emission reduction, Breitschopf et al. (2014) follow Federal Environmental Agency [Umweltbundesamt] (2012) and assume 80 €/t CO_2 as the price for full internalization of external costs. With this price, the authors calculate avoided damages from CO_2 mitigation. They call this estimate a gross calculation, because it does not include partial internalization from the existing emission trading system and existing emission prices.

Figure 8 depicts the increase in avoided damages from GHG reductions since 2008, following Breitschopf et al. (2014). Actual savings from avoided emissions will also increase with increasing CO_2 prices, because each avoided unit is worth more. The projection assumes CO_2 prices to rise to 10 $Euro_{2011}$ in 2020.

Additional emissions reductions in the EW scenario result from a combination of two factors: the steeper decline in primary energy consumption and the increasing role of low- or non-CO_2 emitting energy sources, especially in electricity generation (Fig. 9). About 60 % of the additional reduction in 2020 result from the energy sector. The transportation sector does not contribute significantly to additional reductions.

The scenario exhibits more reductions in its first phase until 2015/16. Most reduction in the energy sector occur in this phase and the largest reductions occur in

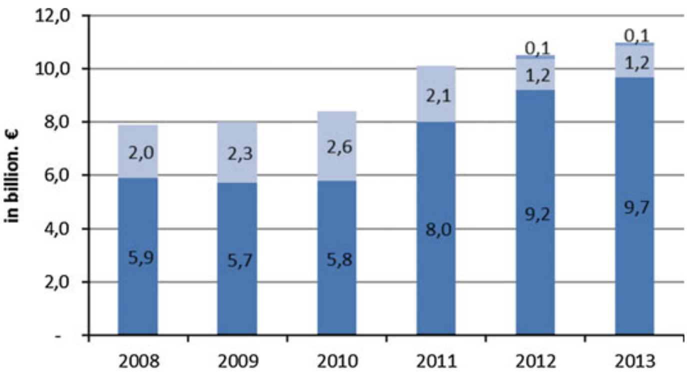

Fig. 8 Avoided damage costs from CO_2 reduction in electricity generation (*dark*), heat generation (*light*) and transport (*medium*), billion Euro. *Source* Breitschopf et al. (2014) and the sources therein

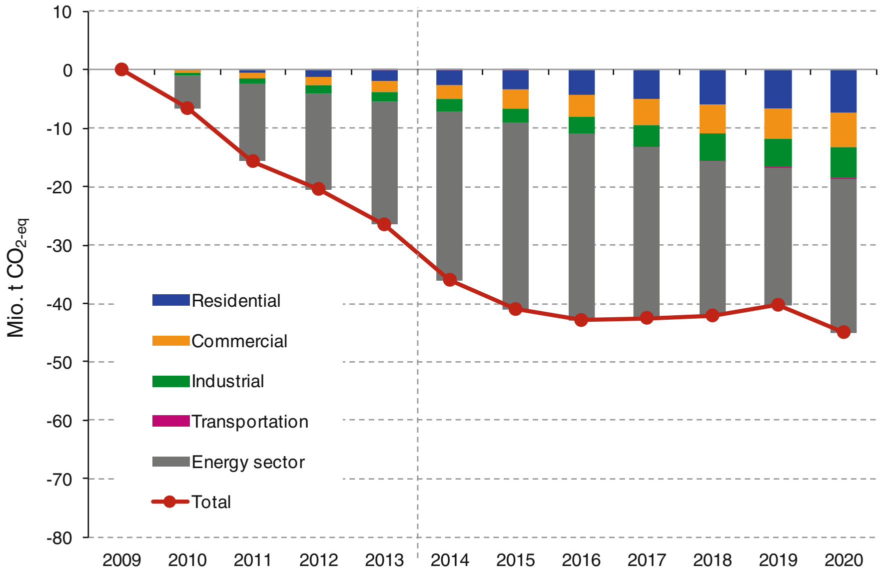

Fig. 9 Additional greenhouse gas emissions avoided in EW scenario by sector, 2009–2020, in million t CO_2 equivalents. *Source* GWS/Prognos/EWI (2014)

the energy sector. Industry and the residential sector pick up energy saving activities in the second phase until 2020. Furthermore, the contributions of the sectors change over time. During the second phase, the contribution of the energy sector slightly drops, whereas the contributions of the industrial, commercial and residential sectors become increasingly significant.

Final energy consumption decreases between 2009 and 2020 by 6 % in the EW scenario and by 3 % in the CF scenario. Fossil fuels decrease and the share of renewable energy increases. Additional savings in the EW scenario in the second half of the observation period mainly falls to the commercial and residential sectors as well as to the use of space heating and mechanical energy.

5 Results—The Economic Effects of the Energiewende in Germany

From the sections above, one can summarize the different impacts on the economic system as price effects, investment effects and long-term cost reductions from energy savings. They differ in their relative quantity over time and yield several economic adjustment processes on the macro level and the sector level. This section will firstly describe the investment effect, because it is the most important direct effect. Additional investment induces additional employment and additional demand for intermediary goods and imports. Secondly, we turn to the overall macro effects and show the changes in GDP. To better understand the different drivers, a sensitivity analysis decomposes the macro effect in the third part of this section.

5.1 Direct Investment Effects

The EW scenario and CF scenario, as has been pointed out above, are based on identical socio-economic assumptions on central quantities, such as international economic development, international energy prices and demography. They differ with respect to electricity generation and the resulting electricity prices as well as the additional investments that are necessary (in the EW scenario) to increase energy efficiency and enhance the expansion of renewable energy.

Especially differences in investment drive economic results. Figure 10 shows the monetary stimulus from energy efficiency investment, concentrating especially on buildings for the residential and the commercial sectors. According to the IEA (2014, p. 47) these investment effects are main drivers for the macroeconomic impacts.

Investment in the energy system mainly differs in the ex-post analysis (Fig. 11). Especially high investment in PV, as mentioned above, drove the additional investment in RE: 15.5 billion Euro in 2010 and 17.5 billion Euro in 2011 reflects

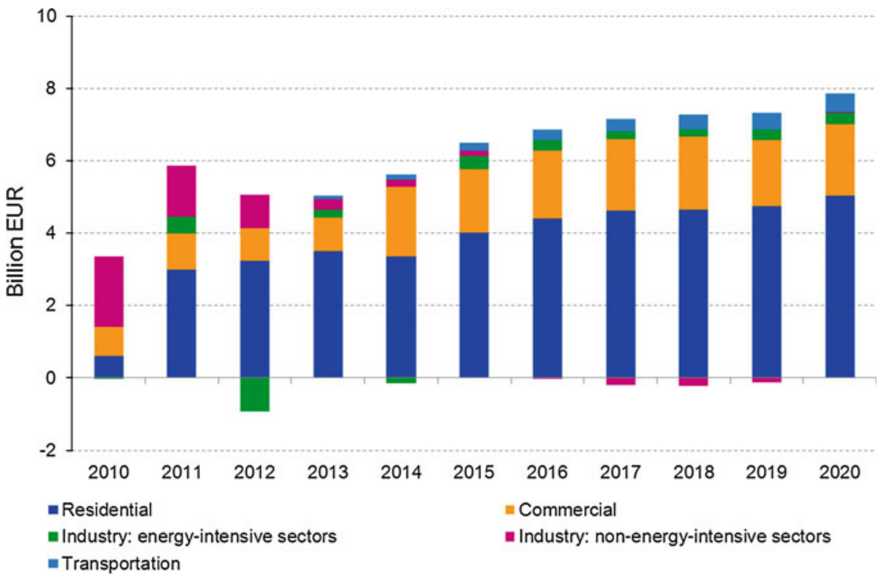

Fig. 10 Differences in investments in the demand sectors of the EW scenario compared to the CF scenario, 2010–2020, in billion EUR. *Source* GWS/Prognos/EWI (2014)

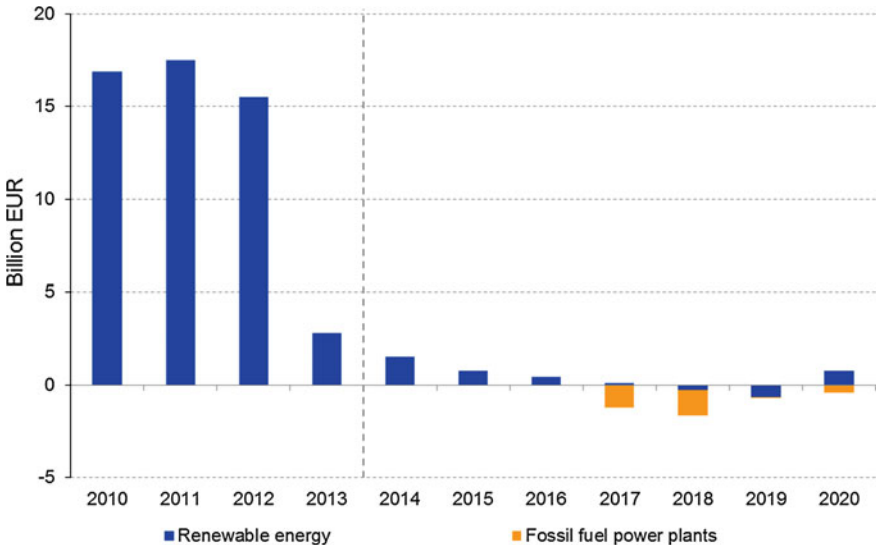

Fig. 11 Differences in investments in the electricity market in the Energiewende scenario compared to the Counter-Factual scenario, 2010–2020, in billion EUR. *Source* GWS/Prognos/EWI (2014)

the average increase of PV capacity by 7 GW in each of these years. In 2012, for instance, PV investment was at 11.2 billion Euro and wind investment reached 3.7 billion Euro (O'Sullivan et al. 2013). In terms of employment, we see a decrease of jobs in photovoltaic module production due to increasing imports from Asia. However, installation is more labor intensive and leads to domestic employment and only the ceiling on installations led to a severe decrease in employment.

The feed-in tariffs are set for 20 years from the start of operation of a renewable energy system. This distributes the refinance of the investment costs of a certain year over the next twenty years, and leads to cumulative effects when several high investment years occur after one another. Therefore, in 2011, electricity prices in the EW scenario are only slightly higher than those in the CF scenario are. The maximum price difference is not achieved until 2019 and is equal to about 2.1 ct/kWh (1.8 ct/kWh without VAT). By 2020, the price difference is still 1.4 ct/kWh for residential customers.

5.2 *Macroeconomic Impacts*

The economy responds to the different stimuli from the two scenarios differently and the economic quantities reflect this. Roughly speaking, we observe two phases. Ex post, until the year 2012, the expansion of renewable energy dominates, driven

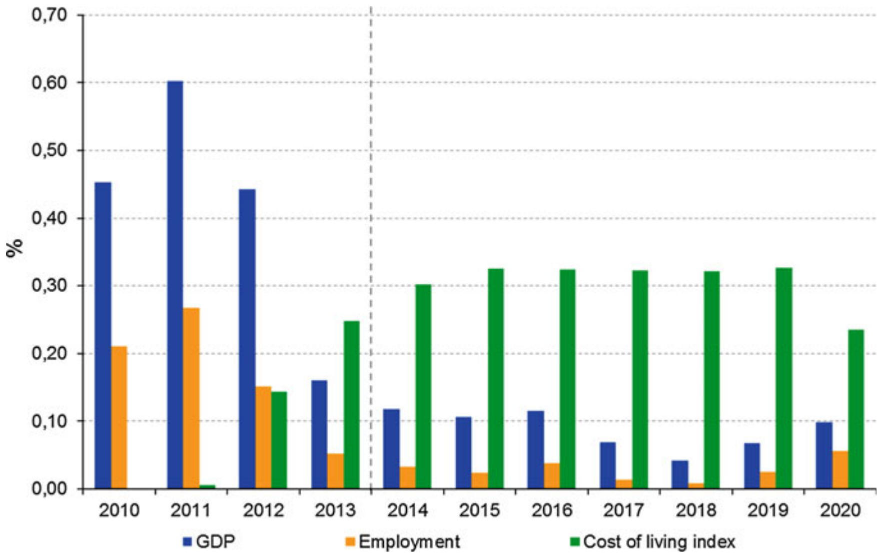

Fig. 12 Deviations of GDP (price-adjusted), employment and the cost of living index in the EW Scenario from those in the CF scenario, 2010–2020, in %. *Source* GWS/Prognos/EWI (2014)

by, in monetary variables, the expansion of photovoltaics. From the ex-ante perspective from about 2015 in the EW scenario, energy efficiency measures as well as increased electricity prices primarily drive the macroeconomic effects.

Especially through the significant investments made in the renewable energy sector from 2010 to 2012, the effects on the GDP are markedly positive (Fig. 12). Nevertheless, long-term financing via the EEG leads to increased electricity prices in subsequent years for all consumer groups, except for the electricity-intensive industries who are able to slightly benefit from the reduction of wholesale prices. The price index of the cost of living rises significantly up to 2014 because of higher electricity prices (Fig. 12; Table 3). Production prices are also higher in the EW scenario than in the CF scenario.

High activities in renewable energy increases leads to additional employment from installation and production of the respective systems. Therefore, employment from 2010 to 2012 is higher than in the counterfactual scenario, the difference between the scenarios shows additional employment of 0.28 %, which translates into more than 100,000 additional jobs.

However, increasing prices, rising wages and decreasing investment dynamics, slow the employment effects over time. Investments in the building sector create additional demand for construction activities and play an important role in the macroeconomic effects. In addition, the commercial sector contributes significantly with additional investments in efficiency measures—especially in the building sector. Again, this supports the construction sector and leads to noticeable (cumulated) effects in subsequent years in the form of lower energy costs.

Table 3 Differences between selected macroeconomic variables in the EW scenario and the CF scenario, 2010–2020, in absolute terms

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	Ex post				Ex ante						
Components of price-adjusted GDP (differences in billion EUR)											
Gross domestic product	10.7	14.7	10.9	4.0	3.0	2.7	3.0	1.8	1.1	1.8	2.7
Private consumption	0.0	2.7	1.9	0.4	−1.2	−2.0	−2.5	−3.4	−4.4	−5.1	−5.3
Government consumption	0.0	−0.3	−0.1	0.0	−0.1	−0.1	−0.1	−0.1	−0.1	0.0	0.0
Machinery and equipment	9.5	10.1	6.8	1.8	0.7	0.6	0.3	−0.8	−1.2	−0.5	0.2
Construction	4.5	6.2	5.6	2.8	3.7	3.9	4.7	4.4	4.4	4.8	5.1
Exports	0.4	0.1	−0.5	−0.9	−1.0	−1.0	−1.0	−0.9	−0.8	−0.6	−0.2
Imports	3.2	3.5	2.3	−0.5	−1.7	−2.1	−2.4	−3.3	−4.0	−4.1	−3.6
Government budget in current prices (differences in billion EUR)											
Net borrowing/net lending	0.7	3.8	0.3	−0.3	0.3	0.7	1.1	0.5	0.5	0.9	1.3
Price indices (differences in percentage points)											
Cost of living	0.00	0.01	0.16	0.29	0.35	0.38	0.38	0.39	0.39	0.40	0.29
Production	0.01	0.05	0.23	0.34	0.39	0.40	0.39	0.38	0.36	0.34	0.23
Imports	−0.03	−0.11	−0.10	−0.06	−0.09	−0.10	−0.12	−0.15	−0.18	−0.21	−0.27
Labor market (differences in 1.000)											
Employment	85.1	108.8	61.9	21.6	13.6	9.5	15.2	5.5	3.5	9.8	22.2
Unemployed persons	−54.4	−65.8	−36.8	−12.0	−7.0	−4.5	−8.0	−2.0	−0.8	−4.7	−12.3

Source: GWS/Prognos/EWI (2014)

In detail, Table 3 provides selected macroeconomic quantities. Private consumption is lower than in the CF scenario, mainly because expenditures for the increase of efficiency in buildings displace private consumption. Investment in construction increases in this scenario and consumption of other goods is cut back. However, we do not assume full crowding out, because energy efficiency investment is supported with the respective governmental programs.

Not only investment in buildings is larger in the EW scenario, also investment in renewable energy is slightly higher. This is counterbalanced by lower investment in conventional energy (see the discussion on investment in Sect. 5.1). This is reflected in the row titled “Machinery and Equipment”. GDP is higher in the EW scenario than in the CF scenario. Even the price level, which reacts delayed due to the design of the EEG surcharge, remains consistently higher in the EW scenario than in the CF scenario because of the higher EEG surcharge.

The effects on the international competitiveness of German companies and on their exports are extremely low because of the vast exemptions for electricity-intensive industries. Higher energy efficiency and ambitious renewable energy expansion lead to a smaller demand for fossil fuel imports. This results in a decline of 534 PJ and corresponds to about 3.2 billion EUR in avoided import costs by 2020.

Employment was particularly higher in the early years of the Energiewende as the ex-post analysis shows. This is mainly due to the increases in renewable energy, notably in PV. PV installations to a large extend are rooftop installed and thus rather labor intensive. Unemployment does not decrease by the same amount as employment increase. This is mainly for statistical reasons: not all additional employment is recruited from unemployed workforce and employment also includes the self-employed, which are not eligible for unemployment benefit and thus not included in the data on unemployment.

5.3 Sensitivity Analyses to Decompose Major Drivers

What are the drivers of these results? Stimuli come from the energy demand side and from the energy supply side. The following sensitivity analysis helps to identify the main triggers.

Important inputs from the bottom-up electricity market model for the macroeconomic analysis include investments (especially in renewable energy), electricity prices per consumer group and net electricity imports. The demand stimuli are broken down into investments in energy efficiency for the residential, commercial, industry and transportation sectors.

Figure 13 shows the time profile of the main impacts. In the ex-post period, almost the whole impact came from the increase in renewable energy, here denoted as electricity sector. However, the main investors were private households and farmers in the case of PV and private investor groups in the case of wind energy, farmers also invested massively in biogas based electricity generation. Commercial

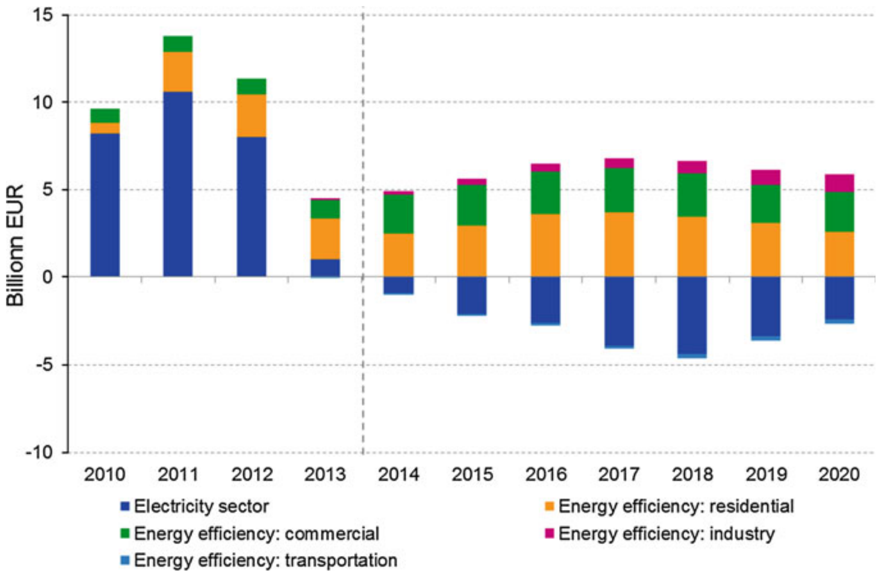

Fig. 13 Breakdown of GDP effects, 2010–2020, in billion EUR. *Source* GWS/Prognos/EWI (2014)

and residential efficiency investment drives additional GDP in the future. The negative impact on GDP in the future period results from increased prices from the refinancing mechanisms of the EEG surcharge for RE. In this context, higher energy efficiency constitutes an efficient means to limit energy costs for households and businesses. Small and medium-sized enterprises represent a large share of the commercial sector. Energy efficiency measures are an important tool for them to bring down their energy bills.

6 Conclusions, Discussion and Outlook

Given the attention and media coverage it received, the results for the economic effects of the Energiewende seem small. Does that mean it is a disappointment? The answer is a twofold no. Firstly, several years ago, economic literature discussed if the distortions from environmental regulation could be small (Jacob et al. 2005) at all. Most authors acted surprised to see that environmental regulation did not cause the end of economic growth. Small but positive effects would have been hailed a couple of years ago. Secondly, the Energiewende is aimed at the change of the energy system. The target of environmental regulation is the environment, although this tends to be forgotten on times of tight budgets, slow growth in parts of Europe and austerity programs as the cure for all.

Is the Energiewende good news for all economic agents? This question goes beyond the macro indicators presented above, which evens economic distribution effects. Price increases for households' electricity consumption, for instance, will have regressive effects. Lower income households are more affected by these price increases and have fewer opportunities for burden decreasing measures such as investing in energy efficient appliances (Lehr and Drosdowski 2014). Households' electricity costs differ annually by more than 500 Euro in 2012. The assumed increases until 2015 according to the latest estimate of electricity prices is 3 % for white collar workers and 3.1 % for blue collar workers, but 3.5 % for pensioners. Supporting redistributive measures range from transfers to lower income groups to cover for the difference in the electricity bill to loans for more efficient appliances.

Some measures, although rewarding from an individual economic point of view face other barriers, which are hard to overcome with economic incentives. A large share of the owners of the building stock is in their retirement age and has very little inclination to take on investments with a 30-year payback period. Soft loans with lower than market rates are not creating strong incentives at the current levels of market rates either. Building ordinances are seen as a large burden with these owners.

Industries differ with respect to their energy needs and their possibilities to buy electricity on the spot market and benefit from lower prices. As long as the exemption from additional charges holds, energy intensive industries rather benefit from decreasing market prices. SMEs, on the other hand, are not exempt as often as other enterprises and in the case of small enterprises often lack time and resources to invest in increasing energy efficiency. The government supports SMEs in particular through tailored information and consulting programs regarding energy efficiency.

Conventional utility companies suffer the largest losses in the short to medium run. Detailed analysis for the largest federal state, North-Rhine Westphalia (Prognos, Energynautics, GWS 2014) estimates job losses in this sectors with up to 5 % until 2030. The current debate on the oldest coal fired power plants adds to the apprehension of this industry.

Several authors have suggested that renewable energy and energy efficiency increases lead to a better position on world markets (for renewable energy e.g. Lehr et al. 2012a, b, c, for energy efficiency see BMU 2012). The logic goes that better domestic environmental regulation results in the establishment of a lead market and more exports. Gehrke et al. (2014) tried to find empirical evidence for this for renewable energy technologies. However, data are only available for wind and PV and both markets changed tremendously in recent years. Trade data do not allow conclusions for other technologies or for production machinery.

To monitor the progress of the Energiewende, data collection therefore remains an important issue. Empirical based models such as the PANTA RHEI model rely on the availability of data. Timely updates and consistency in the data improve the simulations' quality.

How about oil prices? The recent decline of the oil price has led to the question if renewables and efficiency become less attractive in the face of "cheap oil".

However, markets have changed and renewable energy expansion does not react to each decrease of fossil fuel prices as heavily as 20 years ago. Firstly, renewables only compete to oil in very few applications. Today's renewable energy increases mostly focus on electricity generation and apart from small scale diesel generators, oil does not figure largely in this energy sector. Secondly, in electricity generation, renewables are often competitive in generation costs as IRENA (2015) show. And thirdly, low oil prices may free money for other investments—in renewables and energy efficiency among other things.

Facing volatile prices is also an issue of energy security. Thus, renewables with the long-term calculable risk may increase energy security. Moreover, Lehr et al. (2015) have shown that an increase in renewable energy leads to improved energy security, using different versions of diversity indicators. They also include different risk assessment factors for imported fossil fuels and difference costs for renewables. The results are unanimously pointing towards an improvement of energy security from domestic renewables replacing risky imports.

The Energiewende is a long-term transformation of the German energy system. Though the overall economic results are better than expected by many, undoubtedly mistakes have been made, and crucial decisions will have to be taken in the near future. Overshooting PV installations from 2010 to 2012 have increased the EEG surcharge unnecessarily and reduced the space for future balanced development of renewables in the electricity market, while keeping international competitiveness of respective German companies. The EEG amendment (EEG 2.0) from summer 2014 has brought back reliability and reduced future cost increases.

Future design of the German electricity market will have to be decided in the next years, before the remaining nuclear power plants will be shut in the early 2020s. Difficult questions, whether energy-only markets will suffice or capacity markets are needed, have to be answered.

The Energiewende is a process of trial and error. As a frontrunner, Germany moves into unknown land. With the future prospects for more energy efficiency, renewable energy and all associated engineering, technical and legislative solutions being bright, and even brighter with a success of the climate summit in Paris in December 2015, the future benefits seem to outweigh the costs.

References

AGEB (2013) Arbeitsgemeinschaft Energiebilanzen: energy balances for the Federal Republic of Germany, Berlin

Ahlert G, Distelkamp M, Lutz C, Meyer B, Mönnig A, Wolter MI (2009) Das IAB/INFORGE-Modell. In: Schnur P, Zika G (eds) Das IAB/INFORGE-Modell. Ein sektorales makroökonometrisches Projektions- und Simulationsmodell zur Vorausschätzung des längerfristigen Arbeitskräftebedarfs. IAB-Bibliothek 318, Nürnberg, pp. 15–175

Almon C (1991) The INFORUM approach to interindustry modeling. Econ Syst Res 3:1–7

AtG (2011) Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren

Blazejczak J, Edler D, Schill W-P (2014a) Steigerung der Energieeffizienz: ein Muss für die Energiewende, ein Wachstumsimpuls für die Wirtschaft. DIW Wochenbericht Nr. 4.2014, Berlin

Blazejczak J, Edler D, Schill W-P (2014b) Improved energy efficiency: vital for energy transition and stimulus for economic growth. DIW Econ Bull 4:3–15

BMWi, BMUB (2014) Federal ministry of economics and energy (BMWi). Federal ministry for the environment, nature conservation, building and nuclear safety (BMU), Zweiter Monitoring-Bericht „Energie der Zukunft", Berlin

BMWi (2014) Die Energie der Zukunft. Erster Fortschrittsbericht zur Energiewende, Berlin

BMU (2012) Greentech made in Germany 3.0, study commissioned by the German Ministry for the Environment, Nature Conservation and Nuclear Safety

Böhringer C, Keller A, van der Werf E (2012) Are green hopes too rosy? Employment and welfare impacts of renewable energy promotion. Energy Econ. doi:10.1016/j.eneco.2012.08.029

Breitschopf B, Klobassa M, Sievers L, Steinbach J, Sensfuß F, Diekmann J, Lehr U, Horst J (2014) Monitoring der Kosten- und der Nutzenwirkungen des Ausbaus der Erneuerbaren Energien im Jahr 2013. Untersuchung im Rahmen des Projekts „Wirkungen des Ausbaus erneuerbarer Energien (ImpRES)", gefördert vom Bundesministerium für Wirtschaft und Energie. http://www.impres-projekt.de/impres-wAssets/docs/2014_09_10_Monitoringbericht_FINAL_.pdf

Buchanan D (2012) The Energiewende - Germany's gamble. Discussion Paper of the Oxford Institute for Energy Studies

Diefenbach N, Stein B, Loga T, Rodenfels M, Gabriel J, Fette M | IWU,BEI (2012) Monitoring der KfW-Programme „Energieeffizient Sanieren" und „Energieeffizient Bauen" 2011. Auftraggeber: KfW Bankengruppe. Frankfurt

DW (2013) Green revolution or Germany's Nightmare? Conference hosted by Deutsche Welle. http://www.dw.de/green-revolution-or-pure-nightmare-germanys-energiewende/a-16683973

Federal Environmental Agency [Umweltbundesamt] (2012) Ökonomische Bewertung von Umweltschäden. Methodenkonvention 2.0 zur Schätzung von Umweltkosten. Dessau-Roßlau

Federal Environmental Agency [Umweltbundesamt] (2013) National inventory report for the German greenhouse gas inventory 1990–2011, Dessau-Roßlau

Frondel M, Ritter N, Schmidt CM, Vance C (2009) Economic impacts from the promotion of renewable energy technologies—the German experience. Ruhr Economic Paper 156

Gehrke, Schasse & Ostertag (2014) Wirtschaftsfaktor Umweltschutz. Produktion - Außenhandel - Forschung - Patente: Die Leistungen der Umweltschutzwirtschaft in Deutschland. Im Auftrag des Umweltbundesamtes. Umwelt, Innovation, Beschäftigung 01/2014, Dessau-Roßlau

GIZ (2012) German experience on the support mechanism and technical aspects of grid connectivity of solar PV rooftop-systems Delhi, 20 March 2012. Presentation by Matthias Eichelbrönner, Jan-Benjamin Spitzley (MIL), Consultants to GIZ

GWS, EWI & Prognos (2014) Gesamtwirtschaftliche Effekte der Energiewende. Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie, Osnabrück, Köln, Basel

IEA (2013) World energy outlook. International Energy Agency, Paris

IEA (2014), Capturing the Multiple Benefits of Energy Efficiency, Paris

IEKP (2007) Eckpunkte für ein integriertes Energie- und Klimaprogramm

Lehr U, Drosdowski T (2014) Preiseffekte Strom - Merit-Order-Effekt, Bericht zum AP 2.4

Ifeu, Fraunhofer ISI, Prognos, GWS et al (2011) Energieeffizienz: Potenziale, volkswirtschaftliche Effekte und innovative Handlungs- und Förderfelder für die Nationale Klimaschutzinitiative. Endbericht des Projektes "Wissenschaftliche Begleitforschung zu übergreifenden technischen, ökologischen, ökonomischen und strategischen Aspekten des nationalen Teils der Klimaschutzinitiative", Heidelberg, Karlsruhe, Berlin, Osnabrück, Freiburg

IRENA (2015) Renewable power generation costs in 2014. Abu Dhabi, Bonn

Jacob K, Beise M, Blazejczak J, Edler D, Haum R, Jänicke M, Löw T, Petschow U, Rennings K (2005) Lead markets for environmental innovations. ZEW Econ Stud 27

Lehr U, Nitsch J, Kratzat M, Lutz C, Edler D (2008) Renewable energy and employment in Germany. Energy Policy 36:108–117

Lehr U, Lutz C, Edler D (2012a) Green jobs? Economic impacts of renewable energy in Germany. Energy Policy 47:358–364

Lehr U, Lutz C, Pehnt M (2012b) Volkswirtschaftliche Effekte der Energiewende: Erneuerbare Energien und Energieeffizienz (Economic impacts of the energy transition [Energiewende]: renewable energy and energy efficiency). GWS and IFEU, Heidelberg

Lehr U, Lutz C, Ulrich P (2012c) Gesamtwirtschaftliche Effekte energie- und klimapolitischer Maßnahmen der Jahre 1995 bis 2011. Studie im Auftrag des Umweltbundesamtes, Climate Change 15/2012

Lehr U, Lutz C, Ulrich P (2013) Gesamtwirtschaftliche Effekte energie- und klimapolitischer Maßnahmen der Jahre 1995 bis 2012. Studie im Auftrag des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, Osnabrück

Lehr U, Edler D, O'Sullivan M, Peter F, Bickel P, Ulrich P, Lutz C, Thobe I, Simon S, Naegler T, Pfenning U, Sakowski F (2015) Beschäftigung durch erneuerbare Energien in Deutschland: Ausbau und Betrieb heute und morgen. Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie, Osnabrück, Berlin, Stuttgart, März 2015

Lutz C (2011) Energy scenarios for Germany: simulations with the model PANTA RHEI. In: Mullins D, Viljoen J, Leeuwner H (eds) Interindustry based analysis of macroeconomic forecasting. Proceedings from the 19th INFORUM World Conference, Pretoria, pp 203–224

Lutz C, Meyer B, Nathani C, Schleich J (2005) Endogenous technological change and emissions: the case of the German steel industry. Energy Policy 33(9):1143–1154

Lutz C, Lindenberger D, Schlesinger M, Tode C (2014a) Energy reference forecast and energy policy targets for Germany. Die Unternehmung 3:154–163

Lutz C, Lehr U, Ulrich P (2014b) Economic evaluation of climate protection measures in Germany. Int J Energy Econ Policy 4(4):693–705

Lutz C, Meyer B (2008) Beschäftigungseffekte des Klimaschutzes in Deutschland. Untersuchungen zu gesamtwirtschaftlichen Auswirkungen ausgewählter Maßnahmen des Energie- und Klimapakets. Forschungsbericht 205(46):434, Dessau-Roßlau

Maier T, Mönnig A, Zika G (2013) Trade and qualification—linking qualification needs to Germany's export flows. IAB-Discussion Paper 7/2013, Nürnberg

Maier T, Mönnig A, Zika G (2015) Labour demand in Germany by industrial sector, occupational field and qualification until 2025—model calculations using the IAB/INFORGE model. In: Economic Systems Research, vol 27(1), pp 19–42, doi:10.1080/09535314.2014.997678

Mayer JN, Burger B (2014) Kurzstudie zur historischen Entwicklung der EEG-Umlage

Meyer B, Meyer M, Distelkamp M (2012) Modeling green growth and resource efficiency: new results. Min Econ 25:145–154

Meyer B, Lutz C, Schnur P, Zika G (2007) Economic policy simulations with global interdependencies: a sensitivity analysis for germany. Economic Systems Research 19:37–55

Nagl S, Fürsch M, Paulus M, Richter J, Trüby J, Lindenberger D (2011) Energy policy scenarios to reach challenging climate protection targets in the German electricity sector until 2050. Utilities Policy 19:185–192

O'Sullivan M, Edler D, Nieder T, Rüther T, Lehr U, Peter F (2013) Bruttobeschäftigung durch erneuerbare Energien in Deutschland im Jahr 2012 - Eine erste Abschätzung. In: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) (Hrsg.): Beschäftigung durch erneuerbare Energien in Deutschland: Ausbau und Betrieb - heute und morgen, erster Bericht zur Bruttobeschäftigung, Berlin

Prognos, Energynautics, GWS (2014) Entwicklung und Durchführung einer Impactanalyse für den Klimaschutzplan Nordrhein-Westfalen, Study commissioned by the MKULNV of North-Rhine Westphalia, Ministeriums für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz (NRW), Berlin

Prognos, EWI, GWS (2010) Energyzenarien für ein Energiekonzept der Bundesregierung. Study commissioned by the Federal Ministry of Economics and Technology (BMWi), Basel, Köln, Osnabrück

Prognos, EWI & GWS (2014) Entwicklung der Energiemärkte – Energiereferenzprognose. Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie (heute: Bundesministerium für Wirtschaft und Energie), Basel, Köln, Osnabrück

Sachverständigenrat Wirtschaft (2012) Energiepolitik: Erfolgreiche Energiewende nur im europäischen Kontext, Arbeitspapier 03/2012

Stromeinspeisungsgesetz (1990) Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz) Vom 7. Dezember 1990 (BGBl I S. 2633) (BGBl III 754-9)

West GR (1995) Comparison of input–output, input–output+econometric and computable general equilibrium impact models at the regional level. Economic Systems Research 7:209–227

Welfens PJJ, Lutz C (2012) Green ICT dynamics: key issues and findings for Germany. Min Econ 24:155–163

Wiegert R, Hounsell S (2013) The challenge to Germany's global competitiveness in a new energy world. IHS Report Volume 1, Frankfurt am Main