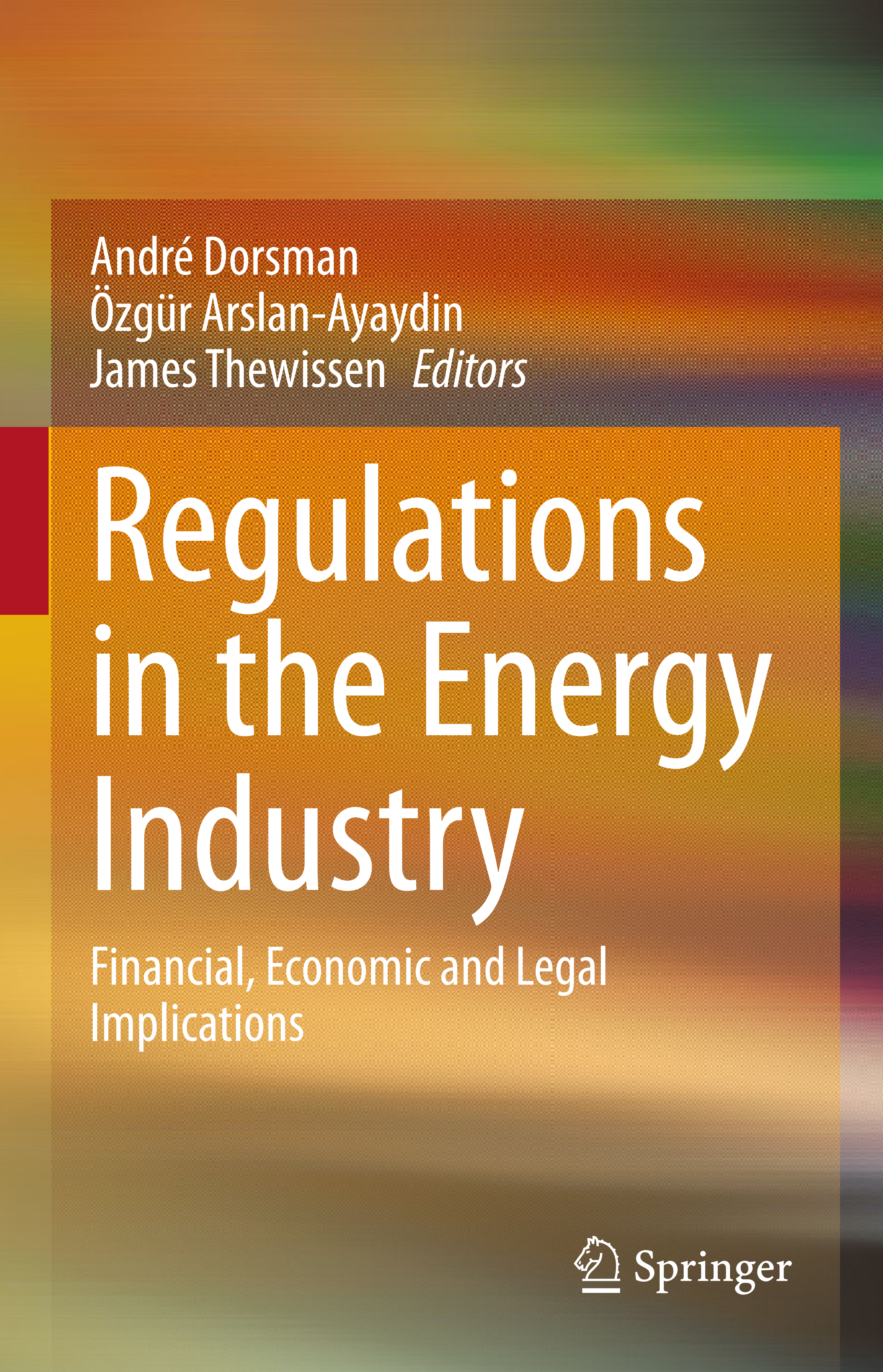

André Dorsman
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Regulations in the Energy Industry

Financial, Economic and Legal Implications

Springer

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Editors

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Foreword

Energy markets are in the middle of the most remarkable transformation in the recent history. We are rapidly moving away from reliance on traditional fossil fuels to renewable energy. Transportation and storage of energy have changed dramatically. New energy providers rise in prominence, while powerhouses of old days decline in significance.

Energy markets are heavily regulated for both economic and political reasons. Economies of scale and high entry costs usually limit competition. The cost of energy is a significant input in virtually all areas of human activity. The ability of households and businesses to rely on uninterrupted access to sources of energy at smooth prices is critical for political and social stability. The cobweb of national and supranational rules, laws, and recommendations further complicates navigation of the regulatory landscape. Understanding institutional environment governing energy markets is therefore crucial for forming informed opinion about them, designing new policies, and making predictions about future directions and trends.

Regulations in the Energy Industry: Financial, Economic and Legal Implications is a collection of essays addressing the aforementioned issues in a timely and rigorous fashion. The first part of the book covers the topics on price and trade controls; the second part elaborates the other regulations on the industry. The last part of this book gathers the chapters that center on the impact of market control on the energy industry. In each chapter, the authors provide both the breadth and depth in the current state of regulation of energy markets across countries. They offer comparative analyses of various regulatory approaches and evaluate the impact of recent regulatory changes. Most importantly, this book offers an integrated approach to energy markets discussing them from economic, legal, and environmental perspectives. It should be a good reading for academics, practitioners, and the general public.

Department of Finance, University of
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Andriy Bodnaruk

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Introduction: Financial Implications of Regulations in the Energy Industry

André B. Dorsman, Özgür Arslan-Ayaydin, and James Thewissen

1 Regulation and the Energy Industry

The primary driver for regulation of infrastructure sectors is generally to ensure proper competition and to prevent the growth of a dominant group or a single utility. Energy utilities are more closely and strictly regulated than many other infrastructure sectors. This is due to the unique characteristics surrounding energy supply and delivery. Unlike many other industries in which there are numerous companies competing to sell the same product or service, electricity, and natural gas distribution and transmission are considered to be "natural monopolies." Specifically, the nature of electricity and natural gas service is actually a natural monopoly because of economies of scale and the significant capital necessary to build power plants, transmission lines, and natural gas pipes and plants. Through the years, laws, regulations, and other requirements have been basically are designed to act as a substitute for the economic forces that would normally be the influence in a competitive market. Another objective of the regulation of energy industry is the need to develop sustainable energy policies and energy efficiency by raising new issues for policymakers, regulators, and activists. Generally, the regulations in the energy sector attempt to integrate possibly conflicting policy goals.

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Industry compliance to regulation is a major business driver to the energy sector. Serious legal and regulatory implications threaten energy organizations that fail to implement the standards to comply with the regulation. Regulations are carried out in a number of different ways and each has strengths and weaknesses. Different types of regulation commonly in use include command and control, self-regulation, incentive-based regulation methods, and market controls.

Regulations are carried out by also different institutions. In other words, there are a number of bodies involved in the regulation of the energy sector. In state-owned systems, the government still plays an important role in deciding which technologies are used to generate power. The most common actors are government departments, specifically the agencies linked to the Ministry of Energy of a country (usually semi-independent) and fully independent regulators. Energy industries are also frequently subject to privatization, particularly when the underlying energy industry in the country transitions from a state-owned system to the liberalized system.

The free market movement of the 1990s started to challenge the concept of treating many fields in the industry as a natural monopoly. Herein, many politicians and academics started to suggest that regulation has outlived its value and markets should be deregulated so that prices can end up being determined through the forces of supply and demand. This deregulation movement has mostly manifested itself in the electricity sector (Steinhurst 2011).

2 Financial Implications of Regulations in the Energy Industry: Issues Covered in This Book

The aim of the book is to provide a broad overview of the financial, economic, and legal implications of regulations in the energy industry across different countries. This is due to the fact that, in the context of significant changes on the international scene, there are different ways to regulate and different institutions can be involved in the regulations. The chapters in this book provide insight on how these regulations on energy sector differ in different countries with different market structures and institutions and also with differing awareness and priorities of policymakers. Major themes covered by this book include laws and regulations geared to market competition and sustainability. In this book, all the chapters have been subject to the blind peer reviews by two referees. The chapters analyze the energy industry from the perspectives of, but not limited to, financial markets, financial risks, asset pricing, capital structure, capital budgeting, corporate (re)structuring, corporate governance, behavioral finance, financial performance, asset pricing, cost control, financial accounting, fiscal and legal issues, institutional, governance and legal aspects.

2.1 Regulations: Price and Trade Controls

The second chapter of this book states that across the European Union members states there is significant cross country variation in the implementation of the European Union's emission trading system (EU-ETS), which is the cornerstone climate policy. Frederiek Schoubben is the author of this chapter and he provides evidence on the existence of regulatory arbitrage as business groups exploit cross country differences in stringency of EU-ETS implementation through national allocation plans. Specifically, the author finds that foreign parent companies generate higher carbon emissions relative to their domestically owned peers. This chapter emphasizes that the opportunities for regulatory arbitrage created by these differences could be an important cause of the systems initial ineffectiveness.

With rising global awareness and binding energy prices, industrial enterprises are under environmental, social, and financial pressure to attain higher levels of efficiency in their usage of energy. Within the scope of energy efficiency, a contemporary approach is the Energy Management System (EnMS) that represents continuous and systematic efforts for improvement in efficient use of energy by the enterprises. The third chapter of this book, written by Kazim Atici, conducts an empirical analysis to measure relative performance of Turkish manufacturing firms that applied EnMS principles and carried out energy efficiency increasing activities between 2015 and 2017. The chapter lists several policy implications for different stakeholders in this matter.

The fourth chapter of this book is titled as "The Convergence of Electricity Prices for European Union Countries" and written by Erdinc Telatar and Nermin Yasar. Their chapter investigates the degree to which the aim of creating a single European market for electricity has been successful in terms of price convergence. Their results lend a considerable support to the nonlinear convergence among the countries.

2.2 Other Regulations

Starting with the fifth chapter, the book has more emphasis on other regulations. The authors of the fifth chapter, Özgür Arslan-Ayaydin, Prabal Shrestra, and James Thewissen, integrate blockchain technology and energy industry. Their chapter provides insights on how this novel technology that offers disintermediation, transparency, and flexibility is providing new ways of interaction to tackle challenges of communication, coordination, and efficiency in the clean energy sector. Along with providing a brief overview of the blockchain technology, the chapter discusses some of the prominent clean energy applications of the technology, such as micro energy exchange grids, cap-and-trade, and electrical vehicle charging networks.

In the sixth chapter, authored by Volkan Ş. Ediger, John V. Bowlus, and Mustafa Aydın, contemporary geopolitics and the security of energy transit by pipeline is examined by focusing on the transit of gas to Europe as a case study. This chapter first provides a framework for understanding energy security and then presents a brief historical and geographic overview of natural gas transit. It moves on to analyze European strategies for gas-supply security in the context of Ukraine and Turkey. The chapter concludes by arguing that securing gas imports by pipeline will require a deeper appreciation of the geopolitics of transit and that consumers should not assess projects solely on market considerations.

The objective of seventh chapter, authored by Wietze Lise and Banu Bayramoglu-Lise, is to assess the contribution and role of National Renewable Energy Action Plan (NREAP) in connection with Turkey's Renewable Energy Source (RES) potential and goals. The authors then present the latest developments regarding RES in Turkey and the relevant literature is discussed and critically assessed. Finally, the chapter summarizes the proposed measures to reach the RES targets and discusses whether additional measures will be needed.

Halit Gonenc, Oleksand Lebediev, and Wim Westerman aim to identify theoretical reasoning in chapter "The Financing Decision of Oil and Gas Companies: The Role of Country Level Shareholder Protection" behind the way the oil and gas companies finance their investments and the determinants of alternative financing choices. Their results cover the period from 2001 to 2015 and provide strong support to the dynamic trade-off theory and partial support to the pecking order and market timing theories. Moreover, they show that companies in countries with a high level of shareholder protection are willing to issue more equity than companies in countries with a low level of shareholder protection.

2.3 Market Control

The remaining five chapters of this book focus on market control in the energy industry. Chapter "Attitudes of SMEs Towards the Elements of Eco-Efficiency: The Turkish Case" is authored by Fatih Cemil Ozbugday, Derya Findik, Sidika Basci, and Kivilcim Metin Ozcan. In this chapter, the authors investigate the attitudes of Turkish SMEs over three items concerning eco-efficiency: (1) increasing resource efficiency investments, (2) producing more environmentally compatible "green" products or services, and (3) the consumption of energy from renewable resources. The authors use Flash Eurobarometer, Small and Medium-Sized Enterprises, Resource Efficiency, and Green Markets (GESIS) 2017 dataset and their sample size is 299 observations. Overall, their chapter concludes that the firms do not prioritize the usage of predominantly renewable energy and production of more green products nor services.

Goknur Buyukkara, Onur Enginar, and Huseyin Temiz are the authors of chapter "Volatility Spillovers Between Oil and Stock Market Returns in G7 Countries: A VAR-DCC-GARCH Model" and they investigate the volatility spillover effects between oil prices and G7 stock market returns, using multivariate VAR-GARCH-DCC analysis. The data set of this chapter is daily oil and stock prices from January 2014 to October 2016. The authors provide strong evidence of time-varying volatility spillovers in the G7 markets. Their results of the portfolio analysis also highlight that investors should consider conditional volatilities and correlations to maximize their returns and risks

Industry-specific regulations and directives related to the energy security and climate change have a considerable impact on the corporate strategies of energy firms. Chapter "Corporate Cash Holdings in the Oil and Gas Industry: The Role of Energy Directives," authored by Yilmaz Yildiz and Mehmet Baha Karan, investigates the impact of the energy directives on the corporate cash holding decisions of the energy firms in Europe. They study 244 firms and 2670 firm-year observations from 24 countries and their results suggest that there are significant differences among countries in terms of the corporate cash holding policies and speed of adjustments toward the target cash position. Their results posit that the role of Energy Directives on corporate cash holding decisions of energy firms significantly differs among countries.

Lars J. Hesselink, Lammertjan Dam, and Wim Westerman are the authors of chapter "The Determinants of Systematic Risk of Renewable Energy Firms." This chapter puts forth a dynamic beta model that estimates the systematic risk for the firms in the Renewable Energy (RE) industry with a combination of global and country-specific macroeconomic factors. The main conclusion of the chapter is that macroeconomic factors do influence systematic risk of the RE sector. Moreover, this chapter finds that the oil-returns is the most dominant factor in explaining the systematic risk of RE firms. Finally, the chapter confirms the effectiveness of environmental stimulating policies as the combination of overall political stability and environmental policy stringency has a diminishing effect on beta.

Our book finalizes with chapter "Optimizing Resource Usage in an Unobtrusive Way Through Smart Aggregation: The Case of Electric Vehicle Charging in Amsterdam," authored by Kees van Montfort, Halldora Thorsdottir, and René Bohnsack. The authors develop an optimization model that applies unobtrusive charging strategies (i.e. postponing, on-off charging, and two charging speed levels) for an electric vehicle (EV) charging aggregator. Its effectiveness is tested on 360,000 charging sessions at public charging points in Amsterdam during the year 2015, providing a realistic assessment of the effects of optimization in terms of reduced costs, change in peak demand, and long occupancy of charging points. Based on the model, an average reduction of electricity costs between 20% and 30% can be achieved, depending on the day of the week. The chapter also shows that changing EV owner's charging preferences such as starting earlier or later can benefit certain groups of EV drivers substantially and reduce electricity charging costs up to 35%.

3 Conclusions

Energy industry is one of the sectors that is subject to highest regulation by various channels. Economic regulation on this industry takes place by the direct intervention by public or governmental agencies into the market when it is deemed to be necessary to achieve public benefits as the market fails to achieve on its own. Energy industry also has a considerable effect on air, water, and land use, and the waste disposal has a significant environmental impact. Therefore, energy firms are also regulated for their environmental impact and usage of land.

Through the years the regulations on this industry change in terms of their intensity, nature, and sources. These regulations also differ across countries. This book presents studies that bring timely and innovative discussions and findings in the energy sector by integrating the areas of economics, finance, law, and legislations of regulations. The chapters of this book provide important results for not only academic research in the area of law, energy markets, financial markets, and energy economics, but also practitioners and policy makers. We hope that the readers both enjoy and benefit from the book.

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Environmental Regulatory Arbitrage by Business Groups in the Context of the European Union's Emission Trading System (EU-ETS)

Frederiek Schoubben

1 Introduction

An important insight from the environmental economics literature is that properly designed environmental regulatory tools influence pollution abatement efforts that ultimately improve environmental performance at the company level (Perino and Requate 2012; Corradini et al. 2014). The reason for this positive relationship is that companies try to offset compliance costs by increasing energy efficiency or reducing pollution. An important drawback of stringent environmental regulation is that it is usually locally binding for companies that are operating in globally competitive product markets (Dechezleprêtre and Sato 2017). This complex relationship with a diversity of local regulations provides multinationals with the opportunity to use internationalization as a strategy to either benefit from or exploit regulatory differences worldwide (e.g., Kolk and Pinkse 2008; Bu and Wagner 2016). Differences in environmental regulatory stringency across countries can, for example, cause a so-called pollution haven effect where especially multinational business groups subject to heterogeneity in environmental regulation, transfer pollution to host countries with weaker regulation (Dam and Scholtens 2008; Ben Kheder and Zugravu 2012). Conversely, multinationals might just as well be motivated to transfer superior eco-efficient technology as it can provide a competitive advantage in host country markets (Bu and Wagner 2016).

As the European Union's emission trading system (henceforth EU-ETS) is a supranational cap-and-trade system for greenhouse gasses, one would not expect pollution havens among countries within the same system. However, although the EU-ETS is implemented in all member states, there is still significant cross-country variation in how the system is implemented. The EU-ETS, launched by the European

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Union in 2005, was the first and is to date the most elaborate international system for trading greenhouse gas emission allowances, covering almost half of EU's greenhouse emissions and operating in 31 countries (European Commission 2013).[1] The idea of the EU-ETS is that carbon-intensive firms have to surrender allowances equivalent to the number of carbon emissions caused by their installations. Data regarding the EU-ETS, both on compliance and trading, are administered and provided to the public by the Community Independent Transaction Log (CITL) on the installation level. Each installation is linked to the owner, which is the firm that manages the allowances.

This chapter contributes to the debate on the effectiveness of the EU-ETS as the cornerstone of Europe's climate policy by looking at the influence of carbon allowances and regulatory differences within Europe on the carbon emissions of European business group affiliates with either foreign or domestic parent companies. Due to the mandatory emission disclosure stipulated by the EU-ETS, we can use a firm's aggregate verified emissions over sales as an objective measure of relative carbon emissions. We analyze these carbon emissions of affiliate firms from 2005 to 2012 (i.e., Phase 1 and Phase 2 of the EU-ETS) to assess whether pollution is influenced by carbon allowances and other firm characteristics both at the affiliate as well as at the parent firm level. Our sample includes European affiliates of business groups with installations covered by the EU-ETS and represents roughly 77% of all carbon emissions within the EU-ETS. The fact that these affiliates have either domestic or international parent companies enables us to not only relate parent firm characteristics but also home versus host country implementation stringency of EU-ETS to carbon emissions at affiliate level.

Our results show that affiliates with foreign parent companies have higher relative carbon emissions, even after controlling for the implementation stringency of EU-ETS in the host country, affiliate's carbon allowances and other firm characteristics. More importantly, host country stringency does not seem to influence carbon emissions of foreign-owned affiliates which provides further evidence that the difference in carbon emissions between domestic and foreign-owned affiliates is related to the potential regulatory arbitrage (RA). However, our results also show that this RA-effect is influenced by the emissions-to-cap ratio of the affiliate. Affiliates with an under-allocation of carbon allowances (i.e., verified emissions > carbon allowances) seem less prone to RA induced emissions. This result stresses the importance of the allocation mechanism for the proper functioning of a cap-and-trade system (e.g., Zetterberg 2014). The results in this chapter support, on the one hand, a pollution haven hypothesis where international business groups indulge in regulatory arbitrage by generating relatively more carbon emissions at over-allocated affiliates in foreign countries. On the other hand, the results provide evidence that not only stakeholder pressure but also the EU-ETS induced incentives still seem able to neutralize the RA-effect as long as affiliates are properly constrained by carbon allowances.

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[1] The EU-ETS operates in the 27 EU countries, the three EEA-EFTA states (Iceland, Liechtenstein, and Norway) and Croatia (joined in 2013).

This study provides a novel insight that business groups operating in different countries potentially engage in regulatory arbitrage by balancing the potential for stakeholder pressure (caused by mandatory carbon emission disclosure) with regulatory pressure (caused by carbon allowance allocation) when optimizing intragroup environmental practices. This contributes to the literature on the environmental impact of multinationals (e.g., Dam and Scholtens 2008), by focusing on companies' behavior with respect to global (environmental) governance and sustainability. Finally, by showing how regulatory stringency at the home and host country level influences affiliates' carbon emissions depending on affiliates carbon allowances, this chapter contributes to our understanding of how corporate behavior relates to the effectiveness of climate policy in general and the EU-ETS in particular (Cole et al. 2008; Vastola et al. 2017).

The remainder of the chapter is organized as follows. Section 2 presents an overview of the related literature on environmental regulation in an international business context and develops the hypotheses. Section 3 describes the data, the variables, and the research methodology. Empirical results are then presented in Sect. 4, followed by the concluding remarks in Sect. 5.

2 Literature Review and Hypothesis Development

2.1 Literature on EU-ETS Effectiveness

As our research question on the role of regulatory arbitrage within the context of EU-ETS is an indirect assessment of the effectiveness of EU-ETS as a policy tool, our study is related to the literature on this topic. EU-ETS related literature has been dominated by studies on government allocation issues (Ellerman and Buchner 2008; Neuhoff et al. 2006; Grubb et al. 2005), studies on the drivers of CO2 prices (Mansanet-Bataller et al. 2007; Alberola et al. 2008; Oberndorfer 2009), and the impact of the EU-ETS on firm performance (Demailly and Quirion 2008; Oberndorfer 2009). While the effectiveness of the ETS has been discussed and criticized in various studies (e.g., Daskalakis 2013; Branger et al. 2015), the main objective of the ETS (i.e., enhance environmental abatement) has only scarcely been studied. Research on this topic typically uses survey data (e.g., Hoffmann 2007) or empirical analyses on a particular country or industry (e.g., Schmidt et al. 2012; Bosco and Altomonte 2013; Segura et al. 2014). A major criticism of the ETS system concerns the fact that too many allowances were created, which reduced the direct incentive to abate emissions (e.g., Ellerman and Buchner 2008). Recent studies (Abrell et al. 2011; De Perthuis and Trotignon 2014; Hu et al. 2015) are trying to draw lessons from the current (in)effectiveness of the EU-ETS in order to propose recommendations for future reforms of the system. The overall critique on EU-ETS is that although there was some emission reduction (Abrell et al. 2011) and some system-induced green innovation (Calel and Dechezleprêtre 2016), it insufficiently triggered incentives for environmental investments and abatement due to insufficient allowance scarcity and corresponding carbon price. The recommendations are, therefore, mostly related to the allowance mechanism (Branger et al. 2015). However, as recent empirical studies show that not only regulation but also stakeholder pressure can provide incentives for warranted corporate behavior (Surroca et al. 2013), similar pressures could apply to the EU-ETS context for several reasons. First, ETS demands that emissions of individual installations are published, which creates transparency. Second, by allocating allowances across installations, ETS has created a benchmark against which good performers (i.e., allowances exceeding emissions) and bad performers (i.e., emissions exceeding allowances) can be distinguished. This benchmark and transparency facilitates the evaluation of firms' environmental performance and may enhance stakeholder pressure, especially for bad performers (Lanoie et al. 1998).

2.2 The Regulatory Stringency Hypothesis

The relationship between environmental regulation and pollution in general is well established in the environmental economics literature. When properly designed, regulation can strongly affect corporate environmental performance by reducing, for example, greenhouse gas emissions (Porter 1991; Perino and Requate 2012; Corradini et al. 2014). This relationship follows from the idea that a stringent regulation is treated as an additional cost that increases total production costs. Empirical evidence shows that stringent regulation has a positive effect on green innovation and energy efficiency as well as pollution abatement (e.g., Dong et al. 2013; Corradini et al. 2014; Barbieri 2015; Calel and Dechezleprêtre 2016). In the context of EU-ETS, it has been shown that although the cap-and-trade system was implemented simultaneously throughout the EU, the actual stringency of the carbon allocation plans varied significantly across countries (e.g., Gilbert et al. 2004; Grubb et al. 2005; Betz and Sato 2006). Based on the arguments and research results above, we expect that countries with stringent allocation plans will have reduced carbon emissions all else equal, which leads to the first hypothesis:

Hypothesis 1 *Stringent implementation of EU-ETS in the affiliate's country reduces relative carbon emissions at the affiliate level.*

2.3 The Regulatory Arbitrage Hypotheses

Affiliates of international business groups are by definition not only subject to their own countries' environmental regulations, but also to those of the parent firm's country. Kolk and Pinkse (2008) state that parent firms take into account the specific advantages of the home and host countries in developing their management policies and practices. International business groups must, for example, decide whether they wish to implement uniform environmental standards or, when operating in countries with lax regulation, simply comply with local standards (Dowell et al. 2000). Parent firms that implement stringent environmental standards are able to transfer advanced environmental management practices to the group affiliates. As a consequence, the group may self-regulate its environmental performance beyond what the law requires (King and Lenox 2001) in a so-called pollution halo effect.

However, in the context of EU-ETS, this halo effect could be costly as it might put affiliates or even the group at a competitive disadvantage. International business groups may be tempted to concentrate some of their carbon-intensive operations at the affiliate level in countries where the regulation was less stringently implemented. This behavior, where poor environmental practices seen as unacceptable in the parent country are applied in host countries, is better known as the pollution haven effect (Wagner and Timmins 2009). The pollution haven hypothesis is not only limited to poor environmental practices but can also be extended to cheap labor and substandard working conditions (Strike et al. 2006). Similar behavior was also found in the context of multinational banks (e.g., Houston et al. 2012; Ongena et al. 2013). International banking groups with stringent home country risk regulation exploit the regulatory difference they face by engaging in so-called regulatory arbitrage when transferring funds to affiliate host countries with lax regulation on risk-taking.

Several papers find evidence for the pollution haven hypothesis and corresponding regulatory arbitrage. Naughton (2014), for example, outlines the effects of host and home country regulation on foreign direct investment (FDI). The author finds that home regulation drives investment from home countries to host countries with weak regulation while an increase in host country regulation results in a negative pollution haven effect. Ben Kheder and Zugravu (2012) explore the FDI activity of French firms and find evidence for the pollution haven hypothesis mainly in the developed, emerging, and most Central and Eastern European (CEE) countries. Dam and Scholtens (2008) establish that it is predominantly firms with poor social responsibility that appear to move their operations to countries with weak regulation. The "good," i.e., most responsible, firms tend to avoid locating their operations in these countries. Finally, Surroca et al. (2013) find evidence for regulatory arbitrage, showing that in some instances multinational enterprises transfer socially irresponsible practices to their foreign affiliates. As within the context of EU-ETS, the difference in implementation across countries creates opportunities for regulatory arbitrage, we formulate the hypothesis that all else equal:

Hypothesis 2 *Foreign ownership of an affiliate increases relative carbon emissions at the affiliate level.*

Whether foreign ownership effectively leads to regulatory arbitrage in all business groups will obviously be influenced by country and group characteristics. For example, stakeholder pressure at the parent level will reduce the opportunities for RA-behavior and incentivize parent firms to adopt high environmental standards throughout the multinational business group (e.g., Choi and Park 2014). Similarly, Choi and Park (2014) suggest that the parent firm, together with the regulator, NGO, and media, are major factors to increase environmental performance of affiliates.

However, stakeholders are less responsive to relative differences between affiliate and parent country regulation than to the regulatory context in the parent country itself (Surroca et al. 2013). Moreover, Witt and Lewin (2007) show that parent firms even try to avoid high stakeholder pressure at home by actively hiding undesirable activities in foreign countries with less institutional constraints. Therefore, we expect that stringent allocation plans in the parent country will increase the potential for regulatory arbitrage, which leads to the following hypothesis:

Hypothesis 3 *Stringent implementation of EU-ETS in the affiliate's parent country increases relative carbon emissions at the affiliate level.*

A final aspect that will influence business group RA-behavior in the context of EU-ETS is the carbon allowance at both the affiliate and parent level. Although a companies' allowance position should not influence abatement incentives according to the Coase theorem (Coase 1960), recent empirical studies show that it influences environmental investment decisions by managers (Venmans 2016). Venmans (2016) shows that the allocated allowances serve as a reference point that influences managerial behavior. He uses survey data to show that managers' perceptions on emission trading affected investment decisions in that a positive emission-to-cap ratio, created more incentives to engage in abatement investments. Similarly, Brouwers et al. (2017) show that a carbon allowance shortage is related to more abatement in later years while a surplus of emissions allowances results in worse subsequent environmental performance. Over-allocated affiliates are expected to be more prone to RA-behavior by their parent firms as the increased carbon emissions will be unnoticeably absorbed by the overall allowance surplus. When the affiliate is already under-allocated, however, increasing emissions would generate necessary carbon trading and induce additional costs (though rather moderate due to the low carbon price environment of the first two phases of EU-ETS) but also exposing the RA-behavior to potential stakeholder pressure. The arguments above lead to the following carbon allowance hypothesis that RA-behavior will be moderated by allowance shortages:

Hypothesis 4 Under-allocation of the affiliate reduces opportunities for regulatory arbitrage.

3 Data, Variables, and Methodology

3.1 Sample Selection

Our study comprises the first and second EU-ETS phase running from 2005 to 2012 and uses a sample of business group members (i.e., affiliates) with installations covered by the EU-ETS. We matched the emissions data from the CITL, provided by

Carbon Market Data[2] to affiliate level accounting data from Amadeus[3] using a two-step matching procedure similar to that of Calel and Dechezleprêtre (2016). First, we record a potential match between an installation and a firm using the names and addresses of the installation or account holder[4] and the firm. Following this approach, we were able to link and aggregate emissions data of 10,762 installations to 5931 firms. As there are 12,998 installations covered by the EU-ETS, our initial dataset represents 82.8% of the total number of installations, covering 88% of total verified emissions in 2012. In a second step, we collect accounting as well as ownership information for these firms that filed unconsolidated complete annual accounts for at least four consecutive fiscal years from 2005 until 2012. The unconsolidated data were obtained from Amadeus and enabled us to employ information at firm level. This reduced the sample to 1997 firms. Using the ownership information, we selected only those companies that are considered to be business group members. More specifically, if the controlling company of the group holds more than 50% of the firm's shares (directly or indirectly), the firm is classified as a business group affiliate. Members of state-controlled business groups were excluded from the sample. In order to control for parent firm characteristics, we augment the affiliate-level data with data from the consolidated financial statements of the affiliate's controlling parent firms. We obtained the group-level consolidated data also from Amadeus. As the Amadeus database is limited to firm-level data for European companies, models using parent firm accounting information are restricted to European business groups only. Following common practice, we omitted firm-years with zero sales and extremely high leverage levels (i.e., above 100% of total assets). This reduced the sample to 1664 affiliates, part of 908 business groups.

Table 1 shows the geographical distribution of affiliates and corresponding business groups in absolute numbers and in percentages of the full sample and compare this with the geographical distribution of all (12998) EU-ETS installations. The countries with the most affiliates in the full sample are the five largest European economies; Germany, France, Italy, Spain, and the UK accounting for 58.30% of affiliates while these countries provide roughly 52% of all EU-ETS installations. The geographical distribution of business groups, however, shows some interesting differences. First, although EU-ETS does not apply to non EU based installations, 198 non EU business groups in our sample own EU based affiliates covered by EU-ETS. This makes them a considerable group that will be controlled for in the initial analysis. Second, a disproportionately large amount of parent companies are located in countries like Luxembourg and The Netherlands, while France is significantly less represented in the business group distribution compared to their affiliate

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[2] Carbon Market Data is a carbon market research company and data vendor. The Carbon Market Data database is based on information published by the CITL and contains all the information on verified and allocated emissions of all installations in the ETS.

[3] Bureau Van Dijck.

[4] The account holder is the entity who manages the installation. The Carbon Market Data database provides information about the installation (name, address, and contact person) and the account holder of the installation.

Table 1 Affiliates and business groups compared to EU-ETS installations

Country	Business groups	%	Affiliates	%	Installations EU-ETS	%
Austria	28	3.08	49	2.94	228	1.75
Belgium	22	2.42	94	5.65	367	2.82
Bulgaria	6	0.66	21	1.26	151	1.16
Cyprus	0	0.00	0	0.00	13	0.10
Czech Republic	12	1.32	49	2.94	427	3.29
Denmark	13	1.43	31	1.86	409	3.15
Estonia	0	0.00	3	0.18	58	0.45
Finland	26	2.86	40	2.40	662	5.09
France	41	4.52	161	9.68	1130	8.69
Germany	149	16.41	299	17.97	2012	15.48
Greece	2	0.22	4	0.24	164	1.26
Hungary	2	0.22	14	0.84	274	2.11
Iceland	0	0.00	3	0.18	4	0.03
Ireland	11	1.21	6	0.36	125	0.96
Italia	82	9.03	174	10.46	1215	9.35
Latvia	2	0.22	2	0.12	111	0.85
Liechtenstein	0	0.00	1	0.06	2	0.02
Lithuania	5	0.55	8	0.48	114	0.88
Luxembourg	27	2.97	6	0.36	15	0.12
Malta	0	0.00	0	0.00	2	0.02
Netherlands	46	5.07	52	3.13	448	3.45
Norway	20	2.20	26	1.56	121	0.93
Poland	17	1.87	99	5.95	943	7.25
Portugal	13	1.43	32	1.92	284	2.18
Romania	13	1.43	38	2.28	280	2.15
Slovakia	9	0.99	28	1.68	203	1.56
Slovenia	6	0.66	12	0.72	100	0.77
Spain	47	5.18	136	8.17	1154	8.88
Sweden	40	4.41	76	4.57	834	6.42
UK	71	7.82	200	12.02	1148	8.83
Non-EU	198	21.81	–	–	–	–
Total	908	100	1664	100	12,998	100

This table reports the distribution of business groups and affiliates with installations covered by the EU-ETS across countries compared to the population of installations based on data provided by Carbon Market Data

representation. Finally, while affiliates from former Central and Eastern European countries represent more than 16% of affiliates in our sample and even more than 20% of installations in the EU-ETS, they only account for less than 8% of the business groups. The most striking example of this is Poland that provides 7.25% of EU-ETS installations, 5.95% of affiliates in our sample but only 1.87% of all business groups in our study. This is a first indication that a lot of mainly Western European business groups own affiliates with EU-ETS covered installations in countries with a relatively lower environmental track record. Similar patterns were already suggested by Ben Kheder and Zugravu (2012) who explore for example the FDI activity of French firms and find evidence for a pollution haven hypothesis in most Central and Eastern European (CEE) countries.

3.2 EU-ETS Related Variables

Our dependent variable is an affiliate's relative carbon emission (*RE*) in a particular year, calculated as an industry and year adjusted ratio of verified emissions over sales.[5] Carbon emissions have become a key component of a company's CSR strategy and are broadly used to represent the environmental performance of a firm (e.g., Aggarwal and Dow 2012; Matsumura et al. 2014). It is important to normalize over sales as well as correct for industries as studies show that although EU-ETS has not lead to a strong reduction in emissions, it was able to make economic growth less carbon intensive due to industry specific abatement initiatives (e.g., Schmidt et al. 2012; Venmans 2016; Brouwers et al. 2018).

As an important control variable for relative carbon emissions, we use the emissions-to-cap ratio (ETC). This variable is calculated as the difference between verified and allocated emissions divided by allocated emissions. Based on the design of a cap-and-trade system, an increasing difference between emissions and allowances should create proper abatement incentives leading to emission reduction in the long run as the resulting surplus in allowance could then be traded in the carbon market. However, as recent studies (e.g., Brouwers et al. 2017) show that incentives might be different depending on whether firms have a surplus ($\text{ETC} < 0$) or a shortage ($\text{ECT} > 0$) of allowances, we also construct a dummy indicating whether an affiliate has an allowance shortage and is therefore under-allocated ($\text{UaA} = 1$) or not. A similar dummy can also be constructed for the parent company (UaP) based on the difference of aggregate emissions and allowances of all EU-ETS covered affiliates related to that business group. In order to control for the fact that firms were able to carry over unused carbon allowances (i.e., banking) during our sample period, we use cumulative emissions-to-cap ratios as an alternative for the ETC variable in some of the models. However, we compute the cumulative ETC (CumETC) within Phase 1 (2005–2007) and Phase 2 (2008–2012) separately as the banking mechanism was not permitted across the two first phases. Using this cumulative measure of under-allocation, we also construct a corresponding dummy CumUaA similar to the UaA dummy.

As regulatory arbitrage can only exist when a business group is confronted with different regulatory contexts, having a foreign parent company is a first condition for the RA-effect. We therefore construct a dummy (ForeignP) indicating whether an

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[5] The emission over sales ratio is adjusted by subtracting the industry-year median of this ratio using the firm's two-digit SIC code industrial affiliation.

Table 2 Implementation stringency across EU-ETS countries and phases

Country	Phase 1	Phase 2	Country	Phase 1	Phase 2
Austria	0	1	Latvia	0	0
Belgium	1	0	Liechtenstein	–	–
Bulgaria	–	–	Lithuania	1	0
Cyprus	–	1	Luxembourg	0	1
Czech Republic	0	0	Malta	–	0
Denmark	0	1	Netherlands	0	1
Estonia	0	1	Norway	–	–
Finland	0	0	Poland	0	1
France	0	1	Portugal	0	0
Germany	1	1	Romania	–	–
Greece	0	1	Slovakia	0	0
Hungary	1	1	Slovenia	0	1
Iceland	–	–	Spain	0	1
Ireland	0	1	Sweden	0	0
Italy	0	1	UK	1	1

This table reports the environmental stringency of countries with installations covered by the EU-ETS. The environmental stringency is based on the National Allocation Plans (NAPs). Stringent Naps for the first phase are plans with fewer allowances allocated than national Kyoto targets (Gilbert et al. 2004; Grubb et al. 2005). Stringent NAPs for the second phase are plans with fewer allowances allocated compared to the 2005 verified emissions (Betz and Sato 2006). “1” stands for stringent, “0” for non-stringent and “-“indicates that the stringency of the NAPs could not be determined (Bulgaria, Romania, Norway, Iceland, Liechtenstein joined the ETS in the second phase)

affiliate has a foreign parent company. Alternatively, we make a distinction between European and non-European foreign parent companies, using a NonEUP dummy in some models.

Next, we assess the stringency of the EU-ETS implementation in either the affiliate’s (StringA) or parent (StringP) country. This measure is based on the national allocation plans (NAPs) issued by every country with installations covered by the EU-ETS.[6] The construction of the NAPs and the stringency of these allocation plans have been thoroughly analyzed in different studies (e.g., Gilbert et al. 2004; Grubb et al. 2005; Betz and Sato 2006). Following these studies, we define stringent NAPs for the first ETS phase as plans that have allocated fewer allowances than national Kyoto targets (Gilbert et al. 2004; Grubb et al. 2005). Second phase NAPs are indicated as more stringent when fewer allowances were allocated compared to the first phase NAP (Betz and Sato 2006). Table 2 reports on the stringency level for the ETS covered countries. Although the European Commission had powers to

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[6] During the first two phases the setting of the cap and distribution of allowances was the responsibility of individual member states in so-called National Allocation Plans (NAPs). In these NAPs EU member states must allocate 95% of emission allowances for free until 2008 and could auction at most 10% of the allowances in the second period 2008–2012 (Article 10, EU 2003).

challenge NAPs under certain circumstances, and has indeed sought to exercise these powers, the principal driver of allocation decisions has unquestionably lain within the domestic politics of member states (Grubb et al. 2005). According to Trotignon and Delbosc (2008) substantial differences between member states in terms of emissions reduction costs, industrial infrastructure, and political views hindered the implementation of the EU-ETS in some countries.

Table 2 shows that while Germany and UK have put strong constraints on emissions from the beginning, other countries including many Eastern European countries, were less stringent in the first phase as they saw carbon constraints as a threat to their potential economic growth. Although most member states reduced allocations for the second phase, the variability in NAPs across countries and phases not only increased complexity and reduced transparency of the EU-ETS (Betz and Sato 2006), but it will certainly also have increased the potential for regulatory arbitrage for international business groups.

3.3 Control Variables and Model Specification

As further explanatory variables for relative carbon emissions, we control for affiliate firm size (SizeA) as well as consolidated parent size (SizeP) measured as the logarithm of the total assets of the respective business group level. Larger firms have more capacity to implement abatement activities due to greater economic power to carry out the necessary investments (Del Río 2009). Next, we also take firm performance into account by using return on assets for the affiliate (RoaA) as well as for the parent company (RoaP). Financial performance is expected to have a negative impact on carbon emissions as it is positively related to environmental performance (Nakao et al. 2007). Finally, we also control for the quality of corporate governance in the parent's (AdiP) and affiliate's (AdiA) country using the anti-self-dealing index from Djankov et al. (2008).[7] Different studies report on a positive association between corporate governance and corporate social responsibility (e.g., Jo and Harjoto 2011).

An overview of all variables used in this chapter can be found in the appendix (Appendix 1). Using EU-ETS related variables and the control variables, the following panel data equation is tested using Ordinary Least Squares (OLS) with period (λ_t) and industry fixed effects (μ_i) in order to explain RE at affiliate level. The standard errors are clustered by firm and year:

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[7] Djankov et al. (2008) construct this new index of shareholder protection against expropriation by corporate insiders. A higher value indicates better protection of investors.

$$\begin{aligned} RE_{i,t} = \alpha &+ \beta_1 ETC_{i,t-1} + \beta_2 StringA_{i,t-1} + \beta_3 ForeignP_{i,t-1} + \beta_4 UaP_{i,\ t-1} \\ &+ \beta_5\ SizeA_{i,t-1} + \beta_6\ RoaA_{i,\ t-1} + \beta_7 AdiA_{i,\ t-1} + \beta_8\ SizeP_{i,t-1} \\ &+ \beta_9\ RoaP_{i,\ t-1} + \beta_{10} AdiP_{i,\ t-1} + \lambda_t + \mu_{i.} \end{aligned}$$

All explanatory variables are lagged 1 year, to avoid reverse causality biases, and variables are winsorized at the first and 99th percentile when relevant to avoid outliers. Not all models contain the same set of variables due to either data availability or the hypotheses that are tested. Several models use interactions between explanatory variables and the UaA (or cumUaA) dummy to assess whether incentives differ between over-and under-allocated affiliates (see further).

4 Results

4.1 Univariate Comparison of Domestically and Foreign Owned Affiliates

Table 3 provides univariate statistics of the variables used in this chapter for the full sample as well as subsamples based on whether an affiliate has a domestic or foreign parent company. These subsamples are quite evenly distributed as roughly half of the observations can be attributed to affiliates with foreign parent firms either from another EU country (32%) or outside the EU (18%). Looking first at the results of the full sample, the environmental variables provide some interesting insights into the environmental performance of the affiliate firms in our sample. The relative emissions have a median value of 0 due to the year/industry correction but is still negative on average. This indicates that some firms in our sample have very low carbon emissions relative to their industry. More interestingly, however, the negative average as well as median values for the ETC and cumETC variables, confirms that most firms where over-allocated during the first two phases of the EU-ETS. A result further confirmed by the UaA dummy showing that only 24.4% of firms were under-allocated during our sample period. When comparing these variables over domestic and foreign parent subsamples, an interesting result emerges. Relative carbon emissions at affiliate level are significantly higher when affiliates have a foreign parent company. This is in line with our second hypothesis and provides some preliminary evidence of potential regulatory arbitrage in international business groups. Moreover, as firms in the foreign parent subsample have on average significantly lower emissions-to-cap ratios and are disproportionately less under-allocated, the higher emission levels strongly suggest that international business groups increase carbon emissions in foreign affiliates willfully.

Other characteristics of affiliates between subsamples are less striking although significant in most cases. Overall, affiliates with foreign parents are not particularly smaller compared to domestically owned affiliates but are somewhat more profitable

Table 3 Univariate statistics and tests

	Full sample		DomesticP		ForeignP		Difference tests	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Environmental variables affiliate								
EP	−0.040	0.000	−0.242	−0.114	0.154	0.104	-10.81^{***}	9.72^{***}
ETC	−0.159	−0.155	−0.144	−0.147	−0.174	−0.161	4.83^{***}	4.54^{***}
cumETC	−0.398	−0.281	−0.358	−0.256	−0.438	−0.303	5.41^{***}	5.46^{***}
UaA	0.244	0.000	0.267	0.000	0.222	0.000	31.09^{***}	
cumUaA	0.214	0.000	0.238	0.000	0.191	0.000	42.26^{***}	
StringA	0.641	1.000	0.634	1.000	0.647	1.000	2.33	
Affiliate controls								
SizeA	19.637	19.528	19.613	19.487	19.660	19.552	−1.64	1.63
RoaA	5.203	4.230	4.983	4.020	5.409	4.440	-2.09^{**}	-2.20^{**}
AdiA	3.482	3.500	3.425	3.500	3.538	3.500	-6.24^{***}	4.52^{***}
Environmental variables parent (EU-ETS)								
UaP	0.213	0.000	0.254	0.000	0.172	0.000	130.86^{***}	
StringP	0.421	0.000	0.503	1.000	0.341	0.000	347.01^{***}	
Parent controls								
SizeP	22.275	22.695	21.664	21.670	22.879	23.208	-22.16^{***}	20.15^{***}
RoaP	4.970	3.930	4.899	3.850	5.039	4.020	−0.81	1.44
AdiP	3.381	3.500	3.439	3.500	3.297	3.500	7.58^{***}	7.71^{***}

This table compares the means and medians of the variables of the domestic parent sample with those of the foreign parent sample. Two tailed T-tests for the mean and Wilcoxon rank sum test statistics for the median are presented. Differences of dummies are tested with the Pearson chi-square test. ***, **,* denote significance at the 1%, 5%, and 10% level

(RoaA). Stringency of affiliate and parent country implementation of EU-ETS is also not that different among subsamples.

4.2 Affiliates' Emissions Depending on Parent Firm Nationality

Table 4 provides the results from the basic regressions explaining relative carbon emissions at affiliate level. First of all, and not entirely unexpected, the coefficient for lagged ETC is positive and significant. This indicates a certain serial correlation

Table 4 Foreign ownership and carbon emissions of business group affiliates

	Full sample		Full sample	Phase 1	Phase 2
	ForeignP	NonEUP			
	(1)	(2)	(3)	(4)	(5)
ETC(−1)	1.130*** (13.30)	1.129*** (13.15)	1.129*** (13.29)	0.944*** (6.58)	1.216*** (11.41)
StringA(−1)	−0.142*** (−3.03)	−0.148*** (−3.12)	−0.139*** (−2.96)	−0.147** (−2.00)	−0.133** (−2.12)
ForeignP	0.412*** (10.22)				
NonEUP		0.175*** (4.06)			
SizeA(−1)	−0.208*** (−12.71)	−0.209*** (−12.79)	−0.208*** (−12.71)	−0.207*** (−8.37)	−0.215*** (−9.77)
RoaA(−1)	−0.006*** (−3.22)	−0.006*** (−3.01)	−0.006*** (−3.19)	−0.004 (−1.24)	−0.009*** (−3.63)
AdiA	−0.060*** (−3.08)	−0.049** (−2.50)	−0.060*** (−3.06)	−0.009 (−0.26)	−0.086*** (−3.54)
EU*ForeignP			0.439*** (9.59)	0.537*** (7.24)	0.374*** (6.43)
NonEU*ForeignP			0.373*** (7.58)	0.263*** (3.31)	0.439*** (7.05)
Constant	4.545*** (15.05)	4.515*** (14.82)	4.541*** (15.01)	4.214*** (9.19)	4.795*** (11.90)
Industry-FE	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes
F	32.62***	28.25***	29.93***	14.77***	21.92***
R^2	0.082	0.072	0.079	0.082	0.081
Obs.	7658	7658	7658	2980	4678
Affiliates	1344	1344	1344	1088	1288

This table reports results for the (fixed industry and year effect) models (White's heteroscedasticity consistent t-statistics in parentheses) with affiliates' relative carbon emission as dependent variable in all models. All other explanatory variables (definitions in appendix) are lagged 1 year to avoid possible endogeneity problems. Level of significance: ***1%; **5%; *10%

in carbon emissions and suggests that an allowance shortage (surplus) in a certain year will not immediately reduce (increase) carbon emissions 1 year later. It is therefore important to control for this initial EU-ETS related environmental performance when explaining differences in relative carbon emissions among affiliates. Although the results for ETC reveal short-term ineffectiveness of the cap-and-trade system, the coefficient for affiliate country stringency (StringA) does provide evidence of some beneficial impact of EU-ETS on firm environmental behavior. In line with our first hypothesis, affiliates generate relatively less carbon emissions in countries with a more stringent implementation of EU-ETS (StringA). Most control variables in the full sample models of Table 4 have the expected sign and are significant. Larger and more profitable affiliates from countries with higher governance quality do indeed generate less carbon emissions all else equal, establishing again the positive link between these control variables and environmental performance.

More interestingly, and in line with our second hypothesis, affiliates with foreign parent firms pollute relatively more than their counterparts with domestic parents. This holds for foreign parents in general (ForeignP) as well as non-EU parents specifically (NonEUP). To further explore differences in affiliate environmental performance depending on parent nationality, we further split up the coefficient for ForeignP depending on EU parent or not in models 3 to 5 of Table 4. Moreover, we also test the model on a subsample of phase 1 (model 4) and phase 2 (model 5) observations separately. Interestingly, although the impact of affiliate country stringency (StringA) does not differ qualitatively between the EU-ETS phases, the impact of parent nationality does. While the impact of non-EU parent on affiliate carbon emissions was significantly lower compared to EU parents in the first phase, this difference disappeared in later years.[8] This result suggests that parents directly influenced by EU-ETS in their home country did exploit regulatory differences more frequently from the start. Non-EU parents on the other hand only caught up with their EU counterparts when the system entered its second and more stringent phase. Although results in Tabel 4 are indicative of the existence of regulatory arbitrage in international business groups, further exploration of affiliates' environmental behavior is needed to increase the validity of our results.

In order to shed more light on the potential RA-related behavior, we split up the coefficient of affiliate country stringency (StringA) based on either affiliate under-allocation (UaA or cumUaA) or parent nationality (ForeignP or NonEUP) in Table 5. Results in models 1 to 4 show that although the impact of country stringency appears similar irrespective of over-or under-allocated affiliates, when cumulative allowances are used to classify under-allocation an interesting result emerges. Affiliates with emissions above allowances (i.e., cumUaA $= 1$) in the previous year do seem to respond significantly more to the stringency of EU-ETS implementation in their country. This provides evidence for the fact that although the allowance position

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[8] A Wald tests for equality of coefficients between EU$*$ForeignP and NonEU$*$ForeignP only reveal a significant difference in model 4.

Table 5 Regulatory stringency EU-ETS and carbon emissions of business group affiliates

	Full sample			Full sample		
	D = UaA	D = UaA	D = cumUaA	D = cumUaA	D = ForeignP	D = NonEUP
	(1)	(2)	(3)	(4)	(5)	(6)
ETC(-1)	1.140*** (12.36)	1.136*** (12.18)			1.126*** (13.27)	1.132*** (13.18)
cumETC(-1)			0.585*** (13.91)	0.582*** (13.70)		
(1-D)*StringA(-1)	−0.148*** (−3.06)	−0.156*** (−3.19)	−0.113** (−2.35)	−0.120** (−2.49)	−0.254*** (−3.72)	−0.192*** (−3.63)
D*StringA(-1)	−0.154** (−1.99)	−0.153** (−1.95)	−0.274*** (−3.48)	−0.272*** (−3.44)	−0.040 (−0.70)	0.059 (0.73)
ForeignP	0.413*** (10.28)		0.415*** (10.29)		0.281*** (4.34)	
NonEUP		0.173*** (3.99)		0.177*** (4.10)		0.006 (0.08)
SizeA(-1)	−0.209*** (−12.76)	−0.210*** (−12.84)	−0.208*** (−12.70)	−0.209*** (−12.78)	−0.207*** (−12.67)	−0.209*** (−12.79)
RoaA(-1)	−0.006*** (−3.36)	−0.006*** (−3.16)	−0.005*** (−2.72)	−0.005*** (−2.52)	−0.006*** (−3.08)	−0.006*** (−3.07)
AdiA	−0.059*** (−3.00)	−0.047** (−2.42)	−0.061*** (−3.10)	−0.050** (−2.52)	−0.060*** (−3.08)	−0.050** (−2.53)
Constant	4.568*** (15.15)	4.538*** (14.92)	4.558*** (15.02)	4.528*** (14.80)	4.635*** (15.17)	4.563*** (14.94)
Industry-FE	Yes	Yes	Yes	Yes	Yes	Yes

Year-FE	Yes	Yes	Yes	Yes	Yes	Yes
F	31.25^{***}	27.03^{***}	31.92^{***}	27.68^{***}	31.46^{***}	27.22^{***}
R^2	0.080	0.069	0.084	0.074	0.083	0.073
Obs.	7634	7634	7654	7654	7658	7658
Affiliates	1343	1343	1343	1343	1344	1344

This table reports results for the (fixed industry and year effect) models (White's heteroscedasticity consistent t – statistics in parentheses) with affiliates' relative carbon emission as dependent variable in all models. All other explanatory variables (definitions in appendix) are lagged 1 year to avoid possible endogeneity problems. Level of significance: ***1%; **5%; *10%

should not influence abatement incentives according to the Coase theorem (Coase 1960), it does seem to provide a difference in incentives. This result is in line with hypothesis 4 and corroborates recent findings from the literature that the over-versus under-allocation distinction influences environmental investments (Venmans 2016).

When splitting up the coefficient of stringency based on parent nationality (models 5 and 6), we find further evidence of regulatory arbitrage. As the coefficient for StringA is only significant when interacted with the domestic parent dummy (i.e., 1-ForeignP), affiliate country stringency only explains carbon emissions when the parent company is domestic. Affiliates with foreign parents therefore not only pollute more relative to peers with domestic parents, but also seem less responsive to regulatory stringency. This result is in line with most pollution haven studies that claim that it is the home and not the host country regulatory stringency that drives the transfer of polluting activities to foreign subsidiaries (Witt and Lewin 2007; Bu and Wagner 2016).

4.3 *Affiliates' Emissions Depending on Parent Country Environmental Stringency*

In order to test hypothesis 3 on the influence of parent country stringency on RA-behavior by international business groups, we have to introduce parent firm as well as parent country characteristics in our estimation models. As stated earlier, this drastically reduces our sample as we can now only include affiliates with foreign parents from EU countries. Table 6 reports the result of this reduced sample of affiliates owned by foreign European parents. This way we can control for the EU-ETS stringency in the parent country (StringP) as well as the affiliate country (StringA). However, the reduction of the sample creates a potential selection bias as the decision to engage in foreign direct investment by adopting (or maintaining) a foreign affiliate is not entirely independent from this affiliate's environmental performance. These selection issues are well known in the financial literature on regulatory arbitrage by multinational banks (e.g., Houston et al. 2012; Ongena et al. 2013) where banks take into account stringency of financial regulation while making foreign investment decisions. To control for this potential selection issue, we include the inverse mills ratio from Heckman (1979) procedures in models 2 and 4 of Table 6. We further elaborate on this procedure and the first stage selection equation in the appendix (Appendix 2). The significance of the inverse mills ratios in both models already shows that there is indeed a selection effect taking place.

Table 6 reports the results on the impact of parent country stringency and affiliate country stringency depending on whether the affiliate is under-allocated or not by interacting the UaA (and 1-UaA) dummy with StringP and StringA, respectively. First, models 1 and 2 of Table 6 show that in line with hypothesis 3 and 4, parent country stringency does indeed increase relative carbon emissions at the affiliate level but only for affiliates with excess allowances (i.e, $\text{UaA} = 0$). The coefficient for

Table 6 Parent country characteristics and carbon emissions of international business group affiliates

	Foreign parent only			Foreign parent only	
	D = UaA	D = UaA		D = UaA	D = UaA
	(1)	(2)		(3)	(4)
ETC(-1)	1.500*** (7.79	1.432*** (6.99)	ETC(-1)	1.646*** (8.64)	1.653*** (8.41)
StringA(-1)	−0.055 (−0.62)	0.135 (1.38)	StringP(-1)	0.125 (1.42)	0.179* (1.93)
(1-D)∗StringP(-1)	0.189** (2.00)	0.241** (2.38)	(1-D)*StringA(-1)	0.056 (0.62)	0.285*** (2.78)
D∗StringP(-1)	−0.112 (−0.78)	−0.073 (−0.47)	D∗StringA(-1)	−0.489*** (−3.39)	−0.418*** (−2.76)
UaP(-1)	−0.377*** (−3.02)	−0.117 (−0.91)	UaP(-1)	−0.297** (−2.33)	−0.013 (−0.10)
SizeA(-1)	−0.254*** (−6.99)	−0.327*** (−7.48)	SizeA(-1)	−0.254*** (−6.96)	−0.327*** (−7.53)
RoaA(-1)	−0.007** (−2.25)	−0.009** (−2.48)	RoaA(-1)	−0.007** (−2.33)	−0.010*** (−2.71)
AdiA(-1)	−0.007 (−0.20)	0.008 (0.20)	AdiA	−0.011 (−0.30)	−0.003 (−0.06)
SizeP(-1)	−0.039* (−1.63)	0.041 (1.25)	SizeA(-1)	−0.038 (−1.61)	0.042 (1.31)
RoaP(-1)	−0.021*** (−3.65)	−0.029*** (−4.46)	RoaA(-1)	−0.021*** (−3.66)	−0.028*** (−4.37)
AdiP(-1)	−0.266*** (−5.82)	−0.213*** (−4.08)	AdiA	−0.265*** (−5.85)	−0.213*** (−4.13)
Mills		−0.041*** (−3.06)	Mills		−0.038*** (−2.91)
Constant	6.571*** (9.66)	5.840*** (7.25)	Constant	6.611*** (9.79)	5.944*** (7.52)
Industry-FE	Yes	Yes	Industry-FE	Yes	Yes
Year-FE	Yes	Yes	Year-FE	Yes	Yes
F	16.64***	14.97***	F	17.25***	15.95***
R^2	0.188	0.211	R^2	0.193	0.221
Obs.	1751	1430	Obs.	1751	1430
Affiliates	338	288	Affiliates	338	288

This table reports results for the (fixed industry and year effect) models (White's heteroscedasticity consistent t-statistics in parentheses) with affiliates' relative carbon emission as dependent variable in all models. All other explanatory variables (definitions in appendix) are lagged 1 year to avoid possible endogeneity problems. Model 2 and 4 show the second stage of a Heckman procedure controlling for the selection of foreign affiliates. Level of significance: ***1%; ∗∗5%; ∗10%

parent country stringency (StringP) is only significant when interacted with the dummy indicating over-allocation (1-UaA). This again indicates that the RA-effect will be reduced by EU-ETS related constraints of affiliates as argued in Hypothesis 4. Conversely, affiliate country stringency (StringA) reduces relative carbon emissions only when affiliates are under-allocated. This effect was already established in Table 5 but holds on the reduced sample of affiliates with foreign European parents only and after controlling for parent country stringency as well as potential selection bias. Concerning the parent control variables, Table 6 shows that mainly the business group's profitability (RoaP) and governance quality in the parent country (AdiP) significantly drive affiliates' carbon emissions. Another interesting result is the coefficient for the under-allocation at parent level (UaP).[9] In line with the effectiveness of the EU-ETS, under-allocated groups are less likely to engage in regulatory arbitrage as their affiliates generate lower carbon emissions. Although this effect loses significance in the models controlling for the selection bias, it sheds a more nuanced image on the RA-effect as only the over-allocated groups significantly increase the relative carbon emissions of affiliates. Business groups do not seem to flee under-allocation at parent level but simply exploit aggregate over-allocation within the group, preferably there where it is least exposed to stakeholder pressure. Similar firm behavior has already been documented by Milani (2017) who shows that increased regulatory stringency will trigger either innovation or relocation depending on industry characteristics.

5 Conclusions

This chapter provides evidence on the importance of carbon allowances in explaining regulatory arbitrage by international business groups in the context of the EU-ETS. Using carbon emission data at affiliate firm level from 2005 to 2012, we find that firms with foreign parent companies generate higher carbon emissions relative to their domestically owned peers. This finding corroborates the existence of regulatory arbitrage as business groups exploit cross country differences in stringency of EU-ETS implementation through national allocation plans. These differences in NAPs adopted by member states during the initial phases of EU-ETS have been recognized before. We are the first, however, to show that the opportunities for regulatory arbitrage created by these differences could be an important cause of the systems' initial ineffectiveness.

Fortunately, not all international business groups engage equally in exploiting the system as the parent companies' influence over affiliates' carbon emissions seems reduced by carbon allowances both at parent and affiliate level. When interacting a measure of under-allocation of carbon allowances at affiliate level with measures of foreign ownership and stringency, an interesting result emerges. Under-allocated affiliates seem less prone to RA-behavior induced by their group. The overall RA-effect can therefore be attributed to the average over-allocation that plagued the first two phases of the EU-ETS (Ellerman and Buchner 2008), which adds to the

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[9] Measured by comparing aggregate verified emissions and carbon allowance of all affiliates linked to a parent.

criticism on the effectiveness of Europe's most important environmental regulatory tool (Branger et al. 2015). Our evidence on the role of carbon allowances in explaining firm-level emissions is in line with recent EU-ETS-related empirical work (e.g., Venmans 2016) but strongly contradicts the Coase theorem in the context of the EU-ETS. Although the Coase theorem predicts that the allocation of carbon allowances should not influence a firm's abatement incentives, we find that the environmental policy within business groups is partly related to the under- or over-allocation of the affiliates under their control and the aggregate emissions-to-cap for the group as a whole.

If parent companies are able to exploit stringency differences within the EU-ETS by obtaining or maintaining polluting operations in other member states, the EU climate goals are in peril. This not only advocates more harmonization of environmental regulation on the European level, but also stresses the need for a global approach to pollution abatement. Policymakers should, therefore, be aware of the potential for regulatory arbitrage especially among large multinational business groups. For researchers on the other hand, considering these intragroup pollution transfers when assessing the impact of benchmarks and other incentive-based environmental regulatory tools (e.g., Zetterberg 2014; Zhu and Ruth 2015) could reconcile conflicting results on the effect of environmental regulatory stringency on particular industries.

Finally, since the regulatory arbitrage behavior of international business groups illustrated in this chapter seems influenced by over-allocation of carbon allowances and stakeholder pressure, it could be considered a symptom of a policy mechanism that was still struggling with design flaws in the first two phases of its existence. But as assessment of future phases (e.g., Hu et al. 2015) cast doubt on whether the main problem of allowance scarcity and harmonization across EU member states could be resolved in the short run, regulatory arbitrage by international business groups will remain a threat for the effectiveness of the system.

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Appendix 1 Variable Definitions

Variable	Description
Dependent variable	
RE	Relative carbon emissions (RE) is calculated as the ratio of verified emissions over sales at the affiliate's level, minus the yearly industry median of this ratio using two-digit SIC codes.

(continued)

Variable	Description
Independent variables	
EU-ETS variables	
ETC	Emissions-to-cap ratio (ETC) is measured as the difference between verified and allocated emissions in a certain year divided by allocated emissions
cumETC	Cumulative emissions-to-cap ratio (cumETC)
UaA	Under-allocated affiliate (UaA) is a dummy that equals 1 if ETC $>$ 0
cumUaA	Under-allocated affiliate (cumUaA) is a dummy that equals 1 if cumETC $>$0
StringA StringP	The environmental stringency of affiliate (A) or parent (P) country is based on the National Allocation Plans (NAPs). Stringent Naps for the first phase are plans with fewer allowances allocated than national Kyoto targets (Gilbert et al. 2004; Grubb et al. 2005). Stringent NAPs for the second phase are plans with fewer allowances allocated compared to the 2005 verified emissions (Betz and Sato 2006). "1" stands for stringent, "0" for non-stringent.
UaP	Under-allocated parent (UaP) is a dummy that equals 1 if aggregate emissions at parent level are larger than aggregate allowances
ForeignP	Foreign parent (ForeignP) is a dummy that equals 1 if the parent company's country is different from the affiliate's country
NonEUP	Non-EU parent (NonEUP) is a dummy that equals 1 if the parent company's country is not an EU member
Parent firm controls	
SizeP	The logarithm of the parent firm's total assets.
RoaP	Net income + interest expenses/total assets.
AdiP	The home country's revised anti-director index (Djankov et al. 2008)
Affiliate firm controls	
SizeA	The logarithm of the affiliate's total assets
RoaA	Net income + interest expenses/total assets.
AdiA	The host country's revised anti-director index (Djankov et al. 2008)

Appendix 2 Heckman Procedure for Selection Bias

The Heckman (1979) model is based on the simultaneous estimation of a selection equation and an outcome equation. To ensure noncollinearity between the selection equation and the outcome equation, the selection equation must include at least one observed variable, the exclusion restriction, which affects the selection but does not influence the outcome variable (Sartori 2003). In the context of this study, the exclusion restriction should impact either the choice to invest in a foreign affiliate or an affiliate from a country with lax environmental stringency and should not affect the dependent variable, relative carbon emissions of the affiliate.

Following Mudambi and Mudambi (2002) among others, we select Size and the Intangibility ratio at both affiliate- and parent firm-level for the first stage selection equation of foreign affiliation as these variables are the prime determinants of foreign direct investment. In addition to these firm characteristics, we add three host country characteristics considered to have an impact on foreign direct investments; Total tax rate (Tax), Number of days to start a business (Days) and Rules governing FDI (Rules) measuring to what extent rules governing FDI encourage or discourage it (1 = strongly discourage FDI, 7 = strongly encourage FDI) (e.g., Mathur and Singh 2013). All these host country variables are obtained from the annual World Economic Forum (WEF) Global Competitiveness Report. Additionally, following Houston et al. (2012), we add the regional mean of the host countries governance quality (AdiA). The regional standards in corporate governance will surely influence the decision to adopt or maintain an affiliate in a host country with lax regulations. Regions are defined using the United Nations' geographic region divisions and separate the EU countries in our sample in four regional groups: Eastern Europe, Northern Europe, Southern Europe, and Western Europe. All the selection determinants, except parent firm Size, are used as instruments as they do not appear in the second-stage regressions reported on in Table 6. We also control for industry and year fixed effects. First step results are not reported for parsimonious reasons, while the inverse mills ratio from this Heckman procedure is then incorporated in the second step models reported as models 2 and 4 of Table 6.

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Measuring the Effects of Energy Efficiency Policies: Evidence from Turkish Manufacturing Industry

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1 Introduction

From the mid-1700s, with the wider use of steam and onset of industrial revolution, coal became a commercial commodity; from the mid-1800s, petroleum rose to prominence; and from the early 1900s, electricity emerged as a modern secondary energy source. In the last quarter of the twentieth century, natural gas became a globally traded energy raw material. Recently, in addition to hydrocarbon resources with historic-high production capacities, renewable resources such as biomass, wind, and solar pushed the energy supply to very high levels. Nevertheless, the fundamental social and technological changes experienced by humanity in the last two centuries caused an increase in the amount of energy demand and prioritized the access to energy resources together with the transportation of energy to the markets with affordable costs and safe routes. Therefore, energy is one of the most important topics on the world's political agenda due to the several factors such as uncertainties caused by the fluctuations in oil and natural gas prices, the interruption of safe energy supply due to regional conflicts, the fact that more people need access to modern energy, and the enormous quantity of funding required. One other reason why energy plays such a big role in the world political agenda is that, no matter which source is used, every unit produced has an environmental impact. Greenhouse gas emissions, as the most important of such impact, increased at unusually high rates, and the global warming resulting from greenhouse effect created the climate change problem.

Today, global warming and climate change that have emerged mostly as a result of intensive fossil fuel use and rapid urbanization following the industrial revolution

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are perceived as common problems for all humanity. The rules and regulations introduced recently have intensified the global efforts, and the governments have been encouraged to take common steps to keep the average increase in global temperature at a safe level. These steps include changing energy policies and improving energy strategies. As a result of the rising global awareness and binding measures, industrial enterprises are under environmental, social, and financial pressure to keep their production processes based on fossil fuels (primarily coal) under control and to use energy in an efficient way. Another driving force for industrial enterprises to use energy efficiently is the increasing energy costs. Industrial enterprises are increasingly looking for ways to reduce energy costs to increase their competitiveness and to produce the same amount of product with less energy. Putting both environmental and financial concerns together, energy efficiency has become one of the key issues of energy-related politics, strategies, and research.

The energy management system (EnMS) is a contemporary approach associated with increasing the efficiency in energy use. It represents continuous and systematic efforts for energy improvements. Within the scope of EnMS, the implementing firms engage consistent audits, ask for consultancy, and carry out several improvements in their processes in order to develop sustainable strategies for efficient use of energy in their operations. ISO 50001 quality system, which standardizes and certifies, has been introduced to reward these efforts.

In this chapter, we aim to provide insight on energy efficiency and its policy applications shaped around the energy management system. First, we present the key concepts of energy efficiency and EnMS. Measuring the effects of EnMS policies, the energy efficiency projects within the scope of EnMS, the non-energy benefits of the application of such management system, and the standardization of efforts under ISO 50001 are the topics discussed throughout the chapter. Following the conceptualization, we conduct an empirical analysis in Turkish manufacturing industry firms that carried out energy efficiency increasing activities between 2015 and 2017. The analysis aims at observing the relative efficiency of the activities in terms of sectors and projects. The data used are collected within the scope of "Improving Energy Efficiency in Industry in Turkey Project" implemented by the Ministry of Energy and Natural Resources in cooperation with the United Nations Development Programme (UNDP) and United Nations Industrial Development Organization (UNIDO), with funding from the Global Environment Facility (GEF). The firms are from different sub-sectors of Turkish manufacturing industry (58 firms), and they carried out a wide range of activities from minor changes such as changing bulbs to more capital-intensive investments such as large-scale isolations in the given years. The analysis provides results from two orientations as firm-based and activity-based. In order to ensure homogeneity at activity-based evaluations, the activities are grouped into 16 different projects. We evaluate the performance of firms and activities with data envelopment analysis (DEA) in creating energy saving using energy, financial, and environmental factors. We interpret the results at sub-sectoral level and identify the efficient sectors. Moreover, the efficient projects are identified and discussed relying on their size. A simulation model is designed to test the robustness of the activity-based evaluations. All evaluations also consider two different subsets of the firms as ISO certification holders and small- and medium-sized enterprises (SMEs).

The chapter is organized as follows: In Sect. 2, we provide basic discussion of energy efficiency concept and the energy management system. Section 3 presents a brief information about the energy in Turkey together with some facts about the energy consumption in Turkish manufacturing industry. Section 4 presents the empirical analysis and its results. Section 5 concludes.

2 Energy Efficiency

In this section, we aim to provide a conceptual framework on energy efficiency shaped around a contemporary concept, energy management system (EnMS), which is born out of systematic and continuous search for the efficient use of energy.

2.1 Definitions

Energy intensity is generally defined as a measure of the amount of energy used to produce a unit of output. At the macro level, the energy intensity of a country is the amount of primary energy consumed per gross domestic product (GDP). A decrease in energy intensity can indicate that the energy is used more efficiently in a given country. According to the Energy Efficiency Report published by the International Energy Agency in 2018, the improvement (reduction) in global energy intensity was found more than 1.5% for 2017 globally. However, the global improvement goal in energy intensity to combat climate change is expected to be 2.4% annually between the years 2015 and 2030. These data indicate that humanity is still far away from targets to combat climate change (International Energy Agency 2018).

Energy efficiency and energy saving are two terms that are often confused and used interchangeably. Although they are in close relation, there exists a difference. Energy efficiency means reducing the energy intensity in each product, process, or production area without affecting the output or comfort level (Hepbaşlı 2010). In other words, energy efficiency is the ability to achieve the same benefit by using less energy. The energy saving, on the other hand, describes the reduction achieved in the amount of energy consumed at each stage of production and service providing as a result of the measures taken to utilize the energy and energy resources more efficiently (Kavak 2005). In other words, energy saving refers to the reduction in energy consumption measured and recorded in physical terms as a result of actions to improve energy efficiency.

Table 1 Expected saving rates through energy management

Investment cost	Payback period	Savings rate (%) to be achieved
Low cost	1 to 2 years	5 to 15
Average cost	3 to 5 years	15 to 30
High cost	Long-term potential	30 to 50

2.2 Energy Management System

Due to increased environmental awareness and increasing energy costs, research on how to use energy more efficiently has increased. The primary concept coming out of the efforts is energy management. It is related with the optimization of energy use and basically defined as to use energy rationally and effectively to maximize profits and increase competitiveness (Hepbaşlı 2010, p. 8). Energy management is inseparable from efforts for energy efficiency. It is related with continuous improvement of the energy performance of the industrial enterprise and paying systematic attention to energy in order to maintain improvements (Practical Guide for Implementing an Energy Management System 2014). Energy management helps firms to improve their productivity and product quality (Doty and Turner 2013).

Energy management is a critical factor for the survival of enterprises in the short term and for their success in the long term. As stated by Doty and Turner (2013), "implementing new energy efficiency technologies, new materials and new manufacturing processes and the use of new technologies in equipment and materials for business and industry is also helping companies improve their productivity and increase their product or service quality." Therefore, energy savings gained by means of energy management provide firms an advantage in terms of energy cost and competitiveness. Table 1 presents the average savings that organizations can expect depending on their investment costs on energy efficiency. Larger savings are expected to be accomplished with higher investments and provide longer-term improvement potentials (Doty and Turner 2013).

Energy management system (EnMS) is the conceptualized term for energy management and stands for a systematic and continuous approach to sustainable energy improvements (Javied et al. 2015). A short definition of EnMS is to make energy efficiency continuous. This can be achieved by adopting a systematic approach to energy management that is based on the Deming cycle in the form of plan-do-check-act (PDCA) for continuous improvement (United Nations Industrial Development Organization-UNIDO 2015). The Deming cycle developed around the 1950s is based on the idea that the *business processes be placed in a continuous feedback loop (Plan-Do-Check-Act) so that managers can identify and change the parts of the process that need improvements* (Deming 1993). The Deming cycle under the EnMS is a process approach that ensures continuous improvement. With EnMS, significant energy and cost advantages can be achieved in both industrial enterprises and houses in proportion to the investment cost.

2.2.1 Measuring the Effects

Energy management system (EnMS) is not a concept that can be instantly applied in an industrial enterprise. In order to make energy efficiency sustainable and spread it to the business as a culture, a system should be formed, and this system should be internalized by all employees. The establishment period of EnMS in an industrial enterprise covers roughly 6–9 months depending on enterprise size, senior management commitment, and resistance to change. In the process of establishing the system, people in the whole enterprise have certain tasks. However, the most important responsibility in implementation is on the energy manager and the energy management unit. Energy manager acts as a bridge between senior management and other units. The important success criterion is senior management commitment to energy management and the space it provides to the energy manager. Senior management's support for the energy manager with all resources, including employees, is one of the important criteria that can increase the quality of the system and speed of implementation (Hepbaşlı 2010).

Several studies have been conducted on the benefits of EnMS for organizations. Caffal (1995) states that 40% savings can be achieved in the total energy consumption of industrial enterprises implementing energy management systems. According to Thollander et al. (2007), with the implementation of energy efficiency programs, it is possible to achieve improvements by 16–40% in energy performance. However, it is not fair to expect such high levels of improvement in all EnMS-implementing industrial organizations. For instance, a survey conducted by Bonacina et al. (2015) reveals that out of 65 participating firms, the firms that implemented EnMS in the short term achieved around 5% savings. The energy saving rate achieved can vary depending on the extent to which the system is implemented. Ates and Durakbaşa (2012) observed in case studies they conducted in iron-steel, paper, ceramics, and textile sectors that only 22% of industrial enterprises implemented the energy management principles properly. Another similar study on this topic is the study of Thollander and Ottosson (2010) with foundries and paper producers in Sweden. The rate of implementing energy management principles in these sectors is 25% and 40%, respectively. In a similar study by Jovanović et al. (2017) for Serbia, this rate was 59%.

There exist several parameters that determine the savings from EnMS. Examples of such parameters may include the sector in which the industrial enterprise operates, its size, location, technological level of its machinery, implementation rate of EnMS principles, and its success. In short, the success of EnMS may vary by correct implementation and continuity. In the empirical analysis section of this chapter, we aim to provide evaluations on applications of EnMS in Turkish manufacturing firms.

2.2.2 Energy Efficiency Projects

Within the scope of EnMS, every measure to reduce energy intensity in industrial enterprises, or in other words to increase energy efficiency, can be defined as an energy efficiency project. By conducting energy audits, businesses can generally determine energy projects, project costs, payback periods, and amount of energy savings to be achieved. Energy audit reveals the instant energy efficiency savings potential of the industrial enterprise or building being audited. For such potential to be realized and provide savings, they must be converted into investment. Firms can have energy efficiency audits done by their internal energy management unit, energy manager, and/or external energy efficiency consultancy (EVD) companies. Our empirical analysis includes firms from Turkish manufacturing that have applied energy efficiency activities between 2015 and 2017.

2.2.3 Non-energy Benefits

The expected impact of energy efficiency projects resulting from an audit in an industrial enterprise is to save energy. However, the impact created within the organizations is not limited to energy saving. There exist some secondary impacts, which may dominate the primary impact in some cases. Below, some non-energy benefits are listed in six categories (adapted from Worrel et al. 2003):

- *Emission*: Reduced CO, CO_2, NO_x, SO_x emissions
- *Operation and Maintenance*: Reduced need for engineering controls, low cooling requirement, increased facility security, reduced wear and tear on equipment and machines, reduced labor requirements
- *Production*: Increased product output and returns, increased equipment performance, reduced process cycle times, increased product quality, increased production safety
- *Waste Management*: Waste fuel, heat and gas usage, reduced product waste, reduced waste water, reduced hazardous waste, reduced used material
- *Business Environment*: Reduced need for personal protective equipment, improved lighting, reduced volume, improved sound quality, improved air quality
- *Others*: Reduced liability, improved firm image, reduced capital expenditure, additional area, increased personnel morale

Considering the multidimensional nature of impact created by activities carried out for energy efficiency, in our empirical analysis, we use multiple factors as energy saving, financial saving, and carbon saving while evaluating the performance of activities in Turkish manufacturing industry.

2.3 ISO 50001: Energy Management Systems Standard

The ISO 50001 quality system is one of the key concepts to review in explaining EnMS. The ISO 50001 quality system is a result of efforts taken by the United Nations Industrial Development Organization (UNIDO). The United Nations Industrial Development Organization (UNIDO) is a United Nations agency established to support sustainable industrial development in developing countries and transition economies. UNIDO works on improving the energy efficiency in industry through the Industrial Energy Efficiency (IEE) program. In this context, UNIDO engages in various structuring works on EnMS and its standards. The request of UNIDO has been effective in the standardization of EnMS. An energy management committee was established in 2008 under the International Standardization Organization (ISO), which develops and publishes international standards and was recognized as a worldwide federation of 162 national standard organizations (ISO 2018). The objective of the Energy Management Systems Standard (ISO 50001) is to standardize the creation of systems and processes to improve the energy performance of organizations (ISO 50001 2011). The ISO 50001 aims to reduce energy costs and carbon emissions by using energy efficiency potential in a systematic way and identifies strategic energy targets and provides guidance to operationalize through action plans (Franz et al. 2017).

The ISO 50001 standard is based on the efficient use of energy in all processes from raw material supply to final product stage. The standard is an energy efficiency guide not only for industrial organizations but also for buildings. In addition to reducing energy costs, there are several advantages for an industrial organization to have ISO 50001 certification. Owning the certificate can be considered as simple evidence for the image that the organization is environment-friendly and may positively impact its brand value. However, not every organization that implements EnMS has the ISO 50001 quality certificate and vice versa. It can be misleading to conclude that every organization with ISO 50001 quality certification is properly implementing EnMS. In our empirical analysis presented in this chapter, we have a sample of firms that are ISO certified firms in the data set. Some evaluations have also been made regarding to have an ISO certificate or not.

3 Some Facts on Energy in Turkey

Due to factors such as population growth, rapid urbanization, rising prosperity, and growing manufacturing industry, the use of energy in Turkey is increasing steadily. While Turkey's primary energy supply in 2000 was 80.6 Mtoe (million tonnes of oil equivalent), this figure increased annually by 3.2% and reached 136.2 Mtoe in 2016

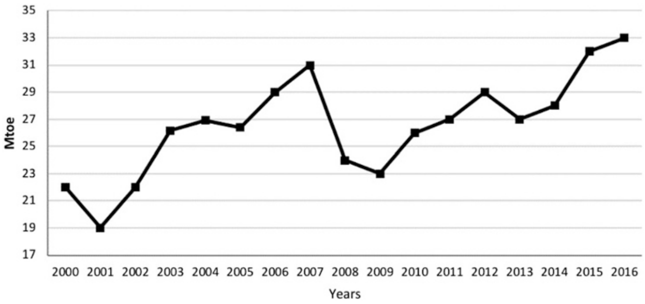

Fig. 1 Manufacturing industry energy consumption by year

(General Directorate of Renewable Energy 2018).[1] The rate of increase in electricity consumption is much higher. In the 10 years between 2007 and 2016, the electricity demand grew 4.3% on average annually, for a total of 46% in the period; and the total electricity consumption increased from 190 TWh (terawatt-hours) to 278.4 TWh.[2]

The share of the manufacturing industry in GDP in 2016 is 16.6% (TURKSTAT 2017). The sector has the second highest share in GDP next to services and is one of the driving factors of growth. The manufacturing sector is followed by wholesale and retail trade with 11.4% and by the construction sector with 8.6%. A significant portion of the manufacturing sub-sectors in Turkey are energy-intensive industries such as iron-steel and those based on stone and clay (cement, ceramics, glass, etc.).

The energy consumption in manufacturing industry in Turkey tends to increase over the years (see Fig. 1 adapted from General Directorate of Renewable Energy (2018) Turkey Energy Efficiency Progress Report (2000–2016)). Turkey is an energy-intensive country compared to developed countries, and its increasing energy demand emphasizes the importance of applying energy efficiency policies in its industries.

Energy efficiency policies in Turkey have been mainly directed by a unit in the Directorate of Electric Works and Studies that is first established in 1981 and later restructured in 1993 as the National Energy Conservation Centre (Kavak 2005). The Energy Efficiency in Industry Branch, a part of the center, conducted studies to increase the energy efficiency in the manufacturing industry. Following the closure of the General Directorate of Electric Works and Studies, the tasks related to energy efficiency were transferred to the General Directorate of Renewable Energy (YEGM) conducting various studies to increase energy efficiency, particularly encouraging industry to increase energy efficiency through various support mechanisms such as Efficiency Improving Projects and Voluntary Agreements.

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[1] General Directorate of Renewable Energy (2018) Turkey Energy Efficiency Progress Report (2000–2016) available at: http://www.yegm.gov.tr/document/enver_gelisim_rapor_2018.pdf

[2] Ministry of Energy and Natural Resources (2016) General Directorate of Energy Affairs, General Energy Statistics available at: http://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari

4 An Empirical Analysis of Energy Efficiency in Turkish Manufacturing Industry

In this section, we aim to present the design and results of a quantitative analysis of energy efficiency projects/activities carried out as a part of Energy Management System (EnMS) strategies (see Sect. 2.2) in Turkish manufacturing firms. We conduct the microlevel analysis in a sample of firms that applied various energy efficiency activities between 2015 and 2017. We derive conclusions on the effectiveness of applying energy efficiency management policies at firm, sub-sectoral, and activity level.

In our empirical analysis, we make use of the data collected within the scope of "Improving Energy Efficiency in Industry in Turkey Project" implemented by the Ministry of Energy and Natural Resources in cooperation with the United Nations Development Programme (UNDP) and United Nations Industrial Development Organization (UNIDO), with funding from the Global Environment Facility (GEF). The data set consists of firm-level energy efficiency activity data. A variety of activities have been carried out by the firms between 2015 and 2017. The data set reports:

- Annual energy consumption per firm
- Sub-sector information of the firms
- Information whether the firm is ISO certified
- Information whether the firm is a small- and medium-sized enterprise (SME)
- Energy efficiency activities applied in the given firm
- Energy saving of the firm out of each activity measured in tonne of oil equivalent (toe)
- Financial saving of the firm out of each activity measured in Turkish liras (TL)
- Carbon (CO_2) emission saving of the firm out of each activity measured in tonnes

There are 58 firms and around 200 activities. We approach to the data from two perspectives and provide two types of evaluations: firm-based evaluations and activity-based evaluations in the following subsections. Before moving to the evaluations, below we provide the method, data envelopment analysis, which is utilized for evaluating the performance at both dimensions.

4.1 Methodology: Data Envelopment Analysis

Data envelopment analysis (DEA) is a nonparametric performance measurement approach for identifying relative efficiency of decision-making units (DMUs) that are producing multiple outputs using multiple inputs. The DEA has been presented to the literature by the study of Charnes et al. (1978). Since then, DEA models have been widely applied for the real-world organizations in different industries including public and private sectors all over the world. In DEA modeling, the efficiency of a

DMU is measured relative to all other units with the simple restriction that all DMUs lie on or below an efficient frontier. A production possibility set containing "all input-output correspondences which are feasible in principle including those observed units being assessed" is constructed (Thanassoulis 2001). DEA modeling does not require any assumptions about the functional form of relationship between inputs and outputs. The efficiency score of each decision unit is obtained by solving linear programs. For each unit in a data set, a separate linear programming model is solved to investigate if there is a possibility for a unit to improve its performance. If there is no potential improvement for a unit (which means that it is performing efficiently relative to others), the linear programming model results in assigning an efficiency score of 100% to that unit. The unit or units with 100% efficiency define the efficient frontier. Below, we provide basic modeling idea of DEA.

Let us consider n decision-making units. We assume that each decision-making unit j for $j = 1, 2, \ldots, n$ uses m different inputs, x_{ij}. For i $= 1, 2, \ldots, m$ and produces s different outputs, y_{rj}. For $r = 1, 2, \ldots, s$. Let ϕ represent the efficiency score for unit o. Variables λ_j are introduced corresponding to each decision-making unit ($j = 1, 2, \ldots, n$) to form a Production Possibility Set (PPS) consisting of observed units, their convex combinations, and outperformed units. The units on the boundary (frontier) of the PPS are defined as efficient and attain the efficiency score of 100%, where the efficiency scores for others are measured relative to the frontier. The linear programming formulation to calculate the efficiency score of unit o is given below (Cooper et al. 2006):

$$Max\ \phi$$

$$s.t.$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \qquad i = 1, 2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq \phi y_{ro} \qquad r = 1, 2, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \qquad j = 1, 2, \ldots, n$$

Data envelopment analysis is a well-established method when multiple factors exist to evaluate the performance of the units. It is widely applied in measuring efficiency in energy sector at different levels (see Zhou et al. 2008; Mardani et al. 2017 for reviews).

Table 2 Sub-sector information of the firms

	Sub-sector	# of firms	# of ISO certified	# of SMEs
1	Automotive	5	3	2
2	Cement	4	3	0
3	Ceramics	3	3	0
4	Chemicals	8	3	2
5	Fabricated metal products	9	4	1
6	Fertilizer	1	0	0
7	Iron and steel	9	5	1
8	Stone and soil based	4	0	2
9	Textile	11	2	0
10	Wood processing and furniture	4	2	0
	Total	58	25	8

Table 3 Input and output factors in evaluating firms

	Factor name	Unit of measurement
Input 1	Annual energy consumption	Tonne of oil equivalent (toe)
Input 2	Total cost	Turkish lira (TL)
Output 1	Total energy saving (yearly)	Tonne of oil equivalent (toe)
Output 2	Total financial saving (yearly)	Turkish lira (TL)
Output 3	Total carbon saving (yearly)	Tonnes

4.2 Firm-Based Evaluations

The data set consists of 58 Turkish manufacturing firms that implemented different types of energy efficiency improvement activities within the period of 2015–2017. The firms operate mainly in ten different sub-sectors of the manufacturing industry listed in Table 1 together with the number of firms from each sub-sector. A subset of firms possesses ISO certificate (see Sect. 2.3), and a smaller subset are small- and medium-sized enterprises (SMEs). The number of ISO-certified firms and SMEs in each sub-sector is also provided in Table 2.

In order to measure efficiency of firms with respect to applied energy efficiency policies, we apply data envelopment analysis (DEA) which allows us a multidimensional and relative evaluation of the performance. Our modeling scheme includes both energy-related factors (annual energy consumption, energy savings, and carbon savings) and financial factors (cost and financial savings). Annual energy consumption is an input indicator to provide homogeneity in assessments since relative evaluation should also consider the size of the operation. Total cost is also taken as an input. Output indicators are related with savings. Table 3 summarizes the input and output indicators used in firm-based evaluations.

A potential question may arise at this point regarding the correlation of output factors. At first glance, output factors of financial and carbon savings may be thought to be correlated with total energy saving. It is important to note that total financial

Table 4 Correlations between output factors

Factors	Correlation with total energy saving
Total financial saving	0.0527
Total carbon saving	0.1312

Table 5 Sub-sectors of efficient firms

Sub-sector	# of firms	# of efficient firms	% of efficient firms
Chemicals	8	6	75
Wood processing and furniture	4	3	75
Cement	4	2	50
Stone and soil based	4	2	50
Automotive	5	2	40
Textile	11	4	36
Iron and steel	9	2	22
Ceramics	3	0	0
Fabricated metal products	9	0	0
Fertilizer	1	0	0
Total	58	21	36

saving and total carbon saving values of the firms have not been produced from their total energy savings. They are independent values relying on the type of the activities carried out. It is possible to have a high level of energy saving but a relatively low level of carbon saving depending on the activities. Similarly, financial saving values are not simply a scaling of energy saving with a fixed rate, since the prices may vary between sub-sectors. In order to clarify this issue, in Table 4, we present the correlation coefficients (Pearson's) between energy saving and two other factors. As seen in the table, the values are quite low to ensure that the analysis can include all three factors as outputs.

By using the input and output factors mentioned above, DEA models provided in Sect. 4.1 are solved for each firm to obtain efficiency scores between 0 and 1. This measure provides the relative performance of a firm in pursuing energy efficiency activities (100% being the efficient firms). Out of 58 firms, 21 firms (almost 36%) are obtained as "efficient." The distribution of efficient firms among sub-sectors is presented in Table 5. Eight out of 21 efficient firms are from chemicals sub-sector. Wood processing and furniture sub-sector is also a successful sector having three firms out of four in this sector obtained as efficient. There are some sub-sectors with no efficient firms such as ceramics, fabricated metal products, and fertilizer. None of the firms in those sub-sectors are relatively efficient in pursuing energy efficiency activities.

The average DEA score of the sample is 81.71%. Figure 2 provides average DEA scores for sub-sectors. On average, stone and soil-based manufacturing sub-sector has the highest level of efficiency out of their activities, followed by cement and chemicals sub-sectors. Although wood processing and furniture sub-sector has three firms out of four as efficient, the average DEA score is approximately 82%, which is lower than most of the sub-sectors. This is due to a very low level of efficiency for

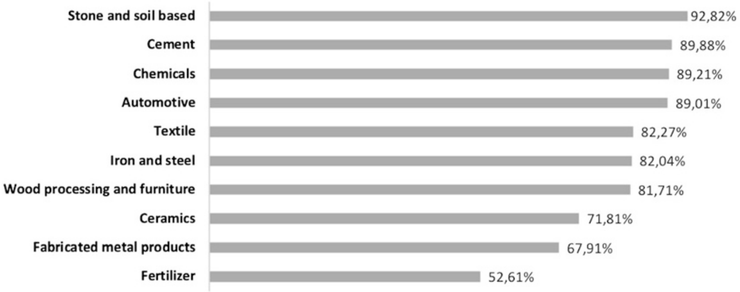

Fig. 2 Average DEA scores with respect to sub-sectors

Table 6 Efficient ISO holders and SMEs

Ratio	% value
Efficient ISO holders/ISO holders	32
Efficient ISO holders/total # of efficient firms	38
Efficient SMEs/total SMEs	50
Efficient SMEs/total # of efficient firms	19

the inefficient firm in this sub-sector. The ceramics, fabricated metal products, and fertilizer sub-sectors are at the bottom of this figure with the lowest average DEA scores. As indicated, no firms in those sectors are found to be efficient. Apparently, the efficiency score levels are also low. It seems the activities in these sub-sectors have not been very efficient compared to other sub-sectors.

Table 6 presents ratios of efficient ISO-certified firms and SMEs. Eight out of 25 ISO-certified firms are found to have a DEA score of 100%. This corresponds to approximately 32% of the ISO holders. The percentage among efficient firms is 38%. The average DEA score of the ISO-certified firms is 79.10%, which is below the average (81.71%). By looking at the ratio of efficient units and the average DEA score, it is not very likely to say that ISO-certified firms are dominating the performance. The half of the SMEs are found to be efficient (four out of eight). The average score for these firms is 85.31%, above average.

4.3 Activity-Based Evaluations

A wide range of energy efficiency activities have been carried out by the firms ranging from minor changes such as changing bulbs to more capital-intensive investments such as large-scale isolations. The original data includes around 200 nonstandardized activities in total. Most activities cover similar tasks but coded differently by the data-providing firms. Our first task is to organize this widespread range of activities into homogeneous groups. With the help of UNIDO experts, the energy efficiency activities carried out are grouped into 16 main projects. Brief descriptions of those projects are given as the following:

Compressed Air Practices: All improvement practices done in compressed air systems are collected under this heading.

Process Investments: Overall improvement activities in production lines and processes.

Periodical Preventive Care: Maintenance of all energy-using equipment in regular intervals.

Isolation: Insulation to prevent heat loss in boilers. (Insulation in furnaces has been undertaken as a separate heading: *Heater Thermal Insulation*.)

Awareness Education: Trainings given to factory employees on energy efficiency. Trainings could be given to the operators of important energy users and/or the entire factory.

Waste-Heat Recovery: Heat recovery in processes that go through heat loss and using this recovery in other processes.

LED Lighting: Replacing bulbs with energy-efficient LED bulbs.

Energy-Efficient Pump Investment: Using energy-efficient pumps.

Improvement of Fan Systems: Adjustments done so that fans can work with optimal efficiency.

Change of Motors: Replacing the engines in the process with energy-efficient engines.

Efficient Boiler and Steam Practices: Boiler rehabilitations, line insulation, steam jacket practices, valve changes, and bluff settings are collected under this heading.

Variable Speed Drive (VSD) Usage: Equipping engines with VSD so that they can work more efficiently with fluctuating load.

Improvement of the Cooling Systems: Improvement work on radiator assemblies, cooling towers, and chillers.

Electrical System, Power Distribution Unit, and Board Investments: All improvements related to the improvement of the factory's electric wiring, control-command settings, and intelligent monitoring systems have been gathered under this heading.

Lighting: All lighting investments except for LED bulb practices have been included under this title (e.g., natural lighting investments).

Heater Thermal Insulation: Heat insulation in furnaces.

The names and the number of implementations in 58 firms are given in Table 7. Note that every firm pursued multiple activities and therefore in total, 299 implementations have been realized within the period of 2015–2017. The most popular project is *compressed air practices* with 40 implementations. It is also one of the most common among ISO-certified firms together with the *process investments*.

In this part of the analysis, we approach to the data set from the activity dimension (the grouped activities are referred to as projects hereafter). We apply DEA to measure the efficiency of the projects listed in Table 7. The input and output factors

Table 7 Implemented energy efficiency projects by the firms

	Project	# of implementations	# of ISO holder implementations	# of SME implementations
1	Compressed air practices	40	13	6
2	Process investments	34	13	6
3	Periodical preventive care	25	10	6
4	Isolation	24	7	6
5	Awareness education	22	9	5
6	Waste-heat recovery	21	10	4
7	LED lighting	19	9	4
8	Energy-efficient pump investment	16	5	2
9	Improvement of fan systems	16	7	2
10	Change of motors	15	8	2
11	Efficient boiler and steam practices	15	6	2
12	Variable speed drive (VSD) usage	13	8	1
13	Improvement of the cooling systems	12	8	1
14	Electrical system, power distribution unit, and board investments	11	8	2
15	Lighting	10	5	3
16	Heater thermal insulation	6	2	0
	Total	299	128	52

Table 8 Input and output factors in evaluating projects

	Factor name	Unit of measurement
Input 1	Total cost	Turkish lira (TL)
Output 1	Total energy saving (yearly)	Tonne of oil equivalent (toe)
Output 2	Total financial saving (yearly)	Turkish lira (TL)
Output 3	Total carbon saving (yearly)	Tonnes

in the analysis are provided in Table 8. Total cost is the input factor, whereas savings are taken as outputs.

Data envelopment analysis scores for projects are provided in Table 9. Four out of 16 projects are found to be efficient. The least efficient projects are found to be *LED lighting* and *periodical preventive care* with low DEA scores. In order to provide insight on what DEA brings to the analysis, Table 8 also includes ranks of projects based on the ratios of each type of saving to the costs. Ranks 1, 2, and 3 correspond to the ranks of projects with respect to total energy saving/total cost, total financial saving/total costs, and total carbon saving/total cost ratios, respectively. The ranks emphasize the multidimensional nature of the analysis. The individual ratios may produce consistent results with DEA such as in *efficient boiler and steam practices*,

Table 9 DEA scores for projects (in comparison with ratios)

Project	DEA score (%)	Rank 1	Rank 2	Rank 3
Efficient boiler and steam practices	100.00	1	1	1
Improvement of fan systems	100.00	2	2	3
Heater thermal insulation	100.00	6	11	9
Electrical system, power distribution unit, and board investments	100.00	15	14	14
Lighting	94.86	12	12	2
Waste-heat recovery	92.27	5	9	5
Process investments	84.47	13	16	12
Awareness education	56.31	3	3	4
Improvement of the cooling systems	34.94	4	5	8
Change of motors	20.51	11	15	13
Compressed air practices	17.13	9	8	10
Isolation	11.61	7	6	6
Energy-efficient pump investment	11.10	16	13	15
Variable speed drive (VSD) usage	9.10	8	4	7
LED lighting	5.77	14	10	16
Periodical preventive care	5.41	10	7	11

which has the ranking as 1 with respect to every ratio. However, in some cases the ratios may be misleading as in *electrical system, power distribution unit*, *and board investments* project. This project seems to be outperformed by many projects regarding the individual rankings; however, it is an efficient project when a multiple factor analysis is performed.

Note that the analysis focuses on a yearly return on investment type of measure since the savings are associated with the first year of the investments. As indicated in Table 1, the effects of the investments are observed over a period depending on the investment cost. Above results provide insight on the **short-term** returns. In order to observe the state of DEA scores regarding the scale of the projects, we provide Table 10. In this table, the projects are ranked with respect to their cost and the DEA scores are also presented. As observed, the efficient projects are distributed among different scales (large-scale, medium-scale, and low-scale). *Electrical system, power distribution unit*, *and board investments* project are the largest-scale projects and one of the efficient ones. On the other hand, two relatively lower-scale projects (*improvement of fan systems* and *heater thermal insulation*) are also obtained as efficient.

Finally, we explore the projects in two subsets of the data set: the efficiency of projects applied by ISO-certified firms and the efficiency of projects applied by SMEs. As indicated before, 128 of 299 implementations have been carried out by the ISO-certified firms, and 52 implementations belong to SMEs. Data envelopment analysis modeling in these two subsets reveals the results presented in Table 11. *Efficient boiler and steam practices* and *electrical system, power distribution unit, and board investments* projects are also efficient for ISO-certified firms. In addition

Table 10 DEA scores for projects ranked by cost

Project	Cost ranking	DEA score (%)
Electrical system, power distribution unit, and board investments	1	100.00
Process investments	2	84.47
Change of motors	3	20.51
Waste-heat recovery	4	92.27
Energy-efficient pump investment	5	11.10
Compressed air practices	6	17.13
LED lighting	7	5.77
Periodical preventive care	8	5.41
Isolation	9	11.61
Efficient boiler and steam practices	10	100.00
Variable speed drive (VSD) usage	11	9.10
Improvement of the cooling systems	12	34.94
Awareness education	13	56.31
Lighting	14	94.86
Improvement of fan systems	15	100.00
Heater thermal insulation	16	100.00

Table 11 DEA scores for projects applied by ISO-certified firms and SMEs

Project	ISO DEA score (%)	SME DEA score (%)
Compressed air practices	7.63	54.66
Process investments	62.12	74.28
Periodical preventive care	3.42	52.13
Isolation	2.45	53.87
Awareness education	18.26	100.00
Waste-heat recovery	79.33	100.00
LED lighting	2.86	14.33
Energy-efficient pump investment	10.50	9.18
Improvement of fan systems	36.44	37.36
Change of motors	2.85	14.59
Efficient boiler and steam practices	100.00	49.03
Variable speed drive (VSD) usage	2.93	87.33
Improvement of the cooling systems	2.30	100.00
Electrical system, power distribution unit, and board investments	100.00	76.50
Lighting	100.00	100.00
Heater thermal insulation	1.52	–

to those, *lighting* project that involves improvements in electric lighting equipment is also obtained as efficient among ISO holders. In small- and medium-sized enterprises, efficient projects are completely different from the previous. (Note that no SME has applied *heater thermal insulation*; therefore there is no score for this project in the related column.) *Awareness education*, *waste-heat recovery, improvement of cooling systems*, and *lighting* projects are the efficient projects for SMEs.

4.4 Robustness of Activity-Based Evaluations

The effects of the investments are observed over a period depending on the investment cost and the sustainability of the changes. In our analysis, we evaluate the short-term results with respect to savings to investment cost. In this part, we aim to analyze potential future performance of 16 projects undertaken in order to observe whether any of projects have potential to change its status to efficient and vice versa. For this purpose, we design a 1000-run simulation model, where in each instance, a 16 × 3 random increase matrix is generated (the random values are in a range between 0% and 50%) and the energy, financial, and carbon savings for the projects are increased by these random rates. Data envelopment analysis models are solved in each run, and as a result, 1000 efficiency scores are obtained for each project assuming that the savings will increase by some random amount in the following years. The analysis enables us to interpret the sensitivity of the results with respect to future potential increases in the savings (energy, financial, and carbon). The average efficiency scores and min-max efficiency scores obtained through simulation are presented in Table 12 together with the original scores (as given in Table 9).

According to simulation results, *efficient boiler and steam practices*, *improvement of fan systems*, and *heater thermal insulation* project protect their status as being efficient (in all 1000 runs). The efficiency of *electrical system, power distribution unit, and board investments* project is still very close to being efficient (ranging from 95.53% to 100% efficiency). Some projects reveal a potential to be in the efficient set relying on their max values such as *process investments*, *waste-heat recovery*, and *lighting*. These projects can also be accounted for potentially effective in the long run. Nevertheless, the simulation results generally point out the robustness of the preliminary efficiency scores with close average scores and a predominantly low level of deviation. The projects with low efficiency levels such as *periodical preventive care* and *LED lighting* keep exhibiting low levels of efficiency throughout the simulation.

Table 12 Simulation results

Project	Original score (%)	Average efficiency (1000 runs) (%)	Min (%)	Max (%)	St. Dev (%)
Compressed air practices	17.13	17.15	11.80	24.74	2.59
Process investments	84.47	83.50	62.38	100.00	8.74
Periodical preventive care	5.41	5.56	3.66	7.95	0.85
Isolation	11.61	11.75	7.80	17.11	1.95
Awareness education	56.31	57.23	39.77	83.51	8.05
Waste-heat recovery	92.27	87.29	60.25	100.00	10.71
LED lighting	5.77	5.86	3.86	8.65	1.02
Energy-efficient pump investment	11.10	11.29	7.64	16.53	1.87
Improvement of fan systems	100.00	100.00	100.00	100.00	0.00
Change of motors	20.51	20.23	13.85	29.52	3.01
Efficient boiler and steam practices	100.00	100.00	100.00	100.00	0.00
Variable speed drive (VSD) usage	9.10	9.22	6.23	13.11	1.46
Improvement of the cooling systems	34.94	35.09	23.57	49.03	5.66
Electrical system, power distribution unit, and board investments	100.00	99.98	95.53	100.00	0.22
Lighting	94.86	91.11	64.25	100.00	9.45
Heater thermal insulation	100.00	100.00	100.00	100.00	0.00

5 Conclusions

With rising global awareness and binding energy prices, industrial enterprises are under environmental, social, and financial pressure to attain higher levels of efficiency in their energy use. Within the scope of energy efficiency, a contemporary approach is the energy management system (EnMS) that represents continuous and systematic efforts for improvement in efficient use of energy by the enterprises. In this research, we conduct an empirical analysis to measure relative performance in Turkish manufacturing firms that apply EnMS principles and carried out energy efficiency increasing activities between 2015 and 2017. Data envelopment analysis (DEA) is employed in two dimensions. Evaluations are presented at two levels: firm level and activity level. A simulation model is also employed to test the robustness of the DEA results in the longer term.

In adapting energy efficiency improvement activities, firm-based evaluations reveal that:

- Out of 58 firms, 21 firms (almost 36%) are relatively efficient. Eight out of 21 efficient firms are from chemicals sub-sector.
- There are some sub-sectors with no efficient firms such as ceramics, fabricated metal products, and fertilizer. These sub-sectors also attain the lowest average efficiency scores.

- Stone and soil-based manufacturing sub-sector has the highest level of average efficiency followed by cement and chemicals sub-sectors.
- Wood processing and furniture sub-sector seems to be a successful sector having three firms out of four in this sector obtained as efficient. However, the average DEA score is approximately 82%, which is lower than most of the sub-sectors. This is due to low efficiency scores for some of the inefficient firms in this sub-sector.
- Thirty eight percent of the efficient firms are ISO certified. The average DEA score of the ISO-certified firms is 79.10%, which is below the average.
- The half of the SMEs are found to be efficient (four out of eight). The average score for these firms is 85.31%, which is above average.

In evaluating 16 projects applied by the firms in the sample, the activity-based evaluations reveal that:

- There are 299 implementations of 16 projects in the manufacturing industry. 128 implementations have been carried out by ISO-certified firms and 52 by SMEs. The mostly implemented project is compressed air practices with 40 implementations.
- Four out of 16 projects are found to be efficient. These are *efficient boiler and steam practices*; *electrical system, power distribution unit, and board investments*; *improvement of fan systems*; and *heater thermal insulation. Electrical system, power distribution unit, and board investments* are the project that the most money have been spent on among 16 projects. I*mprovement of fan systems* and *heater thermal insulation* projects has the least amount of investment, yet efficient.
- *Efficient boiler and steam practices* and *electrical system, power distribution unit, and board investments* projects are also efficient for ISO-certified firms. In addition, *lighting* project that involves improvements in electric lighting equipment is also efficient among ISO holders.
- *Awareness education*, *waste-heat recovery*, *improvement of cooling systems*, and *lighting* projects are the efficient projects for SMEs.
- A 1000-run simulation model verifies the efficient projects and projects with very low levels of efficiency as well as identifies *waste-heat recovery* and *lighting* projects to have a potential to be effective in the long run.

To sum up, energy management has become increasingly crucial for the survival of enterprises in the short term and for their success in the long term. More and more industrial enterprises are taking action to adapt new strategies and apply several changes to increase their energy efficiency levels continuously. Even small changes at microlevel have a potential to create greater impact globally. The rising awareness is expected to force the industry to act in the long term. We believe that such research as presented in this chapter contributes to strategic decisions in applying the energy efficiency improvement activities. It is possible to list several policy implications for different stakeholders. Government bodies, industry chambers, and companies can be counted among these stakeholders. Some policy implications can be listed as shown below:

- The results can guide the determination of industry, company, and project-based energy efficiency incentives.
- The results can guide companies in determining the projects they will implement in energy efficiency.
- The results can be used to strengthen and restructure the legal and institutional frameworks.
- Periodical evaluation of energy efficiency savings will also support sustainability by providing data to education and capacity building.

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The Convergence of Electricity Prices for European Union Countries

M. Erdinç Telatar and Nermin Yaşar

1 Introduction

The goal of achieving a single European market for electricity has been one of the main objectives for European countries since the "Single European Act" of 1988. Over time various legislative measures were created by the European Union (EU) to reach this goal, for instance, Electricity Directive of 1996. This directive provides the members with the set of guidelines required to achieve a single European market for electricity. The convergence of electricity prices toward an equilibrium price may also indicate the competitiveness of electricity market.

There is ever-increasing amount of empirical literature on convergence hypothesis.[1] According to the theoretical literature, there are two kinds of convergence which can be defined as *β-convergence* and *σ-convergence*. The former relates to convergence of the series through the "catching-up" process, while the latter indicates the convergence of cross-sectional dispersion of the series (Barro and Sala-i-Martin 1995). According to Sala-i-Martin (1996: 1020), there is β-convergence if one of series tends to grow faster than others, and a group of series are converging in the sense of σ if dispersion of the series levels tends to decrease over time.

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[1] The Solow Growth Model, which is based on diminishing marginal productivity of capital, is considered to be the origin for the convergence hypothesis. According to this model, production level of different countries with similar level of technological advancement should eventually even up, regardless of initial endowment.

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Bernard and Durlauf (1996) is the first study which uses a time series technique to analyze the convergence hypothesis. This study defines convergence as equality of long-term forecasts at a fixed time and uses the following definition; series i and j converge if the long-run forecasts of both series are equal at fixed time t:

$$\underset{k\rightarrow\infty}{Lim} E\left(y_{i,t+k} - y_{j,t+k} \middle| I_t\right) = 0 \quad (1)$$

where I_t represents the information set available in time. Equation (1) indicates that the convergence between the observed series does not derive if $(y_{i,\ t\ +\ k} - y_{j,\ t\ +\ k})$ does not converge to a limiting stochastic process. According to Bernard and Durlauf (1996), if $(y_{i,\ t\ +\ k} - y_{j,\ t\ +\ k})$ equals 1 in even periods and -1 in odd periods, observed series will fail to converge, even though the sample mean of the differences is equal to zero. Thus, if de-meanded series as $(y_{i,\ t\ +\ k} - y_{j,\ t\ +\ k})$ contain either a zero mean or follow stochastic pattern, then the convergence between the series will be ignored.

One of the well-known studies in this field is Bower (2002) which investigates the convergence of day-ahead electricity prices for 15 European locations by the end of 2001. It concludes that law of one price for electricity is held for observed series. Similar results are obtained by Zachmann (2005) and Robinson (2007) insisting that there is a convergence between the electricity prices of mentioned European Union countries during the observed time period. However, according to Boisseleau (2004), the level of integration of electricity prices of EU countries at the international level is low, which implies that the goal of an integrated or single electricity market has not been achieved yet.

The main purpose of this study is to examine whether the aim of unified electricity market has been achieved in terms of the convergence of electricity prices. This analysis also helps us to understand whether the structure of the electricity market is competitive. For this reason, along with conventional applied techniques, recently improved unit root tests are implemented for both linear and nonlinear data generating processes. It is well known from empirical literature that possible nonlinearities inevitably make the results drawn from a linear structure spurious (Ceylan et al. 2013). To overcome this predicament, along with conventional ADF (Dickey and Fuller 1979) unit root test procedure, we utilize recently improved Kapetanios et al. (2003) nonlinear unit root test procedure which considers the asymmetric adjustment with smooth structural changes in the data generating process.

This paper is organized in the following way. The second section provides the brief overview of the econometric methodology. The third section presents the data set and empirical analysis. The fourth section finalizes study with concluding remarks.

2 Econometric Methodology

Most of the economic time series may follow nonlinear processes. Following Granger and Teräsvirta (1993), in order to get statically significant results, it is crucial to take into account these possible nonlinearities during the data generating process. Moreover, Kapetanios et al. (2003) insist that conventional unit root tests have lower power if the observed data generating process is subject to regime changes. If any investigated time series are globally stationary but follow nonstationary pattern in one of the regimes, then the test procedures which ignore regime-dependent dynamics and nonlinearities might be biased against stationarity.

2.1 Linear Unit Root Test

Conventional Augmented Dickey Fuller technique which can be denoted as Eq. (2) is widely used in the applied literature to investigate the stochastic features of the time series. Let y_t denote electricity price. The ADF test is based on the following:

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + e_t \tag{2}$$

Here, Δ indicates difference operator; x_t' is a vector of optional exogenous repressors, which may consist of a constant or a constant and trend; a, β_i, δ are coefficients intended to be estimated; and finally the e_t is assumed as white noise. The null hypothesis of unit root is $(H_0 : a = 0)$ against alternative of a stationary process; $(H_1 : a < 0)$can be tested by using the usual t-statistics for a as represented below:

$$t_a = \frac{\widehat{a}}{s.e.(\widehat{a})}$$

where $\widehat{a}$ is the estimation of α and $(\widehat{a})$ is the coefficient of standard error.

2.2 Nonlinear Unit Root Procedure

As it well known from empirical literature, nonlinear patterns of series may meaningfully weaken the results of conventional unit root test. Following Hasanov and Telatar (2011), one of the limitations of the ADF process is that it does not provide statistically significant results when adjustment to equilibrium is nonlinear. To overcome this issue, we employ Kapetanios et al. (2003) procedure based on the following exponential smooth transition (ESTAR) estimation model, which, unlike conventional unit root tests, allows for nonlinearities in data generating process:

$$\Delta y_t = \gamma y_{t-1}\left[1 - \exp\left(-\theta y_{t-1}^2\right)\right] + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \tag{3}$$

where y_t is the series under consideration and θ indicates the speed of transition between two regimes that correspond to extreme values of the transition function. The global stationarity of the process q_t can be established by testing the null hypothesis $H_0 : \theta = 0$ against the alternative $H_1 : \theta > 0$. Since the parameter γ is not identified under the null, Kapetanios et al. (2003) substitute the transition function $F(\theta, y_{t-1}) = 1 - \exp\left(-\theta y_{t-1}^2\right)$ by its first-order Taylor approximation around $\theta = 0$, yielding the following auxiliary regression:

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + e_t \tag{4.4}$$

where e_t contains ε_t and the error term resulting from Taylor approximation (Ceylan et al. 2013). The test statistic for null hypothesis of unit root $\delta = 0$, against the alternative one $\delta < 0$, is obtained as below:

$$t_{NL} = \frac{\widehat{\delta}}{s.e.\left(\widehat{\delta}\right)}$$

where $\widehat{\delta}$ is the OLS estimate of δ and s.e. $(\widehat{\delta})$ is the standard error of $\widehat{\delta}$.[2]

3 Data and Estimation Results

We use the annual electricity price data set for 12 European Union countries from 2003 to 2017 which is obtained from Eurostat Data Base and indicated in euro per kWh.

By visual inspection of the plot of data in Fig. 1, one might conclude that the price of electricity of countries converges to a common mean as time progresses.

Similarly, the plot of cross-sectional standard deviation against time in Fig. 2 reveals that there is a convergence among themselves which is σ-convergence as defined in Sala-i-Martin (1996).

The price gaps from the electricity price of Germany data are depicted in Fig. 3, and almost all these deviations approach to zero as time progresses.

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[2] See Kapetanios et al. (2003) for more detailed discussion.

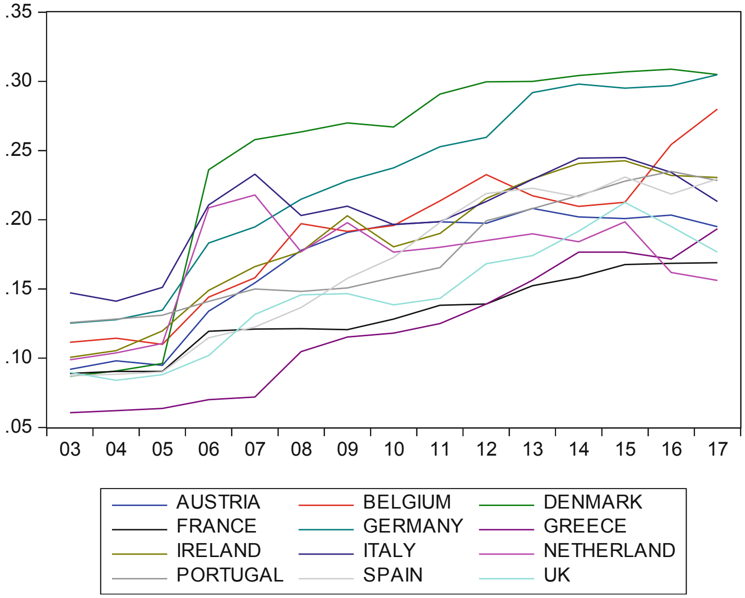

Fig. 1 De-meaned electricity price series of 12 European countries

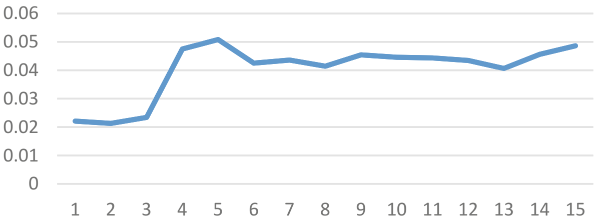

Fig. 2 Cross-sectional standard deviation of the electricity price series against time

After these visual inspections, we now turn to formal analysis. We first test the stationarity pattern of squared de-meaned prices and price gaps from the electricity price of Germany series ignoring possible nonlinearities in data generating process. Dickey–Fuller test is implemented to examine whether series are stationary or follow a unit root process. The ADF unit root results are presented in Table 1.

The ADF test results suggest that squared de-meaned price series for Austria, Belgium, Ireland, Portugal, and the UK are I (0), whereas the rest of the series are nonstationary. Moreover, the ADF test results indicate that there is no strong evidence of convergence between Germany and sample countries. The null of unit root for the series of price gaps from Germany is rejected for Spain, consistent with the convergence hypothesis. Since the conventional ADF test does not consider nonlinear adjustment in data generating processes, the policy implication of this test can be misleading.

To examine whether the series are linear or not, we use conventional LM-type test for $d = 1, 2, 3$ against general nonlinearity in the series.

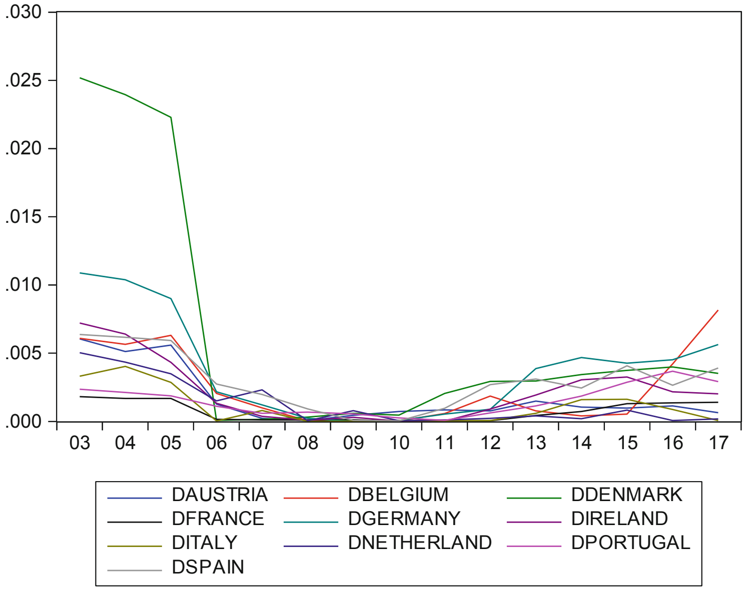

Fig. 3 The price gaps from the electricity price of Germany

Table 1 ADF test results of 12 European countries

	De-meaned price		Price gap from Germany	
Countries	Lag length	t-Statistics	Lag length	t-Statistics
Austria	3	−3.04*	2	1.05
Belgium	1	−1.39*	1	−2.53
Denmark	0	−2.39	0	−1.11
France	0	−1.59	0	−0.95
Germany	1	−2.59		
Greece	3	−1.74	0	−2.19
Ireland	1	−4.16***	2	−0.15
Italy	0	−1.93	0	0.71
Netherlands	3	−1.70	3	−0.38
Portugal	1	−2.71*	0	−1.75
Spain	3	−2.42	3	−3.32**
UK	1	−2.75*	2	−1.18

Note: ***, **, and * show rejection of null hypothesis of unit root at 1%, 5%, and 10% significance levels, respectively. Lag length is determined by AIC

As it is demonstrated in Table 2, the null hypothesis of linearity is rejected for most of observed countries. Next, we consider nonlinear unit root tests of Kapetanios et al. (2003).

Table 3 presents the result of Kapetanios et al. (2003) unit root test for the de-meaned price and the price gap from Germany. In 5 of the 12 de-meaned price

Table 2 LM—linearity test results of 12 European countries

	De-meaned price			Price gap from Germany		
Countries	d = 1	d = 2	d = 3	d = 1	d = 2	d = 3
Austria	0.09	1.09	−2.32*	−1.88*	−0.74	0.56
Belgium	−0.95	−2.09*	−3.43***	0.15	−2.50**	−2.04*
Denmark	0.93	0.01	−9.41***	−0.93	−1.70	−0.47
France	−1.69	−1.93*	−8.83***	−2.49**	−1.89	−0.00
Germany	−0.18	−1.67	−4.06***			
Greece	−0.85	−0.49	−0.45	−1.95*	−0.14	0.78
Ireland	0.51	−2.06*	−4.38***	−0.33	0.25	−2.03*
Italy	0.75	−1.39	−3.24***	0.54	0.46	1.17
Netherlands	2.19**	3.32***	1.89*	−0.81	0.55	1.27
Portugal	−0.49	−3.36***	−5.71***	−3.25***	−0.74	−0.27
Spain	−0.12	−0.36	−1.97*	−0.90	−0.87	−0.55
UK	−1.00	−2.45**	−1.77	−1.55	−0.34	1.59

Note: ***, **, and * show rejection of null hypothesis of linearity at 1%, 5%, and 10% significance levels, respectively

Table 3 Kapetanios et al. (2003) test results of 12 European countries

	De-meaned price	Price gap from Germany
Countries	t-Statistics	
Austria	−2.335*	0.5343
Belgium	−1.348***	−1.567
Denmark	−1.957**	−1.553
France	−2.117**	−1.875
Germany	−1.790	
Greece	−0.872	−2.891**
Ireland	−1.856	−0.970
Italy	−1.325	0.915
Netherlands	−1.371	0.563
Portugal	−0.916	−3.252*
Spain	−1.647	−2.469*
UK	−1.967***	−1.804

Note: Asymptotic critical values for the Kapetanios et al. (2003) test statistics at 1%, 5%, and 10% significance levels are −2.82, −2.22, and −1.92 for the test with the raw data, respectively. *, **, and *** denote rejection of the null hypothesis of unit root at 1%, 5%, and 10% significance level, respectively

series, the unit root of the null is rejected. Germany, Greece, Ireland, Italy, the Netherlands, and Spain are the countries for which we cannot reject the null hypothesis of unit root in the series. Additionally, the null hypothesis of non-convergence can be rejected in 3 of 11 price gaps from Germany series (Austria, Belgium, Denmark, France, Ireland, Italy, the Netherlands, the UK).

4 Results and Discussion

The aim of creating a single European market for electricity has been a challenging issue since the single European Act of 1988. This paper investigates the degree to which this aim has been achieved in the sense of the price convergence. Two commonly used tests of convergence are applied, namely, *β-convergence* and *σ-convergence*. We investigate the convergence hypothesis by testing the stationary of de-meaned price and gap price series of 12 European countries. This study employs not only linear time series method but also nonlinear time series approach.

Overall estimation results of both linear and nonlinear unit root test procedures are able to reject a unit root in de-meanded price and in the price gap from Germany series for several EU countries. Our results imply that, for most of the considered countries, neither *β-convergence* nor *σ-convergence* occurs. It means that the single electricity market for EU countries does not exist and internal dynamics of each country play an important role in terms of determining electricity prices in observed time period. These results correspond with the findings of Boisseleau (2004) which conclude that the aim of an integrated electricity market for European countries has not been reached yet. Liberalization process in the electricity market needs to take into account of political considerations, interest groups, technical constraints, and economic efficiency aspects. According to Boisseleau (2004) overall it is a complicated process that does not happen immediately. Moreover, another issue in Europe is that the intention is not just to develop competitiveness in any country, but it is also to integrate the different markets.

We might conclude that one must be cautious and take account of both possible structural changes and nonlinearities while examining the convergence hypothesis. Convergence among countries might be nonlinear due to some country-specific economic, technological, and political factors. However, linear unit root tests cannot capture nonlinearities and structural changes in the data if the true data generating process is nonlinear or the size of the change in the mean or slope of the trend is relatively high.

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Blockchain as a Technology Backbone for an Open Energy Market

Özgür Arslan-Ayaydin, Prabal Shrestha, and James Thewissen

1 Introduction

Energy systems are evolving rapidly to adjust to the increasing volume of renewable energy generation, such as wind, solar, geothermal, biomass, and hydropower. Supported by the privatization of the energy sector and encouraged by financial incentives, renewable energy sources (RES) have undergone a massive expansion in recent years. In 2017, 17.5% of the EU gross electricity consumption was generated by RES, mainly from wind power, hydropower, solar, geothermal, and biomass, representing a total worth of 226.5 million tons of oil equivalent (EC 2019). Ultimately, the EU seeks to have a 20% share of its gross final energy consumption from renewable sources by 2020. To achieve this objective, member states are required to find innovative ways to manage the energy grid, redefine the cap-and-trade programs, or ensure a steady reduction in the carbon footprint of the transportation industry. Amidst the different technological innovations in the sector, one such technological innovation that is rapidly influencing the industry is the distributed ledger network, or blockchain technology. Blockchains are progressively entering the energy industry to help address the challenges faced by inefficient energy systems. The blockchain technology, primarily characterized by its ability to circumvent intermediaries or a central authority, offers important advantages over

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the traditional energy management in the form of flexibility, security, transparency, and speed.

Despite its increasing importance in the energy industry, a better understanding of this new technology is required to improve our comprehension of its potential for the energy industry. We therefore provide in this chapter a review of the technology underlying blockchain in the energy sector. We discuss how blockchain can benefit energy system operations, markets, and consumers in achieving the ambitious goals set by the EU. We present several cases, such as cap and trades, energy grids, and electric vehicles. These cases clearly illustrate the initiatives of the United Nations in the creation of Climate Chain Coalition in January 2018, which is incorporating blockchain technology to support accurate information recording and sharing (United Nations 2018). We also complement our analyses with first-hand empirical investigation on the proliferation of blockchain technology in the green-energy sector. We identify six prominent categories of blockchain-based green-energy projects from a dataset of ventures that opted to use initial coin offerings (ICOs) to finance their projects. Finally, we analyze their success rates in reaching their funding objectives and their return volatility and compare them to traditional non-green cryptocurrencies.

2 What Is the Blockchain Technology?

One is likely to have encountered the word blockchain in relation to Bitcoins. The widespread attention on Bitcoins is primarily due to the substantial price volatility it has witnessed in recent years. In 2017 alone, Bitcoin's value exponentially increased by approximately 2000%, before it dropped to 50% of its peak value. The stories of overnight riches left most to wonder how they seemingly missed out on the opportunity to stake a claim in the $300 billion worth of Internet money market. However, apart from the market opportunities, Bitcoins caught the attention of many because it exhibited that facilitating transactions and record keeping can be conducted without an oversight of a central authority. The underlying technology behind Bitcoins that enabled the disintermediation is the blockchain technology.

Blockchains are open network protocols that decentralize the storage of data, making it independent of authority, tamper-proof, and transparent (IBM Think Academy 2016). Primarily, the technology is based on peer-to-peer network and cryptography. It entails a decentralized network of computers or "miners," who compete to record and verify specified transactions. The recording and verification processes are based on a consensus mechanism based on complex cryptography. For instance, on the Bitcoin blockchain, when a Bitcoin owner spends a coin, the network of computers or "miners" time-stamps the transaction and groups it with other recent transactions in a block of data. Blockchain then uses algorithms in order for the network participants to come to a consensus and eliminate ambiguity or any conflicting information between the different nodes. The transactions are then permanently recorded on the blockchain using cryptography. One of the key features of the technology is the consensus mechanism. The consensus algorithm divides the right to update the blockchain to a set of network members with exhibited interest. For instance, Bitcoin blockchain uses a proof of work (PoW) consensus mechanism, i.e., requiring miners to compete to be the first to solve a mathematical puzzle. Whoever solves the problem first gets to create the next block and is rewarded with a Bitcoin. In this manner, the blockchain ensures incentive for miners to participate, while making sure that the cost of manipulation exceeds the benefits. What is also crucial is that the network members are widely distributed, such that no single member or cartel can overtake the majority, even if they had the means and the incentive to do so (Tapscott and Tapscott 2016).

The core innovation of blockchain is that it gives the opportunity to have a trusted and decentralized direct exchange between two parties without requiring an intermediary. Blockchain technology offers a way for untrusted parties to reach an agreement on a common digital record that might otherwise be easily faked or duplicated. The recorded transactions are simultaneously kept across all the servers in the blockchain network, and therefore, it circumvents the need for a single point of control. The data on the blockchain are public, easily verifiable by all parties, consistent, and always available. Furthermore, due to their decentralized nature and lack of a central point of failure, blockchains are very resilient to fraud and are immutable, meaning that once inserted in the blockchain, they cannot be changed. In addition, the blockchain contains a verifiable record of every single transaction ever made, allowing traceability and transparency. Once entered, the record is theoretically tamper-proof. No single party can shut the system down, and any attempt by the majority to undermine the network would be visible to the whole network. Moreover, the cost of a majoritarian move to overwhelm the network is designed to be high enough to outweigh the consequent benefits, preventing any such efforts. Furthermore, these functions are executed completely autonomously, independent of any single authority or ownership.

In addition to allowing disintermediation, immutability, and transparency, the wide scope of applications of blockchain stems from its ability to incorporate "smart contracts." Smart contracts are simply digital protocols that automatically execute predefined processes, without an involvement of a centralized intermediary. The ability to make instantaneous and built-in settlements allows blockchain to support such smart contracts. It is the use of these smart contracts that allows us to develop versatile blockchain-based systems that facilitate exchanges and interactions suited to specific contexts. For instance, using such smart contracts, some blockchain-based energy companies have developed automated energy grids that allow exchange of excess energy among the neighboring houses without relying on a central utility provider.

Due to these advantages, blockchain is progressively making its way to the energy industry. The German Energy Agency conducted a survey based on the opinion of 70 managers working in the energy sector (Burger et al. 2016). The results provide evidence that nearly 20% of the managers think that blockchain technology is pioneering for energy suppliers, while the majority of survey participants plans or has already started initiatives for blockchain innovation. In fact, several energy firms have already taken interest in exploring the potential benefits of distributed ledger technology as a catalyst for low-carbon transition and sustainability.

A typical example of a company applying blockchain in the energy sector is Pylon Network. The company produced a smart meter, called Klenergy Metron, which integrates blockchain technologies that can trace and automatically record energy produced and consumed. The technology allows localized electricity market to exist, which leads to greater efficiency in the use of renewable energy. Similarly, a venture called M-PAYG is exploring the use of blockchains to provide pay-as-you-go solar services in the developing world, in order to make access to energy more feasible. M-PAYG allows off-grid low-income households and businesses to access solar energy through small-scale mobile repayments until full ownership transfer. This service relies on blockchain-based solution implementation that offers transparency, real-time monitoring, and control of solar assets. We further discuss prominent applications of blockchain in the energy sector in the following section.

3 Blockchain in the Energy Industry

Blockchain technology is expected to be most useful in industries where there is no physical exchange, such as in the financial sector (Luke et al. 2018). In such industries, blockchains can provide trustworthy records of transactions without a verification of physical exchange in a decentralized fashion. The energy sector is an obvious example of an industry with the potential to integrate the blockchain technology. Electricity is conducted at the speed of light and is impossible to track between two points in an electricity network (Luke et al. 2018). As a result, electricity markets are centralized on trading platforms similar to stock exchanges. Although the centralization of electricity production enables economies of scale in energy generation, it also leads to inefficiencies in transporting the electricity to the consumers, the inability for the consumer to choose between consuming green and fossil energy, and, most importantly, a limited access of electricity-generating prosumers to the energy market to sell their surplus of energy, which remains a privileged playing field for the institutionalized energy suppliers (Kounelis et al. 2017).

There is an increasing interest in academia on the blockchain's potential for the energy industry. Mihaylov et al. (2014)'s paper is one of the first on this topic by considering the use of cryptocurrencies for P2P energy trading. Their paper discusses the use of the technology underlying blockchain in the energy sector. Blockchain presents a new virtual currency that allows the generation and consumption of renewable energy to be directly transformed into virtual coins. Sikorski et al. (2017) further develop a small-scale blockchain-based machine-to-machine electricity market. They find that blockchain technology can successfully support the electricity sector. In addition, Al Kawasmi et al. (2015) develop a local blockchain market model to exchange carbon emissions. The approach in their paper simplifies the anonymous trading between the market participants. This type of anonymous trading is also considered by Aitzhan and Svetinovic (2016). They define a decentralized energy-trading platform based on tokens. They find that blockchains allow for implementing decentralized energy trading and that the reachable degree of privacy is significantly higher than in more traditional centralized trading platforms.

Recognizing blockchain technology's potential value in the energy sector, many companies are investing and are actively involved in blockchain-related projects. As Stefan Jessenberger at Siemens Digital Grid explains: "In our view, the blockchain technology might revolutionize the way DERs [distributed energy resources], grid operators and marketplaces will interact in a secure, efficient and transparent way while also enabling new business models. Especially in combination with artificial intelligence, advanced forecasting algorithms and the usage of geographical information of the assets, the technology offers promising capabilities in order to enable the autonomous trading of energy and flexibility, while incorporating the locational value of DER's and loads." In the following section, we illustrate these new business models by discussing three prominent applications of the blockchain technology in the clean energy sector, along with descriptions of some prominent projects.

3.1 Projects and Applications

3.1.1 Blockchain and Prosumers' Access to the (Micro)grid

The key feature of the blockchain technology in the electricity sector is that they can provide innovative trading platforms where prosumers and consumers can trade interchangeably their energy surplus or flexible demand on a P2P basis. This, in turn, will inform consumers about the real cost of electricity generation, which might lead to a more rational energy consumption (Uddin et al. 2017). Usually, the energy companies would purchase the energy surplus at a discount and sell it to consumers at a standard price. However, if prosumers who have invested in RES facilities, such as small wind turbines or PVs, are allowed to sell their energy without any intermediary, this could potentially lead to energy savings for all stakeholders.

Blockchain technology therefore encourages the development of P2P markets, where both energy producers and consumers can exchange electricity in a local grid. The approach to trading electricity based on blockchain requires fitting communication hardware or a blockchain-connected computer to a smart electricity meter. The smart meter acts as a point of contact and validation between the electricity system and the blockchain. The meter processes electricity generation. This information is converted into tokens, which are then allocated to the market participants as trades take place, by appending transaction to the blockchain. Coins can be stored in "e-wallets" with the meter and can be exchanged using fiat money or cryptocurrencies.

Another key innovation is that blockchain technology provides full transparency on the origin of the electricity consumed. The traceability of energy flows is currently limited (Andoni et al. 2019). Current intermediaries act as market access points for the transmission of energy, but there is no assurance on the origin of the electricity purchased. In fact, there is a high chance that the energy used by the end consumer is provided by the closest fossil-fuel power plant (Andoni et al. 2019). Community energy microgrids based on blockchains essentially allow local energy trading between consumers, while providing information on the origins of the energy and maintaining secure and tamper-proof records.

However, this does not mean that transmission and distribution system operators will become obsolete. These operators still occupy a central place in the electricity market, as they own the physical infrastructure of electricity grids and are responsible for their stability. In addition, they are liable for ensuring that the decentralized energy trades can actually occur. The P2P transactions can only work if the distribution infrastructure is maintained. This means that the pricing scheme needs to be adjusted. Besides helping solve different system vulnerabilities, the operators will need to adjust the pricing structure to charge the consumer separately for their energy usage and for their grid connection (Serpell 2018). Therefore, one could envision a network where a share of every blockchain transaction is given to the transmission operators.

By allowing local market microgrids, blockchains decrease the pressure on transmission networks, improve economics of small-scale renewables, and enrich customers with greater choice and transparency in energy supply. Large corporations such as Ikea have been supporting this new vision of an electric market. Several projects focus on local marketplaces and P2P trading in community projects or microgrids. For instance, LO3 Energy aims at activating German neighborhoods with a new approach to the way renewable energy is bought and sold by testing the German market with an effort to run ahead of a planned nationwide rollout of microgrid technology for renewables (LO3 Energy 2019). Millions of homes and businesses across Germany currently benefit from solar panels fitted to their roofs but must sell the excess power back to the grid at a set price determined by the major utility firms. Solar users will have the opportunity to become prosumers and sell their excess power to their closest neighbors by use of Ethereum-based smart contracts. Tokens specify that a certain amount of energy was produced from the solar panels and can be transferred from a prosumer's smart meter wallet to end consumers by use of blockchain technology. Tokens are deleted by the consumer's smart metering device, as purchased energy is used in the house. Microgrid users interact with the platform by defining their price preferences in the form of willingness to pay or sell electricity. According to Lawrence Osini, LO3 Energy's CEO, this technology will offer "[. . .] many of Germany's early adopters of PV technology, who are reaching the expiration of the feed-in tariff, [. . .] a new way to receive the full benefit from their investment in renewables, while allowing energy consumers the choice to buy energy directly from their neighbors and community. We think many participants will recognize that buying energy locally strengthens their community and the local economy" (LO3 Energy 2019). This project follows the successful development of a US-based microgrid in Brooklyn, New York, and will be set up in Lazarettgarten in Landau and in the Allgau region of Southern Germany.

Ikea is also aiming at supporting green-energy innovation through the Lab Space10, a prototype for how solar energy could be installed in local communities and then shared on a small microgrid. The microgrid will allow people to sell their surplus of energy to others on a blockchain-powered platform. The project is called SolarVille, and it pledges to bring cheaper solar technology to homes in all of these markets by 2025. Ikea has also been selling solar panels in the UK since 2013 and launched a solar panel kit in 2017 (Schwab 2019).

3.1.2 Cap and Trade

There are other domains in the energy sector where the blockchain technology is readily applicable. The purpose of cap and trade is to push companies to reduce their greenhouse gas emissions by limiting (cap) the amount they can emit and allowing them to "trade" excess credits. This is done by a centralized body agreeing to the total quantity of industrial carbon that can be emitted within the jurisdiction. These allowances are distributed to companies that emit carbon, usually by free allocation and auctions. The funds received by the central authority are usually reinvested later in clean energy initiatives. According to the European Commission, in 2010 greenhouse gas emissions from big emitters covered by the EU Emission Trading System (EU ETS) had decreased by an average of more than 17,000 tons per installation from 2005, a decrease of more than 8% since 2005 (EC 2019).

To support the EU ETS, a secondary market has been created, where a company that needs more carbon emission rights than its existing credits allow is required to buy them from another facility. This method is however not free of shortcomings. The major argument against this organization is that the cap-and-trade method is more complicated and opaque than a direct tax on carbon emission. For instance, the lack of carbon labelling standards and a single globally recognized methodology to calculate the carbon footprint is a significant challenge. Calculating the carbon label of a product requires tracing each ingredient or component from the beginning of production to the end product, along with various skills, methods, and personnel. This process is complex, costly, and time-consuming. According to 3M, the cost of calculating the carbon footprint of a single product can be as high as $30,000 (The Economist 2011). In addition, each country has its own set of rules and pricing mechanism. This means that firms are not able to reliably compare the footprint of similar products across countries, creating further challenges when reporting on their carbon credits. Consequently, small energy producers are, in practice, excluded from claiming carbon credits due to the high costs associated with the procedure. In addition, audit processes are often performed manually by a central authority; therefore they are prone to errors and even fraud (Banerjee 2018). This can make cap-and-trade systems more debatable for the public and more difficult to monitor by the authorities. A standardized method to measure the carbon footprint and an internationally accepted pricing become critical to achieve reasonable results with the cap-and-trade system.

Blockchain technology can help companies meet the demand for accurate, reliable, standardized, and accessible information for carbon emission calculation. The instant authentication, uncorrupted data, and smart contracts make it an optimal solution to integrate suppliers, manufacturers, logistics service providers, and stock locations into a single network for rule-based interactions and value generation. Blockchain will therefore provide a standardized and accepted “carbon currency” to calculate carbon emissions, which is the key feature of this integrated network. The authorities, journalists, and analysts would then be able to accurately assess carbon emissions without relying on quarterly reports published by a centralized authority. This means that the purchase and trade of carbon credits between businesses and the state would be transparently and accurately accessible to anyone with an Internet access.

Another limitation to the cap-and-trade system is the inherent possibility of market manipulation (Serpell 2018). In the absence of regulation to limit such opportunistic behavior, business can time the purchase of carbon credits, by purchasing more credits than required when the price is low and sell when the price is high. In the USA, these opportunistic incentives are generally dealt with by limiting the amount of allowances a business can bank for later use. However by using a blockchain technology to maintain the cap-and-trade system, it is conceivable for each token to carry with it unique features, such as an expiration date. The token could then be followed and traded until the expiration date. As the token expires, an equivalent number of tokens could be distributed to carbon neutral or negative businesses, maintaining consistency with the market supply of tokens with no necessary governmental control. Several entrepreneurs are developing blockchain technologies for renewable or carbon certificates and their automatic issuance and trading. For instance, *Volts Markets* uses smart contracts to automatically issue and track renewable energy certificates via an energy assets exchange platform. Similarly, *Veridium* created an Ethereum-based platform to trade carbon credits and natural capital assets through their cryptocurrency *TRG*.

Blockchains, therefore, provide a platform where all stakeholders across the supply chain can work together in a transparent and accountable manner by unifying the cap-and-trade system with accurate and standardized measurements and credits. The World Economic Forum is in favor of the development of such cryptocurrencies and has already lobbied for the use of blockchain technology, arguing that carbon credits are the ideal contenders for cryptocurrency as these are data-driven, depend on multiple approval steps, and are independent from the physical impact to which they correlate (Vanclay et al. 2011).

An example of such platform is the Energy Blockchain Lab, which is collaborating with IBM to develop a blockchain platform for trading carbon assets in China (Coindesk 2016). The platform aims to reduce the costs of China’s national carbon market by 30%. The cryptocurrency not only aims at enhancing carbon reporting by standardizing and recording all relevant emission data but also by ensuring that all value-based transactions are valid and settled automatically. This approach has also been adopted by the Russian startup CarbonX, which aims to incentivize a sustainable consumer behavior by the use of blockchain technology in a P2P carbon trading between consumers. CarbonX is assessing a variety of products and services in terms of their carbon footprint to inform a rational energy behavior.

3.1.3 Electric Vehicle Charging

Over a quarter of greenhouse gases produced in the EU are a result of transportation and contribute to overall pollution levels (EC 2019). On the contrary, electric cars have no emissions and make less noise so their increased use will mean cleaner and quieter cities and towns and improved quality of life. The use of electric cars has significantly increased over the last decade. So much that electric cars are becoming the norm in Norway. In Norway, 60% of the cars sold are electric, bringing the country a step closer to the government's ambitious goal to have all new cars with zero emissions by 2025 (NPR 2019). This marks the first time in history when electric cars outsold gas and diesel in the European country. It also means that electric vehicles are no longer the exception. It however means that we need a widespread and seamless charging infrastructure, which supports seamless charging and billing.

Chapter 13 of this book discusses the increasing predominance of electric vehicles in the Netherlands. The authors develop an optimization model that applies unobtrusive charging strategies (i.e., postponing, on-off charging, and two charging speed levels) for an electric vehicle (EV) charging aggregator. Their results show that applying such a model can significantly reduce energy costs for EV users. However, one aspect of such a technology that is not discussed in the book chapter relates to how consumers often cite range anxiety as a factor in not buying an electric vehicle. The worry is that the vehicle will run out of battery power on a long drive before one can find a charging station. Without the proper critical infrastructure widely available, potential buyers may remain hesitant to purchase an electric vehicle. In fact, more than 80% of vehicle charging occurs at home (The Fuse 2018). Given that electric vehicles have a range of around 250 miles, drivers need to access charging stations frequently, which is where the P2P network may play a major role in the development of electric cars.

Blockchain technology could relieve the uncertainty over refueling and enhance EV charging coordination by facilitating anonymous energy payments at participating homes and allow drivers to make charging decisions based on a map and real-time pricing data. The distributed ledger capability allows for new providers who can sell an access to charging stations for a small amount, which reduces the limitation on where one can buy electricity and from whom they buy. Via a peer-to-peer network, the amount of time and energy used to charge the vehicle is tracked by a proprietary service, and then a ledger transaction takes place with a digital payment from the driver to the owner of the charger. Blockchain would also minimize fraud.

If the user is overcharged, he has the power of challenging against the seller by looking back at the log of transactions.

For instance, Emotors uses *Share&Charge*, which is the first e-mobility transaction platform that uses blockchain. *Share&Charge* is a P2P network that allows EV and charging point owners to rent their charging infrastructure to each other autonomously, securely, and without the need for an intermediary. *Share&Charge* relies on the Ethereum blockchain to track the charging transaction. By May 2017, *Share&Charge* allowed EV owners to charge their vehicles by making digital payments using a mobile app. Charging point owners used the app to notify they have a station available, set the price, and collect fees. Until April 2018, the service was available to about 1000 EV owners with 1250 private and public charging points in Germany. The system used an e-wallet and smart contracts on the public Ethereum blockchain as P2P transaction layer. Based on this experience, *Share&Charge* is now also being tested in the USA, allowing drivers to pay each other for the use of their home chargers.

3.2 Empirical Evidence on Green ICOs

In order to highlight the scope and nature of adoption of blockchain in the clean energy sector, we provide some empirical evidence relating to financing efforts of clean energy projects via initial coin offerings (ICOs). Unlike other traditional modes of financing, ICOs are a financing mechanism particularly catered to blockchain-based ventures. In order to raise funds, ICOs require entrepreneurs to sell virtual tokens (cryptocurrencies) that are managed by a blockchain (Willett 2012). Therefore, ICOs allow ventures and projects to raise funds without an intermediary, such as banks, venture capital firms, and crowdfunding platforms. Using one of the prominent ICO-listing websites, ICOBench.com, we compile a list of 40 clean energy-related ICOs identified from a total ICO dataset of 2509 observations launched between April 2015 and September 2018.[1,2] Furthermore, we use the website coinmarketcap.com to obtain the data on post-ICO prices of the issued tokens (Amsden and Schweizer 2018; Howell et al. 2019).

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[1] To identify ICOs by projects focusing on clean energy, we use dictionary-based approach complimented with manual verification. We search for the words “green energy,” “cleantech,” “recycle,” “wind,” “power,” “solar power,” “biomass,” “renewable energy,” “hydro-electric,” “photovoltaic,” “geothermal,” “sustainable,” “biofuel,” “green transport,” “environmental footprint,” “greywater,” and “electric motor” in the project’s description provided in its ICOBench profile. The words were derived from the definition of cleantech available on Wikipedia and other web pages such as www.cleantech.com. After we identify the list of ICOs with the aforementioned words in the description, we manually checked the shortlisted ICO’s profiles to make sure the identified projects are directly related to clean energy. After the procedure, we remain with 40 ICOs focusing on clean energy.

[2] The Appendix provides the list of green ICOs.

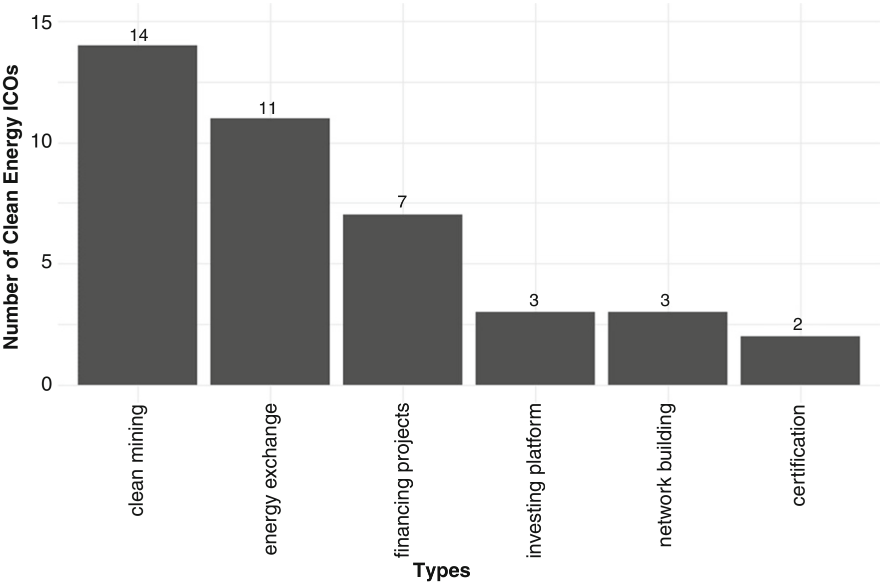

Fig. 1 Number of clean energy ICOs by type

3.3 Types of Clean Energy-Related ICOs

We identify six distinct themes of clean energy-related ICO projects, namely, (1) energy exchange platform, (2) clean mining, (3) financing renewable projects, (4) renewable investment funds, (5) certification/incentive programs, and (6) network building.[3] Figures 1 and 2 provide overviews of the six categories in our sample of clean energy ICOs in terms of the number of projects and success. We find ICOs focusing on clean mining are the most prevalent ones, whereas the ICOs pitching an energy exchange platform witnessed the highest rate of success.

In the following, we provide brief descriptions for each of the six project types:

1. *Clean Mining*: One of the major criticisms of crypto-mining is the high energy requirement. In order to tackle this drawback, various ICOs have emerged proposing to build sustainable mining centers that rely on renewable energy. The incentive to adopt renewables is not solely driven by the desire to mitigate environmental impact, but also to improve the profit margin by incorporating cheaper sources of energy, which constitutes a substantial portion of the mining costs.

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[3] The categories are not mutually exclusive, as the underlying tokens from the ICOs may incorporate more than one type of service. The categories are assigned based on the most salient feature of the ICOs. Due to the flexibility of smart contracts, which are able to incorporate different functionalities and attributes, the issued tokens after a successful ICO can incorporate a combination of the mentioned themes, potentially in different variations.

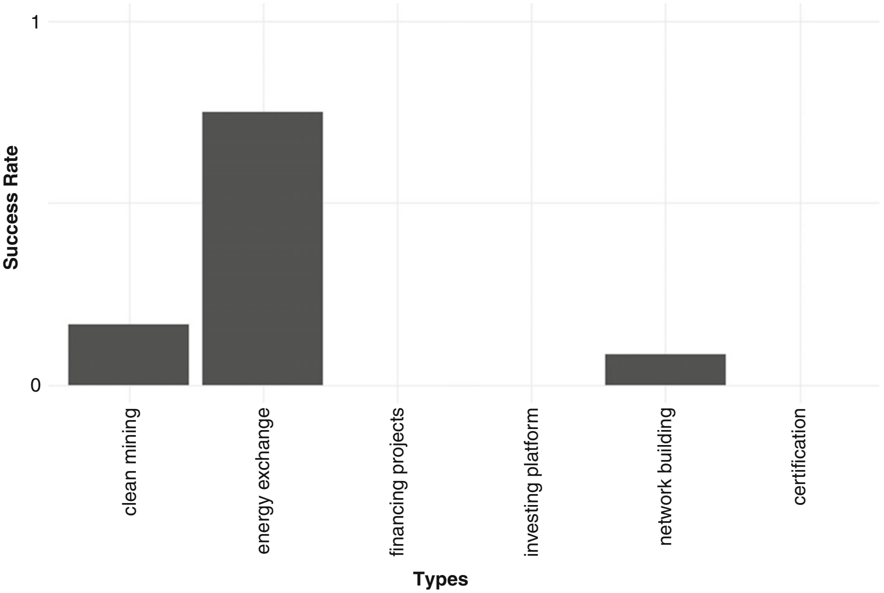

Fig. 2 Success rates by type of clean energy ICOs

2. *Energy Exchange*: We observe that a substantial number of ICOs were related to facilitate electricity exchange, as described in Sect. 3.1. These platforms utilize the blockchain technology to create a decentralized exchange to facilitate energy trade among participants within a network. These systems are mainly focused on improving distribution efficiency, which reduces the waste of produced renewable energy while generating revenue for producers and cheaper energy for consumers.
3. *Financing Renewable Projects*: There are also several projects in our sample that use ICOs simply as a funding mechanism to finance their clean energy-focused projects, offering various forms of returns for funders using smart contracts. These projects may involve different forms of business function, from product manufacturing to expanding an existing business function.
4. *Investing Platform*: Another way that projects use ICOs and blockchain technology to help promote renewable energy sector is by connecting renewable producers in need of funds with consumers or investors by means of pre-purchase of the energy or investment in ownership. For instance, Optonium Coin allows renewable energy developers to sell, in advance, part of the energy to be produced in the future to the consumers.
5. *Certification/Incentive Programs*: Several ventures also introduce tokens as certification or reward for production or adoption of renewable energy. The immutable certifications can be used by firms to fulfill their green reporting requirements and exhibit their commitment to clean energy production to stakeholders. The tokens can also be issued to consumers as a form of reward for using

clean energy. Furthermore, the certification programs help to create immutable time-stamped databases of production of renewable energy.

6. *Network Building*: Another function that blockchain-based clean energy projects seek to provide is to build a network between disparate stakeholders in renewable energy industry based on a common cryptocurrency. The main purpose of the network is to facilitate rapid mutual settlements, helping make communications and transactions between these industry members more efficient.

3.4 Relative Performance of Clean ICOs

In Tables 1 and 2, we provide the descriptive statistics of clean energy-related ICOs and the remaining non-clean ICOs. We report three comparative performance attributes of the ICOs: (1) ICO success, (2) the amount raised, and (3) its impact on the price volatility of the issued tokens. As all ICOs look to issue tradeable tokens, we identify an ICO as a success (*SUCCESS*) if the issued tokens are eventually traded on an exchange (coinmarketcap.com) (Amsden and Schweizer 2018; Howell et al. 2019; Adhami et al. 2018; Fisch 2019). In addition, in order to distinguish the magnitude of success, we also look at the amount raised (*AMOUNT RAISED*) by the projects during the ICO. However, all projects do not disclose the amount raised; therefore the variable only indicates the details of the projects that opted to provide the information. In addition, we measure the token price volatility (*VOLATILITY*) by using the standard deviation of the daily returns (measured by taking the log differences in daily token price series), a method commonly used in measuring volatility of commodity prices (Slade 1991; Fleming and Ostdiek 1999; Regnier 2007). In order to mitigate estimation bias, we only include tokens with more than 90 days of daily price data.

In addition, we compare the clean ICOs with the rest of the ICOs based on various prominent ICO attributes. We report some of the more salient attributes of the ICOs, such as the listing website's (ICOBench.com) assessment of the project (*RATINGS)*, whether a pre-sale of tokens (*PRE_ICO*) or bonuses *(BONUS)* were offered, whether a minimum or a maximum target amount was stated in the ICO (*CAPS_PRESENT*), if the project's blockchain is based on the widely used Ethereum platform (*ETHEREUM*), if the buyers of ICO tokens are verified *(WHITELIST_KYC)*, the number of types of currencies accepted by the ICO (*NUM,_OF_CURR*), whether a fiat currency is accepted (*FIAT*), and the number of members in the team (*TEAM_COUNT*).

3.4.1 ICO Performance

We observe in Table 1 that clean energy-related ICOs are more likely to be successful and raise a higher amount of capital. Moreover, the issued tokens of successful ICOs display lower price volatility in comparison to remaining ICOs. We

Table 1 Summary statistics (clean ICOs)

Statistic	N	Mean	St. Dev.	Min	Median	Max
Performance measures						
SUCCESS	40	0.300	0.464	0	0	1
AMOUNT	19	19,284,899	26,180,655	420	10,000,000	100,012,279
SD _ RET	12	0.137	0.082	0.079	0.114	0.379
Project attributes						
RATINGS	40	3.015	0.676	1.800	3.000	4.600
PRE _ ICO	40	0.600	0.496	0	1	1
BONUS	40	0.475	0.506	0	0	1
CAPS _ PRESENT	40	0.625	0.490	0	1	1
ETHEREUM	40	0.900	0.304	0	1	1
WHITELIST_KYC	40	0.425	0.501	0	0	1
NUM _ OF _ CURR	40	2.125	1.652	1	1	9
FIAT	40	0.025	0.158	0	0	1
TEAM _ COUNT	37	14.568	7.175	4.000	13.000	34.000

Table 2 Summary statistics (other ICOs)

Statistic	N	Mean	St. Dev.	Min	Median	Max
Performance measures						
SUCCESS	2469	0.243	0.429	0	0	1
AMOUNT	1230	16,075,458	122,542,727	26.000	5,100,049.000	4,197,956,135
SD _ RET	601	0.147	0.098	0.046	0.114	1.245
Project attributes						
RATINGS	2469	2.953	0.767	0.700	2.900	4.800
PRE _ ICO	2469	0.438	0.496	0	0	1
BONUS	2469	0.433	0.496	0	0	1
CAPS _ PRESENT	2469	0.663	0.473	0	1	1
ETHEREUM	2469	0.873	0.333	0	1	1
WHITELIST_KYC	2469	0.352	0.478	0	0	1
NUM _ OF _ CURR	2469	1.857	1.472	1	1	13
FIAT	2469	0.018	0.132	0	0	1
TEAM _ COUNT	2261	12.262	7.691	1.000	11.000	67.000

find that 30% of the clean energy-related ICOs eventually issue tokens, which are traded in coinmarket.com. In comparison, other non-clean-related ICOs have a success rate of 24.3%. Furthermore, we observe that on average clean energy-related ICOs raise more than USD 19 million. Among the projects that did disclose the amount raised, the minimum amount raised was USD 420, and the maximum was USD 100 million. The median is USD ten million, which is substantially lower than the mean. This indicates that the distribution of the amount raised is positively skewed, i.e., a few projects raise a substantially greater amount than average projects. The average amount raised among projects that are not characterized as clean energy-related ICOs is lower by USD three million. Among the 40 clean energy-related ICOs, we find that 12 lead to issuance of tokens and had been trading coinmarketcap.com for more than 90 days. We observe that the standard deviation of the price returns of these tokens is on average 0.082, which is lower than the standard deviation observed among other issued tokens 0.098.

3.4.2 ICO Attributes

In this section, we compare the clean energy ICOs with the remaining of the sample with respect to various ICO attributes. First, we find that ICOBench ratings for clean energy projects are on average marginally higher for clean ICOs compared to the ratings for other ICOs [clean ICOs = 3.01, remaining = 2.95]. With respect to launching a pre-ICO sale before the main ICO, the proportion of clean ICOs with pre-sale is substantially higher [clean ICOs = 60%, remaining ICOs = 43.8%]. The greater use of pre-sale among clean energy-related ICOs could be that these projects are generally more likely to lack the resources needed to launch and market an ICO. A greater proportion of clean energy ICOs offers bonus schemes during the ICO [clean ICOs = 47.5%, remaining ICOs = 43.8%]. However, with respect to specifying a soft or a hard cap, the proportion is lower for clean ICOs [clean ICOs = 62.5%, remaining ICOs = 66.3%]. Strikingly, 87.3% of the nongreen sample were based on the Ethereum blockchain, and the proportion was even higher for clean ICOs [90%]. We find that 42.5% of the clean energy ICOs have complied with either or both whitelist and KYC [clean ICOs = 42.5%, remaining ICOs = 35.2%], which indicates that greater proportion of clean ICOs exhibit regulatory compliance. The average number of currency alternatives offered by clean energy ICOs is 2.125, which is greater than the average of 1.85 currencies offered by other projects. The greater number of currency indicates that clean ICOs offer greater purchasing alternatives for investors. We find similarly higher figures with respect to offering fiat currencies as purchasing currency option [clean ICOs = 2.5%, remaining ICOs = 1.8%]. Furthermore, we find that clean energy-related ICOs on average have almost 15 team members and advisors onboard, compared to 12 team members in other projects, suggesting that clean energy projects are generally larger in scale with respect to the number of people involved than most ICO projects.

3.5 Risks and Uncertainties Related to the Blockchain Technology

In spite of its value, the future of the blockchain technology for energy purposes is not set in stone. The technology is new and still involves substantial costs and slow transaction speed, among other technical challenges (Luke et al. 2018). In addition, political issues with grid operators or public perceptions of the technology are potential obstacles for its expansion. Several risks, threats, and challenges await. Here, we discuss two of the technical challenges relating to adoption of blockchain technology.

3.5.1 High Energy Demand

The innovation of blockchain technology is revolutionary because every transaction is verified by using very complex algorithms. This benefits users with a high level of security. However, this security leads to a substantial energy cost. The energy that is required by the Bitcoin network is difficult to assess with certainty because of a very volatile demand and increasing verification complexity. Yet, the usage is estimated to be between 32 and 34 TWh or 250 KWh per block verification (Serpell 2018). This is similar to 1 week of electricity consumption by the average American household. It is estimated that during the recent price spike of Bitcoin in 2017, energy demand increased by 450 GWh every day. This is about 250,000 barrels of oil a day.

While the energy cost of mining Bitcoins is very high, it is not as high as printing physical currency. One must also take into account of the fact that far more physical currency is printed than Bitcoins and that the majority of US dollars in circulation today are digital. As long as blockchains experience a modest growth, this energy consumption should not be an issue. However, if Bitcoin's value continues to rise, the reward a miner receives also increases in value, and therefore he can afford more energy to solve the block algorithm. This could lead to scalability issues for the blockchain technology in the energy industry.

3.5.2 Scalability Issues

Blockchains were defined with a focus on decentralization and security. Yet, this has come at the cost of scalability. Blockchains such as Bitcoin and Ethereum can have extremely slow transaction processing times. The reason is that all full nodes on these blockchains must reach a consensus before the transaction can be processed. Bitcoin can process about nine transactions per second (BitInfoCharts 2019). This is substantially lower than the VISA payment service, which can handle up to 24,000 transactions per second. This has implications on the scalability of the Bitcoin technology.

In fact, the scalability of the blockchain technology is bound to the scalability trilemma. This trilemma, described by Ethereum's Vitalik Buterin, refers to the tradeoffs that blockchain-based projects must make when deciding how to optimize the underlying architecture of their own blockchain. The trilemma involves three components, decentralization, security, and scalability, and states that you can only have two out of the three. Tradeoffs are therefore inevitable and require one to find a balance, without compromising too much on one of the components.

To address this scalability issue, cryptographic strategies for block verification such as the "proof-of-stake" and "directed-acyclic-graph" protocols have been developed (Tapscott and Tapscott 2016). The "proof-of-stake" network participants are able to check transactions based on their ownership of the network's cryptocurrency, rather than by competing with each other to solve a block algorithm (Luke et al. 2018). This protocol, in theory, should substantially diminish the energy consumption of the network and allow more users to take part to the mining process. Directed-acyclic-graph protocols are designed so that it is not possible that a transaction completes until the participants in that transaction verify at least two previously completed transactions. As a result, previously executed transactions are independently verified by a number of following transactions, using less power, compared to other verification methods. However, this protocol may not provide the network security that "proof-of-work" networks like Bitcoin can offer (Luke et al. 2018).

4 Conclusions

In our pursuit for global solutions for the common challenge of climate change, the coordination of actions and the facilitation of cooperation between actors in the green-energy sector is an increasing concern. Blockchain provides the technological basis to achieve such types of interactions. For instance, blockchain allows actors in the green-energy sector to continually update greenhouse emission data from a multitude of sources and share this information in an open and transparent way. Blockchain's potential applications extend to numerous other domains, both private and public, tackling challenges such as monitoring environment treaties compliance, efficient supply-chain management of vital resources, and improving recycling efficiency.

Nonetheless, the blockchain technology and the realization of its potential applications are still in its early phase, and the uncertainties surrounding how its adoption will evolve in the coming years are still profuse. As with the introduction of any new promising technology, the rational assessment around its potential has been marred with speculative exuberance, blurring the line between progress and fad. Furthermore, despite the technology's potential to deinstitutionalize the cumbersome and vulnerable institution-dependent interactions, the process of learning to optimize the technology to create the most value for the wider population still requires much experience. After all, the adoption of a technology is not only based on the merit of the technology itself but also the time-specific social conditions supporting it (Davis 1989). Furthermore, the technology itself is in the process of developing as it still tries to overcome the issues of scalability and efficiency. Nonetheless, despite these tales of caution, its scope to enhance transparency, flexibility, and security is still distinctly relevant for the context of energy industry and, therefore, promises to play an important role in shaping the industry for the future.

Appendix

Table 3 List of ICO clean energy firms based on service category

Clean mining	Energy exchange	Financing renewable projects	Investment platform	Certification/ incentive program	Network building
Airforce Mining	SunContract	Wind Energy Mining	Optonium	Swytch	BioCoin
Minery	PowerLedger	Platio Solar Paving	HydroCoin	Czero	Oilsc
GreenHashes	Pylon Network	Indigo Racing	Bitproperty		EnLedger
Zeus	WePower	NiqBix			
Environ	Universal Brand	Smart City Enterprise			
Cointed	KWHCoin	Reborn Bloc			
Moonlite	Robotina	Sun Money			
EthernityMining	EarthToken	Optonium			
Nauticus	Restart Energy				
CrowdShareMining	Electrify Asia				
BaltiCrypto	Torus				
H2Sol					
OphirCoin					
CryptoSolarTech					

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Geopolitics and Gas-Transit Security Through Pipelines

Volkan Ş. Ediger, John V. Bowlus, and Mustafa Aydın

1 Introduction

The ownership, production, and transportation of energy became integral parts of global discussions about security, politics, economics, and finance after the oil crises of the 1970s. The first such crisis from October 1973 to March 1974, when Arab oil-producing countries except Iraq curtailed production and embargoed the sale of oil to countries that supported Israel during the Yom Kippur War, served as a wake-up call for Western political and strategic communities (Paust and Blaustein 1974). Ending the era of "cheap" energy and turning it into a geopolitical strategic tool (Licklider 1988; Yergin 2008). The embargo forced energy-hungry Western countries to implement policies to diversify their energy sources and their origins (Ediger and Berk 2018). Attention turned to (1) tapping national resources wherever possible, including hydrocarbons, nuclear, and alternative energies, to better coordinate consumer policies, and (2) securing the continuous flow of hydrocarbons from their origin. While the first aim led to the creation of the International Energy Agency in 1974 as the coordinating institution for consumer countries, the second aim led the USA to prepare contingency plans to intervene in oil-rich Middle Eastern states should a similar crisis reoccur (Kissinger 1982; Ikenberry 1986).

The second crisis, resulting from the shortage of supplies brought on by the Iranian Revolution, prompted the creation of the US Rapid Deployment Force (RDF) in 1979, which permitted swift intervention in regions beyond traditional NATO and US operational areas, including the Gulf region. President Carter then

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promulgated the Carter Doctrine in January 1980 after the Soviet Union invaded Afghanistan, explicitly stating that the USA would defend Gulf oil. The creation of US Central Command (CENTCOM) followed in 1983 (Ediger 2007). In addition to helping stabilize the Middle East, the RDF, and CENTCOM could secure the region's oil-transit routes, especially the Strait of Hormuz, the Bab-el-Mandeb, and the Suez Canal. The USA then used military force to protect the flow of oil from the Gulf during the 1984–1988 Tanker War as part of the Iran–Iraq War. These developments contributed to the emergence of International Political Economy as a subsection of International Relations discipline (for the development of IPE as an area of study and the effects of the oil shocks of 1970s, see Hancock and Vivoda 2014). The definition of security also expanded to include first economy, which encompasses energy, and then transit security issues (Baldwin 1997; Møller 2000).

Gerald Manners used the term "geography of energy" about half a century ago to refer to "the spatial characteristics of the production, transport and consumption of energy" (Chapman 1967). Nevertheless, academic discussion of energy transit and its geopolitics was slow to emerge. During the 1970s, the discipline of geography began studying energy issues, but lacked the framework for analyzing politics and security and thus made few insights (Odell 1980; Wilbanks 1985). The definition of security in the field of international relations expanded to include "energy security" in the late 1970s, but pipeline transit issues did not attract much attention, partly because global energy transfers were by seaborne tankers. The only detailed work was on Russian oil and natural gas transit to Western Europe during the Cold War (Adamson 1985; Jentleson 1986), which focused on the issue of dependence on a single energy source and supplier rather than pipeline security.

Pipelines, however, have a long history. First used in the 1850s to transport energy within national borders, cross-border pipelines were inaugurated in the Middle East in the 1930s–1950s. Regional politics and a preference for seaborne tankers, however, caused them to fall out of use by the 1980s, with the exception of the Kirkuk-Ceyhan Pipeline between Iraq and Turkey (Bowlus 2013). The dissolution of the Soviet Union then led to a scramble to build cross-border pipelines from the landlocked Caspian Basin and Central Asia to Europe in the 1990s. In this context, Lawal (2001, p. 94) studied the "new and rapidly increasing role of pipelines in transport geography," while political scientist Paul Stevens analyzed the performance of Arab cross-border pipelines and outlined factors shaping them across the globe (Stevens 2000, 2008). While the Caspian competition generated increased interest from an international relations perspective (Alam 2002; Aydın 2004; Bahgat 2005; Winrow 2007), sustained academic attention emerged only following the natural gas disputes between Russia and Ukraine in 2006 and 2009, which disrupted supplies to Europe (Lehmann 2017). International organizations and investment agencies also recognized the importance of geopolitics in energy-transit security thereafter (UNDP and World Bank 2003; European Commission 2014; Grubliauskas 2014; Energy Charter Secretariat 2015), but geographers still do not (Pasqualetti 2011).

The drive to use cleaner energies that can arrest the pace of global warming is now precipitating "changes in production, trade and transit, supply chain and

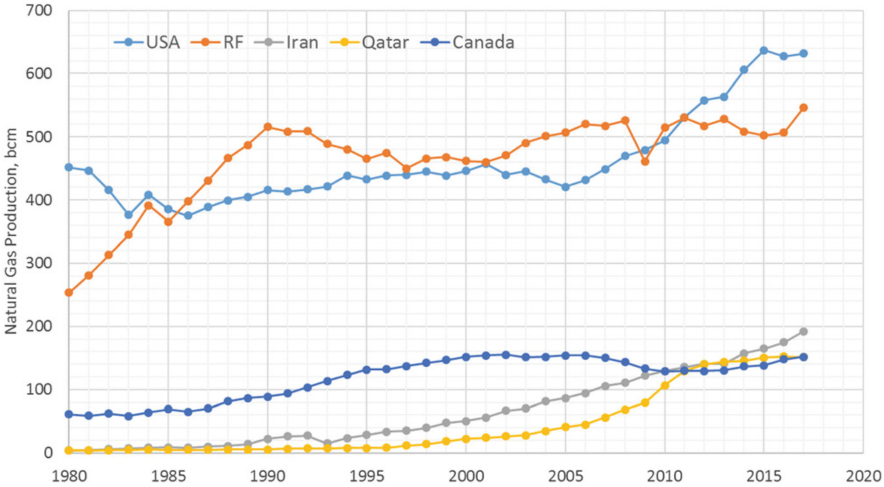

Fig. 1 Main producers of natural gas (Data is from BP Statistical Review of World Energy 2018, https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf)

processing, and consumption will create new energy geography" (Scholl and Westphal 2017, p. 9). Amidst these changes, natural gas, as the cleanest fossil fuel, offers an interim solution to move from a fossil fuel-dominated energy system to a more sustainable one, but the growth in gas demand will increase the geopolitical competition to control resources and transit routes. The USA has led world gas production growth since 2005 (Fig. 1), reaching 511.1 billion cubic meters (bcm) in 2005 and 734.5 bcm in 2017 thanks to the shale gas revolution. Russian production, meanwhile, has remained relatively flat since 1990. The combined gas output from Iran, Qatar, and Canada roughly equals that of Russia.

Besides pipeline exports to Mexico and Canada, the USA relies on seaborne tankers to ship liquefied natural gas (LNG) around the world, whose safe transit is assured by the US navy. Russia is in the early stages of exporting LNG, but it will rely on pipelines for the lion's share of its gas exports to Europe and to China, if the Power of Siberia gas pipeline comes online in 2019 as expected.

Pipelines remain the most reliable, easy-to-secure, and economic means of transporting large volumes of gas (and oil) (Luten 1971; Leal-Arcas et al. 2015). Yet cross-border pipelines are also capital-intensive projects with high operational costs and they are exposed to complex political, environmental, commercial, and legal aspects (Leal-Arcas et al. 2015). Although gas pipelines are "poorly understood and the least appreciated mode of transport" by the general public, as they are "most often underground and invisible," they are vitally important to the economies and energy security of most nations (Liu 2003, p. 9; Di Castri 2014, p. 2).

In this chapter, we examine contemporary geopolitics and the security of energy transit by pipeline, focusing on the transit of gas to Europe as a case study. In recent decades, policymakers in Europe have come to believe that commercial factors drive gas markets and that by making Europe a more free market, the continent's dependence on Russian gas can be mitigated. New LNG supplies from the USA and its allies, moreover, can increasingly substitute for pipeline gas from Russia. This outlook, however, ignores the risk of geopolitics undermining Europe's energy-supply and energy-transit security. The role of Ukraine and Turkey in this context as essential land bridges across which Russian, Caspian, Middle East and eastern Mediterranean gas can transit is fundamental, and demands that EU policymakers prioritize geopolitics in shaping energy-security strategy.

This chapter first provides a framework for understanding energy security as it pertains to transit and then a brief historical and geographic overview of natural gas transit. It moves on to analyze European strategies for gas-supply security in the context of Ukraine and Turkey. It concludes by arguing that securing gas imports by pipeline will require a deeper appreciation of the geopolitics of transit and that consumers should not assess projects solely on market considerations. The dynamics of both geopolitics and gas-transit security have changed dramatically and require policymakers to consider novel approaches.

2 Energy-Transit Security

The concept of energy security has been an important topic in the fields of science and politics since the beginning of the twentieth century, when the transition from coal to oil began (Ediger and Bowlus 2019). Winston Churchill identified the diversity of oil suppliers and supply lanes as the main concern of his oil strategy as articulated to the British Parliament in 1913 (e.g., Yergin 2006; Luft and Korin 2009; Ediger and Bowlus 2019). Since this time, consumers have sought to avoid depending on a single market and/or fuel type. Moreover, "since economic and military power depended on oil-supply security, Western governments took military and hence security-related decisions to address this concern" (Ediger and Bowlus 2019). Based on a review of the secondary literature on security, Winzer (2012, p. 41) found that the common element among definitions of energy security is the absence of protection from or adaptability to threats that are caused by or have an impact on the energy-supply chain.

However, while "security" in traditional international relations literature refers to an essentially political aspect of security, i.e., the absence of an "existential threat to survival of a state" (Buzan et al. 1998, pp. 21–23), it has in time expanded to cover economic, societal, and environmental aspects (Møller 2000, pp. 7–13). In this sense, security came to encapsulate a wider meaning in terms of the "absence of threats" (Baldwin 1997) or even sometimes the "absence of fear" (Wolfers 1962).

The most commonly used definition of energy security is the one made by the International Energy Agency (IEA): "the uninterrupted availability of energy sources at an affordable price."[1] According to the IEA, energy security has many dimensions, such as long-term energy security, dealing mainly with timely investments, and short-term energy security, which focuses on whether the energy system can react promptly to sudden changes within the supply-demand balance. According to this definition, energy security has long been considered synonymous with supply security (Winzer 2011), especially in the oil import-dependent developed world after the oil crises of the 1970s (e.g., Austvik 2016). Still, the definition of energy security is "notorious for its vague and slippery nature" (Isbell 2007, p. 3) because "it is polysemic in nature" (Chester 2010, p. 893), essentially covering the so-called four "As"—i.e., availability, accessibility, affordability, and acceptability (Cherp and Jewell 2014). The definitions are also either "so narrow that they tell us little about comprehensive energy challenges" or "so broad that they lack precision and coherence" (Sovacool and Brown 2009, p. 5). In other words, it has different meanings in different countries and contexts, depending on development levels, economies, administrative systems, energy systems, investment capacities, legal and administrative systems, rates of demand increase, and levels of dependence on foreign sources, natural resources, geography, etc. (Yergin 2006; Isbell 2007; Chester 2010). The definition of energy security, therefore, can only become more operational when it is formulated for "a specific source and country" (Yafimava 2011, p. 14).

The last decade has witnessed considerable changes in the global energy system that have made governments more influential over energy geopolitics. For instance, China's unique government-to-government energy deals have disrupted the international liberal market and endangered the energy security of all nations (Victor and Yueh 2010). Changes in international political economy, therefore, require changes in how we define energy security (Sovacool 2012). As Yergin (2006, p. 69) argued, "the subject [of energy security] now needs to be rethought, for what has been the paradigm of energy security for the past three decades is too limited and must be expanded to include many new factors." He (p. 69–71) proposed the term "demand security" for energy-exporting countries, which seek to guarantee demand for their products because energy exports generate an overwhelming share of their government revenues. This definition covers the large producers in OPEC and Russia (Victor and Yueh 2010).

Most recently, Scholl and Westphal (2017) noted that energy security needs to be reimagined in the light of changes related to the low-carbon energy transition and energy geographies. New priorities are arresting global warming and air pollution, while ensuring economic growth and energy affordability, but the question remains: "Can the world have secure, reliable, and affordable supplies of energy while also transitioning to a low-carbon energy system?" (Sovacool 2012, p. 52 and references therein). According to him, even though the 1970s oil crises shifted consumption to non-fossil fuel sources, most countries are more energy-insecure than ever before.

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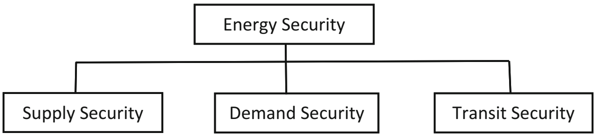
[1] https://www.iea.org/topics/energysecurity/whatisenergysecurity/

Fig. 2 Energy Security



The natural gas dispute between Russia and Ukraine, first in 2006, then more prominently in 2009, again in 2012, and ongoing since 2014, opened a new era in energy security studies. Terms such as “transit state” (e.g., Sharples 2012; Calvert 2016), “transit country” (e.g., Wigen 2012; Weiner 2016), “transiter” (e.g., Sharples 2012), “transit route” (e.g., Wigen 2012), “energy-transit corridor” (e.g., Bilgin 2010; Wigen 2012; Weiner 2016), “energy-transit diversification” (e.g., Pirani et al. 2014), and “energy-transit system” (Leal-Arcas 2015), etc. began to be used more frequently. Yafimava (2011, p. 12, 17) further defined “gas transit security” as “the acceptable level of threat of supply and price disruption arising from risks associated with the transit of gas supplies.” However, the Energy Charter (2015, p. 17) argued: “this is part of energy security of supply” and “it might be reasonable to say that there is no clear concept of energy transit security yet.” European gas-supply security, meanwhile, continues to depend on a highly volatile political relationship between Russia and Ukraine (Graaf and Colgan 2017), with Turkey serving as an alternative for gas transit from the eastern Mediterranean, Caspian, Central Asia, and all-important Middle East (Wigen 2012).

In this study, we propose “energy-transit security” to be one of three important aspects of energy security alongside “energy-supply security” and “energy-demand security” (Fig. 2). In the transportation sector, “transit security” generally means security (e.g., Burges 2013), but in the energy sector, it also pertains to “freedom of energy transit” (Selivanova 2012, p. 397), being free from “terrorist attacks or navigation accidents in the oil industry that might block tanker passage” (Henry et al. 2012, p. 3), or from “terrorist attacks on energy infrastructure and facilities” (Weiss et al. 2012, p. 34). Francés (2011, p. 54) highlighted that the “security of energy supply not only has an objective dimension in terms of dependence, vulnerability, and connectivity, but also depends largely on relations between consumers, producers and transit countries.” Energy-transit security in this article is similar to “gas-transit security,” as discussed by Özdemir et al. (2015, p. 97), and “transit security,” as discussed by Offenberg (2016, p. 1) and Scholl and Westphal (2017, p. 6).

We define energy-transit security as “maintaining a continuous flow of contracted amount of energy from producing to consuming countries in a reliable and sustainable manner.” Within this framework, energy security is “uninterruptedly maintaining energy supply, demand, and transit in adequate quantity and quality at reasonable costs/prices in an environmentally friendly manner for sustainable energy production, consumption, and transportation” (see also Ediger 2007, 2011a, b).

Pipeline security occupies a special place within the concept of energy-transit security. As stationary objects with well-known routes, pipelines and their connected pumps and other related infrastructure are particularly vulnerable to terrorist attracts and criminal violations. Not only do political insecurities and terrorist activities along the route heighten security risks, but various cases of criminal operations, such as tapping into a laid pipeline with intent to steal the transported resource, also carry the risk of damaging pipelines. Even environmental groups pose a threat to the flow of hydrocarbons through pipelines. Therefore the term "critical infrastructure security,"[2] referring to prevention of serious incidents involving airports, highways, railroads hospitals, bridges, transport hubs, network communications, electricity grid, dams, power plants, seaports, oil refineries, and water systems nationally, could be extended to cross-border pipelines and related structures.

Moreover, as fixed structures, it is difficult to create alternatives to pipelines, especially if the transited resources are landlocked. As a result, cross-border pipelines can become a source of political bargaining, threat, and pressure, if the relationship between producer, transit, and consumer countries sours. With few exceptions, international regulations and thus enforcement stipulations govern choke points in and around international straits or canals. Seaborne tankers, moreover, can be re-routed (the same could be argued for much of road and railroad-based routes), whereas pipelines, once laid down, cannot. This creates, to say the least, economic and political vulnerabilities and can become a security issue.

Critical infrastructure including pipelines are also vulnerable to various cyber threats (Dancy and Dancy 2017), as seen by the *Stuxnet* worm attack on Iranian nuclear facilities that first appeared in 2010 and reportedly caused substantial damage to Iran's nuclear centrifuges (Zetter 2014). On a cross-border level, the Baku-Tbilisi-Ceyhan pipeline, which is heavily protected against physical terrorist attacks as it passes through security-sensitive areas in Georgia and Turkey, was blown up in 2008 due by a cyberattack, causing over 30,000 barrels of oil to be lost to spillage, more than $5 million per day in lost transport tariffs for Turkey, and almost $1 billion in lost export revenues for Azerbaijan (Dancy and Dancy 2017). In a similar case, a cyberattack in April 2018 has caused the temporary disruption of natural gas in four US natural gas pipelines (Krauss 2018). Finally, pipeline defects, corrosion, and other accidental damage present pipeline-safety problems, disrupt flows, and threaten energy-transit security.

3 Brief History of Oil and Gas Transit

The geopolitics of oil-transit security through pipelines can yield insights into what might happen in gas. Both hydrocarbons began as local commodities but grew into global ones quickly. Transnational pipelines from the oil-rich Middle East as well as seaborne choke points such as the Suez Canal became critical to Europe's oil-supply

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[2] For an example of how states define and ensure their national critical infrastructure security, see the webpage of the US Department of Homeland Security: https://www.dhs.gov/what-critical-infrastructure

security. In 1956, 1967, 1970–1971, and 1973–1974, problems with oil-transit caused supply disruptions in Europe.

Though Azerbaijan was the world's first oil-producing region in the 1840s (Aliyev 1998), the oil industry, as we know, began in Pennsylvania in 1859 with the application of modern drilling techniques. From the beginning, transit limitations restricted the industry's growth, as drillers used oak barrels to deliver crude to refineries by horse and barge (Waldman 2017) until the first pipelines were built in 1862 (Waldman 2017). These early pipelines were built to transport oil short distances on land to refineries or coastal ports. For long distances, seaborne tankers were the only option, and oil shipment started across the Atlantic with the Elizabeth Watt in 1861 (Lawal 2001). Later, newly developed welding technology made leak-proof, high-pressure, large-diameter, seamless-steel pipelines possible (Liu 2003). With the application of rotary drilling techniques in 1901 and rolling cutter rock bit in 1909, oil production and refining progressed rapidly, especially after the introduction of high-pressure injection in 1913 and catalytic-cracking techniques in 1936 (Smil 2000). Major innovations in pipeline technology in the 1950s occurred alongside rising demand for oil for automobiles. Refineries began to be built near consumers rather than producers (Lawal 2001). Larger tankers were designed in the 1950s and 1960s as well as larger, longer pipelines, which allowed producers to meet consumer demand (Luten 1971). The movement of refrigerated natural gas by tankers, LNG, was also developed (Luten 1971; Smil 2000).

The USA had the longest pipeline network with 434,000 km in 1955 and 687,540 km in 1980, while the Soviet Union had the second longest with 144,000 km in 1983 (Lawal 2001). The Soviets, however, also built the *Druzbha* (Friendship) Pipeline in 1964, the world's longest oil pipeline (4000 km) to carry Soviet oil to Eastern Europe (Lawal 2001). The Druzbha system grew with the construction of parallel lines in the 1970s. Meanwhile, the competition between tankers and pipelines intensified as a result of political issues in the Middle East from the 1950s to 1970s (Bowlus 2013). Thus, tanker sizes doubled, and pipeline diameters grew to more than 50 cm in the 1980s (Smil 2000).

In the past, natural gas was often produced alongside oil by using similar technologies, but it was consumed locally, re-injected into oil fields to increase pressure, or flared (Siddayao 1997). It was introduced to world markets as a consumable energy resource much later than oil. While the USA was the first to use gas economically after World War II (Samsam Bakhtiari and Shahbudaghlou 1998), natural gas demand increased with the adoption of aircraft-derived turbines in power generation in the 1990s, creating a synergy between gas and the power sector (Jonchère 2001).

This new "power-generation revolution" coincided with the dissolution of the Soviet Union in 1991 and the opening of the Caspian basin to global producers (Aydın 2001). At this time, Russia was only exporting roughly 20% of its gas, of which 75% went through pipelines (Smil 2000). Most major pipelines were constructed either during or after World War II (Liu 2003) and most of the East-West gas trade was based on investments made during the Cold War (Austvik 2016). The largest and longest of the gas pipelines, 1.4 m in diameter and 4500 km in length, was built by the Soviet Union in 1981–1982 to carry Siberian gas to Western Europe (Smil 2000). The geographic spread of this Trans-Siberian Pipeline, a.k.a. Bratstvo (*Brotherhood*) pipeline, also had "a symbolic role in the spatial reproduction and 'rolling out' of Soviet power across Eastern and Central Europe" (Bouzarovski 2009, p. 455).

4 World Natural Gas Geography

Fossil fuels have dominated the global energy system since 1881, when the share of coal (49.6%) and oil (0.9%) exceeded wood in the total energy mix (Ediger 2011a, b). The share of fossil fuels, including gas, reached a high of 89.4% in 1973 and decreased, with some fluctuation, to 85.1% in 2017.

Among fossil fuels, hydrocarbons have dominated coal since 1959. Global hydrocarbon production slightly more than tripled during the last half century, from 2444.6 Mtoe in 1967 to 7777.8 Mtoe in 2017, but its share of total primary energy consumption declined from 66.4% 1973 to 57.6% in 2017 because of greater use of nuclear and renewable energies. During this period, oil lost 14.5% (from 48.7% to 34.2%), but gas gained 5.0% (from 18.4% to 23.4%). Also, the share of oil and gas within hydrocarbons was 72% and 28%, respectively, in 1973, and 59.4% and 40.6% in 2017. By applying simple linear regression analysis to past trends, oil and gas curves will cross around 2030.

Hydrocarbons have uneven distribution in reserves, production, and consumption (Table 1), which requires them to be traded internationally. In 2017, 61.7% of the 7108.6 Mtoe of the hydrocarbons produced were traded, 77% of which was oil and 27% gas. In 2017, 92,649 billion barrels of oil per day (bbopd) were produced and 67,592 bbopd exported, roughly 73% of the total. This share was 41.5% during the

Table 1 Five major players in the oil and gas industry, 2017[a]

	Oil			Natural Gas		
Rank	Reserve	Production	Consumption	Reserve	Production	Consumption
1	Venezuela (17.9%)	USA (14.1%)	USA (19.8%)	Russia (18.1%)	USA (20.0%)	USA (20.1%)
2	S. Arabia (15.7%)	S. Arabia (12.9%)	EU (13.4%)	Iran (17.2%)	Russia (17.3%)	EU (12.7%)
3	Canada (10.0%)	Russia (12.2%)	China (13.2%)	Qatar (12.9%)	Iran (6.1%)	Russia (11.6%)
4	Iran (9.3%)	Iran (5.4%)	India (4.8%)	Turkmenistan (10.1%)	Qatar (4.8%)	China (6.6%)
5	Iraq (8.8%)	Canada (5.2%)	Japan (4.1%)	USA (4.5%)	Canada (4.8%)	Iran (5.8%)
Total	61.7%	49.8%	55.3%	62.8%	53.0%	56.8%

[a] Data is from BP Statistical Review of World Energy 2018, https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

Table 2 Hydrocarbon net exports (export-import) of the major regions[a]

MToe	Oil	Natural Gas	Hydrocarbons	
Middle East	1106.0	101.6	1207.6	
Commonwealth of Independent States	487.0	203.2	690.2	
Africa	218.7	72.9	291.6	
South & Central America	71.6	4.7	76.3	
North America	−64.3	7.1	−57.2	
Europe	−535.0	−247.8	−782.8	
Asia-Pacific	−1284.0	−141.7	−1425.7	

[a] Data is from BP Statistical Review of World Energy 2018, https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

Table 3 Gas flows by pipeline and as LNG

Pipeline				LNG			
Exporters		Importers		Exporters		Importers	
Russia	29.1%	Germany	12.8%	Qatar	26.3%	Japan	29.0%
Norway	14.7%	USA	10.9%	Australia	19.3%	China	13.3%
Canada	10.9%	Italy	7.3%	Indonesia	5.5%	S. Korea	13.0%
Total Traded Volume: 740.7 bcm				Total Traded Volume: 393.4 bcm			

oil price collapse in 1986 and has been growing. On the other hand, only 30.5% of the 3551.6 bcm of gas produced was traded in 2017. This share has also been growing.

The major hydrocarbon exporting and importing regions are shown in Table 2. The major transit of hydrocarbons occurs: (1) from the Middle East to Asia Pacific, (2) from CIS to Europe, and (3) from South and Central America to North America. Oil and gas trade is usually made from neighboring countries by pipeline and from distant countries by tankers.

Similarly, pipelines or seaborne tankers transit gas (Table 3). In 2017, the total traded volume of gas was 1134.1 bcm, of which 62.1% was by pipelines (740.7 bcm) and 37.9% was LNG (393.4 bcm).

Europe imported 423.4 bcm of pipeline gas in 2017, which constituted 57.2% of the total pipeline gas trade. It met 47.3% of its gas demand from the neighboring countries (Norway 25.8%, Netherlands 10.2%, UK 2.6%, and other European countries 3.3%) and the rest from Russia (50.9%), Algeria (7.8%), Iran (2.1%), Azerbaijan (2.0%), and Libya (1.0%). North America imported 19.8% of the total traded pipeline gas. The USA imported 80.7 bcm (10.9%) from Canada, and exported 42.1 (5.7%) to Mexico and 24.0 bcm (3.2%) to Canada. The Asia-Pacific region imported 8.4% of total pipeline gas trade, with volumes coming largely from Turkmenistan (50.4%), Myanmar (18.2%), and Indonesia (12.7%). By volume, the largest importers were China with 39.4 bcm, Singapore 8.9 bcm, Thailand 8.2 bcm, Australia 5.8 bcm, and Malaysia 0.7 bcm. On the other hand, 393.4 bcm of the traded gas in 2017 was LNG, of which 72.1% was imported by Asia-Pacific (283.5 bcm).

Of this amount, 26.7% came from Australia, 24.5% from Qatar, 12.7% from Malaysia, 7.5% from Indonesia, and 5.4% from Russia. Japan was the largest LNG importer at 113.9 bcm, followed by China (52.6 bcm), South Korea (51.3 bcm), and India (25.7 bcm).

5 Pan-European Geo-Energy Space

The European Union consumed 1689.2 Mtoe of primary energy in 2017, constituting 12.5% of the world's energy consumption (BP 2018), third after China (3132 Mtoe) and the USA (2235 Mtoe). Its energy mix is composed of 75.9% fossil fuels (38.2% oil, 23.8% natural gas, and 13.9% coal), 11.1% nuclear, 4.0% hydro, and 9.0% other renewables. On the other hand, the EU's primary energy production (PEP) was only 709.4 Mtoe, of which 26.5% is nuclear, 21.5% renewables, 18.4% coal, 14.3% gas, 9.6% hydro, and 9.8% oil. Europe's PEP has been decreasing since 1996, while its primary energy consumption (PEC) has been decreasing only for the last decade. As a result, Europe's production as a share of its consumption has stabilized between 43% and 44% (Fig. 3). From 2006 to 2017, the EU's PEC decreased 10.2% from 1830 Mtoe to 1689.2 Mtoe, but its PEP decreased 13.3% from 825 Mtoe to 709.4 Mtoe. Domestic PEP met only 42.0% of the EU's demand, making the EU the largest net importer of primary energy in the world

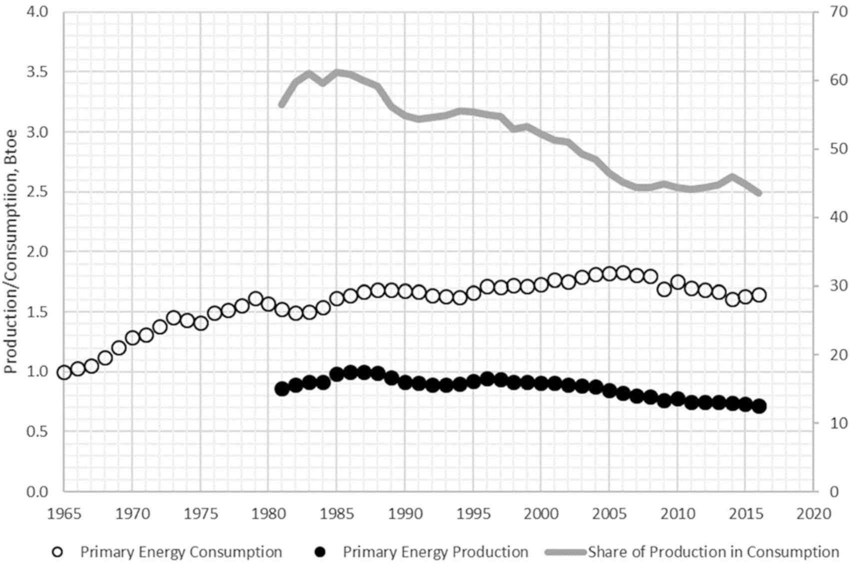

Fig. 3 EU primary energy production, consumption, and shares (Data from BP, 2017) (Data is from BP Statistical Review of World Energy 2018, https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf)

(Eurostat 2018). The energy dependency rate of the EU-28 has also, it should be noted, exceeded 50.0% since 2004.

This situation is partly attributable to the exhaustion of domestic supplies (in the case of gas, the Netherlands) and producers considering the exploitation of limited resources uneconomical (Eurostat 2018). The EU external energy bill represented more than €1 billion per day in 2015 (around €400 billion in 2013) and more than a fifth of total EU imports. The EU imported more than €300 billion of its crude oil and oil products, of which one-third was from Russia. These figures suggest that the EU's import dependency will not decrease, and may well increase, in the near future (Eurostat 2018).

Nearly 80% of the EU's hydrocarbon imports are from its neighbors, Russia and Norway. Russia was still the main supplier of gas with a share of 40.6% of the total in the first quarter of 2018, and of oil with 28% of the total (Eurostat 2018). From 2005 to 2018, Norway was the second-largest supplier, and its share rose during this time. The share of the EU's gas supplies from Algeria declined by half from 2005 to 2018, whereas the share from Qatar rose almost fivefold. Worse than this, 90.1% of the EU-28's gas imports in 2018 came from Russia, Norway, or Algeria (Eurostat 2018). In 2017, total natural gas imports were 1134.1 bcm (65.3% pipeline and 34.7% LNG), consisting of 30.9% of global gas consumption (BP 2018). The European Commission (2014) recognized the EU's dependency on Russian energy in its communication to the European Parliament and the Council, entitled "European Energy Security Strategy":

> The most pressing energy security of supply issue is the strong dependence from a single external supplier. This is particularly true for gas, but also applies to electricity: six member states depend on Russia as a single external supplier for their entire gas imports and three of them use natural gas for more than a quarter of their total energy needs. In 2013, energy supplies from Russia accounted for 39% of EU natural gas imports or 27% of EU gas consumption; Russia exported 71% of its gas to Europe with the largest volumes to Germany and Italy.

The disruptions of gas supplies transiting through Ukraine during the winters of 2006 and 2009 brought the issue of energy-transit security sharply into focus (Leal-Arcas et al. 2015, p. 123). It was described as a "wake-up call" in the European Energy Security Strategy (European Commission 2014). Since 2009, the EU has strengthened its gas-supply security and reduced the number of countries that depend solely on Russia. It has also developed new pipeline strategies that aide oil and gas import-dependent members, especially those considered politically, economically, and socially unstable, and bypass transit countries such as Ukraine with offshore pipelines (Offenberg 2016). Russia, for its part, has tried to avoid binding agreements with the EU, cultivate bilateral relations with individual states, and improve energy relations with the EU by proposing multilateral agreements (Kononenko 2009).

The threats of energy security and the geopolitics of energy transit, however, were foreseen prior to 2006, in a 2004 report by the Clingendael International Energy Program for the Directorate-General for Mobility and Transport. The report asserted a direct relationship between the EU's security of supply and geopolitics: "the socioeconomic and political context of the system of energy supply has an impact in the degree to which oil or gas can be made available in sufficient quantities and at affordable prices" (Van der Linde 2004, p. 84). The report then studied two storylines: "M&I: Markets and Institutions" and "R&E: Regions and Empires." M&I represents "a continuation and intensification of markets (globalization) and the continued co-operation in the intra-national political and economic institutions" in the EU. R&E, on the other hand, refers to "the break-up of the world into integrated political and economic blocks with satellite regions that compete for markets and resources with other blocks." R stands for "regionalism" in the literature, while "empires" refer to a neorealist, state-security-centered competition for power (Walts 1979). The report maintained that the USA had already shifted from M&I to R&E, but that Russia and China seemed to be vacillating between the two approaches, while the EU was firmly entrenching in M&I. The EU, it argued, required a paradigm shift. Correlje and Van de Linde (2006, p. 532) concurred:

> The present world tends towards Regions and Empires and suggests that the EU may have to reorient its energy security policy. Energy policy must become an integral part of EU external trade and foreign relations and security policy. The EU should develop its own strategy, actively investing in dialogues with producer countries in the Persian Gulf and Africa and with Russia.

Mañé-Estrada (2006, p. 3781) also proposed, using the same approach, a new geographical area with a governance structure called "pan-European geo-energy space." She defined a block, by way of analogy with the classical vision of geopolitics as:

> A geographical space where a precise set of energy relationships take place, among different agents—producer states, enterprises and consumer governments—who are active within it and whose borders are wider than those of the present-day European Union—the current EuroMediterranean and the eastern EuroAsian territories.

She argued that the EU should "encourage the creation of an energy community in the wider European area, as a new way of understanding energy policies." Similarly, Francés (2011, pp. 54–55) suggested that the EU should apply the strategy of Europeanization of neighboring countries to the different energy corridors supplying Europe, but this strategy poses "serious difficulties at the political and institutional levels." In addition, bilateral agreements between producers and EU member states are usually criticized, such as the Nord Stream agreement between Germany and Russia.

Yet these studies have not changed EU energy policy because countries are most concerned about national energy interests and perceptions of Russia's motivations in bilateral relationships (Austvik 2016). Some Central and Eastern European states perceive energy security a priority for the EU's common foreign and security policy, but most prefer the M&I approach. In 2011, Jerzy Buzek, former President of the European Parliament, and Jacques Delors, former Commission President, criticized the excessive focus on the regulatory issues and called for a "politicization of EU energy policy." They proposed creating a European Energy Community with a stronger emphasis on the challenges of supply security (Buzek 2011). Nevertheless, neither the Commission nor its member states showed much interest (Austvik 2016).

Later, in 2014, former Prime Minister of Poland and later EU President, Donald Tusk proposed creating an Energy Union "to strengthen policy and expand goals and measures to meet security-of-gas supply concerns" (Austvik 2016, p. 372). Tusk argued that climate and environmental policy received too much attention in the EU's energy policy. Finally, Scholl and Westphal (2017, p. 9) noted that "infrastructure, the physical framework for energy regions, is rapidly developing and changing the energy landscape, requiring the EU to (re) position and adapt to new topographies and (potentially) an increasingly heterogeneous and competitive energy environment."

6 Two Main Energy-Transit Countries

The Middle East is the most important region for seaborne transit of gas because of its location between Europe, Africa, and Asia (Mills 2016). Ukraine and Turkey, on the other hand, are the two most important transit countries for natural gas pipelines coming from the eastern producing regions—the Caspian Basin, Russia, and the Middle East—to Europe (e.g., Raszewski 2013; Aktürk 2008; Leal-Arcas et al. 2015; Pirani et al. 2014; Scholl and Westphal 2017).

6.1 Ukraine

Ukraine has been the historic node for the transit of Russian oil and gas to Europe, beginning in 1964 with the Druzhba oil pipeline. Thereafter, three major gas pipelines (Brotherhood, Soyuz, and Trans-Balkan) were constructed through Ukraine, making it essential to the Soviet Union's energy-demand and energy-transit security by the 1980s (Högselius 2012). The dissolution of the Soviet Union did not imperil these flows, even if gas production in Russia slacked during the 1990s. For a number of domestic political reasons, however, Ukraine began building ties with its non-Russian neighbors (Balmaceda 1998). Then, when Putin assumed power in 2000, it became clear that he would reassert Russia's dominance over its former satellite (Smolansky 2004). Russia had, in fact, already begun to strengthen its position in 1999 with the completion of the Yamal-Europe gas pipeline through Belarus, which bypassed Ukraine. The success of Russia's strategy to diversify its transit options was clear in the early 2000s (Hirschhausen et al. 2005) and laid the foundations for the strategies it would execute following the 2004–2005 Orange Revolution in Ukraine.

Russia's "loss" of Ukraine motivated it to reveal "Ukraine's unreliability and/or inability to provide for secure transit" (Westphal 2009, p. 12) and to build new pipelines—Nord Stream and South Stream—to diversify its pipeline exports to

Europe, its primary market (Henderson 2016). The EU and the USA began to devise ways to reduce Europe's dependence on Russian pipeline gas after 2006, but concrete action was not taken (Cohen 2006) until the 2009 disruption, which galvanized Europe to diversify its suppliers, reduce its demand, and introduce legislation, including the Third Energy Package in 2011, all to curtail Russia's dominant position and create a competitive marketplace (Kovacevic 2009; Henderson 2016). Russia, meanwhile, completed the Nord Stream pipeline by 2011, which could transit 30% of its European-bound imports. Both the EU and Russia have, then, partially addressed their common energy-transit problem in Ukraine, but the disruption of supplies during the run-up to presidential elections in Russia in February 2012 revealed that the problem was far from solved (Henderson and Heather 2012).

The outbreak of political and military conflict in Ukraine in 2014 only intensified EU concern about Russian gas. Meanwhile, the Third Energy Package has put the EU in a stronger position to negotiate its terms with Russia, as has the global surge in LNG supplies (Skalamera 2015). It succeeded in forcing Russia to redirect South Stream through Turkey, lest Russia allow third-party access. Since 2012, Russia has also been working to construct a second, parallel pipeline to Nord Stream, which would double the total capacity of the system from 55 bcma to 110 bcma. Germany started its own construction of the pipeline in May 2018 (EUObserver, 4 May 2018). Nord Stream II has divided Europe between the German-led M&I approach and the Central and Eastern European-favored R&E approach. The former sees more pipelines from Russia as a diversification of routes that enhances the EU's energy security, particularly as market mechanisms prevent Russia from monopolizing the use of any new pipelines. The latter, however, argues that more pipelines will only increase the overall volume of Russian gas in Europe and Russia's geopolitical leverage over the continent.

6.2 Turkey

Turkey has steadily grown as a transit country for Middle East, Caucasian, and possibly eastern Mediterranean hydrocarbons heading to Europe, especially after the Caspian rush of the 1990s (Ruseckas 2000). Its cross-border transit pipelines to Europe now include the Kirkuk-Ceyhan pipeline (Iraqi oil), the Baku-Tbilisi-Ceyhan pipeline (Azeri oil), Baku-Tbilisi-Erzurum pipeline (Azeri gas), and the Trans-Anatolian pipeline or TANAP (Azeri gas) (Akdemir 2011). The first leg of the Turk Stream pipeline (Russian gas) was completed in November 2018, with first gas is expected in late 2019. It is unclear whether Turk Stream will transit Russian gas to southeastern Europe in the future and compete with TANAP.

Turkey is eager to expand its transit profile to increase its geopolitical prestige and earn transit fee revenues. Due to the highly concentrated nature of Turkey's suppliers of oil and gas from Middle East countries and Russia, respectively, Turkey would benefit from diversifying its source base from both pipelines and LNG (Arslan-

Ayaydin and Khagleeva 2014). As also correctly indicated by Pamir (2009, p. 260), "although Turkey's geography offers a very advantageous and unique potential to make it an energy bridge, energy policy errors over the last decades have limited this potential to a certain extent."

For nearly a decade, Turkey has talked of becoming an energy hub, for which it is geographically well suited, but lacks the requisite free market ethos, legal protections, and liquidity of supply (Roberts 2010). Turkey seeks to "exercise influence based on its strategic geopolitical position between an energy-hungry Europe and energy-rich regions to the east and south" (Scholl and Westphal 2017, p. 14). This requires a challenging, delicate set of compromises in Turkey's domestic and foreign affairs, not least because its gas demand has grown steadily over time. Unfortunately, neither the Strategic Plan (2010–2014) of the Ministry of Energy and Natural Resources (MENR 2014), nor the Ministry of Foreign Affairs (2014) and BOTAŞ, the state-owned oil and gas company, consider gas-transit security as factor in their strategies (Energy Charter 2015). Comments by the Minister of Energy in 2017 raised concerns of supply diversification and advocated the contradictory goals of switching from gas to coal and renewables, but also becoming a natural gas trading center (Rzayeva 2018). These goals are unattainable and at odds unless Turkey considers gas-transit security.

The EU understands Turkey's importance as a transit country but is weary of its volatile internal politics and those of its neighbors, notably in the Caucasus, Ukraine, Iraq, and Syria. The country's geography is suitable for gas transit to Europe, but the problem remains that the EU wants to implement energy *acquis* in supplier and transit countries via the Energy Community (Offenberg 2016). Although Turkey is not an Energy Community Contracting Party (Weiner 2016), Mañé-Estrada (2006, p. 3784) contends that within the hypothetical pan-European geo-energy space, Turkey is "the most valuable instrument of energy policy" because of its geography and the gas sector's importance, even if others doubt whether or not Turkey belongs to the same geopolitical space as the EU.

Russia has been cultivating Turkey as a partner in energy cooperation for some time, although it has historically been a Russian competitor for transporting gas to Europe (Kardaş 2012). TANAP can also become a conduit for gas from several other countries, most notably northern Iraq. Russia's annexation of Crimea in 2014 and the subsequent Western sanctions reinforced Turkey's position as a transit competitor to Russia (Tagliapietra 2014). However, after nine months of unforeseen difficulty in Russian–Turkish relations due to Turkey's shooting down of a Russian fighter for violating Turkish airspace over the Turkey–Syria border, Russia shifted its southern strategy in 2016, mended Turkish–Russian relations, and as a result of barriers created by EU regulations on South Stream, abandoned the pipeline and replaced it with Turk Stream to bypass Ukraine (Weiner 2016). By doing so, Russia drew Turkey into its orbit of gas-export pipelines to Europe and deepened Turkey's own dependence on Russian gas—Turkey's reliance on Russian gas is second only to Germany—and diminished its capacity to compete and offer diversified routes and sources of gas for Europe.

Turkey is now balancing its gas-transit policy among three strategies: aiding Russian gas flows to Europe through Turk Stream, growing LNG supplies from the USA and its allies, and serving as a transit state for new cross-border pipelines from the Levant, Persian Gulf, and Caspian to compete with Russia (Austvik and Rzayeva 2017). The primary factors shaping these strategies are geopolitical, not commercial: stabilizing Syria and Iraq, improving relations between Israel and its neighbors as well as Turkey, solving the Cyprus dispute in the Eastern Mediterranean, and navigating relations with Russia and the USA, among others.

7 Discussions and Conclusions

Energy markets change rapidly, and developments currently shaping the global availability and consumption of natural gas are wide-ranging. None is more important than the growth in global gas supplies from the USA and its allies including Australia, Canada, and Qatar, which will need to be transported by seaborne tankers as LNG over choke points and sea routes protected by the US navy. These supplies portend that Europe will increasingly substitute LNG for Russian pipeline gas while it transitions away from fossil fuels.

In addition to ample new supplies, there are reasons to believe that commercial factors will drive the construction and smooth operation of gas pipelines going forward, not least because both producers and consumers are committed to their success. This common reliance, or interdependence, was critical, for instance, in forging initial gas ties between the Soviet Union and Europe during the Cold War (Högselius 2012). Grigas (2017, pp. 276–278) believes that commercial factors, backed by “American leadership and preference for free energy trade,” will ascend over strategic ones due to a new, more supple and flexible market with more diversified sources that fosters an “interconnectedness and interdependence between the importing or exporting state on the one hand and the global gas market on the other.”

Yet the current buyer’s market in gas can quickly turn into a seller’s market, even if supplies are ample. What happens when prices rise and suppliers gain leverage over the market, like they did from 2006 to 2014? LNG may seem to offer a silver bullet for pipeline-dependency challenges, but it will remain meaningfully more expensive than pipeline gas. Cheap prices since 2014 have been a windfall for LNG’s growth worldwide, but these could well rise again in light of the expected increase in demand.

More importantly, interdependence can cut both ways. If market forces ascend, interconnectedness will become less powerful. Fewer bilateral relationships will be underpinned by massive investments in gas-transit infrastructure, upon which the supplier relies for its gas-demand security and the consumer for its gas-supply security. This dynamic could produce more geopolitical volatility (Shaffer 2011). A more diverse set of transit routes can, moreover, undermine single routes that are functioning well. Transit states have incentives not to disrupt the flow of gas through pipelines because they gain foreign direct investment, transit fees, and gas-supply security if they are an off-taker from the pipeline (Stevens 2008), but they can still disrupt pipelines for political reasons. In general, the more pipeline options there are, the greater the possibility of a disruption in one of them. As we saw in Ukraine, and can envision in Turkey, an energy crossroads can become a roadblock.

North America has a certain interdependent logic undergirded by geography and the North American Free Trade Agreement. It also lacks geopolitical volatility. In this context, the M&I strategy for managing growing volumes of gas trade is suitable. But the rest of the world will need more cross-border pipelines to bring gas from and through geopolitically volatile parts of the world if gas is to grow and meet the needs of the low-carbon energy transition. Gas-transit security will therefore require close attention to geopolitics and policymakers to embrace the R&E strategy. Producers and consumers of gas alike must increasingly look to gas-transit security to protect their economic futures.

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Tapping the Potential: Turkey and Renewable Energy Sources

Wietze Lise and Banu Bayramoğlu-Lise

Abbreviations

BP	British Petrol
EIA	Energy Information Administration
EMRA	Energy Market Regulatory Authority
EU	European Union
FIT	Feed-in tariff
GDRE	General Directorate of Renewable Energy
IEA	International Energy Agency
mtoe	Million tonnes of oil equivalent
NREAP	National Renewable Energy Action Plan
PV	Photo Voltaic
RES	Renewable Energy Source
REZ	Renewable Energy Zones
SWH	Solar water heaters

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1 Introduction

The objective of this chapter is to assess the contribution and role of NREAP in connection with Turkey's RES potential and goals. We then present the latest developments regarding RES in Turkey, and the relevant literature is discussed and critically assessed. Finally, the chapter summarizes the proposed measures to reach the RES targets and discusses whether additional measures will be needed.

The international system is faced with an ever-increasing energy demand and is dominated by competition and conflicts among the nations regarding access to a consistent supply of energy. Since the energy demand is expected to increase by another 33–48%[1] (EIA 2016; BP 2016; IEA 2015) until 2040 worldwide, it can be expected that this trend can cause further critical energy security challenges among the world nations. Moreover, provision of energy supply has major negative environmental impact, such as air/water pollution and climate change. Under these circumstances, tapping the RES potential and finding a secure, affordable/competitive and sustainable (minimizing environmental impacts) supply of energy has become inevitable for humanity (see Fig. 1). Moreover, this is also the seventh sustainable development goal of the United Nations, entitled as "ensure access to affordable, reliable, sustainable and modern energy for all" (UN 2018).

Figure 1 shows the trade-off that exists among three policy goals: security of energy supply, competitiveness, and sustainability. Renewable energy certainly contributes to security of energy supply and sustainability, and due to recent rapid reduction in capital expenditures, e.g. solar panels, they have become affordable as well. Therefore, the promotion of renewable energy can be recommended as perfect solution to strike a balance among these three policy goals.

Cheaper, continuous and non-polluting energy sources are indispensable for sustainable development of nations. Renewable Energy Source (RES) technologies integrate many short-term and long-term advantages such as promoting sustainable development, decreasing climate change impacts, providing environmental benefits, enhancing healthy living conditions, creating new job alternatives and motivating social, and political and energy security. Therefore, countries increasingly attempt to enlarge their RES share in their total energy generation. There are various political tools such as RES targets, subsidies, and legislation that countries try to develop in order to reach desirable levels of RES generation. However and unfortunately, even the developed countries of the world could only develop their RES potentials to a rather limited extent.

The Paris Agreement, which aims at strengthening the global response to the threat of climate change by keeping a global temperature rise this century well below

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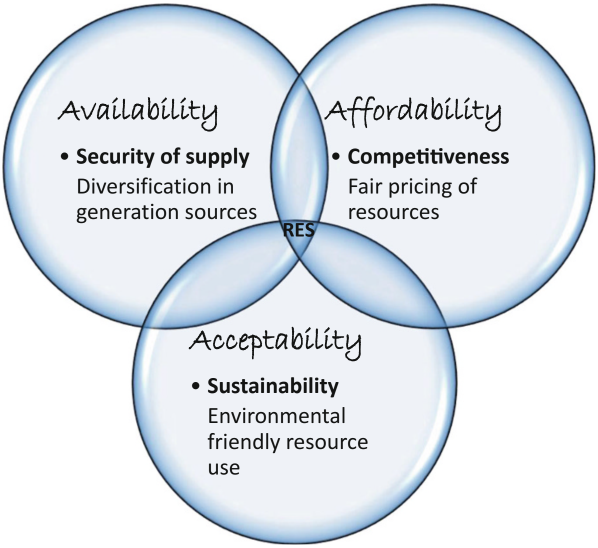
[1] EIA (2016) projects an increase of 48% between 2012 and 2040 in total world consumption of marketed energy in their International Energy Outlook 2016. BP (2016) projects an increase of 34% between 2014 and 2035 in energy consumption in their Energy Outlook. IEA (2015) states that energy use worldwide is set to grow by one-third to 2040 in their central scenario in their World Energy Outlook.

Fig. 1 Policy goals for energy supply; the "triple-A" nexus



2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C, is another development in the combat against global warming and climate change. Although countries such as US plan to withdraw from the agreement, this cooperation is still the first attempt to bring binding targets in reducing fossil fuel usage and decreasing greenhouse gas emissions. In order to achieve the goals of such an agreement radical and urgent changes are required in terms of tapping into RES.

Turkey's power demand is rapidly increasing, namely 6.5% on average over the past 30 years and 4.6% over the past 10 years (TEIAS 2018a), which is mainly driven by population growth, namely 1.5% annually both over past 10 and past 30 years (WB 2019), and the continued high economic growth in the country, namely 4.0% on average over the past 30 years and 5.0% over the past 10 years (TCMB 2018). This demonstrated the need for new and clean energy generation alternatives and improving energy efficiency. Eco-friendly and environmentally acceptable methods of energy generation should be a priority in national energy policy development in Turkey. Consequently, Turkey has to significantly and consistently develop its RES potential as well.

Turkey has very suitable geographical characteristics for the access to valuable RES. As far as wind, solar, geothermal, and hydropower energy sources are concerned, Turkey has a greater potential as compared to many other developed countries. However, in order to utilize these potentials, Turkey is in need of developing and implementing strategic and consistent energy policies.

Turkey has set a target of reaching 30% energy generation from RES by 2023. The main reason for setting a target for 2023 is that the Turkish Republic will celebrate 100 years of existence in 2023. This was already part of the energy supply security paper (SPO 2009) and has been repeated both in the 2015–2019 strategic plan (MENR 2014) and in the National Renewable Energy Action Plan (NREAP) for Turkey (EBRD 2014). The NREAP has been developed for Turkey in connection with the integration process into the European Union (EU). If the target will be reached, an increase in the installed capacity of RES will be needed, which will also lead to an increase in employment related to RES in Turkey. Another general driver is that the share of natural gas in energy generation should be reduced from 48% in 2014 to 30% in 2023.

There are various estimates for the RES potential in Turkey. According to the General Directorate of Renewable Energy (GDRE), the total RES energy generation potential is approximately 1.6 times current demand. The largest potential is found with hydro, followed by wind and solar Photo Voltaic (PV). At present, about 20% of the total economic RES potential has been exploited. There are various factors that can influence the exploitation of the RES potential. However, there are also various barriers in the way of reaching the RES potential in Turkey, and these are generally in line with the barriers found elsewhere, like in the EU. Among the main barriers are administrative hurdles, grid connection, and lack of information, and awareness of the RES benefits. Moreover, new technological developments can lead to more efficient ways to utilize RES, which will increase the overall RES potential.

This chapter highlights the need to further utilize RES in order to reduce negative impacts on the environment. The chapter assesses the current deployment of RES and summarizes the RES economic potential. There is a clear gap between RES potential and realized amount of RES. To realize this RES potential, there are various barriers, which are also mentioned in the literature survey. This chapter provides also some anecdotal evidence to explain delays in developing Wind and Solar PV, whereas Solar Water Heaters (SWH) can be considered a success-story for RES-heat development.

The outline of this chapter is as follows. A literature survey is undertaken in Sect. 2 on RES potential and goals. Section 3, provides an overview of RES generation, potential and targets. The barriers toward RES development are identified in Sect. 4, which also discusses the recent experience with RES development in Turkey. The final section concludes that RES targets can be reached only if hard and consistent work and policies are continued in Turkey.

2 Literature Review

There are various studies which have focused on Turkey's RES issues. These studies have analyzed in detail the current situation of different RES potential and deployment in Turkey, such as wind, solar, hydro, geothermal, etc. This section provides an overview of the literature about the assessment of RES potential in Turkey and the reachability of the set RES targets.

Concerning local brown coal or lignite, a recent proposal for government support for additional investments stands out. In their study, Yenigun and Schlissel (2016) argue that coal has lost its favor in the global market, where the (stock) value of coalfired power plants has plummeted by 60–100%. This is, among others, driven by the recent greenhouse gas reduction agreement in Paris of December 2015. They argue that RES will become more and more popular, and the countries that embrace RES generation will gain a competitive advantage in the near future. In addition, Acar and Yeldan (2016) study the environmental impact of coal subsidies in Turkey. They conclude that by eliminating coal subsidies the level of CO_2 emissions will decrease substantially as well. The current policy in Turkey to support local lignite is, understandably, driven by the need for increase security of energy supply. However, security of energy supply can also be obtained through accelerated RES development. Turkey has a high RES potential, whereas nearly three-quarters of its energy needs are still being imported (Akan et al. 2015). Another interesting link is between RES production and economic growth. Bulut and Muratoglu (2018), however, do not empirically confirm the existence of such a relation. Kok and Benli (2017) argue that both nuclear and RES are needed for security of energy supply and to boost economic growth in the long term to reduce Turkey’s budget deficit.

The importance of RES is also recognized by Delibalta (2016), who argues that the recent focus on the three pillars of natural gas, coal, and dam hydro should be extended by other RES and nuclear energy sources as well. The recent strengthening political ties between Turkey and Russia would increase the importance of nuclear and natural gas, which competes with budgets available for RES development. Melikoglu (2016) estimated that the cost of RES investments would average 61 billion US$ to fulfill the 2023 energy targets for Turkey. Moreover, Melikoglu (2016) adds that it will not be easy for Turkey to reach these targets and he expects a delay in reaching the goals. The need for reducing the dependence on energy imports is also stressed by Kok (2015). He states that Turkey is situated geopolitically at a very important location and can become an energy hub with energy transport gateways. Both Melikoglu (2016) and Kok (2015) stress that the government has to stay committed for the coming years to be able to achieve its visions and targets.

Positive developments have been obtained over the past decade in Turkey regarding RES development and manufacturing. According to Tukenmez and Demireli (2011), the legal aspects of the RES issues are well covered. Turkey wishes to develop its RES potential in a cost-effective manner, and the Turkish government so far focused especially on electricity. Recently, more attention is given to solar and geothermal resources. Tukenmez and Demireli (2011) state that for meeting the target of 30% energy generation from RES by 2023, the support system for RES from electricity relies on feed-in tariffs (FITs) for different RES. Some barriers to the development of RES potential in Turkey are given, such as social acceptance, lack of education and training, administrative problems, and obstacles to grid access.

Regulations and incentives have been developed in Turkey since 2005 by the enactment of Law No. 5346 and restructuring it by Law No. 6094 in 2010. This has regulated the ease of land acquisition and FITs (Baris and Kucukali 2012). Issues such as supporting local production of RES equipment, providing diversity of resources, encouraging solar energy use, providing resource diversity in oil and natural gas, increasing energy efficiency, and introducing Turkey as an energy corridor. are the main priorities in energy policy of Turkey (Basaran et al. 2015).

Concerning wind, Turkey has a much higher potential as compared to many other developed countries (Kaplan 2015). There is no power generation from offshore wind turbines, in spite of the fact that Turkey is surrounded by seas on three sides with a coastline of about 8000 km in length. Slow administrative procedures and, until recently, perceived low FIT to promote wind energy can be considered as the main impediments against efficient wind energy generation and usage in Turkey. The same holds true for other RES technologies, where Turkey again is blessed with a high RES potential, as compared to the European Union Member States (Baris and Kucukali 2012). The authors find it a shortcoming that the FITs take into account the reservoir area instead of installed capacity for hydroelectric power plants. This has led to a problem in early 2016, when 4000 MW of such reservoir type hydro switched to FIT benefits, due to low prices in the spot market. They also point out that the law had a good impact on the diversification of FIT amounts offered for various RES.

3 RES Generation, Potential, and Targets in Turkey

In this section, we will assess the RES potential of Turkey. The situation of 2017 for installed capacity and generation by technology in Turkey is given in Table 1.[2] By using the following formula, it is possible to derive the average capacity factor that has been obtained for each fuel:

$$Capacity\ Factor = \frac{Generation}{Installed\ Capacity \times 8.76}$$

It can be seen from Table 1 that the average capacity factor for fossil fuels is exactly twice as high as for RES. For that reason, although the share of installed RES capacity is already 46%, it only achieves a share of 30% in total generation in Turkey. If we compare this with the shares as found elsewhere, we see that Turkey is perfectly in line with the EU, which has also achieved 30% in 2017, whereas the USA is lagging with 17%.

According to General Directorate of Renewable Energy (GDRE 2016), Turkey's potential for different RES is as follows:

- There is a theoretical potential of 433 TWh and technically feasible potential of 216 TWh of hydro. There is an economically feasible potential of 160 TWh for reservoir type hydro energy, of which 41.3 TWh was generated in 2017. Run-of-river hydro has an economic potential of 38 TWh/year of which 16.9 TWh was

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[2] We note here that reservoir hydro has been considered as RES, which is the convention that is also used in the NREAP for Turkey. It is often challenged to consider dam hydro as RES, because of its invasive and irreversible impact on the environment.

Table 1 Installed capacity (end 2017) and generation (JAN-DEC 2017) in Turkey; share of RES in the EU and USA in 2017

Source	Generation (GWh)	Installed capacity (MW)	Capacity factor (%)
Non-RES technology:	–	–	–
FO, DO, Naphtha	1200	380	36
Coal, Lignite, Asphaltite	97,476	19,308	58
Natural gas, LNG	110,490	26,596	47
Sum	**209,166**	**46,284**	**52**
RES technology:	–	–	–
Reservoir hydro	41,296	19,776	24
Run-of-river hydro	16,923	7497	26
Wind	18,508	6516	32
Geothermal	5523	1064	59
Biomass and waste	2972	642	53
Solar PV	2889	3421	10
Sum	**88,111**	**38,916**	**26**
RES share in Turkey	**30%**	**46%**	–
RES share in EU28	**30%**	–	–
RES share in the USA	**17%**	–	–

Source: TEIAS (2018a), Sandbag (2018), EIA (2018)

Note: Generation for reservoir and run-of-river hydro are given jointly, and generation for Wind and Geothermal are also given jointly. To arrive at the breakdown, the amounts are taken proportional to hourly sales on the spot market, which has values that are somewhat lower than the total amounts per technology

generated in 2017. In total, Turkey has approximately 16% of the Europe's economic hydro potential.

- Wind has an estimated economic potential of 48 GW (38 GW onshore and 10 GW offshore installation), based on the wind atlas as prepared by GDRE. The target is to achieve an installed capacity of 20 GW by 2023. Installed capacity as of end 2017 is 6516 MW, whereas 3355 MW is currently under construction (EMRA 2018).
- There is about 380 TWh of solar energy potential (Turkey Solar Energy Potential Atlas-GEPA, 2010) from an average annual total sunshine duration of 2640 h (Daily total is 7.2 h), and average total radiation of 1500 kWh/m^2-year (Daily total is 4.1 kWh/m^2). Of this, about three quarters is suitable for heating (24.4 mtoe per year), and the remaining quarter is suitable for power generation (8.8 mtoe or 100 TWh per year). By end 2017, there is 3421 MW installed capacity of solar PV in Turkey, while another 1305 MW solar PV capacity is added in the first half of 2018, most of these are unlicensed with project sizes up to 1 MW, while 30 MW of licensed solar PV is under construction (EMRA 2018). Evaluations of applications for licensed solar PV systems are ongoing in Turkey.
- There is a biomass potential from 4.8 million tons of biomass from forests, and over 15.3 million tonnes of agricultural waste having a total calorific value of 303 PJ. In total, biomass potential of Turkey is around 8.6 mtoe, whereas the

Table 2 RES potential in Turkey for power and heating

Source	Generation (TWh)	Capacity (GW)	Assumed capacity factor (%)
Reservoir hydro	160	61	30
Run-of-river hydro	38	14	30
Wind energy	126	48	30
Solar energy (power)	100	57	20
Bioenergy	31	5	70
Geothermal (power)	25	4	70
Total power potential	**479**	**189**	–
Geothermal (thermal)	193	31	70
Solar energy (thermal)	280	160	20
Total heating potential	**473**	**191**	–

Source: ECS (2014)

potential for biogas is around 2 mtoe, this potential also includes landfill gas to power (Lise 2017). This could support around 5000 MW of installed capacity. By end 2017, there is a 642 MW installed capacity of various types of Biomass in Turkey.

- There is 31,500 MW geothermal potential for heating purposes. The target for geothermal has recently been increased from 1 GW by 2023 to 4 GW by 2030, due to accelerated exploration activities in Turkey (Thinkgeoenergy 2018). We use this estimate as the economic potential for geothermal power. Of this, 1064 MW was in operation by end of 2017. Moreover, 174 MW of geothermal is under construction. There are about 190 geothermal fields, 17 of which have a potential that is suitable for power generation.

A set of estimates of achievable potential is summarized in Table 2 and illustrated in Fig. 2 with RES potential for Turkey.

Table 3 presents the latest RES generation targets until 2023, as stipulated in the NREAP (EBRD 2014). These are an extension of previously formulated targets by MENR (2014) and SPO (2009). Note, however, that RES generation would be 41% of total generation (385 TWh)[3] if all individual technology targets would be met.

The RES targets in Turkey were set by following the next steps:

- The technical and economic potential of technology has been identified. These are long-term studies which are regularly updated.
- The RES targets became embedded in the Electric Energy Market and Energy Supply Security Strategy Document of 2009.
- The main criterion was political, namely to put forward reachable targets, whereas the main driver of the strategy document was to show the energy need until 2023.

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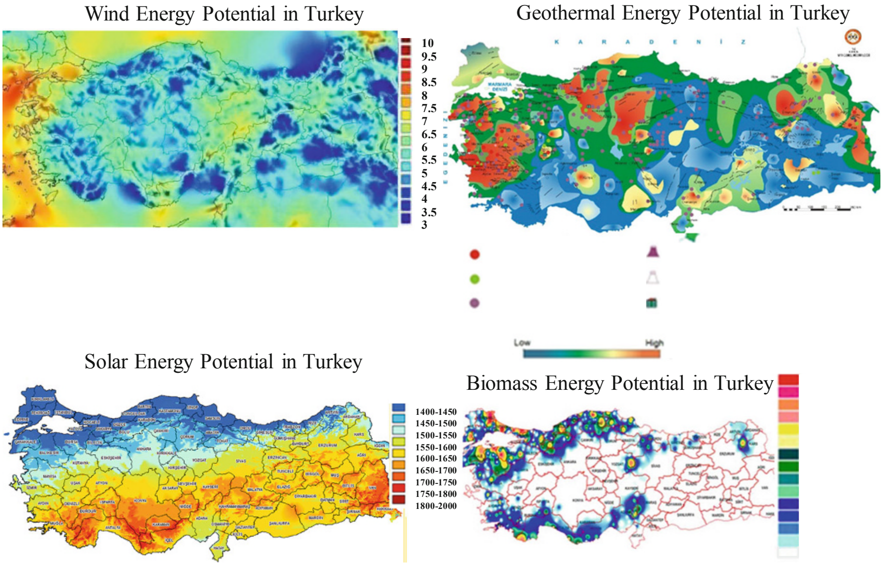
[3] Based on latest official demand forecast (TEIAS 2018b).


Wind Energy Potential in Turkey

Geothermal Energy Potential in Turkey

Solar Energy Potential in Turkey

Biomass Energy Potential in Turkey

Fig. 2 RES potential in Turkey. Source: ECS (2014) For wind map http://www.yegm.gov.tr/YEKrepa/REPA-duyuru_01.html (wind speeds at 50 m), for solar map http://www.yegm.gov.tr/MyCalculator/, for geothermal map: https://www.enerji.gov.tr/tr-TR/Sayfalar/Jeotermal, for biomass map: http://www.yegm.gov.tr/yenilenebilir/tur_or_kay_biyo_pot.aspx

Table 3 RES targets in Turkey for power generation in 2023

Source	Generation (TWh)	Capacity (GW)	Capacity factor (%)
Reservoir and run-of-river hydro	91.8	34	31
Wind energy	50.0	20	29
Solar energy (power)	8.0	5	18
Bioenergy	4.5	1	52
Geothermal (power)	5.1	1	58
Total power generation	159.4	61	–

Source: EBRD (2014)
Note: The biomass target is not yet an official policy

- Hence, the process has been mainly top-down and political. As a result, the targets are ambitious and are often criticized as being unrealistically high and unlikely to be achieved in the set time path.

Figures 3 and 4 show how the RES targets evolve over time according to the NREAP for Turkey. Turkey is below target, as of 2017, especially due to dry year 2017 leading to low hydro generation; clearly, additional efforts will be needed to stay on track and reach the 2023 targets. We stress here that especially the Wind target is ambitious, and investments have to accelerate considerably in order to be able to reach 20 GW by 2023.

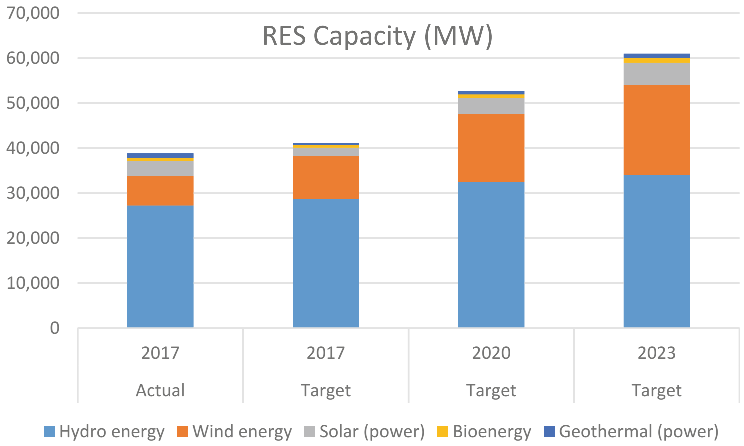


Fig. 3 RES capacity in Turkey: 2017 actual and targets. Source: TEIAS (2018a) and EBRD (2014)

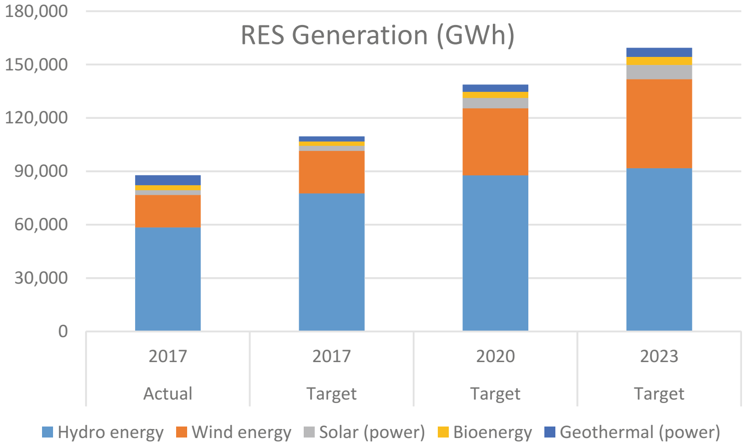


Fig. 4 RES generation in Turkey: 2017 actual and targets. Source: TEIAS (2018a) and EBRD (2014)

Table 1 shows that the share of RES generation has reached 30% in 2017. This shows, on the one hand, that Turkey already met the 30% RES generation target in 2017. However, on the other hand, Turkey will still require substantial additional efforts to reach the individual technology targets, e.g., see Figs. 3 and 4. Moreover, an additional investment of 22 GW new RES capacity is needed. It is also possible to estimate the costs for meeting the RES targets in Turkey. The key assumptions for this are presented in Table 4.

Based on the assumptions in Table 4, we obtain that there is a need for an additional 30 billion US$. Hence, our cost estimate is about half of the cost estimate of Melikoglu (2016). The difference can be explained in recent fall in capital costs,

Table 4 Cost estimate to meet RES targets in Turkey

Source	Additional capacity (MW)	CAPEX ($/kW)
Reservoir and run-of-river hydro	6727	2200
Wind energy	13,484	1000
Solar energy (power)	1579	800
Bioenergy	358	2275
Geothermal (power)	0	2150

Note: Additional capacity is derived from 2023 Target minus 2017 number. CAPEX numbers are based IEA (2015) with updates for wind and solar due to recent fall in CAPEX for these technologies

especially affecting wind and solar investments, and the time horizon has shortened, as our estimate is based on the situation from 2018 onward.

4 Analysis and Discussion: Facilitators, Barriers, Wind, and Solar

After displaying the RES potential estimates in the previous part, this section will analyze the main barriers and impediments toward RES development in Turkey. This is done by first summarizing the main measures that are in place to facilitate RES development. Next, the difficulties faced by wind developers in Turkey are presented. After that the main barriers to RES development are discussed, whereas the section finishes with a positive note with the development of SWHs in Turkey, driven by an “invisible hand.”

4.1 Summary of Measures Facilitating RES Development

The situation in Turkey is unique as compared to other countries and in some aspects favorable for RES development:

- There is a RES Law in place since 2005 (EMRA 2005), providing FIT to RES producers (for 10 years):
  - 73 $/MWh for hydro and wind.
  - 105 $/MWh for geothermal electricity.
  - 133 $/MWh for solar and biomass/waste electricity.
  - Moreover, if local content is added to the project an additional 23–92 $/MWh could be earned (for 5 years) per project (SPO 2009).
- Banking system in Turkey has built up considerable experience with financing RES projects, where several projects have benefitted from subsidized financing arrangements. This is especially the case for run-of-river hydro projects. These

projects can take environmental aspects into account where only environmentally friendly solutions are accepted for loan applications.

The electricity market legislation grants various additional incentives to RES project developers, including, among others:

- An option to make use of state-owned land to construct a RES plant, at a discount of 85% of the land use fees during the first 10 years of the investment and/or operation period, provided that such plant starts its operations before the end of 2020.
- A 99% reduction in the license application fees.
- Exemption from annual license fee payments for the first 8 years following the facility completion date.
- Ability to purchase electricity from private wholesale companies, on the condition that the amount so purchased does not exceed in any calendar year the annual average generation amounts indicated in the license for that calendar year.
- Priority in connecting to the transmission or distribution grid.

As it is stated in the previous sections of this chapter, RES development has been slow in Turkey, even though it has recently accelerated to a certain extent. Moreover, the legislations regarding wind energy development do not seem to constitute a major impediment against RES development.

Based on publicly available data released by the Energy Market Regulatory Authority (EMRA 2018), as of July 2018, 264 RES generation licenses (109 run-of-river hydro, 103 wind, 25 biogas, 10 geothermal, and 3 PV Solar) are under construction representing an aggregate capacity of 4835 MW, whereas another 14 licenses with 2362 MW capacity of dam hydro is currently under construction. There are also a significant number of license applications pending at EMRA—mostly for wind pointing to a potential for continued expansion.

However, many of the existing licenses pertain to plants that are under construction or facilities which have not started their operations, and financing has not been guaranteed for most of the licenses. Accordingly, the RES market is expected to remain relatively unsaturated in the medium term.

Tenders for grid connection have been done for Hydro, Wind, and Solar, where investors bid for a discount on the FIT. The FIT was considered to be low, however, with the current prices in the spot market and depreciation of the Turkish Lira, the FITs have become quite favorable for RES development.

The recently concluded Renewable Energy Zones (REZ) tenders led to a staggering reduction of around 50% as compared to the FIT, namely:

- Solar PV YEKA led to a winning bid of 69.9 \$/MWh (FIT is 133 \$/MWh)
- Wind YEKA led to a winning bid of 34.8 \$/MWh (FIT is 73 \$/MWh)

4.2 Wind Energy Development

Next, we briefly review the history of wind energy issues to show the specific blockages for progress. Actually, wind energy development has been jeopardized due to a decision for collecting all applications on one particular date in 2007. Regarding the parties of the private sector, almost none of them wanted to miss this opportunity and applications for 750 projects totaling 78 GW installed capacity were received on 1 November 2007.[4] Also, among these ones, there were many applications which were for competing sites and there was no procedural clarity for determining the projects with priority, which was a major administrative hurdle. Applicants had to wait with no clarity for the outcome and also had to incur bank costs for keeping the bid bond. Only by 2011, 4 years later, wind tenders have been undertaken following the "same model" as applied to hydro developers, where wind project developers had to tender for available connection capacity. Wind developers (as hydro developers) would have to accept to pay a part of the sales revenue in $/MWh back to the government. This could also be called a "discount" on the FIT. Hence, these processes seriously delayed the development of wind energy investments and potential in Turkey.

A possible reason for this delay in wind energy potential can also be the take-or-pay agreements for gas imports that were signed in early 2000, which also had as a condition that imported gas could not be reexported (Rzayeva 2014). The projected gas consumption amounts turned out to be too high during the global financial crises in 2008, leading to penalties in these gas import contracts of around 2 billion $. A higher level of RES generation would have led to even higher penalties at the time.

In addition to that, there has also been a strong resistance from the Turkish transmission company (TEIAS) against the quick development of wind energy, due to some concerns about transmission system failure. The Transmission Grid often constitutes a barrier toward RES development. In Turkey, grid limitations and the high number of applications have led to some bottlenecks, which have added costs to the RES project development. Without these additional costs, RES development in Turkey could be accelerated and the situation might become more favorable. Therefore, between 2007 and 2010 studies have been undertaken by TEIAS to verify more clearly the impact on the transmission system. Only after clarifying this, the green light was given for tendering transformer capacity for new wind power plants. Additional efforts by TEIAS have led to new transmission connections within Turkey to strengthen the grid so that it will be able to connect 20 GW wind by 2023, and the grid is no longer the bottleneck at present.

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[4] In 2007, the total installed Wind capacity around the world was around 100 GW. Hence, it would be highly unlikely that all projects could be realised.

4.3 Barriers to RES Development

There is a spot market which can function as an alternative sales point for RES generators and it is generally preferred by wind and sometimes by hydro generators. The average spot market price has been above 75 $/MWh until end 2014. However, it has dropped recently to around 45–50 $/MWh in the 2015–2018H1 period and around 52 $/MWh since August 2018 (EPIAS 2018), even though the spot prices may be expected to rise further. Hence, since 2015 the FIT is more attractive than selling to the spot market.

However, due to multiple applications and constraints in the network, tenders have been undertaken to obtain a connection permission, where RES project developers agreed to pay amounts up to 10–30 $/MWh per generated electricity back to the Turkish government. For example, if the generator would be able to sell at the spot market at 50 $/MWh, he will have to repay 10–30 $/MWh back to the government and will earn 20–40 $/MWh. These developers made these high bids based on the expectation to obtain an additional FIT due to local content; otherwise, these projects would not be profitable.

The situation with unlicensed RES generation applications is also important to mention in the chapter. There are various administrative barriers that delayed the investment and generation processes of RES developers. However, fortunately these hurdles have been mainly overcome and unlicensed generation has been spreading in Turkey since 2015. This had mainly led to a temporary investment boom in Solar PV mainly in 2017, reaching 5 GW installed capacity by the end of 2018. This investment boom was driven by the sudden decrease in PV panel costs, where the FIT for solar PV made these investments feasible and even lucrative. However, from early 2018 onward, due to a regulatory change, incentives were provided for self-consumption on-site, by increasing the distribution cost to such an extent that the net FIT for solar PV dropped to around 100 $/MWh. Moreover, within 2017, during the solar PV boom, a key call document ("çagrı mektubu" in Turkish) was no longer issued, which de facto blocked new applications for unlicensed solar PV projects.

Another major barrier to RES development in Turkey is the government support for nuclear and lignite. Concerning nuclear, a FIT of 123.50 $/MWh is offered to the developer of Turkey's first nuclear power plant, Akkuyu in Mersin. The development of nuclear is partly driven by the recent strengthening of political ties between Russia and Turkey. The price guarantee is nearly equal to the highest FIT offered to Solar PV and Biomass power generation. In addition, a FIT for local lignite of 62 $/MWh is currently being debated (Yenigun and Schlissel 2016) and implemented since 2017. Furthermore, as of 2018, a capacity mechanism is implemented in Turkey, providing further support to recent additions of fossil fuel generation units.

4.4 Solar Water Heater Development

Next, let us turn to the success story of the SWHs. According to REN21 (2018), Turkey had 14.9 GWth installed capacity of glazed water collectors in operation by the end of 2016. In 2017 another 1.3 GWth was added to the system reaching 16.2 GWth by the end of 2017. Turkey is third in the world (now close to USA with 18.3 GWth installed capacity) and first in Europe (overtaking Germany in 2015) concerning total installed capacity of SWH.

In addition, it is remarkable that the emergence and growth in SWHs has come about without any government assistance. Moreover, the lack of government intervention has been one of the stimulating factors, as this has prevented regulatory barriers to emerge, which would slow down the investments. The increasing cost of natural gas has made SWH a cheaper alternative to natural gas-heated hot water. This cost advantage has also led to a high awareness of this technology in Turkey. Moreover, in the poorer regions of cities in Turkey, coal is often used for heating the house, and in those cases the availability of SWHs is a good means to provide hot water supply. Hence, the SWH are often found in the poorer regions. Also, it is very popular in the south which has the highest levels of solar irradiation in Turkey. SWH are a “no-brainer,” as their investment cost can be earned back within 2–3 years, depending on the used technology.

Hence, to summarize, the quick growth in SWH in Turkey is due to the high energy costs (natural gas), abundant availability of solar irradiation, the large size of the country, lack of regulatory intervention, and also due to practical reasons: it is straightforward to add a SWH to a house.

5 Conclusions

Developing the RES potential and increasing its utilization is indispensable in the face of the energy security challenges that threaten countries. Turkey is situated in a resourceful and geopolitically critical location with a large potential for RES. Therefore, Turkey set some RES targets for 2023 and tries to achieve these targets with supportive regulations and legislations in order to improve its standards to the European Union levels.

However, the development of RES investments seemed to be growing rather slowly in Turkey until recently, even though it has improved somewhat in the past few years. Nevertheless, it is also apparent that the country is still in need of developing and implementing its RES potential more rapidly.

Among the measures taken to stimulate RES development are the RES law of 2005 and its amendment in 2010, the related FIT and incentives for local production of RES facilities and their components, together with tax incentives. However, additional measures are needed. To this end, Turkey has to strive to overcome the administrative barriers in RES investments, as well as ameliorating lack of information and training, give less government support to lignite and nuclear energy, but increase government support for RES in order to reach its 2023 RES targets.

Based on the literature survey and the above discussion, we conclude that RES policies have come about, and laws are in place. The FIT is the main policy tool to stimulate RES development in Turkey. The contribution of this chapter to the literature is that it presents an up-to-date situation with respect to RES potential, realization, and targets. The key reasons for the difference between realizations and potential are summarized by enlisting the key barriers toward RES development in Turkey. Moreover, the reasons for relatively slow wind development and fast SWH development have been presented.

The main barriers are threefold, namely lengthy administrative procedures, stop on license provision observed in various instances and economic issues.

Overall, we conclude that Turkey has a remarkable economic RES potential, which could serve 1.6 times the current demand, whereas the exploited RES capacity serves 30% of the current demand. This shows that there is still a large untapped potential of RES in Turkey, which can still be taken into production. Therefore, in the current situation, it seems that the 2023 targets can be reached only if hard and consistent work and policies are continued in Turkey.

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The Financing Decision of Oil and Gas Companies: The Role of Country Level Shareholder Protection

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1 Introduction

> The petroleum industry is (. . .) highly capital-intensive, so strong returns are critical to attracting low-cost debt and equity capital. In fact, while many of the integrated companies have the cash flow and financial wherewithal to fund capital spending internally, they frequently rely on external debt and new equity capital, particularly to finance larger acquisitions and mergers.—Rating Methodology: Global Integrated Oil & Gas Industry, Moody's Investor Services, October 2005, p. 12.

The current situation in the energy industry can be described as "severe competition." Up until about 20 years ago, oil and gas companies had a strict capital discipline (Mohn and Misund 2009), but developing financial markets require investments to improve key performance indicators (Osmundsen et al. 2006). Thus, a better outcome orientation leads oil and gas companies to search for new reserves, and then in turn drastically increases the need for sufficient capital. Oil and gas firms can be characterized as having a similar capital structure with heavy use of debt financing, and not hesitating to acquire additional debt to finance vital business opportunities (Inkpen and Moffett 2011).

Previous research has mainly focused on the effect of capital structure on the performance of oil and gas companies (Haushalter 2000; Ewing and Thompson 2016) and the comparison of those companies with other industries (Talberg et al. 2008). To test capital structure hypotheses, the debt-to-equity ratio is used to define the capital mix as an indicator of the asset financing (Ewing and Thompson 2016). The capital structure of the oil and gas companies is of great importance, because they operate in a capital intense industry. Oil and gas companies have a relatively large amount of fixed assets, which they need to run daily activities and can also be used as collateral for debt (Talberg et al. 2008). There has been less attention to the

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determinants of financing sources used to fund the investments of oil and gas companies (Haushalter 2000; Ewing and Thompson 2016). Therefore, we aim to add new findings to the existing literature in order to outline ways for oil and gas companies to finance their investments. We test three major capital structure theories: the dynamic trade-off theory, the pecking order theory, and the market timing theory. The *dynamic trade-off theory* assumes a continuous change in the firm's debt and equity. It implies that the firm tends to adjust its leverage ratio to the targeted one with low transaction costs (Elsas et al. 2014). Under the *pecking order theory*, there exists asymmetric information about the values of investments and financial slack between the firm and investors in the market. Therefore, investors require additional premium in case the firm tries to raise external funds. In order to avoid these uncertainties, firms tend to use internal financing, but when those funds are not enough, they should issue debt first and equity as a last resort (Myers 2001; Frank and Goyal 2007). The third capital structure theory is the *market timing theory*. Under this theory, the firm tries to issue securities priced at maximum attainable value due to favorable market conditions (Korajczyk et al. 1991; Baker and Wurgler 2002; Elsas et al. 2014).

This chapter studies the following research questions: How do oil and gas companies finance their investments? What are the determinants of alternative financing choices? Our aim is to identify the theoretical reasoning behind such choices. Companies in oil and gas industries demonstrate a need for a capital (debt/equity), because they are always in situations of complexity, uncertainties, and risks and tend to use any possible source of capital available. One of the main complexities is the changing price for oil and gasoline. The popularity of oil and gas companies' shares is based on the price of crude oil and gasoline. For example, at the condition of rising prices during the period between 2003 and 2008, the market was eager for the new offerings of publicly traded shares from oil and gas companies. However, when the prices dropped, the popularity dropped as well (Inkpen and Moffett 2011). Since Seth (2015) indicates a relationship between gas and oil prices, price volatility in the oil industry would also have an influence on the gas companies. Therefore, changes in oil prices would be important for the capital formation by those firms. Mohn and Misund (2009) describe that the increase in the price volatility has a significant effect on the capital formation in the oil and gas industry. Therefore, we control for the changes in the oil price and oil price volatility influencing the capital formation.

To be able to test dynamic models, we select a long time period, from 2001 until 2015. We require oil and gas companies to have financial data at least 5 years prior to 2001,[1] which resulted in data collection from 18 countries. We employ a level of shareholder protection index developed by La Porta et al. (2008) and Djankov et al. (2008), and further studied and explained by McLean et al. (2012). The index is directly related to the capital structure of the firms. Higher shareholder protection

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[1] This restriction controls the effects of possible capital structure differences of the IPO (Initial Public Offering) firms on our analysis in few years after they went to the public.

improves corporate access to external finance, which is highly relevant in the capital dependent oil and gas industry (La Porta et al. 1997, 1998). Additionally, in countries with strong shareholder protection, corporate officials are less likely to use internal resources and are therefore eager (compared to weak shareholder protection countries) to go for external financing as the way to benefit shareholders (Wurgler 2000; Shleifer and Wolfenzon 2002; Bekaert et al. 2011).

A short summary of our major findings is as follows. Using multivariate regression analysis, we discover that oil and gas companies rely heavily on debt issues. Companies issue debt to make adjustments toward the targeted leverage ratio. They prefer to issue as much debt as possible and payout when the opportunity arises in order to get more debt financing, consistent with the dynamic trade-off theory. Oil and gas firms with high profits tend to use their income for the financing of their investments, which is in line with the pecking order theory. Surprisingly, they tend to use high profits as a substitution for equity. This contradicts the general idea of the pecking order theory hypothesis to use debt in case of low cash flows. The market timing theory receives partial support, especially with taking the effect of shareholder protection into account. We discover that past period stock returns influence the equity issuance in countries with high level of shareholder protection.

This chapter is structured as follows. The next section is meant for the literature review and the hypothesis development. In Sect. 8.3, we provide a detailed description of the data sample and the methodology. After this, we continue with the results part and we finish with conclusions and limitations.

2 Literature Review and Hypothesis Development

2.1 Internal and External Investment Financing

Myers (2001) describes that gross investments in US nonfinancial companies are largely made internally, covering somewhere around 80% of the total investment at the time. Equally important is that financing deeply varies among industries. For example, in the energy industry, large integrated oil companies rely more on external financing through debt than on internal financing. Thus, it is important to look at if internal financing or external financing is more preferable.

Bond and Meghir (1994) try to resolve the issue about the relation of corporate investments and the availability of internal funds. They employ a hierarchy of finance model and assume that internal financing is available at lower costs than external financing. Additionally, they argue that tax treatment differences make companies to use more of their internal funds because of lost tax shields. Financial decisions of firms should be in line with their investments, because they usually do not have unlimited access to the financing and thus they need to address the potential costs created by external financing. The hierarchy of finance model shows that corporate intentions to invest depend on the availability of internal funds. The authors demonstrate that other ways of investment are basically irrelevant, since new equity issued allows shedding out dividends and does not affect present value. They state that using debt is irrelevant as well, even in the presence of bankruptcy risk (at no deadweight costs of bankruptcy). Firms may find some sources for investment more preferable than others, and the preferable source of investment is internal funds, in case of tax advantages of capital gains over dividend income or significant transactions fees when issuing new shares. Thus, the availability of low-cost funds generated internally might be a huge boost for investments (Myers 1984).

Contrary to Bond and Meghir (1994), Love (2003) indicates the importance of external finance to affect the firm's financial developments and its investment decisions. The importance of the financial sector in pushing the development of markets and firms was already recognized long ago. Modigliani and Miller (1958) showed that on the micro-level with perfect capital markets, finance is not relevant for financial decisions. However, markets are not perfect due to inequality of information between parties, which results in different costs between external and internal financing. From firm-level data, Love (2003) managed to show that financial constraints decrease with financial development, which results in more available external financing. Firms facing those constraints behave as if they have a large cost of capital and thus postpone their investment until a better market situation. Additionally, Demirgüç-Kunt and Maksimovic (1998) found a positive relation between the growth of the firms that are using both internal and external financing and the financial development and legal systems in those countries. Also, Rajan and Zingales (1998) showed that industries with more need for external financing grow faster in the more developed markets. Factors such as legal system, uncertainty, and level of corruption were used by Love (2003), in order to show the influence of country level factors on the supply of external financing for firms. This development adds new relatively less costly ways of raising capital for the investment purposes. This is important for our research, and thus we continue with additional factors that have an influence on corporate investment decisions.

2.2 Influence of Uncertainty on Investments

In the perfect scenario—where everyone has perfect information and no uncertainty, firms can easily decide on how much to invest. Yet, in real-world situations, it is often difficult to determine the exact level of investments that firms want to undergo, which is usually followed by over/under investments (Pindyck and Rubinfeld 1991; Dixit and Pindyck 1994). In our imperfect world, the influence of uncertainty level on investments has always been the main priority for scholars, but still there is no common agreement on the relation between investment and uncertainty. Standard models of investments suggest that this relationship is negative (Dixit and Pindyck 1994). However, according to among others Smit and Trigeorgis (2004), this relationship could be positive, in case a company (especially in gas and oil sectors) stops awaiting future benefits options of its investment when it expects high levels of price volatilities (Kulatilaka and Perotti 1998; Sarkar 2000). Simultaneously, according to Grenadier (2002) and Akdoğu and MacKay (2008), the value of the waiting option would be affected by factors such as imperfect competition and strategic investment. Scholars deliver two types of price uncertainty: temporal and permanent. For the temporary periods of uncertainty, oil and gas companies could consider oil price volatilities as a transition phenomenon Mohn and Misund (2009). This transit phenomenon with high peaks of oil price volatility is considered to be followed by a period of decreasing volatility. This by any means follows the standard investment irreversibility theory. According to this theory, the relationship between investment and uncertainty (oil price volatility in our case) is negative, as was concluded by Favero et al. (1992) and Osmundsen et al. (2006). However, the approach on strategic investments and compound options highlights a positive relation between uncertainty and investments. Scholars did present findings for sample periods of 20 years ago Mohn and Misund (2009), but the current situation could have changed the relation between uncertainty and investments.

Mohn and Misund (2009) delivered their result from a strategic investment approach view, but did not specify the concrete link between this approach and oil pricing. They were referring to Smit and Trigeorgis (2004) that the strategic investment approach dominates the oil and gas companies' investment incentives. During period of uncertainty, firms can wait for new information, thus declining any possible returns from early investments (strategic or not). Henriques and Sadorsky (2011) showed that increases in uncertainty raise the option value of waiting such that investments are postponed. However, things are changing with strategic investments that cannot be postponed forever for the sake of better information. Dedicating attention to this topic is needed, since oil prices significantly affect investment incentives of oil and gas companies. Henriques and Sadorsky (2011) state that the correlation between oil and gas prices ranges from 26% in general up to 70%. In addition, the 2008–2009 global crisis and subsequent oil price drops may shed new insights into the relation between uncertainty levels and investments. After having discussed capital structure and uncertainty factors, we now look more deeply into these and develop our hypotheses.

2.3 Capital Structure Theories and Hypotheses

From one side of the capital structure debate, it is considered that capital structure is stable over a long period of time, that majority of variation in the capital structure is time-invariant, and that much of that variation cannot be accounted for with existing models. Lemmon et al. (2008) showed that the initial leverage ratio of the firm has a significant impact on the future ratio. The second important discovery was that the leverage category contains in itself an unobserved firm-specific component. This component could differ in technologies, market power, managerial behavior, investment, and other company-specific factors (Hoch 1962; Kuh 1963). Additionally, firms with high leverage tend to use equity to reduce their leverage (Lemmon et al.

2008). However, it would be reasonable to discover whether that tendency is related to energy companies.

At another side of the debate, there is the classic work of Modigliani and Miller (1958), stating that capital structure does not influence the firm value, where there is not a single disruptor in the market or in other words: when the market is perfect. Obviously, it is not and disruptions can affect capital structure of the firms. That is why there is still another side of the debate—studies about market imperfections and its effect on the capital structure of the firm. The general idea is here that because of market imperfection, capital structure is related to firms' efficiency and financing (Myers 2001; Flannery and Rangan 2006), thus a focus on the capital structure makes much sense. Whereas the *dynamic trade-off theory* emphasizes on taxes and agency problems, the *pecking order theory* and the *market timing theory* emphasize on differences in information. The pecking order theory implies that companies' shares are generally overpriced. In order to finance projects, firms generate funds internally, then, if the internal funds are insufficient they are going for the safe debt, and the last resort alternative is equity issuance. The market timing theory differs from the pecking order theory in that managers possess internal information about firms and should use their abilities to sell overpriced equity shares (Baker and Wurgler 2002). Flannery and Rangan (2006) argue that the market timing theory allows managers to routinely use information asymmetries to benefit the shareholders. It is important to note that the other two theories are not based on target debt ratios as the dynamic trade-off theory holds. Flannery and Rangan (2006) find various supports for all of the three theories mentioned above, although targeting behavior dominates over pecking order and market timing behavior together.

Elsas et al. (2014) study the topic of the financing problem for large investments. They look mainly to the Statement of Cash Flows (SCF) in order to examine the ratio between external and internal funds used for investment financing. They stated that roughly 67 to 83% of corporate large investments were made internally, while only 31% of small investments were financed externally. Elsas et al. (2014) were not interested in leverage ratio changes. They indicate that the more profitable firms tend to rely more on internal financing, with internal funds replacing potential equity issuance and not debt, which is line with pecking order theory. In this case, leverage remains unchanged, and profitability does not affect leverage when the firms undergo large investments. Researchers focused mainly on firms from mining, information, manufacturing, accommodation, and food services industries. They did not focus on energy firms, because their investments would not satisfy criteria for "large investments" that should be at least 30% of book assets and 200% of corporate trading investment expenditures. However, the value of regular investments by big energy companies might have been even larger than large investments by those companies. This warrants a study on the financing of investments of energy industry companies. In order to test capital structure hypotheses, we must clarify them first. We take on the line of reasoning by Elsas et al. (2014).

Dynamic Trade-off Hypothesis According to the *dynamic trade-off hypothesis*, each company searches for an optimal capital ratio that reflects its specific characteristics. Under this hypothesis, firm should move toward the required target with the issuance of debt or equity. Therefore, we can show the following relation between optimal capital ratio and debt:

Hypothesis 1: A positive deviation from the target leverage of the firms has a positive impact on the amount of the firms' debt.

Pecking Order Hypothesis When a firm is trying to sell its stock to the public, costs are imposed on shareholders. In order to avoid those costs, firms prefer to finance their activities internally. In case internal funds are not sufficient, firms prefer to issue debt over equity. Therefore, we show as relation between profits and levels of debt/equity/cash flows:

- *Hypothesis 2a: Profits of the firms have a positive impact on their cash flows.*
- *Hypothesis 2b: Profits have a negative impact on the level of debt (equity issuance).*

Market Timing Hypothesis Firms are trying to issue stocks in favorable prices when they go to the market in order to spot this "timing." Firms refer to the value of (Tobin's) Q as a measure of the relation between the market value and the book value of the equity. Stock return is also proxy of higher valuation on the market to affect financing decisions. Therefore, we show the relationships between Q and equity issuance and between stock returns and equity issuance separately:

Hypothesis 3: Q and stock returns have a positive impact on the equity issuance.

2.4 *Shareholder Protection Level*

Elsas et al. (2014) did not account for heterogeneity between different countries. In order to do so we address attention to country level factors. Scholars have argued that the investor protection level has a significant effect on the firms' capital structure and therefore on how they finance their investments (La Porta et al. 1997, 2002, 2006, 2008). More recently, McLean et al. (2012) assume that investor protection improves corporate access to external finance for investment projects, which is consistent with La Porta et al. (1997, 2002). Additionally, they link this relationship to Q and discover that when a country has strong investor protection laws, the correlation between Q and external finance is positive. However, they also find that in countries with strong investor protection investment is less sensitive to cash flows and external finance is negatively related to it. Firms with a limited (low) amount of cash flows would require an additional source of financing in the terms of external financing. Following Fazzari et al. (1988) and Hubbard (1997), this was checked for when governments lessened external finance costs. Then there would be a decrease in demand for external financing from firms with a low amount of cash flows that would else resort to easy funds. In countries with strong investor protection, independent variables explaining capital structure of the firm (such as Q, stock returns, profit, and leverage) have a stronger relation with investment prediction than in low investor protection countries. Building upon the former, we develop the following hypotheses on country level effects.

- *Hypothesis 4: With an increase in shareholder protection level, deviation from the target leverage of the firms will have a positive impact on their level of debt.*
- *Hypothesis 5a: With an increase in shareholder protection level, profits of the firms will have a positive impact on their cash flows.*
- *Hypothesis 5b: With an increase in shareholder protection level, profits of the firms will have a positive impact on the level of debt and equity issuance.*
- *Hypothesis 6: With an increase in shareholder protection level, Q and stock returns will have a positive impact on equity issuance.*

3 Data Description and Methodology

3.1 Data Sample Description

All of the sample firms' data are gathered from Tomson Reuters DataStream software. A strive to capture as much energy companies as possible leads to a small bias toward companies represented by certain countries. The initial sample consists of 226 companies, with: USA—60; Australia—55; Canada—26; UK—21; India and Russia—11; Hong Kong and Israel—8; Norway and China—5; Sweden and France—4; Ireland and Argentina—2; the Netherlands, Spain, Poland, and Italy—1. For the period from 2001 until 2015, we have derived investments made by those firms into four categories (cf. Elsas et al. 2014):

1. DEBT—long term debt minus reduction in debt (DataStream items 04401 and 04701).
2. EQUITY—the issuance of new equity minus repurchase of stock (DataStream items 04251 and 04751).
3. CASHFLOW—operating cash flows, calculated as after-tax income before extraordinary items plus depreciation and amortization minus cash dividends and the increase in cash and equivalents (DataStream items 01551, 01151, 04551 and 04851).
4. OTHERS—basically all the other SCF categories for the firms.

Combined together, those four categories must be equal to total investment, or:

$$\text{INVEST} = \text{DEBT} + \text{EQUITY} + \text{CASHFLOW} + \text{OTHER} \tag{1}$$

where INVEST is the sum of the firm's capital expenditures, acquisition of assets, and investments in associated companies (DataStream items 04601, 04355, 02256). The value of mean of DEBT, EQUITY, CASHFLOW, and OTHERS as a proportion to INVEST should add up to 100%. The following mean values for those variables match the criteria: DEBT—21.9%, EQUITY—21.7%, CASHFLOW—49.7%, and OTHERS—6.7%.

The next step was to set criteria that would allow us to test a healthy sample of energy firms. Thus, we decided to remove firms that did not have any capital expenditures and other investment information, as well as firms that had no debt, cash flow expenditures and equity issuance during the time frame, or that did not report those categories. This resulted in a reduction from 226 to 147 firms.

3.2 *Estimating Targeted Leverage*

The aim of estimating the targeted leverage is to compare the trade-off hypothesis with the pecking order hypothesis and market timing hypothesis. Elsas et al. (2014) and Flannery and Rangan (2006) use market value of leverage and define it as:

$$\mathrm{Lev} = \mathrm{D}/(\mathrm{D} + \mathrm{E}) \tag{2}$$

where D—is the book value of debt (DataStream item 03255) and E is the firm's equity value. Firm's equity is expressed as the price per share multiplied by the number of shares outstanding (DataStream items P, 05301 and 05303).

Firms always face some costs when adjusting their capital structure, thus a partial adjustment model is used to describe the firms' leverage (Elsas et al. 2014):

$$\mathrm{Lev(t)} - \mathrm{Lev(t-1)} = \lambda(\mathrm{Lev(t)} * -\mathrm{Lev(t-1)}) + \mathrm{error}. \tag{3}$$

where Lev(t) and Lev (t–1) denote this year's and last year's leverage, respectively, and λ is the adjustment factor.

Elsas et al. (2014) continue that desired/target leverage is usually described as a combination of a firm's lagged characteristics X(t–1), which gives a rebuilt equation:

$$\mathrm{Lev(t)} = (\lambda\beta)\mathrm{X(t-1)} + (1-\lambda)\mathrm{Lev(t-1)} + \mathrm{error}. \tag{4}$$

where β denotes the regression coefficient of X(t–1) without the adjustment factor.

Elsas et al. (2014) confirm the line of previous studies, saying that vector X includes earnings, depreciation, fixed assets; assets market to book ratio, the natural logarithm of total assets and firm fixed effects. They did not model a constant, but include it in the estimation and find it to be insignificant. After defining a firm target leverage ratio as Lev(t)∗, they computed each firm's deviation from its targeted leverage as (the deviation was used in further models):

$$\mathrm{Dev(t)} = \mathrm{Lev(t)} * -\mathrm{Lev(t-1)} = (\lambda\beta)\mathrm{X(t-1)} - \lambda\mathrm{Lev(t-1)}. \tag{5}$$

3.3 Evidence on Adjustment Toward Estimated Target Debt Ratios

Elsas et al. (2014) are interested in the speed of moving toward the target leverage. So, in order to receive the value of the deviation in (5), we estimated a panel regression from (4) using the Blundell–Bond system generalized method of moments (GMM) estimation, for the data gathered from DataStream in a period from 2001 until 2015. The instruments that were used for this GMM were the second lag in leverage and the additional generated lagged variable BDR (BDR is a ratio of total debt to total assets), this is in line with the studies of Flannery and Rangan (2006) and Lemmon et al. (2008) that were referenced in Elsas et al. (2014).

The results of the GMM estimations are provided in Table 1. From the table, we can see the estimated coefficient of Lev(t–1) is 0.531, implying that the annual adjustment speed is 0.469. Having the results from Table 1, we can compute the targeted leverage for all firms in our sample and therefore can calculate deviation from its target leverage. In order to calculate the final DEV(t), we saved the predicted values of vector βX(t−1) multiplied by λ from the regression in (4) and then deduct from those values the value of λLev(t−1), see (5).

Table 1 Adjustment speed estimation

Variable (dependent: Lev(t))	Coefficient (*p*-value)
Lev(t–1)	0.531^{***} (0.000)
Profit	0.002 (0.621)
Q	-0.004^{***} (0.00)
Depreciation/TA	−0.012 (0.491)
Size	0.010^{*} (0.077)
Fixed asset ratio	0.031^{**} (0.041)
Constant	−0.004 (0.977)
N	1125 (147 firms)

***, **, and * indicate significance at 1, 5, and 10% levels, respectively

3.4 A Model for Testing Pecking Order, Trade-off, and Market Timing

We test the various capital structure hypotheses by estimating a set of four SURs (Seemingly Unrelated Regressions) in order to explain how firms pay for their investments:

$$\begin{aligned} \mathrm{F(i,t)} = {} & \alpha + \beta 1 * \mathrm{Dev(i,t-1)} + \beta 2 * \mathrm{Profit(i,t-1)} + \beta 3 \\ & * \mathrm{Stock\ return(i,t-1)} + \beta 4 * \mathrm{Q(i,t-1)} + \beta 5 \\ & * \mathrm{Investment\ ratio(i,t)} + \beta 6 * \mathrm{Fixed\ asset\ ratio(i,t-1)} + \beta 7 \\ & * \mathrm{Size(i,t-1)} + \beta 8 * \mathrm{Volatility(t-1)} + \beta 9 * \mathrm{Oil\ price(t-1)} \\ & + \mathrm{error} \end{aligned} \tag{6}$$

where:

F—the proportion of four sources of financing (Debt, Equity, Cashflow, or Others) of the firm to the firm's investment value, during year *t*.

Dev—from Eq. (5), showing the deviation from targeted leverage at year t–1.

Profit—net annual income before extraordinary items, as a proportion of book assets (Elsas et al. 2014). It is a proxy for cash flow, which is according to the pecking order hypothesis the primary source of finance.

Stock return—stock returns of the firm. According to Korajczyk et al. (1991), firms tend to issue stock, when they face an increase in stock returns. Data are obtained from the DataStream item "RI."

Q—Tobin's Q ratio, which is calculated as market value of equity to book value of equity. Authors suggest that Q may include several factors that could have an influence on corporate investing and financing behavior.

Investment ratio—the value of investments to the book total value of assets. Some investments may require additional external financing, or firms can save cash when waiting for a future investment.

Fixed asset ratio—year-end book value of fixed assets divided into total assets. A larger amount of fixed assets generates larger internal cash flows, which could reduce the use of external financing.

Size—natural log of firm's book assets, used as a control variable.

Volatility—volatility measure for the oil price. Researching oil and gas companies creates a need to address attention to external factors such as volatility. Its measurement is described by Mohn and Misund (2009).

Oil price—an additional way to control for the oil price. It is measured as the natural logarithm of average yearly oil price (Salas-Fumás et al. 2016).

The descriptive statistics are found in Table 2 and their correlation coefficients are presented in Table 3. Our primary interest is related to the first four explanatory variables, which would capture the three alternative capital structure hypotheses

Table 2 Descriptive statistics, capital structure model

	Mean	Median	Maximum	Minimum	Std. Dev.	Observations
Lev	0.22	0.19	0.94	0.00	0.18	1125
Profit	0.03	0.06	0.93	−1.56	0.16	1125
Dev	0.04	0.01	3.10	−2.43	0.41	1125
Stock return	0.19	0.06	10.41	−0.94	0.68	1125
Q	1.87	1.66	5.87	−0.55	1.13	1125
Investment ratio	0.52	0.31	12.87	−0.27	0.89	1125
Fixed assets ratio	0.61	0.64	1.91	0.00	0.25	1125
Size	13.92	14.13	19.61	4.96	2.83	1125
Volatility	1.32	1.26	2.52	0.53	0.49	1125
Oil price	4.18	4.24	4.67	3.22	0.44	1125

(Elsas et al. 2014). For example, **Dev** is measured as the difference between target and actual leverage ratios and according to the trade-off hypothesis, its coefficient should be positive (negative) in the Debt (Equity) regression, since higher profits should be accompanied by less external financing and in particular less debt financing. **Stock return** and **Q** are referred to by the market timing hypothesis. Those variables could capture opportunistic behavior with equity issuances. Alternatively, according to Elsas et al. (2014), they may also indicate an abundance of investment opportunities that goes according to the trade-off hypothesis with a preference for equity financing. **Q** by itself should be targeting leverage and it does not have any trade-off related effect in (6), but on the other hand, **Stock return** reflects different sets of investment opportunities, so it might have an influence for the trade-off interpretation in (6).

3.5 Extending a Model for Testing of Shareholder Protection Hypothesis

Elsas et al. (2014) do not account for country level factors, because their model was originally developed for US domestic companies. That is why, in order to test the shareholder protection hypothesis, we add a shareholder protection variable. In the extended model, we use an index from McLean et al. (2012) and Djankov et al. (2008). This anti-self-dealing index (*Anti-self)* is created by Djankov et al. (2008). *Anti-self* is meant to regulate an opportunistic behavior of a person who is in control over two firms, and whose transactions between those two firms have a potential objective to increase that person's own welfare. A higher value of *Anti-self* means the implication of tight regulations, which protects shareholders. Our model is:

Table 3 Correlations

	Profit	Dev	Stock returns	Q	Investment ratio	Fixedassetsratio	Size	Volatility	Oil price
Profit	1.00								
Dev	−0.06	1.00							
Stock returns	0.30	−0.39	1.00						
Q	0.16	−0.14	0.23	1.00					
Investment ratio	0.14	0.06	0.14	0.11	1.00				
Fixed assets ratio	0.01	0.07	−0.09	0.05	0.16	1.00			
Size	0.40	0.04	0.00	−0.04	−0.09	0.06	1.00		
Volatility	0.03	0.03	−0.01	−0.07	−0.06	−0.05	0.13	1.00	
Oil price	0.01	0.02	−0.02	−0.08	−0.10	0.00	0.22	*0.63*[a]	1.00

[a] There is an observable high correlation between Volatility and Oil price. That is why we decided to run separate SURs using only one variable (from the two) at one time, in order to compare the differences between outputs. Yet, the differences in the outputs were minor: all of the coefficients of the independent variables maintained their values and significance levels

$$\begin{aligned} \mathrm{F(i,t)} = {} & \alpha + \beta 1 * \mathrm{Dev(i,t-1)} + \beta 2 * \mathrm{Profit(i,t-1)} + \beta 3 \\ & * \mathrm{Stock\ return(i,t-1)} + \beta 4 * \mathrm{Q(i,t-1)} + \beta 5 * \text{Anti-self} + \beta 6 \\ & * \mathrm{Dev(i,t-1)} * \text{Anti-self} + \beta 7 * \mathrm{Profit(i,t-1)} * \text{Anti-self} + \beta 8 \\ & * \mathrm{Stock\ returns(i,t-1)} * \text{Anti-self} + \beta 9 * \mathrm{Q(i,t-1)} * \text{Anti-self} \\ & + \beta 10 * \mathrm{Investment\ ratio(i,t)} + \beta 11 * \mathrm{Fixed\ asset\ ratio(i,t-1)} \\ & + \beta 12 * \mathrm{Size(i,t-1)} + \beta 13 * \mathrm{Volatility(t-1)} + \beta 14 \\ & * \mathrm{Oil\ price(t-1)} + \mathrm{error} \end{aligned} \tag{7}$$

where:

Anti-self index is a shareholder protection proxy derived from Djankov et al. (2008).

Other variables are from the capital structure model (6).

4 Results

4.1 Determinants of Financing Choices

Table 4 represents results of (6). The positive coefficient of **Dev** (0.359∗∗∗) in the Debt regression shows that underleveraged oil and gas firms use more debt financing when they deviate relatively much from their targeted level of leverage. This is consistent with *trade-off hypothesis 1* and with results of Elsas et al. (2014). The coefficient of **Dev** in the Equity regression is insignificant at −0.013. This is an indicator that at first, debt is playing a more significant role in the target adjustment toward target leverage ratio than equity, and second that this is an indicator of a specific feature that can be related to oil and gas companies, with a preference for debt issuance over equity. One standard deviation increase in **Dev** (41% in percentage points) has an impact on the entire debt funding by increasing it by 41% ∗ 0.359 = 14.79%. Thus, *trade-off hypothesis 1* receives significant support.

From the regression on cash flow, we discover that for oil and gas companies that are more profitable are eager to finance their investments with internal cash flows, the value of the coefficient for **Profit** is positive and highly significant (0.549∗∗∗). This is a clear indicator that firms that are more profitable prefer internal financing for the financing of their investments over external financing, which supports *pecking order hypothesis 2a*. However, from here additional analysis is required, because according to pecking order theory firms tend to issue debt when their internal funds can suffice investments. From our results, we can conclude that a zero coefficient of **Profit** on Debt, and a highly significant but negative coefficient in the Equity regressions are indicators that cash flow substitutes for equity issuance. This is consistent with *pecking order hypothesis 2b* (Myers 1984) but contradicts Elsas et al. (2014).

From the regression on Equity, it is possible to derive results for *market timing hypothesis 3*. Stock returns are considered to be the most important factor for the

Table 4 SUR estimates

Dependent variable	Debt	Equity	Cashflow	Others
Dev	0.359^{***} (0.00)	−0.013 (0.62)	-0.221^{***} (0.00)	-0.097^{***} (0.01)
Profit	−0.009 (0.87)	-0.471^{***} (0.00)	0.549^{***} (0.00)	0.018 (0.83)
Stock return	0.033^{***} (0.00)	0.06^{***} (0.00)	-0.068^{***} (0.00)	0.005 (0.79)
Q	0.01^{***} (0.00)	-0.007^{**} (0.03)	−0.003 (0.56)	−0.002 (0.56)
Fixed assets ratio	−0.004 (0.91)	0.049 (0.23)	0.556^{***} (0.00)	-0.416^{***} (0.00)
Investment ratio	−0.001 (0.39)	0.00 (0.85)	−0.002 (0.36)	0.003 (0.15)
Size	0.00 (0.91)	-0.036^{***} (0.00)	0.02^{***} (0.00)	0.019^{***} (0.00)
Volatility	-0.058^{***} (0.01)	0.022 (0.38)	0.05 (0.2)	0.008 (0.81)
Oil price	0.093^{***} (0.00)	−0.018(0.53)	-0.102^{**} (0.02)	−0.01 (0.81)
Constant	-0.266^{***} (0.01)	0.648^{***} (0.00)	0.207 (0.22)	0.343^{**} (0.02)
N	1125	1125	1125	1125
R^2	0.186	0.167	0.138	0.063

***, ** and * indicate significance at 1%, 5%, and 10% levels, respectively

market timing theory, because they could capture the opportunistic behavior with equity issuances. The positive **Stock return** coefficient in the Equity (0.06∗∗∗) regression indicates that firms use higher stock returns to finance their investments. The positive and significant coefficient of **Stock return** on Debt (0.033∗∗∗) represents a signal to lenders that a firm has growth opportunities, which reduces uncertainty and thus leads to more debt issuance. Additionally, a negative and significant coefficient of **Stock return** on Cashflow demonstrates that with high returns firms tend to substitute internal investments with debt and equity, thus giving additional indirect support to the pecking order theory. The significant but negative coefficient on **Q** (−0.007∗∗∗) adds zero additional support for the *market timing hypothesis 3*. Therefore, with mixed results about *market timing hypothesis 3*, it can be partially supported.

The remaining coefficients for the control variables have their own effect on funding. Insignificant values of the **Investment ratio** coefficient indicate that oil and gas firms prefer not to issue additional source of funding when they want to make a certain investment—they are constantly spending funds for investment purposes. **Fixed asset ratio** coefficients show that firms with more tangible assets rely more on internal funds (the coefficient for Cashflow is positive and significant at 0.556∗∗∗), which confirms Elsas et al. (2014) in that tangible assets generate greater depreciation related cash flows. The **Size** coefficient shows no impact on Debt issuance, while showing a significant but negative coefficient for Equity (−0.036∗∗∗) and a positive/significant coefficient for Cashflow (0.02). The coefficient on Equity can be explained by uncertainties and fear of having undervalued equity from managers who are running a relatively large company. The positive value on Cashflow is related to the same issue: because of that uncertainty, they prefer to use internal funds. The firm level control variable conclusions can be linked to the pecking order theory. **Volatility** and **Oil price** represent macro-level control variables. The results are quite expectable—an increase in oil price volatility would decrease the amount of debt issued to oil and gas companies because of the increased level of global uncertainty—the coefficient on **Volatility** is significant and negative at −0.058∗∗∗. An **Oil price** increase would have an opposite effect, raising the value of possible Debt issue, with a positive and significant coefficient of 0.093∗∗∗. Additionally, **Oil price** has a significant but negative effect on Cashflow, indicating that in periods of high oil prices (decreasing levels of uncertainty for stakeholders), oil and gas firms tend to use external financing in terms of debt instead of their own funds—the coefficient being −0.102∗∗.

4.2 The Role of Shareholder Protection

From Table 5 it can be drawn that the value of coefficient on **DEV** has increased compared to Table 4, but this is partially offset by the interaction value between **DEV** and Anti-self index. With these results, it is possible to calculate the overall coefficient of **DEV** for the maximum and minimum values (Hong Kong and The Netherlands: NL, the list of all values is in Appendix A) of the Anti-self index. For example, by focusing on the results from regression with the dependent variable Debt, for Hong Kong—[0.807 + 0.96∗(−0.605) = 0.226]; for NL—[0.807 + 0.2∗(−0.605) = 0.686]. Both of these coefficients are positive, which lead to the acceptance of the *trade-off theory hypothesis 4*. The coefficient of 0.226 is lower than previously reported in Table 4 (0.359), indicating that firms in the high Anti-self countries do not have high deviations from their targeted leverage, compared with countries with a small Anti-self index (the value for **DEV** is for NL 3 times bigger than for Hong Kong).

The regression on Cashflow shows a significant value for **Profit** (1.024), which is higher than reported in Table 4 (0.549). The value of the interaction coefficient **Anti-self** and **Profit** is insignificant, but it is important to derive the overall coefficient on **Profit** since the coefficient of stand-alone variable **Profit** is still statistically significant. For Hong Kong it is maximal at 1.024 + 0.96∗(−0.625) = 0.424 and for NL it is minimal at 0.807 + 0.2∗(−0.625) = 0.682. Having positive results for the overall profit coefficient is not enough to satisfy criteria for *pecking order theory, hypothesis 5a*. Because the interaction coefficient is insignificant, our sample does not support this hypothesis. Despite being insignificant, the overall coefficient shows us that in high Anti-self index countries companies prefer to use less internal cash flows than

Table 5 SUR estimates with shareholder protection variables

Dependent variable	Debt	Equity	Cashflow	Other
Dev	0.807*** (0.00)	−0.004 (0.97)	−0.718*** (0.00)	−0.396** (0.02)
Profit	−0.004 (0.99)	−0.567* (0.08)	1.024** (0.05)	−1.469*** (0.00)
Stock return	0.307*** (0.00)	−0.107** (0.05)	−0.035 (0.67)	−0.057 (0.46)
Q	−0.058*** (0.00)	−0.01 (0.60)	−0.02 (0.46)	0.036 (0.15)
Anti-self	0.006 (0.94)	0.099 (0.25)	−0.032 (0.8)	−0.324*** (0.01)
Dev∗ anti-self	−0.605*** (0.00)	−0.038 (0.81)	0.745*** (0.00)	0.414* (0.08)
Profit∗ anti-self	−0.016 (0.97)	0.123 (0.77)	−0.625 (0.35)	1.947*** (0.00)
Stock return∗ anti-self	−0.321*** (0.00)	0.228*** (0.00)	−0.062 (0.57)	0.066 (0.51)
Q∗anti-self	0.091*** (0.00)	0.005 (0.84)	0.025 (0.5)	−0.051 (0.14)
Fixed assets ratio	0.018 (0.62)	0.064 (0.12)	0.563*** (0.00)	−0.492*** (0.00)
Investment ratio	−0.002 (0.27)	0.001 (0.78)	−0.002 (0.37)	0.004 (0.13)
Size	0.002 (0.57)	−0.033*** (0.00)	0.02*** (0.00)	0.014*** (0.01)
Volatility	−0.056*** (0.01)	0.02 (0.41)	0.046 (0.23)	0.005 (0.88)
Oil price	0.091*** (0.00)	−0.026 (0.35)	−0.096** (0.03)	−0.003 (0.95)
Constant	−0.301*** (0.01)	0.57*** (0.00)	0.201 (0.32)	0.656*** (0.00)
N	1125	1125	1125	1125
R^2	0.218	0.175	0.146	0.073

***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively

in countries where this index is low (the value for **Profit** for NL is 1.6 times bigger than for Hong Kong).

The value of **Profit** for the dependent variable Equity is negative and significant (−0.567), and smaller than the value in Table 4 (−0.471). The value of the interaction coefficient is not significant, but still the overall value of the coefficient on **Profit** in Equity is for Hong Kong −0.567 + 0.96∗(0.123) = −0.449 and for NL it is −0.567 + 0.20∗(0.123) = −0.542. In countries with high Anti-self index, Cashflow substitutes less for equity issuance than in countries with lower Anti-self index values. Because the interaction coefficient is insignificant, we do not have sufficient evidence for the *pecking order theory, hypothesis 5b.*

In regression with the dependent variable Equity, the values of coefficients on **Stock return** and its interaction with Anti-self are significant. The coefficient on the **Stock return** is negative but the interaction variable has a positive coefficient. With an increase of the shareholder protection level, as presented by Anti-self index, the overall influence of the **Stock return** would increase. The values are for Hong Kong $-0.107 + 0.96 * (0.228) = 0.112$ and for NL $[-0.107 + 0.20 * (0.228) = -0.061$. With the increase in shareholder protection as represented by Anti-self index there is an increase in **Stock return**, which affects Equity issuance. The mean value of Anti-self index is 0.667, indicating an overall average value of **Stock return** of 0.045. The coefficients on Q for Equity, are not significant for both **Q** and its interaction with Anti-self. Thus, this leads us to the partial support of the *market timing theory, hypothesis 6* (in the countries with a high Anti-self index).

5 Conclusions and Limitations

The main goal of this chapter is to discover what factors affect the decisions of oil and gas companies to finance their investments. We aim to fill the gap between studies on the capital structure for oil and gas versus other companies. In order to do so, we collect data from 18 countries, for 147 oil and gas companies having relevant data for the period from 2001 until 2015. For analyzing the data, we follow methods used by Elsas et al. (2014) to test capital structure hypotheses and by McLean et al. (2012) to test for shareholder protection hypotheses. In order to test capital structure hypotheses, we calculate the target leverage deviation, using a methodology by Flannery and Rangan (2006) whereby we calculate the speed of capital structure adjustment (using GMM estimation). Having all of the required variables, we compute a system of Seemingly Unrelated Regressions in order to test the capital structure hypothesis.

Our results show that the dynamic trade-off theory receives significant support, indicating that oil and gas companies are using a large proportion of debt in their activities in order to meet a target leverage level. Viewed from the country level, the dynamic trade-off theory receives significant support as well, indicating additionally that firms in countries with a high shareholder protection level have less deviation from their targeted leverage (and as a result want to take on less debt) than firms in countries with less shareholder protection.

The pecking order theory receives mixed support. We show that highly profitable oil and gas companies indeed use their income (or internal financing) for financing investments, which is in line with pecking order theory. Yet, we also find support for substitution of internal cash flows by equity in both capital structure and shareholder protection issues, which is not perfectly in line with pecking order theory. Additionally, on shareholder protection, we find out that oil and gas companies that face a low level of internal funds tend to issue debt, which is in line with pecking order theory. Country level differences are found to be insignificant.

The market timing theory meets partial support in relation to capital structures and country levels. High stock returns of the oil and gas companies significantly influence equity issuance in countries with a high shareholder protection index. This effect reduces with the level of shareholder protection and can be even negative.

Our study has some flaws. It is limited to 18 countries with a great representation of the USA, the UK, Australia, and Canada. Those countries have in general well-developed stock markets with a large number of companies functioning since the 1980s, while companies from other countries are functioning since the 1990–1995 years. This problem could be overcome later when there will a greater amount of companies from different countries, considering that a vast majority of those companies started to report their activities since the 2005–2008 years.

Our research can be used from a managerial perspective as well. The main finding is that oil and gas companies highly rely on debt and internal funds in all countries, while the financing by equity is not so important in low shareholder protection countries, which have low or late stock listings and low equity values. For investment purposes, oil and gas companies count more on internal funds (with 50% of the investment financed by cash flows) than on equity and debt (22% each), consistent with Elsas et al. (2014). Managers should be aware that oil and gas companies, when adjusting toward the targeted leverage level, mainly rely on debt and not on equity issuance. Country level factors are playing a significant role as well, affecting mainly debt and equity issuance, consistent with McLean et al. (2012). Oil and gas companies tend to issue equity in countries with high shareholder protection, where high values correspond with countries with long history of stock listings and high equity values, with the level of shareholder protection not being relevant for debt taking.

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Attitudes of SMEs Toward the Elements of Eco-efficiency: The Turkish Case

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1 Introduction

Eco-efficiency is one of the latest buzzwords in many subfields of economics. Its achievement requires creating more value with less environmental impact. Since small- and medium-sized enterprises (SMEs) are responsible for most of the production in the industrial output, their adoption of elements of eco-efficiency is crucial for green growth. The adoption of eco-efficiency practices by SMEs is especially valuable in emerging economies such as Turkey where environmental regulations are less stringent. However, studies that focus on the attitudes of Turkish SMEs toward elements of eco-efficiency are limited. In this study, we investigate the attitudes of Turkish SMEs over three items concerning eco-efficiency: (1) increasing resource efficiency investments, (2) producing more environmentally compatible "green" products or services, and (3) the consumption of energy from renewable resources.

According to the World Business Council for Sustainable Development (WBCSD), "*eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the*

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life-cycle to a level at least in line with the Earth's estimated carrying capacity." In other words, eco-efficiency is concerned with creating more value with less environmental impact, which is also what green growth envisages. The OECD (2019) defines green growth as "*fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies.*"

In many countries, SMEs are the backbone of the economy and contribute considerably to economic growth (OECD 2013; IEA 2015). Consequently, it is not a stretch to say that SMEs can play a significant role in green growth and creating an industrial and economic environment that has a positive impact globally. SMEs can act to reduce the environmental impact of their energy consumption.

This study focuses solely on Turkish SMEs. Turkish SMEs play a significant role in the Turkish economy. They make up 91.9% of all enterprises, provide 78% of all employment, constitute 55% of the GDP, and 50% of total investment.[1] Here, we examine the attitudes of Turkish SMEs to resource efficiency investments, the supply of green products or services and on-site energy generation from renewable resources in a descriptive way. To our knowledge, this is the first study which uses a sample that can represent all SMEs in Turkey concerned with this issue. Previous studies on the attitudes of SMEs to renewable energy resources have used very limited samples constructed based on region and sector. Furthermore, although there are studies measuring Turkish SMEs' resource efficiency and examining their attitudes toward resource management, there has been no study of Turkish SMEs' views of resource efficiency investments from an economic perspective. Similarly, no existing study has yet addressed Turkish SMEs' attitudes toward green products or services.

The Flash Eurobarometer, Small and Medium Sized Enterprises, Resource Efficiency and Green Markets (GESIS) dataset includes extensive information related to Turkish SMEs. Therefore, using this dataset provides us with the opportunity to analyze the issue in a more general sense. Two hundred and ninety-nine (299) representative firms are included in the last wave (2017 wave) of the dataset. The findings indicate that despite the presence of a largely positive attitude toward resource-efficient actions, 40% of firms from the dataset commented on the difficulties arising from administrative and legal procedures. The results further show that most SMEs rely on their own financial resources to become more resource efficient. However, they still require external support such as new technologies, grants, subsidies, or consultancy to improve resource efficiency in their activities. Interaction with other enterprises is seen as particularly crucial since cooperation with other companies is regarded as the most important method when becoming more resource efficient.

The results of the attitudes of Turkish SMEs toward the generation of on-site energy from renewables demonstrate that a small fraction of the firms (around 11%) use renewable energy sources for self-generation. These results indicate that Turkish

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[1] See Başçı and Durucan (2017) for a review study on Turkish SMEs.

SMEs do not place much emphasis on achieving eco-efficiency through energy from renewables despite legislation that provides generous subsidies to firms.

For the outcomes of resource efficiency actions, 37% of the firms report that they have slightly decreased production costs. The results also reveal that the majority of the firms are reluctant to produce green products or services. One reason for this finding could be a lack of incentives. A vast majority of the SMEs believe that the presence of financial incentives for future projects would help them develop new green products or services.

This chapter contributes to the literature as it is the first academic study to focus on the attitudes of Turkish SMEs to on-site energy generation from renewable resources, resource efficiency investments, and supply of green products/services by using a sample capable of representing all SMEs in Turkey. The findings of this study verify the predictions of the theoretical literature on barriers to the investments on the elements of eco-efficiency. Insufficient information, missing markets or transaction costs in the form of increased bureaucracy are preventing Turkish SMEs from investing in the elements of eco-efficiency even though these investments will eventually yield greater pecuniary or nonpecuniary returns. This finding also concurs with the findings of the empirical literature on barriers to eco-efficiency investments or practices by SMEs (e.g., Fleiter et al. 2012; Rizos et al. 2016; Potapenko et al. 2017; Ghenta and Matei 2018). The Turkish government should intervene to remove the market frictions that serve as barriers to eco-efficiency investments to correct for this type of market failure. One intervention could be designing leaner regulatory and administrative structures for eco-efficiency increasing investments.

The chapter proceeds as follows: Sect. 2 presents the relevant literature; Sect. 3 presents the institutional set up in Turkey; Sect. 4 provides the tables and data used in the study; and Sect. 5 concludes.

2 Literature Review

2.1 SMEs and Eco-efficiency

In this section, we provide a summary of the literature on barriers to eco-efficiency increasing practices or investments by SMEs. The theoretical literature on barriers to the investments on the elements of eco-efficiency focuses on market imperfections such as transaction costs, missing markets, or informational problems (see Sutherland 1991; Howarth and Andersson 1993; Rentschler et al. 2018). These market imperfections may obstruct the rational agent from investing in the elements of eco-efficiency even though these investments eventually bring about greater pecuniary or nonpecuniary returns. This strand of the literature proposes regulatory intervention to eliminate barriers to efficiency investments.

The empirical literature on barriers to eco-efficiency investments or practices by SMEs mostly revolves around energy efficiency investments. There is an abundance of empirical analyses on the barriers to energy efficiency investments by SMEs in different markets in many developed and less developed countries. These articles can be classified as case studies, descriptive studies, and econometric analyses. The results of the related articles are summarized in Table 1.

As shown in Table 1, there are a number of common themes in the results of previous studies. The most important factors among them are the lack of energy efficiency among priorities, financial problems (access to capital, length of return of investment), and lack of information. Thus, it can be concluded that the empirical studies verify the role of market imperfections implied by the theoretical literature. This suggests that even though there is a widespread need for increased efficiency, empirical analyses indicate that required measures are not always taken.

A related concept in the eco-efficiency literature is the "circular economy," which means "*keeping resources in use for as long as possible, extracting the maximum value from them whilst in use, then recovering and regenerating products and materials at the end of each service life*" (WRAP 2019). Although SMEs are increasingly aware of the benefits of a circular economy, they face various challenges in their transition toward it. These challenges are a lack of financial resources and technical skills and increased bureaucracy in evaluating the compliance of the activities performed by SMEs (Rizos et al. 2016; Ghenta and Matei 2018). Thus, the recently emerged literature on circular economy verifies the role of market imperfections as well.

The recent literature on transforming business models into more environmentally friendly business models also indicate market imperfections such as insufficient information for the adoption of eco-efficiency practices. For instance, Potapenko et al. (2017) examine the barriers to "green" modernization of SMEs and look into possible ways to overcome them in Ukraine. The results indicate that nearly 40% of SMEs do not have sufficient information on the means by which to transform their business into a more environmentally friendly one.

Another strand of the literature focuses on the importance of developing an environmental responsibility orientation among SMEs that would positively affect the adoption of eco-efficiency practices. For instance, based on evidence from the Eurobarometer 381 Survey on SMEs, Resource Efficiency and Green Markets González-Moreno et al. (2016) analyzes the environmental responsibility of European SMEs operating in the hospitality industry in Spain. The findings show that having an environmental responsibility orientation produces a positive and significant effect on sales growth in this industry. Aguado and Holl (2018) analyze the factors that are related to SMEs' environmental attitude by measuring environmental attitude with Corporate Environmental Responsibility (CER). They focus on Spain and Norway, as the two different countries in this regard. By using The Flash Eurobarometer 381 Survey data, Aguado and Holl (2018) test the hypothesis that Norwegian and Spanish SMEs present significant differences toward the implementation of CER. The results show that there is a significant difference in environmental commitment in favor of Norway. However, even after controlling for such firm-specific differences, Norwegian firms still show a higher probability for a pro-environmental attitude. Moreover, estimation results reveal that the incentive

Table 1 Barriers to energy efficiency investments by SMEs

Articles	Country	Sectors	Sample size	Basic findings
Country case studies				
de Almeida (1998)	France	Electric motor market		The inconsistency of the incentives and the limited rationality are obstacles to investments that increase energy efficiency
Ostertag (2012)	Germany	Electric motor market	10	The inconsistency of the incentives, the lack of information and the high transaction costs constitute an obstacle to investments that increase energy efficiency
O'Malley and Scott (2004)	Ireland	Mechanical engineering industry	7	Projects on energy efficiency were considered as low priority
Rohdin and Thollander (2006)	Sweden	Energy-intensive manufacturing sectors	8	It was found that the projects on energy efficiency were a low priority, there were time constraints, and the cost of disruptions in production resulting from energy efficiency investments was high
Cooremans (2012)	Switzerland	Electricity-intensive manufacturing sectors	35	Lack of strategic dimension of energy efficiency was found, and financial factors were found to be less important
Descriptive studies				
Gruber and Brand (1991)	Germany	SMEs	500	Both the low priority of projects on energy efficiency and a lack of information prevent energy efficiency investments
Harris et al. (2000)	Australia	All sectors	100	Reimbursement time and rate of return are obstacles to investments
Sorrell et al. (2004)	United Kingdom	Brewery	53	Low priority of energy efficiency projects, time constraint, and inadequate technology undesirably affect energy efficiency

(continued)

Table 1 (continued)

Country case studies				
Articles	Country	Sectors	Sample size	Basic findings
Thollander et al. (2007)	Sweden	SMEs for nonenergy production	47	Low priority of energy efficiency projects, time constraints, access to capital, and problems of capital use prevent investments in energy efficiency
Rohdin et al. (2007)	Sweden	Foundry industry	28	The difficulties in accessing capital and technical risks affect energy efficiency investments negatively
Thollander and Ottosson (2008)	Sweden	Pulp and paper industry	40	Technical risks and possible disruptions in production hinder energy efficiency investments
Thollander et al. (2015)	Japan and Sweden	Manufacturing industry	3139—Japan 74—Sweden	Subsidies for energy audit programs are the most-effective policy for SMEs in industrial sector
Catarino et al. (2015)	Portugal	Food, agriculture, ceramic and glass, timber, furniture, metal, and textile	549	In this paper, the barriers to energy efficiency were listed as lack of information and lack of time, economic and financial barriers. In addition, organizational, training/behavioral barriers can be seen in lack of employees' knowledge and aptitude
O'Keeffe et al. (2016)	United Kingdom	Several manufacturing sectors		Green Deal's energy-efficient methods were applied. The biggest gain is the employment in the green sector creation
Rahbauer et al. (2016)	Germany	Electricity sector	8996	This article provides solutions to the barriers that prevent the implementation of green electricity in 8996 firms in Germany
Tallini and Cedola (2016)	İtaly	Industry and service sector manufacturing		Implementation of energy efficiency methods in Italian manufacturing industry and service sectors and achieving cost-effective solutions

(continued)

Table 1 (continued)

Country case studies				
Articles	Country	Sectors	Sample size	Basic findings
Fresner et al. (2017)	Austria, Bulgari, Cyprus, Italy, Romania, Slovakia, Spain	Several manufacturing sectors	280 Firms	Six thousand five hundred toe of primary energy savings and a reduction in 13,500 tons of greenhouse gas emissions are achieved
Econometric analyses				
Velthuijsen (1995)	Netherlands, Slovakia, Czech Republic	Manufacturing Industry	313 (NL), 40–55 (SK), ~40 (CZ)	Problems in accessing capital, high risk, very long turnaround time, and poor market conditions are the obstacles to energy efficiency investments
de Groot et al. (2001)	Holland	9 Manufacturing industries	135	The low priority of projects related to energy efficiency and investments made negatively impact on energy efficiency investments
Diederen et al. (2003)	Holland	Greenhouse	603	Uncertainty about future energy prices is considered a negative factor
Anderson and Newell (2004)	USA	Manufacturing SMEs	>9000	Return time, costs, lack of personnel and liquidity constraints negatively affect energy efficiency investments
Schleich and Gruber (2008)	Germany	Service industry and small industries	Per sector 57–291 firms	Lack of information on energy consumption and the inconsistency of incentives is an obstacle to energy efficiency investments
Schleich (2009)	Germany	Service industry and small industries	>2000	Lack of information on energy consumption, energy efficiency measures, time constraints, and different priorities pose an obstacle to energy efficiency investments
Muthulingam et al. (2011)	USA	Manufacturing SMEs	>9000	Energy efficiency investments are shaped by the institutional hierarchy within the company

(continued)

Table 1 (continued)

Country case studies				
Articles	Country	Sectors	Sample size	Basic findings
Kostka et al. (2011)	China	SMEs	479	Lack of information is an obstacle to energy efficiency investments
Trianni and Cagno (2012)	Italy	Manufacturing SMEs	128	Access to capital hampers energy efficiency investments

Source: Table 1 is taken from Fleiter et al. (2012) and is reorganized by adding new literature which appeared after 2012

for firms to go beyond environmental legislation is not the same in Norway and Spain. Norwegian firms are more market-driven than Spanish firms in their pro-environmental attitude.

In brief, the related studies in the theoretical and empirical literature indicate various market imperfections as barriers to eco-efficiency investments or practices. In addition, institutional background and cultural differences also explain SMEs' environmental responsibility orientation that has an influence on the adoption of eco-efficiency practices.

2.2 *Turkish SMEs and Eco-efficiency*

Studies that focus on the attitudes of Turkish SMEs toward elements of eco-efficiency are limited. Although there are studies measuring Turkish SMEs' resource efficiency and examining their attitudes toward resource management (Önüt and Soner 2007; Ates and Durakbasa 2012), no study exists on Turkish SMEs' views of resource efficiency investments from an economic perspective. Similarly, there is no study addressing Turkish SMEs' attitudes toward green products/services. Furthermore, previous studies on the attitudes of SMEs to renewable energy resources (Uslu and Türkmenoğlu 2016) are also limited in the sense that they have used inadequate samples constructed on the basis of region and sector.

Among the studies examining Turkish SMEs' attitudes toward resource management, Önüt and Soner (2007) perform a data envelopment analysis (DEA) on the energy efficiency of 20 medium-sized enterprises in the metallic goods industry. Ates and Durakbasa (2012) present multiple case studies of SMEs in energy-intensive industries (iron, steel, cement, paper, ceramics, and textile) to investigate industrial energy management practices in Turkey. Their findings indicate that few of the surveyed SMEs actually implement corporate energy management in Turkey.

Uslu and Türkmenoğlu (2016) investigate the perception of SMEs in the central and eastern Black Sea region of Turkey to renewable energy. They focus on renewable energy trends in SMEs situated in major cities in these regions. Ninety-two medium SMEs enterprises in the cities of Samsun, Ordu, and Trabzon took part in face-to-face interviews and online reviews. The results show that most of the businesses are aware of renewable energy; however, the government needs to do more to encourage SMEs to pursue renewable energy sources.

3 The Legal and Institutional Background for On-Site Electricity Generation from Renewables and Energy Efficiency Investments in Turkey

In this section, we present the legislative framework for the two elements of eco-efficiency in Turkey: on-site electricity generation (distributed generation) from renewables and energy efficiency investments. The reason for focusing on energy efficiency is that among the legislation and policies on resource efficiency, the most relevant and developed one relates to energy efficiency. Likewise, on-site electricity generation from renewables is brought forward by policymakers, and the relevant legislation is highly advanced.

3.1 Distributed Generation (On-Site Electricity Generation from Renewables)

The Turkish electricity market has experienced a radical transformation in the last two decades. Once organized around a vertically integrated public monopoly, the sector has transformed into a model of regulated competition with unbundled enterprises. All network operators and associated supply companies, as well as some of the generation assets, were further privatized. While the public transmission company (TEİAŞ) was preserved under public ownership, access to the grid has been regulated. Organized wholesale markets such as day-ahead and intraday markets were established in addition to a residual balancing market. The electricity generation and retail sale markets have been gradually liberalized. An essential element of the liberalization of the generation and retail electricity markets was the introduction of the unlicensed electricity generation (UEG) in 2010, of which the primary objective of the UEG is to meet the electricity needs of consumers at the closest generation assets.[2]

As a rule, all market activities in the supply chain of electricity must be licensed by the Energy Market Regulatory Authority (EMRA) in Turkey. However, unlicensed electricity generators are exempted from obtaining a license. Article

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[2] By-Law on Unlicensed Electricity Generation in the Electricity Market, Turkish Official Gazette, 02.10.2013, No. 28783.

Table 2 Feed-in-tariffs for unlicensed electricity generation based on a renewable energy source

Production plant type (based on a renewable energy source)	Rate (US dollar cent per kWh)
Hydroelectric power plant	7.3
Wind power production plant	7.3
Geothermal power production plant	10.5
Biomass power production plant (incl. landfill gas)	13.3
Solar power production plant	13.3

Source: The Law on the Utilization of Renewable Resources to Generate Electric Energy (Law No. 5346)

14 of the Electricity Market Law (EML, Law No. 6446) outlines activities that are exempt from obtaining a license.[3] These license-exempt activities provide many administrative advantages to investors and consumers. For instance, there is no mandatory guarantee by the investor at the application stage. The measurement of performance parameters is not required for wind and solar power investments, unlike licensed electricity generation investments. Thus, UEG investors avoid massive hurdles for electricity generation investments. Furthermore, UEG allows consumers to become prosumers[4] by enabling them to feed any excess electricity they generated from renewable resources back into the grid at predetermined feed-in-tariffs.[5] This, in turn, allows easier financial investments. Thus, among the license-exempt activities, the most attractive and popular option is to establish power plants based on renewable energy sources (such as solar or wind power) with a capacity up to One Megawatt (MW). The feed-in-tariffs provided for different renewable energy sources are displayed in Table 2. These tariffs are defined under the YEK Support Mechanism, and outlined in the Law on the Utilization of Renewable Resources to Generate Electric Energy (Law No. 5346). These rates are offered for a 10-year period that starts with the commissioning of the UEG asset.[6]

Thus, UEG is, in many ways, similar to distributed generation (DG). Both enable generating electricity at the point of consumption in smaller scales. Renewables such as solar and wind power are the most common sources used when generating electricity in both UEG and DG. Therefore, when counting the benefits of UEG, one can readily refer to the benefits of DG. Ozbugday and Ozgur (2018) briefly explain the benefits of DG. It reduces the load on the network and becomes a substitute for sizeable investments in distribution and transmission lines, and the

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[3] Article 14 of the Electricity Market Law (EML, Law No. 6446) constitutes the legal basis for the By-Law on Unlicensed Electricity Generation in the Electricity Market. The By-Law regulates the provisions for UEG. The Communique on the Implementation of the By-Law on Unlicensed Electricity Generation in the Electricity Market, offers clarifications and explanations concerning the implementation of the provisions in the By-Law.

[4] Prosumer is a new concept in the energy economics literature. It refers to consumers who generate their own energy for self-consumption.

[5] Article 22 of the By-Law.

[6] Previously, an extra premium was added to these feed-in-tariffs, if generators use domestically produced components. This has been changed with a recent alteration in the legislation.

construction of giant generating plants (El-Khattam and Salama 2004). DG enhances energy security owing to the diversification of energy sources (Lopes et al. 2007), alleviates environmental problems due to the use of renewable sources (Akorede et al. 2010), and improves the quality of supply (Bayod-Rújula 2009).

In addition to those macro-level benefits, UEG can provide new opportunities for electricity consumers in Turkey. Households, commercial or industrial enterprises, and agricultural facilities can generate electricity to meet their energy needs without obtaining a license from the EMRA. They further benefit from feed-in-tariffs, should they generate electricity from renewable resources. In this respect, UEG is particularly attractive for SMEs with large electricity bills. A case study below explains how UEG can contribute to a reduction in an SME's electricity bill and an improvement in its cash flow.

3.1.1 Case Study: A Wind Power Plant in the Backyard of a Factory

Let us consider a manufacturing SME that established an unlicensed wind power plant with a capacity of 500 kW in its backyard. If the capacity factor is 30%, we can calculate that this asset can generate $500 \times 0.30 = 150$ kWh of electrical energy per hour. Let us further assume that this power plant can work 8 h per day depending on weather conditions. Thus, a daily total of $150 \times 8 = 1200$ kWh of electricity is generated by this wind power plant. If the daily electrical consumption of the factory is 3000 kWh, then $3000 - 1200 = 1800$ kWh of electricity is withdrawn from the system (as a result of netting). Let us further assume that the power plant operates with a capacity factor of 20% following day. Then the hourly electricity generated is $500 \times 0.20 = 100$ kWh. If electricity is generated for 4 h, then a daily total of $100 \times 4 = 400$ kWh of electrical energy is produced. Once again, if the factory consumes 3000 kWh of electricity on the same day, then $3000 - 400 = 2600$ kWh of electricity will be withdrawn from the system. If the factory operates 26 days each month, and the power plant works with a capacity factor of 30% for half of these days and operates with a capacity factor of 20% for the remaining half, the total savings of electricity through the wind power is equal to $1200 \times 13 + 400 \times 13 = 20{,}800$ kWh. Considering that the industrial rate for electricity is 0.2834 TRY per kWh, we can calculate that the total monetary value of savings is equal to 5894.72 TRY.

Let us also suppose that the factory does not work 4 days in a month (say, on Sundays). The wind plant still generates electricity. Let us assume that on two of these 4 days the wind plant operates with a capacity factor of 20% (and 4 h a day), and on the other two days it operates with a capacity factor of 30% (and 8 h a day). Thus, the total electricity generated on these free days is equal to $2 \times (500 \times 0.3 \times 8) + 2 \times (500 \times 0.2 \times 4) = 2400 + 800 = 3200$ kWh. The feed-in-tariff for wind power plants is 7.3 US dollar cents per kWh (see Table 2). Thus, the total income for owner of the wind power plant equates to $3200 \times 0.073 = 233.6$ USD. As of October 2018, the USD is worth approximately 6 Turkish Liras. Then, the total monthly income is equal to $233.6 \times 6 = 1401.6$ TRY.

Combining these figures, we can compute that the monthly contribution of the power plant to this factory equates to 5894.72 + 1401.6 = 7296.32 TRY. If other items such as distribution and transmission fees and various taxes are included, then the total monthly contribution nears 9000 TRY. Of course, this figure is a lower bound for the estimation of the benefits, since there might also be indirect benefits such as abatement in CO_2 emissions.

There are approximately three million SMEs in Turkey. If only 1% of these companies (30,000 enterprises) could make similar investments from generating electricity through renewable resources, the total monthly contribution would be approximately 270,000,000 TRY (3.24 billion TRY annually).

3.2 Energy Efficiency Policies in Turkey

Among the legislation and policies on resource efficiency, the most relevant and developed one relates to energy efficiency. Energy efficiency policies in Turkey are based on the Energy Efficiency Law (No. 5627), passed in 2007. The essential aim of the Law is to prevent waste and to increase the efficiency of energy resources and energy use in order to ease the burden of energy costs on the economy and protect the environment. The Law consists of different sections on the organization of the administrative structure, educating the population on energy efficiency matters, sectoral subsidies, and administrative fines.

The National Climate Change Strategy Document for 2010–2023 backs up the policies laid down in the Energy Efficiency Law. Within the scope of the Document, it aims at increasing energy efficiency and reducing greenhouse gas emissions in building, industry, transportation, and energy sectors. Another relevant strategy document is the Energy Efficiency Strategy Document for 2012–2023. The Document plans the determination of a policy set supported by result-oriented targets and actions needed to be taken to reach the targets. Furthermore, energy efficiency measures to be taken during the period 2014–2018 are described in the Program for Improving Energy Efficiency section (No 1.14) of the 10th Development Plan. In addition, energy efficiency targets are defined in the 2015–2019 Strategic Plan of the Ministry of Energy and Natural Resources, under "Theme 2: Energy Efficiency and Energy Saving."

In line with the Directive 2012/27/EU of the European Parliament (also known as the Energy Efficiency Directive), the National Energy Efficiency Action Plan was approved by the High Planning Council on December 29, 2017 (decision number 2017/50) and entered into force on January 02, 2018. The targets of the National Energy Efficiency Action Plan are linked to the legislation outlined above and are also involved in the scope of the National Energy and Mining Policy prepared by the Ministry of Energy and Natural Resources in 2017.

The government provides generous subsidies to achieve the targets specified in the legislation outlined above. For instance, investments in energy efficiency by existing manufacturing industry plants with a minimum annual energy consumption of 500 toe (tonnes of oil equivalent) to save energy at a minimum rate of 20% per unit and with a maximum payback period of 5 years will benefit from subsidies such as value-added tax exemption, customs duty exemption, tax deduction, employer's share of insurance premium support, interest rate support or investment place allocation (Council of Minister's decision no. 2014/6058).

More generally, efficiency-improving projects have been systematically supported by the government since 2009. Projects prepared in accordance with the procedures and principles published by the General Directorate of Renewable Energy are considered as EfficiencyImproving Projects (EIP) and for EIPs with a total cost of less than one million Turkish liras and with a payback period of less than 5 years, at most 30% of the project fee is conferred as a grant.

Another subsidy is known as Voluntary Agreement (VA) supports. These are grants given to enterprises that reduce energy intensity levels by at least 10% according to a pre-committed reference energy density level, which is the average of the 5-year energy densities, following a 3-year monitoring period. Should an enterprise make a voluntary agreement and fulfill its commitment, 20% of its energy expenditures (so long as they do not exceed 200,000 TRY) in the year of the agreement is provided to the enterprise in cash.[7]

To sum up, the legislative background in Turkey provides SMEs a number of ways to benefit them from generating electricity by using renewable resources and energy improving investments. The success of the relevant policies depends on whether the Turkish SMEs truly understand the value of energy from renewable resources and energy-improving investments, and relevant government subsidies to boost these.

In the following sections, the attitudes of Turkish SMEs to on-site energy generation from renewable resources, resource efficiency investments, and supply of green products/services will be examined in a descriptive way.

4 Data and Methodology

4.1 Sample Selection

In this study, we analyze the perceptions of SMEs in Turkey toward resource efficiency, green products or services, and the use of renewable energy sources in their production by using the last wave of Flash Eurobarometer, Small- and Medium-Sized Enterprises, Resource Efficiency and Green Markets (GESIS) Survey (2017). This survey includes a set of questions ranging from firm-specific variables as firm size, age, sector, and turnover to SMEs' perceptions of resource efficiency. Additionally, in the survey, there are questions revealing SME's potential to produce

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[7] http://www.enerji.gov.tr/tr-TR/Sayfalar/Enerji-Verimliligi-Destekleri (last accessed on 11 March 2019).

green products and services. Firms, therefore, are asked whether they involve themselves in green production, or whether they have a certain level of intention to produce such products or services.

This survey was conducted in 2012, 2013, 2015, and 2017, respectively. Each wave includes questions measuring SMEs' perceptions of resource efficiency and green production. In this study, we use the last wave of the survey due to the difficulty of capturing the same information throughout the entire survey period. The last wave elaborates all questions related to resource efficiency and green production extensively.

The main reason for selecting Turkish data is that there has been an increasing trend among SMEs in Turkey to apply resource-efficient tools in their production. There are 299 observations in the sample. Nearly a quarter of the sample is composed of medium-sized firms (24%) while 40% of the sample consisted of small firms. There are 12 sectors defined in the questionnaire from mining to professional, scientific, and technical activities. Among these, the wholesale and retail trade sector has the largest share in the sample. Manufacturing and construction sectors have shares of 28% and 16%, respectively. A significant portion of the sample is composed of firms established before 2010 (77%). Considering the perceptions of firm performance, a large proportion of the sample has a positive evaluation of the current year's performance; nearly half (49%) indicate an increase in their companies' performance in comparison to the previous year.

4.2 Descriptive Analysis

From a methodological point of view, we use descriptive analysis and cross-tabulations to put forth the current situation of energy efficiency and distributed generation in Turkey.

4.2.1 Resource Efficiency

As far as the questions on resource efficiency are considered, topics could be summarized as resource efficiency, effects of resource efficiency on production, types of support for resource efficiency, use of environmental management system, difficulties of following resource-efficient strategy, and the tools required to be more resource efficient.

As shown in Table 3, firms use (and plan to use according to Table 4) different alternatives to achieve resource-efficient production. However, three of them come to the fore, which are minimizing waste, saving water, and selling scrap materials to other firms. Designing a new product, on the other hand, has the smallest share compared to other actions suggesting that firms in the sample rely on existing resources rather than generating new solutions.

Table 3 Attitudes toward resource efficiency

What actions is your company undertaking to be more resource efficient?	Freq.	Percent
Save water	53	17.73
Save energy	30	10.03
Use predominantly renewable energy	33	11.04
Save materials	43	14.38
Minimize waste	57	19.06
Sell your scrap material to another company	48	16.05
Recycling by reusing material or waste within the company	30	10.03
Designing products that are easier to maintain, repair, or reuse	5	1.67
Total	299	100.00

Table 4 Additional resource efficiency actions

Over the next 2 years, what are the additional resource efficiency actions?	Freq.	Percent
Save water	50	16.72
Save energy	20	6.69
Use predominantly renewable energy	26	8.70
Save materials	26	8.70
Minimize waste	52	17.39
Sell your scrap material to another company	53	17.73
Recycling by reusing material or waste within the company	50	16.72
Designing products that are easier to maintain, repair, or reuse	22	7.36
Total	299	100.00

Table 5 Target population

Is your company selling its products or services…?	Freq.	Percent
Directly to customers	214	71.57
Other firms	46	15.38
Public administration	35	11.71
n.a.	4	1.34
Total	299	100.00

This sample is largely composed of firms selling their products directly to customers. However, other firms or public administration agencies also constitute a target population for a considerable number of firms in the sample (see Table 5).

Despite the presence of a positive attitude toward taking resource-efficient actions, as shown in Table 6, 40% of the sample comment upon the difficulties arising from administrative and legal procedures. In the questionnaire, we do not observe any specific example for administrative and legal procedures. Thus, we assume that these procedures could be related to bureaucratic operations that assess whether firms in the sample are eligible for resource-efficient actions. Additionally, there are some problems concerning firms' adaptability to environmental regulations

Table 6 Difficulties of undertaking actions to achieve resource efficiency

Did your firm encounter the following difficulties when trying to set up resource efficiency actions?	Freq.	Percent
The complexity of administrative and legal procedures	109	40.07
Difficulty in adapting environmental legislation to your company	26	9.56
Technical requirements of the legislation not being up-to-date	26	9.56
Difficulty in selecting the right resource efficiency actions for your company	28	10.29
Cost of environmental actions for your company	28	10.29
Lack of specific environmental expertise	32	11.76
Lack of supply of required materials, parts, products, or services	14	6.15
Lack of demand for resource-efficient product or services	9	3.31
Total	272	100.00

Table 7 Type of support for resource-efficient production

Which type of support does your company rely on in its effort to be more resource efficient?	Freq.	Percent
Not mentioned	86	31.62
Its own financial resources	186	68.38
Total	272	100.00

implying that these firms may not have the required internal precautions to sustain environmentally friendly production.

In today's world, rapid technological changes necessitate a gradual update in production systems. If the technical requirements of the legislation are not updated according to the changes in the production systems, firms will show a reluctance to implement these requirements. This result is observed in this study in which 10% of the firms declare that outdated requirements threaten their actions toward resource efficiency. Moreover, in this sample, some firms have difficulties in selecting the best strategy to achieve resource efficiency. The costs of environmental actions and absence of expertise in related environmental effects are other challenges that firms need to overcome.

Another question in the survey is the type of support needed to achieve resource efficiency in SMEs' production processes. Table 7 reveals that a large proportion of the firms in the sample rely on firms' own financial resources.

Although firms sustain their production activities largely by relying on their own resources, they do require external support such as new technologies, grants, subsidies, or consultancy that enable them to improve resource efficiency in their activities. Among these, cooperation with other companies is stated as an essential tool in being more resource efficient (see Table 8).

Another relevant question relates to the effects of resource efficiency actions on production costs. Of the sample, 37% indicate that it has slightly decreased. However, there is a considerable share of negative perceptions among firms that point out increasing production costs (see Table 9).

Table 8 Type of tools for resource efficiency

Which of the following would help your company to be more resource efficient?	Freq.	Percent
Not mentioned	206	68.90
Better cooperation between companies	93	31.10
Total	299	100.00

Table 9 Impact of resource-efficient strategy on costs

What impact has resource efficiency actions had on the production costs over the past 2 years?	Freq.	Percent
Significantly decreased	23	9.46
Slightly decreased	101	37.13
Slightly increased	54	19.85
Significantly increased	36	13.24
Not changed	20	7.35
DK/NA	38	13.97
Total	272	100.00

4.2.2 On-Site Electricity Generation from Renewable Resources

Tables 3 and 4 also provide information on the attitudes of Turkish SMEs toward generating on-site energy from renewables. As can be seen from Table 3, only 11% of the firms use renewable energy sources for self-generation. These results indicate that Turkish SMEs do not put much emphasis on achieving eco-efficiency through energy from renewables despite legislation that provides generous subsidies to firms. As exemplified in the case study in Sect. 3.1.1, an SME with an unlicensed power plant that uses renewable resources can decrease its energy bill, avoid transmission and distribution fees and various taxes, and abate CO_2 emissions. Furthermore, as the feed-in-tariffs displayed in Table 2 are much higher than the market-clearing electricity prices in Turkey, SMEs could also earn extra income by selling the excess electricity they generate back to the grid. However, the results indicate that these benefits do not accrue since very few Turkish SMEs are interested in renewable energy sources for self-generation.

4.2.3 Green Production

When looking at green products and services, 11% of the sample is involved in the providing products and services relevant to the industry. Additionally, there is a considerable number of firms intending to become involved in green production in the future. However, the majority of firms are reluctant to produce green products or services (see Table 10).

Table 10 Green production

Does your company offer green products or services?	Freq.	Percent
Yes	33	11.04
No, but you are planning to do so in the future	43	14.38
No, and you are not planning to do so in the future	200	66.89
DK/NA	23	7.69
Total	299	100.00

Table 11 Duration of production activities

	Percent	Cum.
Less than 1 year	5	15.15
Between 1 and 3 years	8	24.24
More than 3 years	20	60.61
Total	33	100.00

Table 12 Type of market

In terms of turnover over the past 2 years, what were the main markets	Freq.	Percent
Not mentioned	8	24.24
National market	25	75.76
Total	33	100.00

Table 13 Type of financial resources

What type of support does your company rely on for its green production?	Freq.	Percent
Not mentioned	15	45.45
Financial incentives for developing production	18	54.55
Total	33	100.00

Only a small percentage of the firms selling green products and services for more than 3 years implement green production activities (see Table 11). They predominantly sell their products to national markets (see Table 12). In terms of financial and technical resources, they rely on their own financial resources and technical expertise (see Table 13). However, as shown in Table 14, 55% of them believe that the presence of financial incentives for future projects would help them develop new products. This dimension is also supported extensively by firms that do not produce green products and services.

Table 14 Alternative support for green production

What type of support would help most in expanding your range of green production?	Freq.	Percent
Not mentioned	15	45.45
Financial incentives for developing production	18	54.55
Total	33	100.00

5 Conclusion

In this study, we provide empirical evidence on the attitudes of Turkish SMEs toward the elements of eco-efficiency and descriptively examine their approach to on-site energy generation from renewable resources, resource efficiency investments, and the supply of green products or services. We use Flash Eurobarometer, Small- and Medium-Sized Enterprises, Resource Efficiency and Green Markets (GESIS) 2017 dataset for this purpose. There are 299 observations in the sample. Our observations show that only 19% of the firms try to minimize waste to be more resource efficient. On the other hand, the usage of predominantly renewable energy is 11%, which is not very high when compared with other actions undertaken for this purpose. When asked about resource efficiency plans for the next 2 years, firms respond with the following priorities: saving water, minimizing waste, selling their scrap material to another company, and recycling by reusing material or waste within company. Using predominantly renewable energy is not among the main concerns (11%).

Regarding the difficulties when trying to set up resource efficiency actions, firms declared the complexity of administrative and legal procedures as the most significant difficulty, noted by 40% in the survey. Sixty eight percent of the firms rely on their financial resources while trying to be more resource efficient. Nearly a third (31%) of firms believe that this difficulty can be solved by external supports such as new technologies, grants, subsidies, or consultancy. In order to solve this, cooperation with other firms can be a viable method. One interesting observation is about the production costs over the past 2 years when resource efficiency actions had been undertaken by the firms. Survey results show that only 9% of the firms think that their costs significantly declined, which is very low.

Finally, 11% of the sample produces green products or services, 14% of the sample is planning to do so in the future, and 67% of the firms are not planning to produce green products or services.

Based on these observations, we can say that the usage of predominantly renewable energy and production of more green products or services are not among the priorities of the firms. The two leading causes mentioned are the complexity of administrative and legal procedures and financial problems. Firms are looking for new technologies, grants, subsidies, or consultancy to change this situation and believe that this can better achieved by cooperating with other firms.

These results imply that there is a distance between Turkish SMEs and the elements of eco-efficiency. They still need external support to improve resource efficiency. Only a small fraction of Turkish SMEs introduces green products or services into the market, and most of them are not interested in electricity generation from renewable energy resources. Insufficient information, missing markets, or transaction costs in the form of increased bureaucracy are preventing Turkish SMEs from investing in the elements of eco-efficiency even though these investments will eventually yield greater benefits. These findings concur with the predictions of the theoretical literature and the findings of the empirical literature on barriers to the investments on the elements of eco-efficiency. As SMEs construct a sizeable portion of the output in the economy; the findings indicate that the contribution of SMEs to green growth will be lacking in the coming years unless further action is taken, and support provided by the Turkish government.

One intervention could be designing leaner regulatory and administrative structures for eco-efficiency increasing investments. It is evident that Turkish SMEs perceive legal and administrative barriers to resource efficiency investments. The reduction in red tape and simplification of administrative procedures eventually decrease transaction costs and make Turkish SMEs more eager to invest in resource efficiency.

Furthermore, the external support needed by firms about the technical and financial aspects of resource efficiency investments could be provided by the government. Similarly, public consultancy programmes on electricity generation from renewable resources could also be constructive for Turkish SMEs to overcome transaction costs and informational problems which prevent them from reaping the benefits of green energy.

Finally, in addition to consultancy services, to increase the share of SMEs that offer green products or services, the Turkish government could make these products or services more attractive by reducing taxes. The decrease in the taxes on green products or services makes the demand for these products or services increase which, in turn, makes the green market more profitable for SMEs.

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Volatility Spillovers Between Oil and Stock Market Returns in G7 Countries: A VAR-DCC-GARCH Model

Göknur Büyükkara, Onur Enginar, and Hüseyin Temiz

1 Introduction

Volatility transmission became an important phenomenon after the financial markets were liberalized and integrated as a result of globalization and the rapid development of communication technologies. Information is transmitted across markets through returns and volatility (Baele 2002; Bekaert and Harvey 1997; Christiansen 2003; Ng 2000; Worthington and Higgs 2004). If two markets are integrated, then any external shock in one will not only affect the mean, but also the variance of returns in other markets (Singh et al. 2010). In this study, we use a standard vector autoregressive (VAR) model to determine the relation between the stock returns of G7 countries and the oil market return. Our purpose is to quantify how oil market events such as OPEC supply decisions and stock market events change the volatility transmission between these markets.

Understanding time-varying volatility and the volatility transmission mechanisms between energy prices and stock markets is essential for researchers, academics, investors, and policymakers. Investors want to know how the risk and value of their portfolios are affected by important fluctuations in oil prices, especially in recent years. Volatility spillovers are usually explained by information flows between markets and a financial contagion mechanism that transmits the volatility of one market to the other (Hassan and Malik 2007). Generally, oil prices transmit information to the stock market by changing cash flows for firms due to costs and inflation. Although the stock market does not always move in the same direction as the oil market, evidence in the literature indicates that declines in oil prices are associated with increases in stock prices. On the other hand, the stock market could

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be leading the oil market, since the stock market is forward looking. For instance, by applying a multivariate Baba–Engle–Kraft–Kroner (BEKK 1990) model, Malik and Hammoudeh (2007) show the oil market generally transmits volatility to the stock markets in the Gulf area, except in Saudi Arabia, where there is significant volatility spillover from the stock market to the oil market. This result underlines the major role the Saudi stock market plays in the global oil market, since it signals the position of the Saudi economy, the world's largest oil exporting economy. Hence, policymakers in oil-sensitive economies follow the Saudi equity market for potential changes in the oil market.

We employ dynamic conditional correlation (DCC) in multivariate generalized autoregressive conditional heteroscedasticity (M-GARCH) models to examine the potential for volatility spillovers and time-varying correlations. The DCC model fits our purposes and data set better than parsimonious BEKK models, which require too many parameters and do not indicate cross-dynamics in diagonal options, or a constant correlation model that assumes constant correlations between asset returns (Bauwens et al. 2006).

Our motivation for this study is the common trend in oil and stock market prices that signals the presence of volatility spillover. As depicted in Fig. 1, except for the Nikkei 225 and the Standard & Poor's (S&P) 500, the stock market indexes in the G7 countries (CAC 40 in France, DAX in Germany, FTSE 100 in the UK, FTSE MIB in Italy, Nikkei 225 in Japan, S&P 500 in the USA, and S&P/TSX Composite in Canada) declined with Brent oil prices after the Organization of Petroleum Exporting Countries (OPEC) oil supply increase in June 2014, with co-movement between the stock and oil markets. The 70% oil price drop during that period was the third highest level since World War II and the longest lasting since the supply-driven collapse of 1986. Large global oversupplies between 2014 and 2016 that led to price decreases were increased by production from OPEC, notably Saudi Arabia.

Arouri et al. (2011a) analyze two stock market indexes, the STOXX Europe 600 Index for Europe and the S&P 500 for the USA, and find bidirectional volatility spillover in the USA but unidirectional spillover from the oil to the stock markets in Europe between 1998 and 2009. Mensi et al. (2013) use a VAR-GARCH model to investigate the relations for returns and volatility transmission between the S&P 500 and West Texas Intermediate (WTI) and/or Brent energy commodity prices. However, they use a constant conditional correlation (CCC) model, where the correlations between system shocks are assumed to be constant to facilitate the estimation and inference procedure. Analyzing daily US stock returns with multivariate DCC-GARCH models, Mollick and Assefa (2013) find that stock returns were negatively affected by oil prices before the 2008 global financial crisis (GFC) and positively affected afterwards. The time-varying correlation between the stock market prices and oil prices of oil-importing countries (the USA, Germany, and the Netherlands) and oil exporting countries (Canada, Mexico, Brazil) does not change, according to Filis et al. (2011). However, the correlations could decrease because of precautionary demand problems caused by oil price shocks, such as during Iraq's invasion of Kuwait, the collapse of the Soviet Union, and the 9/11 terrorist attacks in the USA. The authors find that non-economic crises induce an even stronger

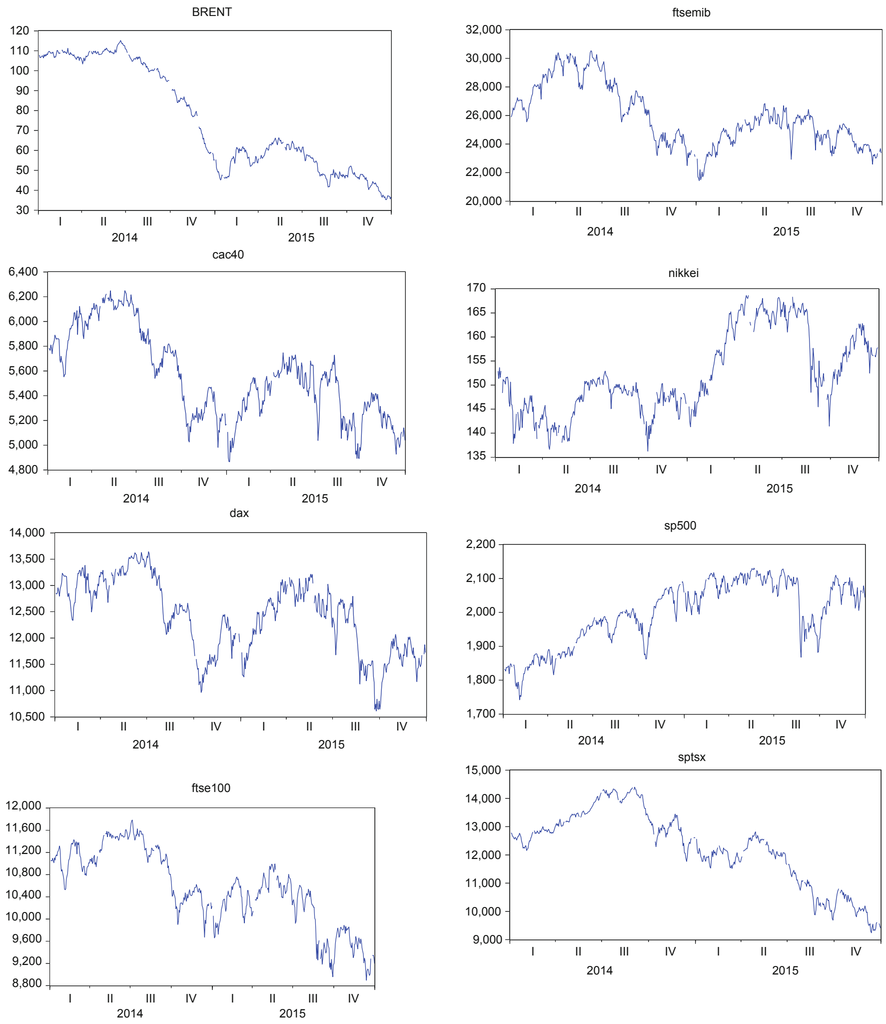

Fig. 1 Brent oil and the financial markets of the G7 countries

negative link between oil prices and stock markets. Sadorsky (2012) uses a multivariate DCC-GARCH model to test the relation between oil prices and the stock prices of clean energy and clean technology companies and finds that the stock prices of clean energy companies are affected more by technology prices than by oil prices.

Our multivariate DCC model indicates bilateral causality between the oil market and each stock market. We also find that this causality varies over time. We show that the conditional correlations exhibit an increasing pattern, especially since the 2014 OPEC oversupply period, whereas the correlations decrease again since the

2016 OPEC rebalancing period. The positive correlations between the oil and stock markets can be explained by the fact that the OPEC oversupply caused oil prices to decline heavily. For oil importing G7 developed countries, the decrease in oil prices from June 2014 through February 2016 seemed advantageous for the stock market due to cost declines in the oil market.

Although production cuts after 2016 did not create a demand shock or an oil crisis, our results show that OPEC production rebalancing and production cuts after 2016 decreased volatility spillover between the oil and stock markets of G7 countries. Contrary to Filis et al. (2011), our findings indicate that OPEC's production policies had a significant impact on the correlation between the oil and stock markets during this period. Our evidence verifies that OPEC's oversupply increases the dynamic conditional correlations between oil and G7 stock markets till rebalancing as OPEC's decision to increase increased production has depressed the price of oil. Under these conditions, our results recommend a portfolio strategy that equally weights the stock and oil markets. By taking long positions in the oil market, stock market risk can be effectively hedged.

This chapter contributes to prior literature in three ways. First, we extend on the spillover literature by extending the analysis to G7 country indexes. Khalfaoui et al. (2015) find some evidence for G7 countries with a BEKK approach. However, they use level prices and nonstationary time series to conduct wavelet analysis. Using daily stationary data from 2014 to 2016, we mainly find evidence of significant return and volatility spillovers between the oil and stock markets in the G7 countries. Second, we allow DCCs in the VAR-GARCH model. Third, we provide empirical evidence on the interrelationship between oil and stock prices by using a more recent, post-GFC data set.

The remainder of this chapter is structured as follows. Section 2 presents the literature on the links between oil prices and stock markets. Section 3 specifies our VAR-DCC-GARCH model. The data are analyzed in Sect. 4. Section 5 reports the empirical results. Section 6 presents the portfolio analysis constructed from the conditional correlations of the model in the oil and stock markets. Finally, Sect. 7 discusses the results and concludes the chapter.

2 Literature Review

Oil price changes significantly affect macroeconomic conditions. The earlier evidence of Hamilton (1983) indicates that seven of eight post-World War II recessions were followed by a dramatic increase in the price of oil in the USA. Most of the empirical papers have established that oil price shocks have significant effects on macroeconomic variables ranging from employment to exchange rate changes in developed and emerging countries (Brown and Yücel 2002; Du et al. 2010; Filis 2010; Hamilton 2003; Jiménez-Rodríguez and Sánchez 2005; Kilian 2008; Lorde et al. 2009; Rafiq et al. 2009).

Examining the effect of stock markets on oil shocks, Jones and Kaul (1996) find that, after World War II, the reaction of US and Canadian stock prices to oil shocks become more evident. Sadorsky (1999) uses vector autoregression to show that both oil prices and oil price volatility play important roles in real stock returns in the USA. Other studies on the relations between stock returns and the oil market in the context of developed countries use various approaches, such as a VAR model, international multifactor asset pricing models, cointegration, and a vector error correction model (Apergis and Miller 2009; Boyer and Filion 2007; El-Sharif et al. 2005; Papapetrou 2001; Park and Ratti 2008). Based on these studies, Apergis and Miller (2009) decompose oil price changes into three components: oil supply shocks, global aggregate demand shocks, and global oil demand shocks. However, they find that these shocks cannot explain the variations in international stock markets under the VAR model.

The oil and stock market literature extensively tests for volatility spillover between the crude oil market and financial markets. For instance, Malik and Ewing (2009) employ bivariate GARCH models with BEKK parameterization to simultaneously estimate the mean and conditional variance between five different US sector indexes and oil prices. The authors examine weekly returns from January 1, 1992, to April 30, 2008, and find evidence of significant transmissions of shocks and volatility between oil prices and some of the examined market sectors. Arouri et al. (2012) investigate volatility spillover effects between the oil and sector stock markets in Europe. Their VAR-GARCH evidence indicates significant cross-market volatility transmission, with spillover effects more obvious from the oil to the stock markets and entirely due to shock transmission. Arouri et al. (2012) use a CCC model and note that the CCC assumption can be considered restrictive, because the correlation coefficient is likely to vary over time as a response to changes in economic and market situations. Chang et al. (2013) emphasize that the DCC estimates of conditional correlations are always significant and the assumption of CCCs is not supported empirically. However, the authors' evidence of volatility spillover between WTI and Brent oil and the FTSE 100, S&P 500, and New York Stock Exchange markets is insufficient to empirically suggest transmission between these markets.

Analyzing the oil and stock markets in the Gulf Cooperation Council (GCC) countries that depend on oil, Arouri et al. (2011b) determine volatility spillovers between world oil prices and the GCC stock markets. For the GCC countries, Awartani and Maghyereh (2013) indicate that returns and volatility transmission were bidirectional from 2004 to 2012 and that dynamic correlations were momentarily magnified following the GFC. By applying DCC to the VAR-GARCH model in Middle Eastern countries, Aimer (2016) concludes the DCCs between the oil and stock markets vary dramatically over time, again peaking during the 2008 GFC. Gomes (2014) uses BEKK parameterization in 21 MSCI frontier markets and finds bidirectional spillovers that are investable but with lower market capitalization and liquidity than traditional developed and emerging markets. Singhal and Ghosh (2016) use a VAR-GARCH-DCC model to show that the spillover from the international oil market to the Indian stock market is only significant in sectors such as automotive, power, and financials; they find the parameter of dynamic correlations to be significant in all cases.

Although numerous studies test the effect of oil market shocks on macroeconomic indicators, the evidence of these shocks on the spillover literature is ambiguous and is not tested separately after 2008 GFC. In other words, studies on the volatility transmission generally report a negative or positive correlation between stock and oil markets for economic shocks such as GFC and Asian crisis or noneconomic demand-based shocks, such as Iraq war or 9/11 terrorist attacks with past data set. Supply side shocks, such as OPEC events, are often neglected or have inconclusive results in the above literature. By using a more recent data set and applying the proposed DCC technique for VAR-GARCH models, we provide empirical evidence on the spillover relations between stock and oil markets and the effects of OPEC oversupply events in the G7 markets.

3 Econometric Methodology

Huge flows of information are constantly processed and reflected in asset prices that can be directly observed by interested parties. However, there is also a latent part that cannot be directly observed, the volatility component of price processes. Volatility can be measured via the standard deviation of prices, which could be a constant or a real-valued process changing over time. In this time-varying (non-constant) setting, volatility is modeled econometrically via GARCH-type models (Bollerslev 1986; Engle 1982). Univariate GARCH models are employed to solve statistical inference problems or to model the volatility of a process. Moreover, multivariate volatility models, such as the BEKK (Baba et al. 1990), CCC (Bollerslev 1990), and DCC (Engle 2002) models, are the main tools for modeling conditional volatility that varies both in time and across other assets. However, the main disadvantage of these models is that their fitting is computationally expensive.

We employ a VAR(1)-GARCH(1,1) setting to model the integration of the first and second moments of price processes to examine the return and volatility transmission of stock prices and oil prices. The VAR(1) setting allows us to determine how oil and stock prices evolve together and the GARCH(1,1) portion allows us to conclude how the volatility of these prices is related. Following Arouri et al. (2011a), we define the following equations for the VAR(1)-GARCH(1,1) model:

$$\begin{cases} Y_t = c + \phi Y_{t-1} + \epsilon_t \\ \qquad \epsilon_t = h_t^{1/2} \eta_t \end{cases} \tag{1}$$

where $Y_t \left(r_t^{oil}, r_t^{stock} \right)$ indicates the returns of oil and stock exchanges, respectively, at time t with a 2×2 coefficient matrix ϕ, and $\epsilon_t \left(\epsilon_t^{oil}, \epsilon_t^{stock} \right)$ is the residual for the oil and stock exchanges, respectively, in the mean model. Additionally, $\eta_t \left(\eta_t^{oil}, \eta_t^{stock} \right)$ represents independent and identically distributed oil and stock exchange innovations, respectively, with unit variance. Finally, $h_t^{\frac{1}{2}}$ represents the diagonal elements of $\left(\sqrt{h_t^{oil}}, \sqrt{h_t^{stock}}\right)$, where $\sqrt{h_t^{oil}}$ and $\sqrt{h_t^{stock}}$ are the conditional variances of r_t^{oil} and r_t^{stock}, respectively, with

$$h_t^{oil} = c^{oil} + \alpha^{oil}\left(\epsilon_{t-1}^{oil}\right)^2 + \beta^{oil} h_{t-1}^{oil} + \alpha^{stock}\left(\epsilon_{t-1}^{stock}\right)^2 + \beta^{stock} h_{t-1}^{stock} \tag{2}$$

$$h_t^{stock} = c^{stock} + \alpha^{stock}\left(\epsilon_{t-1}^{stock}\right)^2 + \beta^{stock} h_{t-1}^{stock} + \alpha^{oil}\left(\epsilon_{t-1}^{oil}\right)^2 + \beta^{oil} h_{t-1}^{oil} \tag{3}$$

A transmission effect is observed in Eqs. (2) and (3) via the parameters α^{oil} and α^{stock} that represents short-term persistence, and β^{stock} and β^{oil} capture long-term dependencies in volatility between r_t^{oil} and r_t^{stock}.

As can be seen above, our setting covers both the first and second moment integration of oil and stock prices together through ϕ, α^{oil}, and α^{stock} and β^{stock} and β^{oil}. We use quasi-maximum likelihood to estimate the model parameters.

4 Data and Preliminary Analysis

We obtain daily stock price data for the G7 countries between January 1, 2014, and October 24, 2016, from the Bloomberg database. Brent crude oil price data for the same period are obtained from the US Energy Information Administration. Brent spot prices are used to represent the international crude oil market because they usually serve as a reference for pricing crude oil and many other derivatives and products with oil as the underlying asset. We exclude holiday days for which market data are not available rather than use the closing prices on the last day before a holiday. This two- to three-year period is chosen because it does not include the GFC period, which inflated volatility, and is a more recent period that is considered stable according to economic indicators. We selected such a short period because longer periods could exaggerate volatility, given the high frequency of economic cycles and crises. Daily data are used to capture the intensity of dynamic interactions between oil and stock prices. In addition, traders such as market makers and speculators deal with the dynamics of daily energy prices and execute large volume transactions at relatively high frequencies (Wang and Wu 2012).

The benchmark stock price index returns of France (CAC 40), Germany (DAX), the UK (FTSE 100), Italy (FTSE MIB), Japan (Nikkei 225), the USA (S&P 500), and Canada (S&P/TSX) are calculated as the logarithms of the returns. The returns of the Brent oil market are also calculated in logarithmic form. We calculate daily returns as:

$$r_t = \ln\left(p_t/p_{t-1}\right)$$

Table 1 shows descriptive statistics of the daily returns belonging to these markets. The USA (S&P 500) has the highest mean positive return and Japan

(Nikkei 225) the second. On the other hand, the lowest mean negative return and highest standard deviation are observed in the Brent oil market, which seems riskier than the stock markets considered. The data set in our analysis exhibits non-normality, based on the Shapiro normality test (Royston 1982).[1] Additionally, based on the adjusted Dickey–Fuller test (Fuller 1996), the data set is stationary but exhibits ARCH effects (McLeod and Li 1983). Therefore, an investigation of variance makes sense.

Table 2 exhibits the correlations between the markets. Except for the Nikkei 225, all correlations between the stock markets and the Brent oil market are greater than 30%, which could increase the possibility of spillovers.

5 Results

In Table 3, we find that DCC parameters are always significant. This result indicates that all the individual stock market time series have a DCC with the Brent oil price series. The significance of joint DCC parameters suggests a bilateral causality between the stock and oil markets, rather than unidirectional causality from the oil market to the stock market. We conclude that the G7 stock market indicators are as important as Brent oil prices in the market's information flow.

The ARCH and GARCH parameters shown in Table 3 indicate that the volatility of the oil and stock indexes depends on past memory and historical volatilities. The sum of the ARCH and GARCH coefficients is close to unity, showing that the volatility of the stock and oil markets is persistent. However, the estimates for the mean equation are not significantly meaningful in all cases. Brent oil significantly affects the Nikkei 225 and CAC 40 in the mean equation. Interestingly, S&P/TSX affect Brent oil prices, since Canada has the only oil exporting firms within the selected G7 countries. Moreover, the FTSE MIB, Nikkei 225, and S&P/TSX are affected by their own lagged terms, since the stock market is generally affected by its own lagged prices rather than oil prices.

In Figs. 2, 3, 4, 5, 6, 7, and 8, we plot the DCC of stock prices with Brent oil prices. The first event in the oil market after the GFC is the OPEC oversupply in June 2014, when oil prices started to fall from a peak of $115 per barrel, dropping below $35 in February 2016. Consistent with this oversupply, the dynamic correlations between the oil and stock markets began to exhibit an increasing pattern, whereas the correlations started to decrease after OPEC's rebalancing efforts in February 2016.

We also find that the oversupply period stimulated a stronger positive link between oil prices and the stock market, since the stock market reacted positively to declines in oil prices. The supply reduction after February 2016 decreased the DCCs between the oil and stock markets, since the more expensive oil market did not continue to offer good investment opportunities to firms. After the decline in oil

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[1] We eliminate outlier values below -3σ and above $+3\sigma$.

Table 1 Descriptive statistics

	Brent	S&P 500	S&P/TSX	CAC 40	DAX	FTSE MIB	Nikkei 225	FTSE 100
Min	−0.080825	−0.040211	−0.034471	−0.100454	−0.087281	−0.149923	−0.048771	−0.105650
Max	0.098961	0.038291	0.039232	0.041585	0.040002	0.047750	0.063649	0.055037
Median	−0.000764	0.000289	0.000104	0.000086	0.000089	−0.000111	−0.000121	0.000425
Mean	−0.001062	0.000224	−0.000176	−0.000208	−0.000128	−0.000454	0.000107	−0.000354
Std. Dev.	0.022568	0.008432	0.010468	0.012224	0.012444	0.016304	0.012405	0.011758
Shapiro Norm. Test	0.9559***	0.9664***	0.9834***	0.9517***	0.9709***	0.9383***	0.9663***	0.9118***
ARCH–Lagrange multiplier	115.8772***	243.1821***	211.498***	54.66082***	47.89844***	40.37878***	78.24347***	167.9439***
Dickey–Fuller	−7.58450	−9.30680	−8.27570	−9.23760	−9.05540	−8.70910	−9.00590	−9.44480

*** signify significance at the 1% level

Table 2 Correlations

	DBrent	DCAC 40	DDAX	DFTSE 100	DFTSE MIB	DNikkei225	DS&P 500	DS&P/TSX
DBrent	1							
DCAC 40	0.391993	1						
DDAX	0.329596	0.938864	1					
DFTSE 100	0.450771	0.886949	0.838216	1				
DFTSE MIB	0.351161	0.893175	0.85133	0.807687	1			
DNikkei 225	0.069482	0.172303	0.136355	0.209884	0.101955	1		
DS&P 500	0.313739	0.550225	0.516502	0.55995	0.51256	0.030532	1	
DS&P/TSX	0.566968	0.570446	0.516353	0.64382	0.510565	0.086488	0.689764	1

Table 3 Estimates of VAR(1)-GARCH(1,1) for G7 countries and Brent oil

Mean Equation	DAX	Brent		FTSE MIB	Brent		Nikkei 225	Brent
Constant	−0.000117	−0.000990	Constant	−0.00048	−0.000991	Constant	0.000272	−0.000997
	(0.799176)	(0.2355774)		(0.424981)	(0.235321)		(0.534)	(0.2323742)
DAX(1)	−0.042021	−0.058501	FTSE MIB(1)	−0.098551	0.007586	Nikkei 225 (1)	−0.211358	0.0323786
	(0.281407)	(0.4076096)		(0.012564**)	(0.889829)		(0.000009***)	(0.6307426)
Brent(1)	0.026600	0.0831306	Brent(1)	0.034686	0.070963	Brent(1)	0.1252012	0.0718414
	(0.216485)	(0.4076096)		(0.224227)	(0.073025*)		(0.000001***)	(0.0525055*)
Variance Equation								
Constant	0.000010	0.000001	Constant	0.000071	0.000001	Constant	0.000006	0.000001
	(0.000000***)	(0.596890)		(0.064961*)	(0.600584)		(0.335529)	(0.597695)
ϵ_{t-1}	0.105332	0.067296	ϵ_{t-1}	0.263754	0.067296	ϵ_{t-1}	0.132513	0.067296
	(0.000000***)	(0.000011***)		(0.045320**)	(0.000016***)		(0.000142***)	(0.000012***)
h_{t-1}	0.830708	0.931704	h_{t-1}	0.476270	0.931704	h_{t-1}	0.833310	0.931704
	(0.000000***)	(0.000000***)		(0.025893**)	(0.000000***)		(0.000000***)	(0.000000***)
dcc	0.915071		*dcc*	0.065514		*dcc*	0.914997	
	(0.000000***)			(0.060965**)			(0.000000***)	

Mean Equation	FTSE	Brent		S&P 500	Brent		S&P/TSX	Brent		CAC 40	Brent
Constant	−0.000322	−0.000985	Constant	0.000228	−0.001039	Constant	−0.000152	−0.001015	Constant	−0.039699	−0.000993
	(0.458616)	(0.2376923)		(0.476608)	(0.212847)		(0.6933801)	(0.2219441)		(0.6906178)	(0.2344974)
FTSE (1)	0.083407	0.0594071	S&P 500(1)	−0.004622	0.142671	S&P/ TXS(1)	0.0908553	0.2488975	CAC 40 (1)	−0.039699	−0.020817
	(0.040706)	(0.6695023)		(0.905102)	(0.167588)		(0.0381611***)	(0.0082587***)		(0.3190162)	(0.7773051)
Brent(1)	0.009067	0.0597825	Brent(1)	0.005860	0.057236	Brent(1)	0.005308	0.010568	Brent(1)	0.0458944	0.0771411
	(0.669502)	(0.1431363)		(0.685925)	(0.138627)		(0.7941044)	(0.8090468)		(0.0335446***)	(0.053136**)
Variance Equation											
Constant	0.000007	0.000001	Constant	0.000008	0.000001	Constant	0.000001	0.000001	Constant	0.000011	0.000001
	0.257314	0.597919		(0.000000***)	(0.598943)		(0.942810)	(0.596359)		(0.000000***)	(0.597776)
ϵ_{t-1}	0.200126	0.067296	ϵ_{t-1}	0.200954	0.067296	ϵ_{t-1}	0.087916	0.067296	ϵ_{t-1}	0.160561	0.067296
	(0.000030***)	(0.000013***)		(0.000000***)	(0.000011***)		(0.552317)	(0.000012***)		(0.000000***)	(0.000011***)
h_{t-1}	0.764692	0.931704	h_{t-1}	0.693365	0.931704	h_{t-1}	0.910308	0.931704	h_{t-1}	0.774682	0.931704
	(0.000000***)	(0.000000***)		(0.000000***)	(0.000000***)		(0.000000***)	(0.000000***)		(0.000000***)	(0.000000***)
dcc	0.035923		*dcc*	0.987652		*dcc*	0.026751		*dcc*	0.467852	
	(0.020572**)			(0.000000***)			(0.001736***)			(0.005287***)	

***, **, and * signify significance at the 1%, 5% and 10% levels, respectively

Fig. 2 DCC of the FTSE 100 with Brent oil

Fig. 3 DCC of the S&P 500 with Brent oil

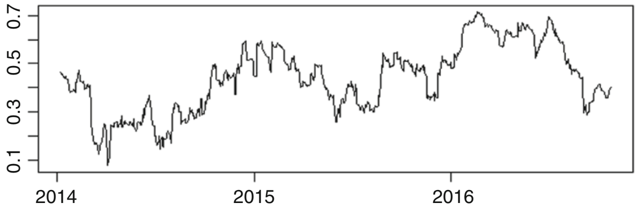

Fig. 4 DCC of the S&P/TXS with Brent oil

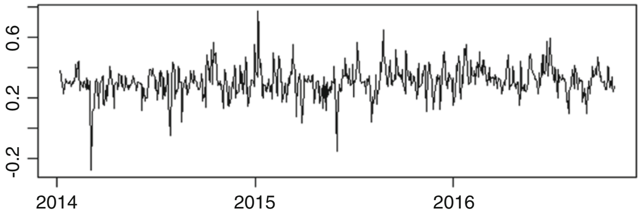

Fig. 5 DCC of the CAC 40 with Brent oil

prices, starting in June 2014, the stock markets in the USA, Europe, Japan, and Canada started to show an increasing pattern until February 2016. We can therefore conclude that the declines in oil price increased volatility spillover after 2014, but the initiation of oil price increases in February 2016 interrupted the upward pattern of

Fig. 6 DCC of the DAX with Brent oil

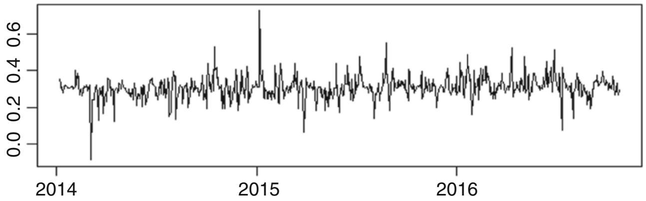

Fig. 7 DCC of the FTSE MIB with Brent oil

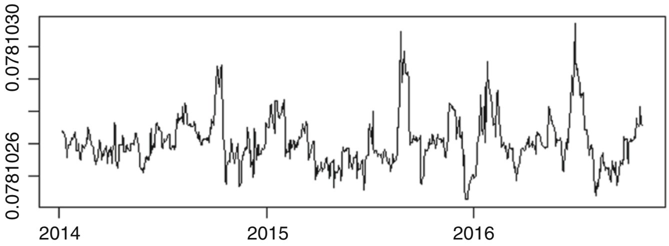

Fig. 8 DCC of the Nikkei 225 with Brent oil

DCCs. In particular, Figs. 2, 3, 4, and 5 indicate that dynamic correlations increased in early 2014, before the OPEC oversupply period.

6 Optimal Portfolio and Hedging Ratios

In this section, we investigate the value of investment opportunities in the oil and stock market to strengthen our DCC results. We consider a portfolio composed of oil and stocks that attempts to minimize risk without reducing expected returns. According to Kroner and Ng (1998), the optimal weights of two assets (oil and stock market indexes) are

$$w_{os,t} = \frac{h_t^s - h_t^{os}}{h_t^o - 2h_t^s + h_t^s}$$

with

$$w_{os,t} = \begin{cases} 0, \text{if } w_{os,t} < 0 \\ w_{os,t}, \text{if } 0 \leq w_{os,t} \leq 1 \\ 1, \text{if } w_{os,t} > 1 \end{cases},$$

where h_t^s and h_t^o are the conditional variances for stocks and Brent oil, respectively, at time t; h_t^{os} is the conditional correlation between stocks and oil at time t; and $(1 - w_{os,\ t})$ represents the weights for the portfolio stocks.

For hedge ratios, Kroner and Sultan (1993) consider a portfolio of two assets (the oil and market stock indexes in our case). To minimize the risk of a two-asset portfolio, a long position of $1 in the oil market should be hedged by a short position of β_t dollars in the stock market index. $\beta_{os,\ t}$ is defined as follows:

$$\beta_{os,t} = \frac{h_t^{os}}{h_t^s},$$

where h_t^{os} and h_t^s are defined as before.

Table 4 reports the average values of $w_{os,\ t}$ and $\beta_{os,\ t}$ for the estimation period. The results suggest that, for an entirely optimally hedged $1 portfolio, 48.4036% should be invested in the S&P 500 and 51.5963% should be invested in oil. Generally, the investors of these stock indexes should construct almost equally weighted portfolios consisting of oil and stocks to be hedged. Additionally, according to the $\beta_{os,\ t}$ values, $1 long in the oil market should be shorted 25.9446 cents in the S&P 500. Hedge ratios indicate that stock price risk can be hedged by taking a short position in the stock market. Good opportunities therefore arise in the market during the OPEC oversupply period, when stock prices were expected to increase and oil prices decreased. The hedge ratios are approximately the same for all the indexes in this study, since G7 countries have similar stock market development characteristics.

To validate the efficiency of the two asset portfolios constructed, we divide our data set into an estimation period and a test period and then calculate the portfolio weights. We allocate 0.7% to the estimation period and 0.3% to the test period. Table 5 presents the optimal portfolio weights and beta values in the estimation period.

Table 4 Weights and hedge ratios

	S&P 500	S&P/TSX	CAC 40	DAX	FTSE MIB	Nikkei 225	FTSE 100
$w_{os,\ t}$	0.484036	0.491388	0.488487	0.488322	0.492215	0.449852	0.489574
$\beta_{os,\ t}$	0.259446	0.369997	0.43048	0.458359	0.589772	0.398073	0.393492

Table 5 Weights and hedge ratios for ex post analysis

	S&P 500	S&P/TXS	CAC 40	DAX	FTSE MIB	Nikkei 225
$w_{os,\ t}$	0.3779591	0.414551	0.3845704	0.4346838	0.699485	0.4295641
$\beta_{os,\ t}$	0.5392732	0.4008894	0.6047149	0.5903251	0.6159116	0.2484654

Table 6 Portfolio construction

Portfolio I	S&P 500	S&P/ TXS	CAC 40	DAX	FTSE MIB	Nikkei 225	FTSE 100
Return	0.0001	0.0005	−0.0001	0.0000	−0.0010	0.0002	−0.0004
Std.	0.0087	0.0127	0.0142	0.0139	0.0199	0.0142	0.0153
Ret/Std.	0.0140	0.0377	−0.0104	0.0005	−0.0521	0.0131	−0.0279
Portfolio II	Oil–S&P 500	Oil–S&P/ TXS	Oil–CAC 40	Oil–DAX	Oil–FTSE MIB	Oil–Nikkei 225	Oil–FTSE 100
Return	0.0006	0.0007	0.0005	0.0006	0.0002	0.0004	0.0003
Std.	0.0112	0.0097	0.0139	0.0135	0.0151	0.0100	0.0128
Ret/Std.	0.0522	0.0698	0.0382	0.0429	0.0135	0.0382	0.0270

We construct a portfolio with the weights calculated in Table 5. We simply calculate the return and standard deviation efficiency of the optimal portfolio in the test period. We then compare the hedged portfolio with risk-adjusted stock index investments in G7 countries. According to Table 6, the risk-adjusted returns of the two asset portfolios (oil and stock indexes) based on the weights calculated in Table 5 outperform the index investments. Therefore, Table 6 confirms that our optimal portfolio weights efficiently manage oil and stock investment risk. To this end, hedged stock/oil Portfolio II has better returns and lower risk than Portfolio I with only unhedged stock indexes. The DCC results are robust, since our results also indicate that it is wise to hedge stock market risk by taking long positions in the oil market, since oil became cheaper after the OPEC oversupply.

7 Conclusion

This chapter provides empirical evidence on the volatility transmission between G7 stock and oil market after the GFC. In particular, we investigate the volatility spillover effects between oil prices and G7 stock market returns, using multivariate VAR-GARCH-DCC analysis and a data set of daily oil and stock prices from January 2014 to October 2016. We provide strong evidence of time-varying volatility spillovers in the G7 markets. The VAR-GARCH-DCC analysis shows that oil and stock market prices are directly affected by their own news. In addition, oil price (stock price) volatility affect stock price (oil price) volatility for all the analyzed DCC relation between G7 stock market indexes and Brent oil market return. Our findings corroborate previous studies showing significant volatility spillovers between oil prices and the equity market (e.g., Arouri et al. 2011a, b, 2012; Mensi et al. 2013).

This chapter contributes to the volatility spillover literature in three ways: First, we use more recent, but relatively neglected data of G7 countries since the GFC. Second, we apply DCC on the VAR-GARCH model as most of the literature proposes. Third, we expose the effect of the OPEC oversupply period in the oil market with daily data. Inconsistent with Filis et al. (2011), we assert that, recently, not only demand shocks, such as the GFC or the war in Iraq, but also oil supply shocks, such as OPEC events, can have a significant impact on the correlation between oil and stock market prices.

The results of our portfolio analysis also highlight that investors should consider conditional volatilities and correlations to maximize their returns and risks. Hence, investors should be careful about the interrelations between the stock and oil market to hedge market risk and profit from the investments.

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Corporate Cash Holdings in the Oil and Gas Industry: The Role of Energy Directives

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1 Introduction

The phenomenon of globalization, which started in the early 1990s has led to significant economic changes in the past 25 years and increased the uncertainty in the global economic conditions (Prasad et al. 2007). The global growth period in early 2000s followed by the 2008 crisis as well as monetary easing and tapering periods created uncertainty by affecting all countries, companies, and financial markets. As a result of these changes in the global market and corporate environment, almost all the corporate financial policies such as cash holding, capital structure, and investment policies of the firms have been reinvestigated by the scholars to provide additional insights on how firms react to major shifts in the global economy.

Apart from the changes in the macroeconomic conditions such as the financial crisis, the energy industry has experienced significant changes due to the implementations of the new regulations related to the generation, transmission, and distribution of electricity and gas. To ensure free trade and increase the competition among energy suppliers, the First Energy Directive has been ratified in 1992 by the member states of the European Union and put into force in 1996. The directive aims at establishing general rules about the internal electricity markets.[1] It undertook several steps to create a new energy market by unbundling the monopolistic

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[1] Directive 96/92/EC of the European Parliament and of the Council.

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corporations and increasing the competition among the energy distributors by giving the option to the consumers to select their energy distributor (Jakovac 2012). Following these regulative changes, the Second and Third Energy Directives have, respectively, been issued in 2003 and 2009 by the European Commission to strengthen the functionality of the internal markets, as well as to enhance the efficiency of the energy supply, market integration and consumer protection.[2,3] Passed in June 2003, the Second Energy Directive aims at overcoming the deficiencies in the First Directive in terms of transparent energy distribution, consumer protection, and also efficiency in energy supply (Jakovac 2012). As an additional step, the purpose of The Third Energy Directive, put into force in 2009, was to improve the liberalization process in energy markets by eliminating the current problems in energy distribution, integrating the energy markets, and clarifying the common rules in energy generation and distribution. Moreover, renewable energy sources have gained significant attention due to environmental concerns such as climate change and environmental pollution. Overall, energy directives in electricity and gas industry aimed to liberalize energy production and distribution via implementing common rules and regulations for energy companies. Not surprisingly, energy companies face more competitive market conditions and increasing uncertainty, which in turn force them to take necessary actions in terms of corporate policies and to adopt their financial positions to the new macro environment. Therefore, it becomes even more important to investigate how energy companies react to these reforms in the market in terms of major corporate financial decisions.

In this chapter, we investigate the cash holding decisions of oil and gas companies in Europe. Specifically, we examine both the firm-specific determinants of cash holdings in different country-groups and the impact of regulative changes on the cash holding decisions. In addition, we also provide evidence on the adjustment process toward the target cash position. As being one of the important corporate strategies, motives of cash holdings are significantly related with the uncertainty and future cash flow volatility. Firms with uncertain operational and macroeconomic environment tend to hold significant amount of cash in order to hedge against the future cash shortages, which is also called as the precautionary motive of cash holdings. According to this motive, firms tend to accumulate cash to meet the future investment opportunities, as well as the future unexpected cash requirements, which arise from the rapidly changing economic conditions if the cost of other resources are expected to be larger in the future (Ferreira and Vilela 2004; Ozkan and Ozkan 2004). Therefore, due to increasing uncertainty and competition with the implementation of energy directives, energy firms are expected to change their strategies in terms of the cash holding decisions to hedge against the future cash flow uncertainty.

Including 244 firms and 2670 firm-year observations from 24 countries, our results suggest that there are significant differences among countries in terms of the corporate cash holding policies and speed of adjustments toward the target cash position. More importantly, the role of energy directives on corporate cash holding decisions also differs among countries. The implementation of European Energy

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[2] Directive 2003/54/EC of the European Parliament of the Council.

[3] Directive 2009/72/EC of the European Parliament of the Council.

Directives increases the cash accumulation in the energy firms in Nordic and Western European countries, which is an evidence of the precautionary motive of cash holdings, but other country-groups are insensitive to the regulative changes. Regarding the target adjustment behavior, our results suggest that Nordic and Western European energy firms tend to adjust their cash positions toward the target level faster than the firms in the UK and Eastern Europe. The adjustment speed toward target cash position is approximately 64% in Nordic countries, 56% in Western European countries, and 52% in the UK. The slowest adjustment speed (about 20%) is observed in Eastern European countries. These findings indicate that country-specific factors have a strong impact not only on determinants of cash holdings, but also on the speed of adjustment toward the target cash level. Moreover, speed of adjustment in Eastern European (Nordic) energy firms decreases (increases) with the implementation of the directives but firms in the UK and Western Europe are less sensitive to the policy changes in terms of the speed of adjustment toward the target cash position. Overall, the findings of this study reveal that directives and regulations in the energy industry has a considerable impact on the cash holding decisions of the Nordic, Western, and Eastern European firms in terms of both cash accumulation and speed of adjustment.

This study has several contributions to the growing "cash" literature. First, to the best of our knowledge, it is the first study that investigates the cash holding decisions in oil and gas industry using a large sample of firms from Europe. As discussed before, industry-specific factors such as the regulations, directives, and increasing competition have a strong influence on the corporate policies. Since oil and gas industry significantly differ from other industries in terms of regulative changes in the recent history, the findings of this study provide important insights on the cash holding dynamics in this industry. Second, by employing a comparative perspective, we show that the impact of policy changes on corporate policies is not same for all firms. Country-specific factors have a strong influence on the magnitude of the impact of these policy changes. Overall, the findings of this study extend the issue beyond the country-specific or institutional context by focusing on a specific industry through a comparative perspective.

In the next section, we discuss the main developments in the energy industry and relevance of energy directives with the motives of cash holdings. Section 3 describes the data with a brief literature about the variables used in the study and methods of estimations including robustness checks. In Sect. 4, we discuss the main findings. Section 5 concludes the chapter.

2 Developments in the Energy Industry and Cash Holdings

Since the seminal paper of Opler et al. (1999), there is a growing interest in providing explanation for the motives and determinants of cash holdings. One of the main reasons of this growing attention is that firms tend to increase their cash holdings over years. For example, Bates et al. (2009) suggest that firm-level cash holdings are almost doubled from 1980 to 2006 for the US setting. Dittmar and Mahrt-Smith

(2007) find that about 13% of the US firms' total assets are held as cash or cash equivalents. Several other studies extended the issue by providing additional evidence on the markets other than the USA. These papers include Ozkan and Ozkan (2004) for the UK, Ferreira and Vilela (2004) for EMU context, and García-Teruel and Martínez-Solano (2008) for Spain. Moreover, several other researchers provide international evidence on the determinants and value of cash holdings by incorporating both macroeconomic, governance related, and national characteristics of the countries into their analytical framework. The main conclusion of these studies is that in addition to the firm-specific factors such as agency costs, information asymmetries, or financial constraints, institutional and macroeconomic factors have a strong influence on the firm-level cash holdings. For example, Dittmar et al. (2003) find that governance characteristics of the countries play a significant role in cash holding decisions. In a similar vein, Kalcheva and Lins (2007) show that firm values are lower in the countries with weak investor protection if managers hold too much cash. Chang and Noorbakhsh (2009) and Chen et al. (2015) extend the issue by incorporating the impact of national culture on the cash holding decisions. Overall, these studies show that not only firm-specific factors but also country- and industry-specific factors have a strong influence on the corporate cash holding policies.

Although there is extensive evidence on the determinants of cash holdings both in single country or international studies, industry-level differences in cash holding decisions are often neglected. Specifically, cash holding policies are expected to differ according to industry-specific factors such as the cash flow uncertainty, industry-specific regulations, and sensitivity of industries to the macroeconomic shocks. The energy or oil and gas industry is significantly different from the other industries for several reasons. First, due to their special conditions, the 1990–2015 period has been more complicated for energy companies. The energy sector has not only shifted from a monopolistic market to a competitive market in the globalization period, but also obliged to solve two major problems, such as energy security and climate change. The situation of the European Union market, which leads the other countries by organizing and planning the reform of energy markets, is much more specific. The energy sector in Europe has undergone major changes in the last two decades, which is rarely seen in any business environment. The European energy companies are simultaneously faced with market reforms including organizational setting, market structure, regulatory framework, ownership arrangement, and innovational challenge, which arises from environmental concerns and technological advancements. Since the early 1990s, the traditional vertically integrated structure of the energy sector has unbundled into four segments of generation, transmission, distribution, and retail. Competition accelerated with the entry of many companies into generation, transmission, distribution, and sale stages of energy sector. New national authorities and a common regulatory mechanism are established in Europe. Most of the energy companies entered the privatization process following the EU Directives (Capece et al. 2013). Still, the new structure of European energy markets has been developing with discovery and involving continuous interactions between the market players and the regulatory agencies. Over the years, many other pieces of the energy market legislation have been adopted and the energy market experienced a remarkable change (Karan and Kazdagli 2011). Inevitably, the new energy paradigm created problems in energy markets. Since, most of the European countries and companies had energy plans or policy statements, the shift in policy objectives and priorities had not yet been matched immediately (Helm 2014). The new paradigm simply does not get replaced by another and created significant uncertainties for companies.

Second, the great shift in the energy technology is mostly in the field of renewable energy, and traditional energy sources are starting to change rapidly. Since renewable energy is crucial to any move toward a low carbon economy, the promotion of renewable energy became an essential part of EU energy policy. Currently, the electricity sector has seen the fastest growth in renewable share, which currently reaches 28.3% of total electricity production. Also, it is achieved a 16% share of renewable energy in 2014 and it is estimated to be greater in the near future.[4] Wind energy and solar photovoltaic development has been uneven, and together, other renewables constitute 12% of the EU gross electricity production. Most of the EU countries are well on track to reach their targets for renewable energy (EU renewable energy progress report 2015-16). This transition phase has not been easy for the energy sector companies. It is an expensive and risky process, as stated by the European Commission.[5] Europe is trying to develop this policy by considering three main concerns that are conflicting among themselves: energy security problems, concerns about climate change, and economic realities (Johnson and Boersma 2015). Undoubtedly, this complexity also increases the risks of energy companies.

The market reform in Europe has been initiated by the British experience and further developments have been observed in the rest of the Europe. The energy market in the UK is well established and competitive relative to the other markets. The annual switching rate is about 18% and consumers are well informed about the competition in the market and they know that they can switch their supplier if they want (Karan and Kazdagli 2011). On the other hand, Nordic countries distinguishes from the other countries in terms of the market dynamics such as the competition among the market players and the challenges, which are waiting to be addressed. The adoption of integrated energy market is much more challenging for the Nordic firms since the success of the system depends on some country-specific factors such as the supply of the alternative energy, capacity of the energy production units, and also deregulation of the market (Amundsen and Bergman 2006). The liberalization process of the energy market in the Continental Europe has been initiated by Germany in the 1990s and followed by the France, Netherlands, and Belgium. With the substantial progress of the Spain and Portugal in terms of the supply of alternative energy and market efficiency, Continental Europe has been adopted a

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[4] The web link for the following report: https://ec.europa.eu/energy/en/topics/renewable-energy/progress-reports

[5] The web link for the following report: https://ec.europa.eu/energy/en/topics/technology-and-innovation

well-functioning integration strategy, but further developments required to improve the efficiency and overcome the significant challenges such as the energy security and political instability. Different than the other countries, the liberalization process of the energy market in Eastern Europe is relatively slow and needs further improvements. The competition among the market players are generally low in these countries, which hinders the diversification and integration. Therefore, energy directives and regulations have a delayed impact on the overall market as well as the energy firms (Karan and Kazdagli 2011).

With the increasing uncertainty as a result of market reform, energy directives, and regulations, energy firms are facing with a more challenging environment than in the past. Thus, firms in the energy industry are expected to face some difficulties in accessing external funds. As confirmed by the precautionary motive of cash holdings, firms tend to increase their cash levels to cope with the risky cash flows and uncertainty arising from the more competitive markets (Bates et al. 2009; Chen et al. 2015). Therefore, energy firms are expected to increase their cash holdings due to increasing competition among the market players as an outcome of the energy directives and regulations. In other words, increasing market and industry-specific risks as discussed above are expected to force energy firms to accumulate cash as a buffer against the uncertain future cash flows. Several studies in the literature provide support for the precautionary motive of cash holdings in uncertain market environments. The main finding of these studies is that firms tend to hoard cash as a cushion against the uncertainty. For example, Al-Najjar (2013) investigate the cash holdings in emerging markets and provide support for the precautionary motive of cash holdings due to greater market imperfections, uncertainty, and bankruptcy risk in these markets. In a similar vein, Song and Lee (2012) investigate the cash holding decisions of Asian firms during the Asian crisis (1997–2998) and provide strong evidence of precautionary motive due to increasing uncertainty in that time period. Also, the findings of Duchin (2010) and Ramirez and Tadesse (2009) support the precautionary motive for the firms operate in volatile markets and industries. Similarly, the oil and gas industry is one of the most volatile sectors due to its strong dependency to external factors such as specific regulations and directives. Therefore, we predict that energy firms in Europe will increase their cash holdings with the implementation of the energy directives.

3 Data and Methodology

3.1 Overview of Data

Our sample includes a total of 244 firms operate in oil and gas industry and 2670 firm-year observations from 24 European countries for the period 2000–2016. Specifically, our sample includes 25 (298) firms (observations) form Eastern European countries, 58 (640) firms (observations) from Nordic countries, 107 (1117) firms (observations) from the UK and Ireland, and 54 (615) firms

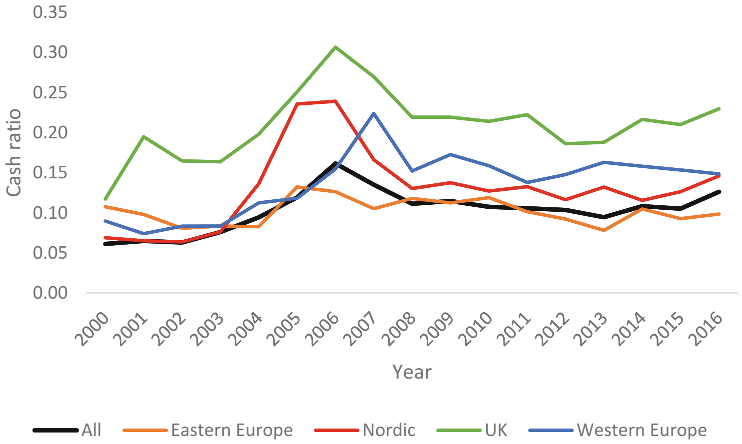

Fig. 1 Cash ratios over years

(observations) from Western Europe. We only include firms with at least 5 years of consecutive observations and without any missing data.[6] The data for the dependent and explanatory variables is obtained from the Datastream.

We present the distribution of cash ratio[7] over years for each country-group in Fig. 1. The firms in our sample hold cash approximately 10.6% of their total assets, however, cash ratio is not stable over time. Regarding the entire sample, median cash ratio is highest in 2006 as approximately 16% and lowest in 2000 as 6.1%. Moreover, the median cash ratio decreases to 13.5% in 2007 after a considerable increase in 2006 and it stays at 10–11% level afterwards. Moreover, we observe that the oil and gas firms in the UK hold relatively larger cash balances (14.6%) compared to the Western European (10.4%), Nordic (9.3%), and Eastern European (5.9%) firms. When we review prior studies, we observe significant differences in terms of average cash positions among countries. For example, Al-Najjar and Belghitar (2011), Al-Najjar (2013), and Dittmar et al. (2003) report 9%, 10% and 8% for the UK, respectively. In addition, in their comprehensive study about the cash holding decisions of multinational firms, Fernandes and Gonenc (2016) report approximately 20% for the UK, 14% for France, 15% for Germany, and 14% for Finland. The difference between the cash ratios reported in this study with previous studies arise from several reasons. Most importantly, there is no other study that focuses on oil and gas industry in the prior literature. Abovementioned studies include all available industries except financing sector. As it is discussed before, cash holding decisions in oil and gas industry can be significantly different from

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[6] Eastern Europe countries are Croatia, Cyprus, Czech Republic, Greece, Hungary, Poland, Romania, Slovenia, and Turkey. Nordic countries are Denmark, Finland, Norway, and Sweden. Countries in the UK group are United Kingdom and Ireland. Western Europe countries are Austria, Belgium, France, Germany, Italy, Netherlands, Portugal, and Spain.

[7] The ratio of cash and equivalents to the total assets.

Table 1 Variable definitions

Variable	Definition
CASH	The ratio of cash and equivalents to the total assets
NET CASH	The ratio of cash and equivalents to the total assets minus cash and equivalents
SIZE	Natural logarithm of total assets in dollars
CAPEX	The ratio of capital expenditures to the total assets
CFLOW	The ratio of pre-tax income plus depreciation to the total assets
LEV	The ratio of total debt to the total assets
MB	The ratio of book value of total assets minus the book value of equity plus the market value of equity to book value of total assets
NWC	The ratio of current assets minus cash and current liabilities to the total assets
DIV	Dividend dummy equals to 1 if firm pays dividend and 0, otherwise
RD	R&D dummy equals to 1 if firm makes R&D investments and 0, otherwise
Second Directive	Includes the years from 2004 to 2009
Third Directive	Includes the years from 2010 to 2016
E. Europe	Equals to 1 if the firm is in Eastern Europe
Nordic	Equals to 1 if the firm is a Nordic country
UK	Equals to 1 if the firm is in the UK
W. Europe	Equals to 1 if the firm is in Western Europe

This table presents the variables used in this study

other industries due to industrial dynamics such as industry-specific regulations/directives and so on. The difference in the sample period is also another reason of the reported cash ratio. As it is evident in Fig. 1, the cash ratio is not stable over time, which leads significant differences on the reported statistics in the prior literature.

We use two measures of cash holdings, namely the ratio of cash and equivalents to the total assets (CASH) and the ratio of cash and equivalents to the net assets, which is measured as total assets minus cash and equivalents (NET CASH). Table 1 provides the definitions of each variable used in this study. We discuss the operationalization of these variables as follows:

ENERGY DIRECTIVES Our main variable interest is the Energy Directives. As discussed before, The Second and The Third Energy Directives were put into force in 2004 and 2009, respectively. We use dummy variable equal to 1 if the year belongs to the 2004–2009 period, and 0 otherwise (*Second Directive*). In other words, 2004–2009 period is the period when the Second Energy Directive was in force. Moreover, we also use another dummy variable for the years from 2010 to 2016 to indicate the period in which the Third Energy Directive is effective (*Third Directive*). Finally, 2000–2003 period is our base period and denotes the period that the First Energy Directive was enforced.

In addition to the dummy variables for the Energy Directives, we also use several explanatory variables to explore the firm-specific determinants of cash holdings in

European oil and gas industry. In the following, we briefly explain the relevance of each variable on the cash holding decisions.

SIZE Firm size is one of the important determinants of cash holdings for several reasons. First, smaller firms are expected to hold greater amount of cash since they are more prone to information asymmetries, bankruptcy costs and, they have less access to the external funds (Al-Najjar and Belghitar 2011; Opler et al. 1999). On the other hand, given that small firms experience more financial distress than the large firms (Titman and Wessels 1988), one may expect that they hold larger amount of cash balances than large firms. Therefore, we expect a negative relationship between firm size and cash holdings. Our proxy for the firm size (*SIZE*) is the natural logarithm of total assets in dollar terms.

CAPEX The relationship between investments or capital expenditures are not straightforward since two theories about cash holdings propose opposing views about the impact of investments on cash accumulation. According to the Pecking Order Theory,[8] firms with greater investments should hold less cash due to usage of internal resources (Opler et al. 1999). On the other hand, Trade-off Theory[9] predicts a positive relationship between capital expenditures and cash holdings. Our measure (*CAPEX*) is the ratio of capital expenditures to the total assets.

CFLOW According to the Pecking Order Theory, firms prefer internal finance over external finance, which implies a positive relationship between cash flow and cash holdings. Moreover, cash flow is also considered as proxy of growth opportunities (Ozkan and Ozkan 2004), firms with greater cash flows are expected to have larger amount of cash according to the predictions of the Trade-off theory. Our measure (*CFLOW*) is the ratio of earnings before extraordinary items plus depreciation to the total assets.

LEV Baskin (1987) argues that cost of liquid assets is greater as the leverage increases, which induce a negative relationship between leverage and cash holdings. This argument is in line with the Pecking Order Theory, which suggests that profitable firms pay their debt, make their investments, and accumulate the remaining as cash. In other words, any increase in cash amount also indicates a reduction in the leverage. On the other hand, increasing financial distress with the

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[8] The Pecking Order Theory suggests that firms first use internal funds, then safe debt, and equity as a last resort to finance their investments. If the cash flows are enough to finance the new projects, firms repay their debt and accumulate the remaining as cash. Therefore, firms do not have any target cash balances, instead they use cash as a buffer against the future shortages in internal funds (Myers 1984).

[9] The Trade-off Theory postulates that firms set their target/optimal cash balances by weighing the marginal costs and marginal benefits of cash holdings. Marginal benefits of cash accumulation are the cushion against the future uncertainty in the cash flows and marginal costs of cash holding is the opportunity costs, which arise from the lower returns of cash and cash equivalents (Ferreira and Vilela 2004).

leverage may motivate firms to hoard larger amount of cash balances. Our measure of leverage (*LEV*) is the ratio of total debt to total assets.

MB Another important determinant of firm-level cash holding is the firms' growth opportunities. It is suggested that the problem of information asymmetry is more severe for the firms with greater growth options (Myers and Majluf 1984). In addition, firms with greater growth opportunities tend to hold excess cash to meet future cash requirements when they can invest in positive NPV projects (Ozkan and Ozkan 2004). Moreover, bankruptcy costs are higher if the firm has greater growth options since the proportion of intangible assets is greater in these firms (Shleifer and Vishny 1992). Thus, we predict a positive relationship between growth opportunities and cash holdings. Our proxy of growth opportunities is the market-to-book ratio (*MB*), which is measured as the ratio of book value of total assets minus the book value of equity plus the market value of equity to book value of total assets.

NWC Firms can use substitutes of cash holdings rather than using external financing when they face shortfalls in their cash positions. In other words, converting liquid assets into cash is much easier than converting non-liquid assets (Ferreira and Vilela 2004). Thus, a negative relationship is expected between the proportion of liquid assets and cash holdings due to the substitution effect of liquid assets. We use the ratio of current assets minus current liabilities to the total assets (*NWC*) as a measure of liquidity.

DIV The relationship between dividend payments and cash holding policy is twofold. In one hand, firms that pay dividend have a greater flexibility as they can cut their dividend payments when they face a cash shortage (Opler et al. 1999). As a result, a positive relationship between dividend payments and cash balances is expected. On the other hand, dividend cuts may not be favorable for firms since it may be perceived by shareholders negatively. Therefore, firms that persistently pay dividends may hoard cash to meet the future dividend payments in case of cash shortage (Ozkan and Ozkan 2004). Our measure of dividend payments (*DIV*) is a dummy variable equals to 1 if the firm pays dividend and 0, otherwise.

RD As a final determinant of cash holdings employed in this study, R&D expenditures exerts a negative influence on the cash holdings. Like the arguments in the relevance of market-to-book ratio, Trade-off Theory predicts that firms with greater R&D expenditures should accumulate more cash since they have greater information asymmetry problems. Our measure of R&D expenditures (*RD*) is a dummy variable equals to 1 if the firm make any R&D investments and 0, otherwise.[10]

Table 2 presents the descriptive statistics of the variables employed in this study by country-groups as Western Europe, Nordic, the UK, and Eastern Europe. When we compare the summary statistics among the country-groups, we observe that oil and gas firms in the UK significantly differ from the firms in other countries.

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[10] We treat an observation as zero if the information about the R&D expenditures is missing.

Table 2 Descriptive statistics

Country	No. of firms	No. of observations	CASH	NET CASH	SIZE	CAPEX	CFLOW	LEV	MB	NWC	DIV	RD
Eastern Europe—Total number of firms (observations) = 25 (298)												
Croatia	1	8	0.017	0.018	15.099	0.086	0.096	0.265	1.591	−0.342	1.000	0.000
Cyprus	1	11	0.039	0.041	12.026	0.055	0.093	0.290	0.834	0.034	1.000	0.000
Czech Republic	1	14	0.048	0.051	14.619	0.048	0.061	0.071	0.924	1.026	0.000	0.000
Greece	2	32	0.060	0.064	14.758	0.055	0.110	0.376	1.170	−0.022	1.000	0.500
Hungary	1	17	0.055	0.058	16.065	0.082	0.105	0.254	1.043	−1.308	1.000	0.000
Poland	6	65	0.060	0.064	15.110	0.055	0.089	0.168	0.991	0.112	0.000	0.000
Romania	8	73	0.041	0.043	11.486	0.062	0.085	0.024	0.829	0.086	0.000	0.000
Slovenia	1	14	0.025	0.026	13.951	0.049	0.077	0.370	1.142	−0.057	0.000	0.000
Turkey	4	64	0.143	0.167	14.982	0.036	0.085	0.284	1.080	−0.083	1.000	0.000
Median			0.059	0.062	14.503	0.055	0.089	0.202	1.015	−0.017	1.000	0.000
Nordic—Total number of firms (observations) = 58 (640)												
Denmark	3	36	0.050	0.053	12.403	0.072	0.078	0.187	1.294	−0.171	0.000	0.000
Finland	1	11	0.061	0.064	15.678	0.073	0.090	0.279	1.169	0.030	1.000	1.000
Norway	42	478	0.096	0.107	13.270	0.081	0.064	0.410	1.129	−0.363	0.000	0.000
Sweden	12	115	0.099	0.109	9.705	0.058	−0.030	0.077	1.472	−0.184	0.000	0.000
Median			0.093	0.103	12.985	0.076	0.059	0.316	1.180	−0.307	0.000	0.000
UK—Total number of firms (observations) = 107 (1117)												
UK	101	1042	0.149	0.175	11.229	0.043	−0.023	0.047	1.384	−0.016	0.000	0.000
Ireland	6	75	0.114	0.128	11.295	0.064	−0.035	0.035	1.003	−0.043	0.000	0.000
Median			0.146	0.171	11.239	0.043	−0.024	0.045	1.355	−0.017	0.000	0.000
Western Europe—Total number of firms (observations) = 54 (615)												
Austria	2	30	0.096	0.106	15.547	0.084	0.146	0.209	1.206	0.017	1.000	1.000
Belgium	2	17	0.163	0.195	14.557	0.039	0.092	0.324	0.687	−0.039	1.000	0.000
France	11	146	0.104	0.116	14.476	0.047	0.091	0.174	1.218	0.008	1.000	0.000

(continued)

Table 2 (continued)

Country	No. of firms	No. of observations	CASH	NET CASH	SIZE	CAPEX	CFLOW	LEV	MB	NWC	DIV	RD
Germany	24	224	0.134	0.154	11.765	0.046	0.046	0.193	1.200	0.050	0.000	1.000
Italy	6	68	0.083	0.091	15.134	0.049	0.096	0.204	1.232	–0.038	1.000	0.000
Netherlands	3	51	0.051	0.054	15.091	0.101	0.154	0.305	1.354	–0.003	1.000	1.000
Portugal	1	10	0.061	0.066	16.060	0.075	0.085	0.287	1.539	0.032	1.000	0.000
Spain	5	69	0.131	0.151	15.255	0.030	0.064	0.309	1.173	–0.095	1.000	0.000
Median			0.104	0.116	13.995	0.054	0.081	0.081	1.200	0.008	1.000	0.000

All numbers except number of firms and number of observations are country medians of the variables. *Median* indicate the median of the variables for the overall country-group. Definitions of variables are presented in Table 1

Regarding the investment level of oil and gas firms in Europe, UK firms have the lowest capital expenditures (0.043) over the sample period. In addition, the leverage ratio of UK firms is considerably lower (0.045) than those of other country-groups. Interestingly the median cash flow ratio is negative for UK firms. Overall, oil and gas firms in the UK have considerably lower investments, leverage, and most importantly negative cash flows. On the other hand, Nordic firms differ from the other oil and gas firms in the Europe by their high leverage. Median debt ratio in Nordic firms is almost 32%, which is considerably higher than those of other firms (second highest is for the Eastern European firms as 20%).

3.2 Model Formulation

We employ several estimations to investigate the impact of energy directives on the cash holdings. In addition to the estimation for the whole sample, we run separate estimations for the country-groups to observe how the impact conventional firm-specific variables as well as the energy directives differ by countries. As discussed before, the dependent variable of our model is CASH, which is defined as the ratio of cash and equivalents to the total assets. We also use NET CASH, which is defined as the ratio of cash and equivalents to the net total assets (total assets minus cash and equivalents) for robustness purposes. Our baseline model is as follows:

$$\begin{aligned} CASH_{i,t} = {} & \beta_0 + \beta_1 SIZE_{i,t-1} + \beta_2 CAPEX_{i,t-1} + \beta_2 CFLOW_{i,t-1} + \beta_3 LEV_{i,t-1} \\ & + \beta_4 MB_{i,t-1} + \beta_5 NWC_{i,t-1} + \beta_6 DIV_{i,t-1} + \beta_7 RD_{i,t-1} \\ & + \beta_8 Second\ Directive + \beta_9 Third\ Directive + \varepsilon_{i,t} \end{aligned} \tag{1}$$

In Eq. (1), $CASH_{i,\ t}$ denotes the ratio of cash and cash equivalents to the total assets. The definitions of the explanatory variables are defined in Table 2. $\beta_{1-}\beta_9$ denote the coefficients of explanatory variables. Finally, $\varepsilon_{i,\ t}$ is the error term of the equation. It should be noted that we use lagged values of the independent variables to mitigate the simultaneity and endogeneity concerns. We report robust standard errors, which are clustered at the firm level to account for the heterogeneity in the standard errors. In the second stage of this chapter, we also run GMM estimations to account for the dynamic nature of the panel data and weighted least square estimations and least absolute deviation regressions, which will be discussed later.

4 Multivariate Results

4.1 Determinants of Cash Holdings

In the first stage of our analysis, we estimate the cash holdings (CASH and NET CASH) for the whole sample without including the Second and Third Directives to see the impact of conventional firm-specific factors on the corporate cash holdings decisions of the energy firms. We employ two separate estimations one including the country dummies and other with the country-group dummies to account for the country-specific factors. We also run each estimation by using NET CASH as our dependent variable. Finally, we also run Fama-Macbeth regressions as an alternative to the OLS estimations. Table 3 presents our results.

First, the coefficient of SIZE is negative and significant at 1%, which suggests that small firms hold more cash than large firms, which is consistent with the prior literature (Al-Najjar and Belghitar 2011; Opler et al. 1999; Ozkan and Ozkan 2004). Small firms are more prone to information asymmetries and have less access to the external funds. Therefore, they tend to hold a larger amount of cash in order to mitigate the adverse effects of financial distress. The impact of capital expenditures (CAPEX) on cash holdings is negative as expected. Interestingly, our results suggest a negative impact of cash flows (CFLOW) on cash holdings. Specifically, firms with greater cash flows tend to hold less cash, which is contrast to the theory, but in line with some of the prior findings (Ozkan and Ozkan 2004). We also find a negative relationship between leverage (LEV) and cash holdings as expected. The coefficient of market-to-book ratio (MB) is positive and significant at 1%, which suggests that firms with greater growth opportunities hold less cash. As discussed earlier, firms with greater growth opportunities are more exposed to asymmetric information problem and their future cash need is expected to be larger than the firms with less growth opportunities, especially in case of a cash shortage. The relationship between net working capital (NWC) and cash holdings is negative, but the significance level is low. Moreover, we find a negative relationship between cash holdings and R&D expenditures (RD) similar to the coefficient of market-to-book ratio. Finally, dividend payments do not exert any significance on the cash holding decisions. Overall, our baseline results are generally in line with the predictions of the theory and with the prior findings. The results are also insensitive to the model selection (country fixed effects vs. country-group-fixed effects), different methods of estimations (fixed OLS vs. Fama-Macbeth estimations) and different operationalization of the dependent variable (CASH vs. NET CASH) with the only exception of CFLOW and RD, which are not significant in Fama-Macbeth regressions when we use NET CASH as our proxy for the cash holdings.

In the second stage of our analysis, we employ separate estimations for each country-group and incorporate the impact of the Second and the Third Directives on the cash holding decisions. As it is presented in Table 4, there are significant differences across the determinants of cash holdings by country-groups, especially regarding the impact of energy directives on the cash holding decisions. First of all,

Table 3 Determinants of cash holdings

	Dep. variable = CASH$_t$			Dep. Variable = NET CASH$_t$		
	(1) OLS	(2) OLS	(3)F-M	(4) OLS	(5) OLS	(6) F-M
SIZE$_{t-1}$	−0.012*** (0.003)	−0.011*** (0.003)	−0.012*** (0.002)	−0.013*** (0.004)	−0.012*** (0.004)	−0.012*** (0.002)
CAPEX$_{t-1}$	−0.104** (0.043)	−0.134*** (0.044)	−0.131*** (0.035)	−0.116** (0.051)	−0.150*** (0.051)	−0.155*** (0.042)
CFLOW$_{t-1}$	−0.105*** (0.038)	−0.114*** (0.040)	−0.077* (0.038)	−0.086** (0.036)	−0.093** (0.038)	−0.051 (0.038)
LEV$_{t-1}$	−0.186*** (0.031)	−0.162*** (0.031)	−0.132*** (0.017)	−0.213*** (0.032)	−0.184*** (0.033)	−0.153*** (0.020)
MB$_{t-1}$	0.014*** (0.004)	0.014*** (0.004)	0.012*** (0.003)	0.012*** (0.003)	0.012*** (0.003)	0.012*** (0.004)
NWC$_{t-1}$	−0.005 (0.010)	−0.008 (0.009)	−0.009 (0.008)	−0.008 (0.011)	−0.012 (0.011)	−0.014 (0.009)
DIV$_{t-1}$	−0.006 (0.012)	−0.004 (0.012)	0.004 (0.006)	−0.007 (0.013)	−0.006 (0.013)	−0.000 (0.006)
RD$_{t-1}$	0.050*** (0.019)	0.046** (0.018)	0.027** (0.011)	0.043** (0.017)	0.040** (0.017)	0.017 (0.012)
Nordic		0.024 (0.024)	0.022** (0.009)		0.041* (0.024)	0.039** (0.013)
UK		0.044* (0.026)	0.046*** (0.006)		0.066** (0.025)	0.069*** (0.006)
W. Europe		0.032 (0.023)	0.026*** (0.008)		0.052** (0.024)	0.045*** (0.010)
Constant	0.247*** (0.055)	0.234*** (0.052)	0.282*** (0.026)	0.287*** (0.070)	0.267*** (0.057)	0.315*** (0.024)
Year fixed	Yes	Yes	No	Yes	Yes	No
Country fixed	Yes	No	No	Yes	No	No

(continued)

Table 3 (continued)

	Dep. variable = $CASH_t$			Dep. Variable = NET $CASH_t$		
	(1) OLS	(2) OLS	(3)F-M	(4) OLS	(5) OLS	(6) F-M
R^2	0.277	0.256	0.282	0.260	0.238	0.270
N	2670	2670	2670	2670	2670	2670

This table presents the OLS and Fama-Macbeth (F-M) estimation results of CASH and NET CASH. Variable definitions are presented in Table 1. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. Standard errors (in parenthesis) are clustered at the firm level

Table 4 Determinants of cash holdings: The role of energy directives

	Dep. variable = CASH_t				
	(1) All	(2) E. Europe	(3) Nordic	(4) UK	(5) W. Europe
SIZE_{t-1}	-0.012^{***} (0.003)	-0.011 (0.010)	-0.024^{***} (0.008)	-0.005 (0.005)	-0.012^{**} (0.005)
CAPEX_{t-1}	-0.099^{**} (0.042)	0.120 (0.125)	-0.131^{**} (0.051)	-0.099 (0.072)	-0.200 (0.120)
CFLOW_{t-1}	-0.105^{***} (0.038)	-0.178 (0.112)	-0.099 (0.068)	-0.080 (0.054)	-0.124^{*} (0.064)
LEV_{t-1}	-0.188^{***} (0.030)	-0.239^{**} (0.102)	-0.086^{*} (0.044)	-0.267^{***} (0.057)	-0.149^{**} (0.067)
MB_{t-1}	0.014^{***} (0.004)	0.027^{*} (0.014)	0.006 (0.005)	0.018^{***} (0.004)	0.040^{***} (0.012)
$\text{NWC}_{t\text{-}1}$	-0.006 (0.010)	0.004 (0.017)	-0.002 (0.011)	0.042 (0.057)	-0.157^{**} (0.063)
DIV_{t-1}	-0.006 (0.012)	-0.051 (0.031)	0.030 (0.019)	-0.062^{**} (0.024)	0.032 (0.023)
RD_{t-1}	0.050^{***} (0.019)	0.026 (0.029)	0.044^{**} (0.021)	0.074^{*} (0.043)	0.050^{***} (0.018)
Second Directive	0.050^{***} (0.014)	0.034 (0.020)	0.085^{***} (0.024)	0.034 (0.030)	0.039^{**} (0.019)
Third Directive	0.036^{***} (0.013)	0.038 (0.023)	0.045^{**} (0.018)	0.024 (0.029)	0.053^{***} (0.018)
Constant	0.262^{***} (0.054)	0.213 (0.175)	0.371^{***} (0.100)	0.233^{***} (0.070)	0.183^{**} (0.083)
Year fixed	No	No	No	No	No
Country fixed	Yes	Yes	Yes	Yes	Yes
R^2	0.271	0.266	0.325	0.219	0.343
N	2670	298	640	1117	615

This table presents the OLS estimation results of cash for different country-groups controlling for energy directives. Variable definitions are presented in Table 1. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. Standard errors (in parenthesis) are clustered at the firm level

the energy directives have an impact on the cash holding decisions only for the Nordic and Western European firms. More specifically, oil and gas firms in Nordic and Western European countries tend to increase their cash holdings with the implementation of energy directives. As discussed earlier, energy directives significantly changed the rules of the game in energy sector. Through the unbundling process and greater focus on the renewable energy, firms encounter with a more competitive and uncertain financial environment. Positive coefficient of directives suggests that firms may consider the cash holdings as an alternative tool to hedge against the future uncertainty (precautionary purpose). In other words, changing market dynamics force firms to be more cautious about their future well-being and in turn take corrective actions in terms of enhancing their flexibility by increasing their cash balances especially for the Nordic and Western European firms. However, energy firms in the UK and Eastern European countries are insensitive to the energy directives in terms of the cash holding decisions.

Considering the impact of firm-specific factors, the only significant variables are the leverage (LEV) which has a negative impact and market-to-book ratio (MB) has a positive impact on the cash holding decisions for the energy firms in Eastern Europe. Cash holding policies in these firms are insensitive to the other factors. Nordic case shows that majority of the variables have a significant influence on the cash holdings. Specifically, SIZE, CAPEX, and LEV have a negative, RD has a positive impact on cash hoarding. Regarding the UK firms, LEV, and DIV have a negative; MB and RD have a positive impact on the cash holdings as in line the predictions. Finally, all the predicted determinants except CAPEX and DIV are significant for the Western Europe case. Specifically, SIZE, CFLOW, LEV, and NWC have a negative, MB, and RD have a positive impact on cash accumulation. Overall, the determinants of cash holdings are significantly different by country-groups. Majority of the determinants are insignificant for the Eastern European firms. On the other hand, the results for UK, Nordic, and Western European firms are generally in line with our predictions. Moreover, when we compare the predictive power of the estimated models, we observe the smallest R^2 for UK case. Finally, the determinants of cash holdings are generally in line with the Western European firms evident by the highly significant coefficients of the determinants and largest predictive power of the model (R^2 is 34%).

4.2 Adjustment Toward Target Cash Holdings

In addition to the estimations regarding the impact of energy directives on the cash holding decisions, we also investigate the adjustment speed toward target cash balances. As it is discussed before, Trade-off Theory suggests that there are marginal benefits and costs of holding cash. Therefore, rather than immediate, a partial adjustment process to target cash holdings takes place due to transaction costs (Ozkan and Ozkan 2004). To this aim, we include the lagged dependent variable into our model to account for the dynamic process. However, employing conventional OLS regressions yields biased results since lagged dependent variable is correlated with the unobservable firm-fixed effects. To mitigate this concern, several alternative approaches are discussed in the literature. We employ dynamic system-GMM (Blundell and Bond 1998) estimations to observe the adjustment speed toward the target cash position, which enables us to instrument the endogenous variables such as lagged dependent variable with the past realizations. Moreover, GMM estimations also allow us to mitigate the endogeneity concerns by treating the explanatory variables as predetermined or endogenous. We use NET CASH instead of CASH to mitigate the autocorrelation on the CASH variable. We also report post-estimation statistics such as AR (1) and AR (2), which indicate the first- and second-order correlations in the residuals under the null hypothesis of no serial correlation and Hansen value, which tests the over-identification of instruments under the null hypothesis of instruments are valid. Our dynamic GMM model is as follows:

$$NET\ CASH_{i,t} = \beta_0 + \beta_1 NET\ CASH_{i,t-1} + \beta_{2-9} \sum W_{i,t-1} + \varepsilon_{i,t} \tag{2}$$

In our dynamic system-GMM estimation (Eq. 2) we employ the lagged dependent variable ($NET\ CASH_{i,\ t\ -\ 1}$) as endogeneous and used second to third lags as instruments. $W_{i,\ t\ -\ 1}$ denote the vector of explanatory variables including the Second and the Third Directives which are discussed before and demonstrated in Eq. (1). $\beta_{2\ -\ 9}$ are the coefficients of the explanatory variables and $\varepsilon_{i,\ t}$ is the error term.

Table 5 presents the dynamic panel estimations (system-GMM) of cash holdings. The coefficient of the lagged dependent variable ($NET\ CASH_{i,\ t\ -\ 1}$) for the whole sample (Column 1) is 0.48, which indicates a 52% (1–0.48) adjustment speed toward the target cash positions. In other words, it takes approximately two years to reach the target cash level for the oil and gas firms in Europe. In addition, we also compare the target adjustment behavior of oil and gas firms separately for the country-groups. As it is expected, there are significant differences in the adjustment speeds among country-subgroups. The highest adjustment speed is observed in Nordic firms as it is approximately 64% (1–0.36). Larger adjustment speeds toward the optimal level indicates that adjustment costs are significantly lower for Nordic firms. On the other hand, the lowest adjustment speed is observed for the Eastern European firms as approximately 20%. In other words, it takes almost 5 years for these firms to reach the target cash level. The adjustment speed is about 56% for the firms in Western Europe, and 52% for the firms in the UK. Overall, the results exert some important implications about the cash holding policies of the European energy firms. As having the first and second largest adjustment speed, energy firms in Nordic and Western European countries do not face with significant adjustment costs and reach their target level relatively faster. Put differently, the marginal cost of being suboptimal in terms of the cash position exerts larger costs than the adjustment costs. This finding supports our earlier results. Nordic and Western European firms are very sensitive to the changes in the market dynamics such as the implementation of the energy directives. As a result, they tend to stay close to the target cash level to hedge against the unexpected losses due to the increasing competition and uncertainty. Finally, energy firms in the UK has a moderate level of adjustment speed compared to the other country-groups. Overall, our findings suggest that country-specific factors have a significant influence not only on the cash holdings decisions but also on the adjustment behavior. Firms in Nordic and Western Europe tend to stay close to the optimum cash levels. On the other hand, Eastern European oil and gas firms struggle to stay at the optimal levels due to their dependencies to the other countries in terms of energy supply and market development. Eastern European countries are generally developing countries, and they may face additional financial constraints to adjust their cash positions quickly.

Table 5 Speed of adjustment

	Dep. variable = NET CASH$_t$				
Variable	(1) All	(2) E. Europe	(3) Nordic	(4) UK	(5) W. Europe
NET CASH$_{t-1}$	0.483***	0.804***	0.360***	0.478***	0.439***
	(0.046)	(0.102)	(0.073)	(0.059)	(0.121)
SIZE$_{t-1}$	−0.008***	0.004	−0.013**	−0.009**	−0.010**
	(0.002)	(0.003)	(0.007)	(0.003)	(0.004)
CAPEX$_{t-1}$	0.073	0.068	−0.049	0.139*	−0.081
	(0.048)	(0.148)	(0.048)	(0.082)	(0.092)
CFLOW$_{t-1}$	−0.066***	−0.178***	−0.059	−0.031	−0.094
	(0.025)	(0.068)	(0.053)	(0.036)	(0.063)
LEV$_{t-1}$	−0.051**	0.003	−0.011	−0.088*	−0.041
	(0.022)	(0.031)	(0.037)	(0.045)	(0.047)
MB$_{t-1}$	0.003	0.002	−0.002	0.005	0.008
	(0.003)	(0.012)	(0.005)	(0.003)	(0.011)
NWC$_{t-1}$	0.023**	0.043**	0.017	0.013	−0.004
	(0.010)	(0.019)	(0.012)	(0.040)	(0.057)
DIV$_{t-1}$	−0.006	−0.005	0.006	−0.017	0.020
	(0.008)	(0.011)	(0.015)	(0.015)	(0.014)
RD$_{t-1}$	0.019**	−0.019	0.026	0.017	0.040***
	(0.009)	(0.013)	(0.017)	(0.020)	(0.015)
Second Directive	0.019*	0.007	0.071***	0.004	0.024*
	(0.011)	(0.018)	(0.024)	(0.022)	(0.013)
Third Directive	0.018*	−0.010	0.045***	0.000	0.040***
	(0.009)	(0.012)	(0.014)	(0.020)	(0.015)
Constant	0.185***	−0.013	0.234***	0.213***	0.179***
	(0.033)	(0.039)	(0.088)	(0.048)	(0.066)
AR (1)	0.000	0.024	0.000	0.000	0.000
AR (2)	0.128	0.239	0.353	0.328	0.272
Hansen	0.403	1.000	0.237	0.305	0.709
N	2425	272	581	1010	562

This table presents the GMM-BB estimation results of NET CASH for different country-groups. Variable definitions are presented in Table 1. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are in parenthesis. Second to third lags of NET CASH are used as instruments. AR (1) and AR (2) test the first- and second-order correlation among residuals under the null hypothesis of no serial correlation. Hansen is a test of instrument validity under the null hypothesis of instruments are valid

4.3 Adjustment Toward Target Cash Holdings: The Role of Energy Directives

Although the estimation results of Eq. (2) show how energy directives impact the cash holding decisions in a dynamic framework, they do not reveal the impact of the directives on the adjustment speed toward the target cash balances. Following

Guariglia and Yang (2018), we estimate the speed of adjustment in different time periods by employing the following equation:

$$\begin{aligned} NET\ CASH_{i,t} = \beta_0 &+ \beta_1 NET\ CASH_{i,t-1} * First\ Directive \\ &+ \beta_2 NET\ CASH_{i,t-1} * Second\ Directive \\ &+ \beta_3 NET\ CASH_{i,t-1} * Third\ Directive + \beta_{4-11} \sum W_{i,t-1} \\ &+ \varepsilon_{i,t} \end{aligned} \tag{3}$$

In Eq. (3), we interact $NET\ CASH_{i,\ t\ -\ 1}$ with the First, Second, and Third Directives (dummy variables) to observe how adjustment speed changes with the implementation of the energy directives. Specifically, $1 - \beta_1$, $1 - \beta_2$, and $1 - \beta_3$ in Eq. (3) shows the adjustment speeds during the periods where the First, Second, and the Third Energy Directives are in force.

The results in Table 6 show that energy directives have a significant impact not only on the cash accumulation decisions but also on the adjustment speed toward the target level. However, the impact is not the same for all country-groups. First of all, energy firms in Eastern Europe have a significantly lower speed of adjustment with the implementation of the Second and the Third Energy Directives. After the implementation of the Second Energy Directive speed of adjustment in the Eastern European energy firms drop to 10% (1–0.90) from 47.5% (1–0.525) and it stays at 16.2% (1–0.838) during the period when the Third Energy Directive is in force. This finding implies that adjustment costs for the Eastern European energy firms are significantly greater than the costs of being away from the target level. In other words, Eastern European firms experience some difficulties to stay at the optimum cash level with the increasing uncertainty arising from the implementation of energy directives. In contrast to Eastern European firms, Nordic firms increase their speed of adjustment with the implementation of energy directives, particularly with the Second Energy Directive. The speed of adjustment for Nordic firms increases from 20% (1–0.804) to 58% (1–0.423) with the implementation of the Second Energy Directive and it stays about 40% (1–0.397) during the Third Energy Directive period. Although there are some changes in the speed of adjustment toward the target cash level for the firms in the UK and Western Europe, the changes are not statistically significant. Overall, the findings suggest that the implementation of energy directives has a negative influence on particularly Eastern European firms with a lower adjustment speed after the implementation of the regulations. On the other hand, Nordic firms react to the new environment by staying close to the optimum level in terms of their cash position, which also shows their ability or willingness to stay at the optimum level.

Table 6 Speed of adjustment: The role of energy directives

Variable	Dep. variable = NET CASH$_t$				
	(1) All	(2) E. Europe	(3) Nordic	(4) UK	(5) W. Europe
NET CASH$_{t-1*}$First Directive	0.626^{***}	0.525^{***}	0.804^{***}	0.571^{***}	0.524^{***}
	(0.072)	(0.127)	(0.181)	(0.095)	(0.068)
NET CASH$_{t-1*}$Second Directive	0.506^{***}	0.900^{***}	0.423^{***}	0.433^{***}	0.538^{***}
	(0.052)	(0.045)	(0.102)	(0.076)	(0.122)
NET CASH$_{t-1*}$Third Directive	0.595^{***}	0.838^{***}	0.397^{***}	0.591^{***}	0.662^{***}
	(0.044)	(0.066)	(0.091)	(0.058)	(0.081)
SIZE$_{t-1}$	-0.007^{***}	0.005	-0.012^{*}	-0.008^{**}	-0.006^{*}
	(0.002)	(0.003)	(0.006)	(0.003)	(0.004)
CAPEX$_{t-1}$	$0.092*$	0.111	−0.038	0.154^{*}	−0.033
	(0.049)	(0.133)	(0.047)	(0.084)	(0.091)
CFLOW$_{t-1}$	-0.064^{**}	-0.184^{***}	−0.062	−0.027	−0.088
	(0.025)	(0.065)	(0.052)	(0.037)	(0.063)
LEV$_{t-1}$	−0.030	0.012	−0.011	−0.063	0.004
	(0.021)	(0.031)	(0.036)	(0.044)	(0.038)
MB$_{t-1}$	0.003	−0.000	−0.002	0.005	0.000
	(0.003)	(0.012)	(0.005)	(0.003)	(0.010)
NWC$_{t-1}$	0.027^{***}	0.046^{***}	0.018	0.012	0.041
	(0.010)	(0.018)	(0.012)	(0.040)	(0.053)
DIV$_{t-1}$	−0.005	−0.006	0.006	−0.014	0.019
	(0.008)	(0.011)	(0.015)	(0.014)	(0.013)
RD$_{t-1}$	0.015^{*}	−0.019	0.025	0.010	0.035^{**}
	(0.009)	(0.015)	(0.017)	(0.018)	(0.014)
Second Directive	0.038^{***}	-0.034^{*}	0.095^{***}	0.039	0.022
	(0.015)	(0.020)	(0.030)	(0.031)	(0.020)

Third Directive	0.018	-0.043^{**}	0.071^{***}	-0.009	0.012
	(0.014)	(0.022)	(0.021)	(0.030)	(0.020)
Constant	0.142^{***}	0.004	0.185^{**}	0.184^{***}	0.115^{**}
	(0.032)	(0.040)	(0.078)	(0.053)	(0.049)
AR (1)	0.000	0.022	0.000	0.000	0.000
AR (2)	0.084	0.466	0.341	0.297	0.224
Hansen	0.347	1.000	0.257	0.265	0.783
Diff (First vs Second Directive)	0.151	0.007^{***}	0.093^{*}	0.215	0.918
Diff (First vs Third Directive)	0.706	0.044^{**}	0.070^{*}	0.852	0.160
Diff (Second vs Third Directive)	0.132	0.226	0.831	0.072^{*}	0.288
N	2425	272	581	1010	562

This table presents the GMM-BB estimation results of NET CASH for different country-groups. Variable definitions are presented in Table 1. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. Robust standard errors are in parenthesis. Second to third lags of NET CASH are used as instruments. AR (1) and AR (2) test the first- and second-order correlation among residuals under the null hypothesis of no serial correlation. Hansen is a test of instrument validity under the null hypothesis of instruments are valid

Table 7 Additional tests: Weighted least squares and least absoule deviations regressions

	Dep. variable = $CASH_t$		
Variable	(1) WLS 1	(2) WLS 2	(3) LAD
$SIZE_{t-1}$	-0.013^{***}	-0.013^{***}	-0.008^{***}
	(0.003)	(0.004)	(0.002)
$CAPEX_{t-1}$	-0.095^{**}	-0.105^{**}	-0.114^{***}
	(0.040)	(0.042)	(0.042)
$CFLOW_{t-1}$	-0.108^{***}	-0.080^{**}	-0.083^{***}
	(0.037)	(0.040)	(0.024)
LEV_{t-1}	-0.179^{***}	-0.163^{***}	-0.098^{***}
	(0.030)	(0.030)	(0.021)
MB_{t-1}	0.014^{***}	0.014^{***}	0.020^{***}
	(0.003)	(0.003)	(0.002)
NWC_{t-1}	−0.006	−0.006	0.003
	(0.010)	(0.010)	(0.010)
DIV_{t-1}	−0.003	−0.005	0.006
	(0.012)	(0.012)	(0.010)
RD_{t-1}	0.047^{***}	0.044^{***}	0.028^{***}
	(0.016)	(0.013)	(0.009)
Second Directive	0.050^{***}	0.042^{***}	0.026*
	(0.013)	(0.014)	(0.014)
Third Directive	0.037^{***}	0.040^{***}	0.030**
	(0.012)	(0.014)	(0.013)
Constant	0.272^{***}	0.275^{***}	0.180^{***}
	(0.056)	(0.061)	(0.046)
Country fixed	Yes	Yes	Yes
R^2	0.279	0.288	0.115
N	2670	2670	2670

This table presents the weighted OLS and least absolute deviations regression estimation results of cash for the whole sample. Variable definitions are presented in Table 2. In Panels 1 and 2, we weigh the standard errors using inverse of the square root of the number of observations per country (WLS 1) and country-group (WLS 2), respectively (weighted least square estimation). In Panel 3, we employ least absolute deviation (LAD) regression instead of standard OLS estimation. ***, **, and * denote the significance level at 1%, 5%, and 10%, respectively. Standard errors (in parenthesis) are clustered at the firm level

4.4 Additional Tests

Our main results about the impact of energy directives on cash holding accumulation could be driven by our model specification or sample heterogeneity. It is therefore necessary to conduct a series of robustness tests to validate our conclusions.

One of the potential concerns about the analysis is the heterogeneity in the number of observations per country and country-group. To control for the differences in the sample size across the countries and country-groups, we perform

Weighted Least Squares regression. Specifically, we use the inverse of the square root of the number of observations per country and country-group in calculating the standard errors to eliminate the impact of sample size heterogeneity across countries. According to the results presented in Table 7 and Panel 1–2, our main findings are not sensitive to the sample size heterogeneity. The coefficients of the Second and Third Directives are positive and significant at the 1% level, which imply that with the implementation of the further directives, European energy firms increase their cash level. Moreover, the impacts of firm-specific variables are quite similar when we undertake Weighted Least Squares regression.

The standard linear regression models estimate the relationship between the dependent and explanatory variables conditional on the mean function. However, with the presence of outliers and concerns about the assumptions of the parametric estimation, median regression, or least absolute deviations (LAD) provide more robust results. To account for this, we also employ LAD regression to test the impact of energy directives on the cash holdings (Table 6 and Panel 3). Our results are similar when we employ LAD regression instead of OLS regression.

As a final robustness check, we follow Kalcheva and Lins (2007) and control for country-level anti-self-dealing index as a proxy for investor protection and gross domestic product (GDP) as a proxy for economic development in addition to the other variables used in the empirical model. Untabulated results show that our findings are robust even after controlling for investor protection and GDP level. In other words, the energy directives have a significant impact on the cash holding policies of the energy firms even after controlling for other factors such as GDP and investor protection level of the country.

5 Conclusion

In this chapter, we investigate the impact of energy directives on corporate cash holding policies of the energy firms in Europe. The energy industry has substantially different institutional and macroeconomic settings than other industries. The energy sector has experienced radical changes in terms of the unbundling process, developments in the energy security, and concerns about the climate change as well as the increasing importance on the usage of renewable energy all over the world. Moreover, energy directives have significantly changed the business environment for energy firms by increasing the uncertainty in generation, transmission, and distribution of energy. Although the energy industry has some unique characteristics in terms of the business dynamics and regulative issues, corporate financial policies of the energy firms is often neglected in the energy economics literature. Therefore, understanding the cash holding decisions of these firms will enhance our understanding about the corporate policies of the firms operating in the energy industry. Moreover, we expect to bridge the gap between corporate finance and energy economics by focusing on the one of the most important field of corporate finance, cash holdings.

We adopt a similar methodological approach to prior research by including several firm-specific and macroeconomic variables and by employing both static and dynamic regressions. As expected, the determinants of cash holdings are significantly different among countries and country-groups. More importantly, the implementation of energy directives has a different influence on cash holding policies. Oil and gas firms in Nordic and Western European firms significantly increase their cash holdings after the implementation of the Second and Third Directives, however, firms in other countries are insensitive to the changes in the energy industry. Moreover, target adjustment behavior also differs among country-groups. The firms in Nordic and Western European countries have a relatively quick adjustment processes to reach the desired cash levels. Therefore, it may be implied that firms in these countries face lower adjustment costs or greater costs of being suboptimal and as a result they tend to operate close to their target cash position. On the other hand, greatest adjustment costs are observed in Eastern European firms as they have the considerably slower adjustment processes. Moreover, implementation of the energy directives increases (decreases) the speed of adjustment in Nordic (Eastern Europe) firms. Therefore, it can be inferred that implementation of the energy directives has a considerable impact not only on the cash accumulation but also on the speed of adjustment to the desired cash level.

Overall, the findings of this study are expected to enhance the understanding of the cash holding policies in a unique industry in terms of the different micro and macro environmental and financial settings. Further studies can extend the issue by incorporating other countries outside of Europe. There is still enough room for investigating other corporate policies such as investment, capital structure, or dividend policies in this industry to gain better understanding of corporate decisions of these firms. This awaits further research.

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The Determinants of Systematic Risk of Renewable Energy Firms

Lars J. Hesselink, Lammertjan Dam, and Wim Westerman

1 Introduction

In the last decade, global investments in energy capacity shifted from investing in fossil fuels to investing in renewable energy from naturally replenished natural resources, including biomass, waste-to-energy, geothermal, wind generation hydropower, wave and tidal energy, biofuels and solar (New Energy Finance 2016). However, the risk–return relationship (Sadorsky 2012), on which investment decisions are based, is hard to assess in case of renewable energy investments. This relationship is important for managers when they value a private firm by discounting an investment's future cash flows with the weighted cost of capital. To calculate the equity component of this cost of capital, contemporary finance scholars focus on the systematic risk (beta) of public comparable firms (Damodaran 1999b). However, these are hard to be found and also comparable firm beta estimations do not reflect the opportunities and uncertainties in renewable energy investments (Menegaki 2008). Furthermore, beta estimations range from twice as risky as a well-diversified portfolio to half as risky (Sadorsky 2012; Donovan and Nuñez 2012; Bohl et al. 2013). So, there is a need to come up with common drivers that affect the systematic risk of renewable energy firms.

Sadorsky (2012) finds that oil returns positively influence the beta of renewable energy firms, but country-specific factors can also influence a renewable energy firm's beta. On the one hand, Inchauspe et al. (2015) find that renewable energy investments grew at different paces in different countries, and Donovan and Nuñez (2012) empirically find country differences in beta. On the other hand, the literature describes several country-dependent risk factors important to renewable energy firms (Popp et al. 2011; Barroso and Iniesta 2014; Kim et al. 2016). These country

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dependencies give rise to the idea that country-specific factors can influence the beta of renewable energy firms. However, these risk factors are not yet empirically tested as a determinant of a renewable energy firm's systematic risk. First, oil prices are likely to influence the beta of a country's renewable energy firms due to a substitution effect (Klevnäs et al. 2015). Second, a country's energy security influences the propensity to invest in renewable energy (Sen and Ganguly 2017). Third, a country's technological innovation potentially benefits renewable energy firms as innovation closes the price gap with fossil fuels (Khan et al. 2017). Fourth, literature documents on governmental policies as a means to reduce risk by securing cash flows in renewable energy investments (Sadorsky 2012). Therefore, the following research question is formulated: how do oil return, country-level net-imports, technological innovation, and environmental policies affect the beta of renewable energy firms?

An alternative to the static CAPM beta is the dynamic beta approach. This allows for beta to vary with a set of factors (Rosenberg and Marathe 1976). Our dynamic beta approach relates that systematic risk renewable energy firms vary with oil returns (Sadorsky 2012), and the level of a country's net-imports, technological innovation, and environmental policies. We employ a cross-country panel data set with 578 traded renewable energy firms over the period 2005–2016. We find that systematic risk, beta, is negatively influenced by oil returns and that country-level net-imports, and environmental policies discriminate risk between countries. Oil returns are the most dominant factor, a one standard deviation fluctuation in monthly oil prices leads to a fluctuation in beta of 0.17. Also, a one standard deviation difference in the level of net-imports and environmental policy affects beta with 0.14 and 0.09, respectively.

These results give insights on the beta of renewable energy firms. Macroeconomic factors influence the beta of the renewable energy sector and should not be forgone in comparable firm analysis. From here, country-specific factors help to convert the risk of comparable renewable energy firms abroad to the investment's country of interest. Also, this study provides insights on nonfinancial drivers (Trueman et al. 2000) of a renewable energy firm's beta and answers Sadorsky's (2012) call for further analysis of variables affecting the beta of such firms.

This chapter is structured as follows: Section 2 focuses on literature concerning beta estimation in renewable energy. From here, we derive hypotheses to answer the research question. Section 3 outlines the methodology and describes the data used. Section 4 presents the results and evaluates the hypotheses. Section 5 consists of a discussion and conclusion.

2 Literature Review

This literature review starts with an overview of investment decision-making based on the cost of capital. We describe limitations of the practitioner's method on renewable energy (hereafter RE) valuation. Given these limitations, we suggest an alternative solution based on evidence from the technology sector. We describe variables that affect the systematic risk of renewable firms. Lastly, the research framework is displayed.

2.1 Investment Decision-Making and the Cost of Equity Capital

The standard valuation approach is to discount an investment's future cash flows (DCF), based on a discount rate that represents the opportunity cost of making this investment (Koller et al. 2015). The discount rate is a percentage based on the weighted average cost (WACC) of debt and equity capital used. The cost of equity reflects the rate of return for the equity investor and the cost of debt the rate of return for the debt investor. To reflect benefits of the tax deductibility of interest, the cost of debt should be after corporate tax (Brotherson 2013).

The cost of equity is a challenging aspect of the WACC calculation (Donovan and Nuñez 2012). Sharpe (1964) and Lintner (1965) were the first to frame this cost of equity in their capital asset pricing model (CAPM). This model describes the cost of equity by means of a risk-free rate, a market risk premium, and a stock's sensitivity to the market index. This sensitivity is the stock's systematic risk, beta. Practitioners use the beta of comparable public firms (peers) to determine a private firm's cost of equity (Brotherson 2013; Koller et al. 2015). Thus, to arrive at the cost of equity for private RE firms, we need the beta of comparable listed RE firms.

2.2 Limitations to the Practitioner's Method in Renewable Energy Valuation

The practitioner's method faces limits in the case of valuing a private RE firm. One limitation concerns the estimation of the peer beta. There is little evidence on the systematic risk of RE firms because of the short-lived nature as an independent business (Donovan and Nuñez 2012). Thus, it is hard to find comparable listed firms with enough stock return observations to base beta on. Alternatively, accounting betas are used (Damodaran 1999a). However, in technology-based industries, such as the RE industry, nonfinancial data largely dominates the accounting information (Jorion and Talmor 2001). Also, historical information is likely to be less useful than in more established industries or even in non-high-tech industries (Trueman et al. 2000).

The limited evidence on the systematic risk of RE firms shows mutually deviating betas, since scholars use different samples and market index proxies. Table 1 provides an overview. Donovan and Nuñez (2012) fit CAPM-derived models for emerging markets' RE firms over the period 2006–2009. They find betas that range from 0.55 to 1.45 (Table 1). By using German data, Bohl et al. (2013) find a

Table 1 Literature on the systematic risk of renewable energy firms

Author(s)	Sample	Time-period	Market index	Beta	Research aim	Main finding
Donovan and Nuñez (2012)	Selected RE firms from China, Brazil, and India	2006–2009	Monthly return	1.30	Examining the key methodological challenges in determining the cost of equity for RE firms in emerging markets	For the multinational investor, RE possesses average market risk, but for the local investor market risk deviates between lower than average and higher than average. Thus, it is important to know who the marginal investor is
			MSCI-ASCI			
			China	0.82		
			Brazil	0.55		
			India	1.46		
Bohl et al. (2013)	ÖkoDAX Index and Renewable Energies Index	2004–2011	Monthly return CDAX	Time-varying, between 2.10 and 1.6	Examining the risk factors of RE stock returns, based on Carhart's four factor loadings	German RE stocks outperformed the market in 2004–2007, but this completely reversed in 2008–2011
Henriques and Sadorsky (2008)	Wilderhill Clean Energy Index firms	2001–2007	Monthly return S&P	1.40	Investigating the relationship between alternative energy stock prices, techno-logy stock prices, oil prices, and interest rates	Shocks to technology stock prices influence stock prices of alternative energy firms, however, oil prices only have a little significant impact
Inchauspe et al. (2015)	New Energy Global Innovation Index firms	2001–2014	MSCI Index	Time-varying between 0.9 and 1.2	Examining factors impacting the NEX and giving insights in the dynamic nature of these factors	The NEX is highly correlated with the MSCI, the technology stock index is an additional pricing factor and impact of oil prices on returns is weak. Time-varying coefficients illustrate changing relationships
Sadorsky (2012)	Wilderhill Clean Energy Index firms	2002–2007	Monthly return NYSE Index	1.96	Finding determinants of RE systematic risk	Increases in oil price returns increase the systematic risk of RE firms. Firm sales growth lowers the systematic risk

The MSCI (-ASCI = All Country World Index) is the Morgan Stanley Capital International on 23 developed and 24 emerging markets. The ÖkoDAX comprises the ten largest German RE firms, whereas the Renewable Energies Index is a bit broader with 23 firms. The CDAX is the composite index of all stocks traded on the Frankfurt Stock Exchange. The WilderHill Clean Energy Index compromises RE technology firms from the USA. The New Energy Global Innovation Index (NEX) is a well-diversified portfolio across RE subsectors and regions. See for more information the respective websites of the indices beta of 1.6, 1.65, and 2.10 for 2004–2007, the 2008–2011, and the full sample period, respectively. This evidence of a time-varying beta is backed up by a study of Inchauspe et al. (2015) on a well-diversified industry and country portfolio. The authors find a beta of 0.9 in 2003–2005 and a beta greater than 1.2 from 2013 and onwards. Inchauspe et al. (2015) also show similarities to Henriques and Sadorsky (2008) when studying market index, oil prices, and technology stock prices effects on the prices of RE stocks. Sadorsky (2012) studies mainly US technology-oriented RE firms. He finds that they are twice as risky as the market. Hence, a beta of 1.96 would be applicable.

Lastly, Menegaki (2008) argues that quality and market responsiveness of RE technologies cannot be modeled in terms of cash flows. Kim et al. (2016) join this view and argue that technological innovation and global climate change harm the definite cash flow assumption under the DCF method. As an alternative, they propose to use a real option valuation approach. So, questioning the overall DCF method also discredits the use peer betas, because the beta is central to the cost of equity calculation and in turn DCF calculation.

Taking into consideration the importance of the cost of equity and the "proven limitations" of the practitioner's method, Barroso and Iniesta (2014) argue not to reject it but instead to supplement it with techniques that more accurately assess and adjust to the reality of projects that generate uncertainties in some of their parameters (cf. Menegaki 2008; Kim et al. 2016).

2.3 Alternative Solution Based on the Evidence from the Technology Sector

Regressing the beta on variables other than accounting ratios can help to give insights on systematic risks of a novel industry, such as the RE industry. Central here is the relationship between technology stocks and RE stocks. Henriques and Sadorsky (2008) find a significant response of the RE index to technology index shocks. They argue that investors consider RE stocks closely related to technology sector rather than energy sector movements. Inchauspe et al. (2015) confirm this relation and ascribe this to the competition for the same inputs.

Another common factor is the limited availability of data. Jorion and Talmor (2001) acknowledge the limited availability of historical information and the domination of nonfinancial data in the early days of the technology sector and argue that "neither growth nor net income, nor cash flows, nor return on investment should be emphasized to the exclusion of other meaningful measures" (p. 13). The study by Sadorsky (2012) is the only one that researched the determinants of the systematic risk of RE firms. So, based on the similarities between the (early day) technology sector and the RE sector, this chapter advocates that non-accounting variables may be an important determinant of the systematic risk of RE firms.

2.4 Determinants of Renewable Energy Systematic Risk

Section 2.4.1 discusses a global factor that affects the systematic risk of RE firms, namely oil returns. Next, Sect. 2.4.2 discusses five country-specific factors that affect the systematic risk of RE firms, respectively energy import dependency, technological innovation, political risk, environmental policy stringency, and environmental policy stability.

2.4.1 A Global Factor Affecting the Systematic Risk of Renewable Energy Firms

The first potential determinant of RE systematic risk is global oil returns. Oil prices affect the costs of goods and services, impact inflation, and influence consumer confidence (Nandha and Faff 2008). In this way, oil returns affect stock prices, which ideally reflect "the market's best estimate of the future profitability of firms" (Jones and Kaul 1996, p. 24). So, increasing oil prices raise the cost of doing business and therewith affect equity returns of nonfossil fuel-related firms. Nandha and Faff (2008) find for 35 DataStream global industries that rising oil prices negatively impact on equity returns, except for oil, mining, and gas industries. Sadorsky (2012) tests the impact of oil returns on the systematic risk of mostly US tech-oriented RE stocks and finds a positive effect on the beta.

The relation of oil prices to a broader sample of RE firms can be various. Gogineni (2010) finds that industries do not rely evenly on oil as an input to conduct business. Consequently, stock prices of less oil-reliant firms are less influenced by oil price increases relative to a broad market index. This results in a lower beta for RE firms, because RE operations rely less on oil. Second, RE is a substitute for oil, and especially for fuels and coal (Klevnäs et al. 2015; Khan et al. 2017). So, if oil price increases reduce the demand for oil (Gogineni 2010), RE is perceived as more attractive (Khan et al. 2017). Vice versa, RE becomes less attractive when oil prices decrease and a RE firm's beta is expected to increase. This chapter goes with the second view: RE firm returns are less sensitive than the market to oil price increases and RE acts as a substitute for fossil fuels. Thus, oil returns and a RE firm's beta are negatively related.

H1: A price increase [decrease] in oil leads to a lower [higher] beta for RE firms

2.4.2 Country-Specific Factors Affecting the Systematic Risk of RE Firms

Country level compound annual growth rates in RE investments range from 17% to 57% over the period 2004–2011 (Inchauspe et al. 2015) and studies (Table 1) show mutually deviation betas. Also, the literature describes several country-dependent risk factors important to RE firms (Popp et al. 2011; Barroso and Iniesta 2014; Kim et al. 2016). This gives rise to the idea that, on top of oil, country-specific factors can influence the beta of RE firms.

Energy Import Dependency

The objective of countries to reduce uncertainty in energy supply (Sen and Ganguly 2017) reduces the systematic risk of RE firms. However, this reduction depends on the proportion of a country's energy imports. Based on a literature study, Vivoda (2009) holds that one way to secure a country's energy supply is to diversify sources from where oil is imported. However, diversification does not reduce oil price volatility. Hence, the higher the level of energy imports the larger the magnitude of oil price volatility.

Various empirical studies find negative effects of oil price volatility on economic activity of net-oil importing countries—Hamilton (2003) on nonlinear effects on the GDP growth, Cuñado and Pérez de Gracia (2005) on the consumer price index (CPI) and production in Asian countries, Gronwald (2008) on U.S. GDP growth, consumer- and import prices, and Álvarez et al. (2011) on European and Spanish CPI. Hence, the higher the level of imports the higher the impact of oil price volatility becomes. The adverse effects of oil price volatility ask for a solution to curb their impact on economic activity. Here, RE's hedging role serves as a solution. Rentschler (2013) simulates oil price volatility and finds that increasing the share of RE avoids GDP losses.

Therefore, a country's pursuit of energy independence creates a favorable environment for RE firms. It secures their cash flows. From here, investors reward RE firms with a lower risk perception. Vice versa, RE firms do not face this lower risk perception in countries with greater domestic energy resources. Thus, there is a negative relationship between energy imports and the systematic risk of RE firms. Hence, higher net energy imports decrease the beta of RE firms.

H2: Investing in a country which is relatively more dependent on energy imports [exports] decreases [increases] the beta for RE firms

Technological Innovation

Literature acknowledges the importance of technology in the RE sector, but has not yet examined technological innovation as a determinant of systematic risk of RE firms. Empirically, papers focus on the explanatory power of technology stock return on RE stock return (Henriques and Sadorsky 2008; Inchauspe et al. 2015), on the effect of technological innovation on the use of RE technologies (Popp et al. 2011) and on the diffusion of these technologies (Verdolini and Galeotti 2011). Theoretically, papers put forward the uncertainty from cost fluctuations in the RE sector (Barroso and Iniesta 2014), security of demand for RE because of digitalization (Khan et al. 2017) and cost competitiveness with fossil fuels due to technological innovation (Popp et al. 2011). In sum, there is evidence that technological innovation plays an important role within the RE sector.

This role is not yet translated into a determinant of systematic risk. However, most of the energy-related innovations are carried out in a few countries and the diffusion of technological innovation for RE cannot be taken for granted in all countries (Verdolini and Galeotti 2011). Thus, there is an unequal effect on systematic risk of RE firms between countries. Verdolini and Galeotti (2011) model the probability that an innovation generated in country *j* becomes available in country *i*. They find that most innovations never cross a country's border, but if an innovation crosses the border, geographical distance is not significant anymore.

On the one hand, costs of RE are likely to decrease in the future, but this is most likely in countries with high technological development. Consequently, this competitive advantage decreases the systematic risk for RE firms residing in countries with a higher technological innovation, relative to firms from countries with a lower technological innovation. On the other hand, investing in energy systems results in irreversible investments (Verdolini and Galeotti 2011). This creates a "lock-in" in the chosen technology, despite further technological RE innovation (Foxon 2007). From here, unequal diffusion of technology results in unequal risk distribution. Consequently, RE firms in countries with high technological development are more likely to face these breakthroughs, which create a source of long run risk (Hsu 2010).

This chapter goes with the view that the cost-reducing effect of technological innovation outweighs the effect of technological breakthroughs as a source of long run risk. Potential breakthroughs nowadays are likewise to ones that could have happened 10 years ago. Thus, there is a negative relationship between technological innovation and the beta of RE firms.

H3: The higher (lower) the technological innovation in a country the lower (higher) the beta of RE firms

Political Risk, Environmental Policy Stringency, and Environmental Policy Stability

The United Nations induced an international agreement to reduce emissions, the Kyoto Protocol (UNFCCC Protocol 1997), to commit its member countries to adopt RE practices. Subsequently, countries employ various RE policies. Popp et al. (2011) distinguish between "R&D, investment incentives (e.g., risk guarantees, grants, and low-interest loans), tax incentives (e.g., accelerated depreciation), tariff incentives (e.g., feed-in tariffs), voluntary programs, obligations (e.g., guaranteed markets and production quotas), and tradable certificates" (p. 649).

Authors point to the implications of their research for governmental policies on RE. The same survey among 60 private equity investors conducted in 2007 and 2010 gives insights on the right policies to mitigate investment risk (Bürer and Wüstenhagen 2009; Hofman and Huisman 2012). Popp et al. (2011) uses a sample of 26 OECD countries over the period 2011. He finds that governmental policy, proxied by ratification of the Kyoto Protocol and two specific policies, enhance RE investment. Moreover, the majority of the real option literature focusses on feed-in tariffs as the main market uncertainty (Kim et al. 2016). In sum, different types of research link RE investments to environmental policies. However, none of them examines if these policies reward RE firms in that country with a lower systematic risk.

The governmental environmental policies affect the systematic risk of RE firms in three ways: (1) the policies create a predictable demand (Sadorsky 2012), (2) the policies reduce the costs of renewable relative to fossil fuels by penalizing firms that pollute the environment and by including favorable tariffs (Kim et al. 2016), and (3) uncertainty in environmental policies poses a risk on RE investments. From here, strict environmental policies in a country would exert a positive effect on future profitability of RE firms (Bohl et al. 2013). Stringent environmental policies reduce systematic risk, but loose environmental policies do increase it.

An issue is how environmental policy stringency depends on political stability. Fredriksson and Svensson (2003) study a sample of 31 countries and cannot reject that the marginal effect of political instability on environmental policy is zero. Political risk in its broadest meaning is the adverse effect on the value of an investment, as a consequence of government actions, or imperfections of a country's executive, legislative, or judicial institutions, or internal and external conflicts (Bekaert et al. 2016). This chapter tests the effect of country's political risk on the systematic risk of RE firms, the effect of environmental policy stringency on systematic risk and the combined effect (here after environmental policy stability) on systematic risk.

Countries with a low political risk do not necessarily have stringent environmental policies and vice versa. In countries with stringent policies but high political risk, investors still perceive a higher risk. If not including the combined effect, this results in a downward biased estimate of beta because of stringent environmental policies, while neglecting political risk in general. Even where strict environmental policies are in place, legislative institutions may fail. For example, Schuman and Lin (2012) state that in China, despite its RE laws and large RE sector, firms are hardly penalized for not obeying these laws. Thus, we assume is a negative relationship between environmental policy stability and the beta of RE firms.

H4.1: The higher (lower) the political risk in a country the higher (lower) the beta of RE firms

H4.2: The higher (lower) the environmental policy stringency in a country the lower (higher) the beta of RE firms

H4.3: The higher (lower) the overall environmental policy stability in a country the lower (higher) the beta of RE firms

Figure 1 graphically displays the derived hypotheses from the literature review. Oil returns negatively influence the systematic risk of renewable firms. Net-imports negatively affect the systematic risk of RE firms. Technological innovation lowers the beta and political risk positively influences it. Both environmental policy stringency and stability lower the beta.

2.5 Research Framework

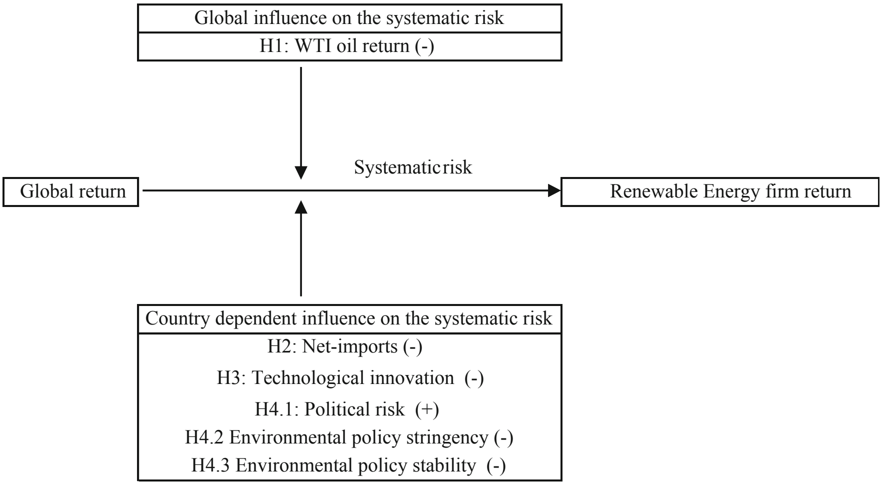

Fig. 1 Research framework

3 Methodology and Data

This chapter uses a dynamic beta model, in line with Sadorsky (2012), as will be elaborated on. Also, this section describes the firms included in the sample, as well as the macroeconomic data on global- and country-specific variables. The time period covered is 2005–2016.

3.1 Methodology

A dynamic beta model (Abell and Krueger 1989) can describe the systematic risk of RE firms. "Papers published in the 1980s used the term variable beta. Today, the terms variable beta, time varying and dynamic beta are used interchangeably" (Sadorsky 2012, p. 42) to describe the type of model. The model is an extension of the capital asset pricing model (CAPM), which is often referred to as Sharpe's single index model (SIMM) (Sharpe 1964).

Abell and Krueger (1989) use the method to determine the apparently similar macroeconomic effects on beta across US industries. Whereas their study focuses on macroeconomic influences on beta, it has similarities with Glova (2014), who described Central, Eastern, and Southeastern Europe (CESEE) country betas based on global risk factors and local risk factors. Therefore, this chapter uses the methodology described by Abell and Krueger (1989), with one variable that is irrespective of a firm's country and five variables that are country specific: oil return, and net-imports, technology, political risk, environmental policy stringency, and environmental stability. We aim to explain the effect of these variables on the systematic risk of RE firms.

The structural model in this chapter extends the SIMM with a set of other factors, $\delta' Z_{it}$, explaining stock return R_{it} of RE firm i at time t. In this multifactor model (1),

$$R_{it} = \alpha_i + \beta_i R_{mt} + \delta' Z_{it} + \varepsilon_{it} \tag{1}$$

R_{it} represents the RE firm's monthly stock return, calculated as $ln(p_t/p_{t-1})$ and adjusted for dividend payments and corporate actions. R_{mt} are the monthly returns of the MSCI All Country World Index (ACWI), referred to as global return. The corresponding β_i measures the sensitivity to the global return (systematic risk) of RE firm i. The α_i is the component of a security's return that is independent of the global return, and the ε_{it} is the error term.

The CAPM can be adapted to a dynamic beta model if beta varies with a set of fundamental factors (Rosenberg and Marathe 1976). Such a model provides investors with valuable information on the sensitivity of beta to certain factors (Abell and Krueger 1989). We expect that the beta depends on the set of variables from Fig. 1. Our model describes beta in terms of a constant influenced by a global variable and five country-specific variables. This leads to,

$$\beta_{it} = \theta_i + \gamma' X_{it} + v_{it} \tag{2}$$

with θ_i as the constant and X_{it} as a vector of variables affecting the beta of a RE firm i, at time t, hence β_{it}. So, β_{it}varies linearly with a set of descriptors X_{it}. Also, γ are coefficients of the proportion by which the beta is adjusted in response to movements in these descriptors (Abell and Krueger 1989). The v_{it} are random error terms. In most of our regressions we use pooled OLS, meaning that $\theta_i = \theta$. This θ_i can also depend on country or industry. Importantly, using country-dependent variables as descriptors of beta yield a beta that is expected to be the same for all firms from that country at time t. This is a strong assumption. However, the aim is to estimate the effects on beta rather than individual firm betas. Also, it is not possible to directly estimate the effects on beta as beta is unknown in Eq. (2). Thus, we estimate the effects on beta jointly in a reduced form by substituting Eq. (2) with Eq. (1). This yields:

$$R_{it} = \alpha + (\theta_i + \gamma' X_{it}) R_{mt} + \delta' Z_{it} + \vartheta_{it} \tag{3}$$

In this case α_i becomes α. This means that α is no longer firm dependent. Furthermore, $\vartheta_{it} = \varepsilon_{it} + v_{it} R_{mt}$ is assumed to be normally distributed with zero mean.

Now, we can indirectly determine values for parameters γ in Eq. (2) by the estimation of Eq. (3). In this model, $\theta_i R_{mt}$ (the constant) is the separate influence of the world index (global return) on firm return after incorporating the hypothesized effects on systematic risk. The information of the effect of these variables on beta comes from the γ coefficients in Eq. (3). Hence, a negative coefficient γ indicates that the beta of Eq. (3) is reduced because of an increase in X_{it}. Vice versa, a positive coefficient indicates that the beta increases because of an increase in X_{it}. Hypothetically, if $\theta_i R_{mt} = 1.2$, and $\gamma_i = -0.1$, the global return has a diminishing effect on a RE firm's return at a higher X_{it}. For each unit that X_{it} increases, the market index effect on firm return decreases by $-0.1*1$, ceteris paribus.

Firms and their country-specific factors are matched based on ISO Code. One drawback of this is that firms have operations in multiple countries. However, ISO codes mostly reflect the country in which most revenue is gathered, management is settled, and laws are obeyed. The unbalanced panel is examined over a period of 12 years and per month, which results in a maximum of 144 monthly observations per firm. Furthermore, this panel data set is estimated using OLS and corrected for panel standard errors (PCSE), which makes the model robust to heteroscedasticity and contemporaneous correlation (Beck and Katz 1995).

3.2 Data

This research uses a large sample of stocks listed RE firms based on Bloomberg Industry Classification Standards (BICS). Previous studies mainly focused on either RE indices (Henriques and Sadorsky 2008; Inchauspe et al. 2015), or small samples of firms from these indices (Sadorsky 2012; Bohl et al. 2013), or a sample of emerging market RE firms (Donovan and Nuñez 2012). These samples included less than 70 firms. We start with 644 firms from 53 different countries (based on ISO code) that are listed on stock exchanges around the world.

The BICS classifies firms on primary business by measuring the source of revenue, operating income, assets, and market perception (Bloomberg Index Methodology 2015). We included all listed firms with BICS codes 1311 and 19101112, which respectively reflect all firms majorly engaged in "RE and Renewable Electricity." These firms range from wind generation firms, to producers of their equipment and from fuel cell producing firms to RE construction firms.

Furthermore, firms need enough stock return observations to result in a beta that accurately reflects the systematic risk of the firm. Here, we follow Damodaran (1999b). Whereas annual and quarterly data may result in too less observations, beta estimations based on daily data may suffer from a nontrading bias. It is best to use at least 36 monthly return observations. We retrieved monthly return data, conditionally on at least 24 months of observations. We are interested in the aggregate beta of multiple firms in a country rather than individual firm betas. Consequently, the sample consists of 578 firms from 52 countries (see Table 2).

Table 2 Number of sampled renewable energy firms per country, 2005–2016

Country	ISO Code	Number of firms	Country	ISO Code	Number of firms	Country	ISO Code	Number of firms
UAE	AE	1	Hungary	HU	5	Peru	PE	2
Austria	AT	1	Indonesia	ID	1	Philippines	PH	2
Australia	AU	26	Ireland	IE	1	Pakistan	PK	1
Bosnia and Herzegovina	BA	4	Israel	IL	6	Poland	PL	12
Bangladesh	BD	2	India	IN	33	Romania	RO	1
Bulgaria	BG	2	Italy	IT	15	Serbia	RS	2
Brazil	BR	4	Jordan	JO	1	Russia	RU	3
Canada	CA	43	Japan	JP	4	Sweden	SE	8
Switzerland	CH	5	Kenya	KE	1	Singapore	SG	2
China	CN	104	South Korea	KR	19	Thailand	TH	10
Czech Republic	CZ	2	Kuwait	KW	1	Tunisia	TN	1
Germany	DE	35	Sri Lanka	LK	5	Turkey	TR	4
Denmark	DK	2	Malaysia	MY	7	Ukraine	UA	4
Spain	ES	6	Netherlands	NL	1	United States	US	108
France	FR	13	Norway	NO	4	Vietnam	VN	14
Great Britain	GB	21	New Zealand	NZ	4	South Africa	ZA	2
Greece	GR	1	Oman	OM	1	Total		578
Hong Kong	HK	20	Panama	PA	1			

Firm count is based on the ISO code belonging to the firm according to Bloomberg. Great Britain also includes firms from Jersey and Isle of Man. China's count also includes Taiwanese firms. Source: Bloomberg

Table 3 Global- and country-level influences on the systematic risk of renewable energy firms

Variable	Description
Global influence on systematic risk	
	Monthly
WTI oil return	Log return on the WTI crude oil generic 1st
Country influences on systematic risk	
	Yearly
Imports	Energy imports relative to energy use
Technology	(Patent applications/population) times thousand
PRS	Score on the Political Risk Index
EPS	Score on the Environmental Policy Stringency Index
(PRS+EPS)	Equally weighted score of PRS and EPS

Sources: Bloomberg, World Bank, WIPO, OECD, PRS group

3.3 A Global Factor

Oil price returns are measured as the monthly log return using the last day's closing price on the West Texas Instruments (WTI) Crude oil Generic 1st. These are the oil prices based on the nearest future contract and are the most widely traded physical commodity in the world (Henriques and Sadorsky 2008). Oil prices are retrieved from Bloomberg. See also Table 3.

3.4 Country Factors

3.4.1 Energy Imports, Net (% of Energy Use)

Data on net-imports is retrieved from the World Bank Databank and available until 2014 for most countries. Net-import is one of the most commonly used measures of security of energy supply (Kruyt et al. 2009). They are estimated relative to energy use in oil equivalents. A positive percentage indicates that a country imports more energy than it produces. A negative percentage indicates the opposite. Whereas a country can import a maximum of 100% of its total use, export quantities can exceed 100%. For example, UAE and Norway exported respectively 190.1% and 543.7% of their energy use in 2013. Energy use refers to the use of primary energy before transformation to other end-use fuels (Botta and Kozluk 2014).

3.4.2 Technology

This chapter measures technological innovation by focusing on the total patent applications in a country, as is widely done in the RE research (Verdolini and Galeotti 2011). This may not grasp the full benefit for RE firms. Patent applications on industry level are also available, but less extensive. We checked if environmentally related patent and total patent applications differ strongly, but they are 0.91 correlated. Data on patent applications is available until 2015 and retrieved from the WIPO Patent Database. Applications include both applications by residents and nonresidents counted by a filling office within a country. To be able to compare different countries regarding their patent applications, we calculated patents per thousand inhabitants.

3.4.3 Political Risk

Data about a country's political risk is based on the December reports of the International Country Risk Guide (ICRG) provided by the Political Risk Services group. The data is available until 2015 and retrieved from the World Bank. This political risk index (PRS) measures the political riskiness of a country and is a frequently used measure of political risk (Erb et al. 1996; Bekaert et al. 2014). A country's score depends on six dimensions. The yearly country score is the average of these components scores. The maximum score is 1 and the minimum score is 0. The higher the score on the political risk index, the lower the political risk. The highest score is 0.99 in our sample and the lowest score is 0.38 (Table 4).

3.4.4 Environmental Policy Stringency

Data on the environmental policy in a country is provided by the Organization for Economic Co-operation and Development (OECD) and available until either 2012 or 2015 for the majority of the countries. Environmental Policy Stringency (EPS) is defined as "the policy-induced cost of polluting by firms across different industries and policy instruments" (OECD 2016). The score is based on a composite-index approach (Botta and Kozluk 2014), focusing on fifteen instruments, subdivided over market- and nonmarket-based policies. The maximum achievable score is six (most stringent) and the minimum is zero (least stringent). In this sample, the Netherlands scores the highest in 2010 with a score of 4.13. Contrary, Brazil scores the lowest in 2011 with a score of 0.375 (Table 4).

3.4.5 Environmental Policy Stability

This chapter equally weights the score of the PRS and EPS. The PRS score ranges from 0 to 1 and the EPS score from 0 to 6. So, we multiply the PRS score by six and add the score to the EPS score to estimate the environmental policy stability of a country. This results in a minimum score of 3.3 for Indonesia in 2005 and the highest, 9.7 for the Netherlands in 2011 (Table 4).

Table 4 Summary statistics for listed renewable energy firms worldwide and country characteristics, 2005–2016

	Monthly firm return (%)	Monthly global return (%)	Monthly WTI oil return (%)	Yearly net-imports (%)	Yearly patent applications	Yearly PRS score	Yearly EPS score	Yearly (PRS + EPS score)
Mean	−2.0	0.3	0.2	20.9	0.4	0.75	2.5	6.9
Median	−0.9	0.7	1.0	27.0	0.2	0.79	2.5	7.5
Maximum	75.1	10.0	22.5	99.6	2.6	0.99	4.1	9.7
Minimum	−87.2	−13.6	−23.3	−764.3	0.0	0.38	0.38	3.3
Std. Dev.	22.9	4.4	9.0	71.0	0.4	0.14	0.93	1.6
Skewness	−0.2	−0.6	−0.4	−5.9	2.1	−0.53	−0.33	−0.5
Kurtosis	6.3	4.0	3.1	53.4	9.4	1.9	1.97	1.9
Observations (× 1000)	59.3	92.7	92.7	77.6	87.4	91.7	70.7	70.7

The sample contains 578 renewable energy firms from 52 countries. Monthly firm returns, Global returns, and WTI oil returns are winsorized on the 1st and 99th percentile. Net-imports are the total imports relative to a country's energy use (negative if net-exporter of energy). Patent applications are measured per thousand inhabitants. PRS is the score on the Political Risk Index and EPS is the score on the Environmental Policy Stringency. (PRS + EPS) is the equally weighted score and only used if both scores are available. Sources: Bloomberg, World Bank, WIPO, OECD, and PRS group

4 Results

In Table 5, this chapter shows pooled OLS estimates. Every column shows a new model. The first one has a single index model (SIMM). For completeness, we include the other variables of interest and estimate their effect on the monthly return of RE firms (Column 2). Third, we include the interaction effects between the global return and the WTI oil return, Net-imports, technology, PRS, and EPS one by one (Column 3–7). Fourth, we estimate the whole model (Column 8). The interaction effects are the main coefficients of interest for verifications of the hypotheses and represent the effect on systematic risk. The combination of the coefficient of global return and the coefficients of the interaction effects constitute the dynamic beta.

In the single index model (SIMM), Table 5 Column (1), the coefficient with global return is 1.18. This indicates that a 1% increase of the global market return leads to an expected aggregate increase in RE firm return of 1.18% and vice versa. So, RE firms are on average riskier than the market. This estimate does not deviate strongly from Damodaran's (2017) industry beta estimate of 1.14. Also, this estimate falls well with earlier research (see Table 1).

In Column (2), we see that the return of RE firms increases with WTI oil returns, indicating a substitution effect into RE stocks if oil prices rise. This finding contradicts the Henriques and Sadorsky (2012) argument that oil price movements are less important to RE firms. Hence, oil returns do matter. Furthermore, we see a negative effect of PRS on the return of RE firms. A higher score indicates a lower political risk and thus leads to a lower return. This confirms a positive relationship between political instability and stock market returns (Chen et al. 2016).

In Column (3), we see a negative effect of oil returns on systematic risk. Herewith, we accept *H1*: an oil price increase leads to a lower level of systematic risk for RE firms. This result is in sharp contrast with Sadorsky (2012), who finds a positive effect of oil returns on systematic risk. This chapter finds that a 1% increase in oil prices leads, ceteris paribus, to a 1.95% decrease of systematic risk. One standard deviation increase in oil returns reduces beta by 0.17 (Table 6). This means that the sensitivity of RE firm with respect to global market returns decreases in times of increasing oil prices, whereas it increases in times of decreasing oil prices.

Column (4) shows a positive influence of net-imports on systematic risk, which contradicts *H2* that being relative more dependent on energy imports decreases the systematic risk of RE firms. One standard deviation increase in a country's energy import relative to its use results in a deviation of 0.14 in beta and vice versa (Table 6). A difference between net-exporting 50.1% and net-importing 56.4% yields a difference in beta of 0.21. Global market returns have an increased effect on RE firm returns in cases of relatively high net imports. An explanation of this finding may be that an increased energy import from abroad outweighs the incentive to invest more in RE. This results in uncertainty in future cash flows and increased sensitivity to global returns. Also, countries with higher net-imports may still view importing energy as a more cost-effective solution to energy security, while neglecting the societal benefit of RE.

Table 5 Dynamic beta model of 578 renewable energy firms over the period 2005–2016

	SIMM (1)	Multifactor (2)	H1 (3)	H2 (4)	H3 (5)	H4.1 (6)	H4.2 (7)	H4.3 (8)
Constant	−0.024*** (−8.605)	0.032** (2.328)	0.035** (2.529)	0.032** (2.334)	0.032** (2.303)	0.031** (2.202)	0.031** (2.287)	0.033** (2.427)
Global return	1.184*** (18.470)	1.115*** (13.740)	1.075*** (13.500)	1.083*** (13.329)	1.152*** (12.872)	1.45*** (4.951)	1.396*** (9.039)	1.394*** (5.984)
WTI oil return		0.148*** (3.613)	0.141*** (3.538)	0.148*** (3.612)	0.148*** (3.615)	0.148*** (3.612)	0.148*** (3.645)	0.141*** (3.550)
Net-Imports		1.56E-05 (0.919)	1.50E-05 (1.005)	9.67E-06 (0.0596)	1.57E-05 (0.926)	1.57E-06 (0.926)	1.57E-05 (0.929)	1.13E-05 (0.699)
Patents		−0.004 (−1.170)	−0.005 (−1.368)	−0.004 (−1.153)	−0.004 (−1.126)	−0.005 (−1.150)	−0.004 (−1.194)	−0.005 (−1.338)
PRS		−0.072*** (−3.264)	−0.069*** (−3.184)	−0.072*** (−3.259)	−0.071*** (−3.247)	−0.069*** (−3.150)	−0.0725*** (−3.312)	−0.068*** (−3.120)
EPS		−0.002 (−0.515)	−0.002 (−0.614)	−0.002 (−0.529)	−0.003 (−0.519)	−0.002 (−0.548)	−0.001 (−0.344)	−0.002 (−0.581)
Dynamic beta								
Global return ∗ WTI oil return			−1.954*** (−3.110)					−1.943*** (3.099)
Global return ∗ Net-imports				0.002*** (4.411)				0.002*** (4.331)
Global return ∗ Patents					−0.090 (1.182)			−0.043 (−0.561)
Global return ∗ PRS						−0.429 (−1.260)		

Global return ∗ EPS							-0.121^{**} (−2.343)	
Global return ∗ (PRS + EPS)								-0.047^{*} (−1.591)
Cross-sections included	578	445	445	445	445	445	445	445
Total panel (unbalanced) observations	59305	39084	39084	39084	39084	39084	39084	39084
Adjusted R-squared	0.052	0.058	0.060	0.059	0.058	0.059	0.059	0.061

The dependent variable in this model is monthly firm return. This table displays models based on an unbalanced panel OLS regression in the reduced form $R_{it} = \alpha + (\theta_i + \gamma' X_{it})R_{mt} + \delta' Z_{it} + \vartheta_{it}$, in which $\theta_i = \theta$ for all firms, reflecting a global beta influenced by factors X_{it}. $\delta' Z_{it}$ reflects a vector of variables explaining firm return. R_{mt} is the global market return. ϑ_{it}, constitutes the error term. Column (1) displays the baseline single index model. Column (2) shows a multifactor model describing the effects of individual variables on firm return. Column (3)–Column (8) adds the interaction between the hypothesized variables and systematic risk. The interaction coefficients explain the effect on systematic risk in response to movements in these variables. Net-imports are the total imports relative to a country's energy use (negative if net-exporter of energy). Patent applications are measured per thousand inhabitants. PRS is the score on the Political Risk Index and EPS is the score on the Environmental Policy Stringency. (PRS + EPS) is the equally weighted score and only used if both scores are available. The model is robust to heteroscedasticity and contemporaneous correlation (PCSE). ***, **, * refer to statistical significance at a 1%, 5%, and 10% level, respectively. T-statistics are reported between brackets. Sources: Bloomberg, World Bank, WIPO, OECD, and PRS group

Table 6 Impact of significant variables on the systematic risk of renewable energy firms, 2005–2016

	−2s	−s		$\bar{x}$		+s	+2s
WTI oil return	−0.178	−0.088	−0.043	0.002	0.047	0.092	0.182
Impact on beta	0.346	0.170	0.084	−0.004	−0.09	−0.178	−0.352
Net-Imports (%)	−121.1	−50.1	−14.6	20.9	56.4	91.9	*
Impact on beta	−0.242	−0.100	−0.029	0.042	0.113	0.184	*
(PRS+EPS)	3.588	5.227	6.047	6.866	7.686	8.505	10.144
Impact on beta	−0.169	−0.246	−0.284	−0.333	−0.361	−0.420	−0.477

This table displays the impacts of the significant effects on systematic risk based on Column (8) of Table 5. $\bar{x}$ indicates the sample mean. s is the sample standard deviation. Illustratively, a one standard deviation decrease in oil prices has an impact on beta of 0.17. Net-imports are the total imports relative to a country's energy use (negative if net-exporter of energy). PRS is the score on the Political Risk Index and EPS is the score on the Environmental Policy Stringency. (PRS + EPS) is the equally weighted score and only used if both scores are available. Sources: Bloomberg, World Bank, WIPO, OECD, and PRS group. * the maximum net-imports are 100 (%), due to skewness two standard deviations fall outside the maximum range

In Column (5), we find no evidence in favor of *H3*. There is no significant effect of a country's technological innovation on the systematic risk of RE firms. Investors do not reward RE firms with a perception of lower risk, because of a higher technological innovation in their main country of business. This finding opposes Verdolini's and Galeotti's (2011) argument that there are barriers to wide-scale deployment technological innovation.

In Column (6), we find no significant effect of PRS on systematic risk and therewith this rejects *H4.1*. This is contradictory to a negative relationship between PRS and return. This could imply that a country's political risk is not systematic in nature. This is in line with Bekaert et al. (2016) who state that for the global investor political risk is only systematic in rare cases.

In Column (7), we find evidence in support of *H4.2*. Environmental stringent policies reduce the systematic risk of RE firms. The constant value of beta increases to 1.40 relative to Columns (1)–(5). However, EPS has a negative and significant effect of −0.121 on systematic risk. This means RE firm return is less sensitive with respect to global market returns in cases of a relatively high EPS scores. This confirms Sadorsky's (2012) proposal that governments can reduce systematic risk by indirectly stimulating consumers to purchase RE, by taxing fossil fuel usage and by imposing carbon taxes.

The main interest is the combined effect of PRS and EPS. The results confirm *H4.3*: overall, environmental policy stability reduces systematic risk. Column (8) shows that a combination of a stable government and stringent policies reduce beta with 0.047 if the score increases with 1%. The impact of a standard deviation increase in environmental policy stability (PRS + EPS) is a 0.09 decrease of systematic risk. The coefficient on the isolated effect of EPS in Column (7) indicates a predominant effect of EPS over PRS. Even though the Columns make up different models, we assume a higher EPS impact, given the range of possible values for both variables and the significance of this variable. The results confirm a negative effect of political instability on environmental policy (Fredriksson and Svensson 2003). The effectiveness of environmental policies is indeed partly dependent on political risk.

The results in Table 6 do not indicate if the effects of the hypothesized variables are the results of country differences or an evolvement of the variables over time. However, country differences in the variables deviate more than the development of the variables over time within a country. Thus, results are likely due to cross-country differences. We use country dummies to isolate the country effects in a country's individual beta. The remaining interaction effects are the result of the time effect. Table 7 displays the result of this isolation method.

The effect of oil returns on systematic risk remains the same. In Column (1) (Table 7) the interaction coefficient is −1.84, and in Column (3) (Table 5) it is −1.95. This should not be surprising, because all country returns, irrespective of country, are dependent on the same oil returns. Interestingly, the coefficient of the interaction term Global return∗Net-imports becomes insignificant. If we capture the country-effect in the country dummy, there is no significant effect of net-imports on systematic risk anymore (Column 2). This means that there is no effect of changing net-imports over time and hence RE firms in countries with higher net imports have a higher systematic risk.

The interaction effect of technology and systematic risk remains insignificant (Column 3). Technological innovation does not reduce systematic risk and cross-country differences do not account for systematic risk differences. The interaction effect of PRS and systematic risk remains insignificant (4). This confirms Bekaert et al. (2016): for the global investor political risk is only systematic in rare cases. The interaction coefficient, Global return∗EPS becomes insignificant. Therefore, the evidence found in Table 6 is the result of cross-country EPS differences. This finding further supports *H4.2* and indicates that RE firms in countries with more stringent policies are less sensitive to global market returns and hence have a lower beta.

Lastly, Column 6 shows a negative, −0.267, coefficient on the interaction Global Return and (PRS + EPS). This coefficient tops the −0.047 found in Table 5, indicating that the sensitivity to global returns is lower in times of a high (PRS + EPS). Thus, the improvement of environmental policy stability over time reduces the systematic risk of RE firms. Also, the sensitivity to global returns is low in countries with a high (PRS + EPS) score. RE firms are inherently less risky in terms of beta in countries with high scores that further improve over time. This underlines that some country's policies are better facilitators for RE firms than others (Noothout et al. 2016).

Table 8 summarizes the results from Tables 5 and 7. It also shows the hypothesized direction and the actual direction of the effect of oil return and country level factors on systematic risk of RE firms. Hypothesis *H1*, *H2*, *H4.2*, and *H4.3* also hold when we remove countries with an overrepresentation or under representation in the sample (unshown results).

Table 7 Dynamic beta model of 578 renewable energy firms with country-dependent betas over the period 2005–2016

	H1 (1)	H2 (2)	H3 (3)	H4.1 (4)	H4.2 (5)	H4.3 (6)
Dynamic beta						
Global return ∗ WTI oil return	−1.842*** (−3.273)					−2.014*** (−3.015)
Global return ∗ Net-imports		0.002 (0.571)				0.005 (1.117)
Global return ∗ Patents			−0.221 (0.294)			−0.107 (−0.384)
Global return ∗ PRS				0.158 (0.192)		
Global return ∗ EPS					−0.193 (−1.463)	
Global return ∗ (PRS + EPS)						−0.267* (1.931)
Cross-sections included	578	542	545	571	448	445
Total panel (unbalanced) observations	59305	48118	55635	58057	44401	39084
Adjusted R-squared	0.058	0.057	0.055	0.057	0.054	0.059
Global return ∗ Country dummy	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable in this model is monthly firm return. This table displays models based on an unbalanced panel OLS regression in the reduced form $R_{it} = \alpha + (\theta_i + \gamma' X_{it})R_{mt} + \vartheta_{it}$, in which θ_i reflects a country-dependent beta that is influenced by factors X_{it}. R_{mt} is the global market return. ϑ_{it}, constitutes the error term. Column (1)-Column (6) show the interaction between the variables and systematic risk. Net-imports are the total imports relative to a country's energy use (negative if net-exporter of energy). Patent applications are measured per thousand inhabitants. PRS is the score on the Political Risk Index and EPS is the score on the Environmental Policy Stringency. (PRS + EPS) is the equally weighted score and only used if both scores are available. The model is robust to heteroscedasticity and contemporaneous correlation (PCSE). ***, **, * refer to statistical significance at a 1%, 5%, and 10% level, respectively. T-statistics are reported between brackets. Sources: Bloomberg, World Bank, WIPO, OECD, and PRS group

Table 8 A summary of the hypothesized influences on systematic risk and the main results in Tables 5 and 7

Variables	Hypothesis	Expected sign	Sign (pooled)	Significance (pooled)	Sign (country dummies)	Significance (country dummies)	Country effect
Global influence on systematic risk							
WTI oil return	H1	–	–	***	–	***	No
Local influence on systematic risk							
Imports	H2	–	+	***	+		Yes
Technology	H3	–	–		–		No
PRS	H4.1	–	–		+		No
EPS	H4.2	–	–	**	–		Yes
PRS+EPS	H4.3	–	–	*	–	*	Yes

Net-imports are the total imports relative to a country's energy use (negative if net-exporter of energy). Estimations are robust to heteroscedasticity and contemporaneous correlation (PCSE). ***, **, * refer to statistical significance at a 1%, 5%, and 10% level, respectively. Patent applications are measured per thousand inhabitants. PRS is the score on the Political Risk Index and EPS is the score on the Environmental Policy Stringency. (PRS + EPS) is the equally weighted score and only used if both scores are available. Sources: Bloomberg, World Bank, WIPO, OECD, and PRS group

5 Discussion and Conclusion

The hot topic of climate change in today's society boosts the demand for renewable energy (RE) in the coming years and ahead. However, the diversity within the sector, its innovative nature and the continuing developments ask for measures of systematic risk beyond current practices. This chapter puts forth a dynamic beta model that estimates this systematic risk with a combination of global- and country-specific macroeconomic factors. The main conclusion is that macroeconomic factors do influence systematic risk of the RE sector and should not be forgone in comparable firm analysis. From here, country-specific factors help to convert the risk of comparable RE firms abroad to the investment's country of interest.

First and in line with earlier research we can conclude that RE firm's beta deviate strongly from country to country, and from RE sub-industry to RE sub-industry. Second, this chapter finds that the global factor, oil-returns, is most dominant in explaining the systematic risk of RE firms. Increases in oil prices reduce the systematic risk of RE firms. Therefore, investors are willing to accept RE projects against a lower cost of capital if oil prices are expected to rise. Third, this chapter finds a small increasing effect of net-imports on systematic risk. In other words, countries that are net importers of energy increase the systematic risk of RE firms. Fourth, this chapter confirms the effectiveness of environmental stimulating policies. The combination of overall political stability and environmental policy stringency has a diminishing effect on beta. Especially, the latter is evident. So, governments can reward the RE sector with a lower risk assessment by creating market- and nonmarket-based environmental policies.

This chapter does not find an effect of a country's technological innovation on the systematic risk of RE firms. Therefore, we cannot shed further insights on technological innovation effects. In addition, this research cannot confirm the increasing effect of political risk on the beta of RE firms. Thus, the study joins the view that political risk is diversifiable.

The evidence opens up to several managerial implications. First, this research shows managers that RE projects do not have to be valued on an isolated basis. RE investments share common grounds of beta risk that can be quantified. Secondly, this research makes managers aware that betas from peer RE firms can differ as a result of country-dependent variables. Consequently, practitioners can decide to focus solely on peers from countries with the same energy trade balance and environmental policy stability.

However, there are limitations to this research that in turn open up to further research. The main limitation of this study relates to the short-lived nature of RE as an independent business. This study does not distinguish between firms that became a RE firm throughout the sample period and born RE firms. Furthermore, this chapter identifies RE firms based on BICS codes, which do not distinguish between firms with, e.g., 60% RE operations and, e.g., 100% RE operations. Herewith, this chapter cannot tell if its results are entirely attributable to the systematic risk of RE firms, or to a broader range of firms closely related with RE. From here, research could test the systematic risk of firms with varying RE activity. Furthermore, distinguishing between degrees of renewable activity potentially gives insights on the magnitude of, e.g., environmental policy on the systematic risk of firms with different degrees of RE activity. Donovan and Ñunez (2012) provide a method to find the “true” RE firm. They weight a RE firm by its intensity of activity in the RE sector (proxied by revenues from RE operations).

This study neglects the multinational natures of RE firms. We study the effect on the systematic risk from country to country. Firms are linked with country variables based on ISO codes that relate to the main country of business and do not represent the true exposure to country-specific variables in case of multinational operations. Others may want to study this.

Lastly, this chapter provides the first empirical evidence that environmental policy stability reduces the systematic risk of RE firms, so further research should focus on which policy instruments are a RE firm’s best friend (Bürer and Wüstenhagen 2009). The environmental policy stringency index (EPS) gives an aggregate score, but it would be interesting to see whether investors discriminate between policy instruments when assessing a firm’s risk.

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Optimizing Resource Usage in an Unobtrusive Way Through Smart Aggregation: The Case of Electric Vehicle Charging in Amsterdam

Kees van Montfort, Halldora Thorsdottir, and René Bohnsack

1 Introduction

The United Nations has adopted the first international regulation (ENECE Regulation 100) and the European Union and Japan confirmed to adopt this UNECE Regulation for the technical standards of Electric vehicles (EVs). These regulations aim at the development of the technological innovations of EVs to make them safer and more environmentally sound.

EVs deliver a number of potential benefits (Eberle and Helmolt 2010; Skerlos and Winebrake 2010; Mak et al. 2013; Bohnsack et al. 2014; Bohnsack 2018). EVs have no tailpipe emissions and thus produce less pollution on the end-user side. Furthermore, the total emissions by EVs in the entire electricity supply chain are relatively low, because of the potential usage of cleaner and more efficient power generators like solar panels and wind turbines. Finally, EV operations are relatively insensitive to factors such as the depletion of fossil fuels and supply uncertainty of crude oil. In short, EVs are viewed as part of a more sustainable and cleaner future.

In the Netherlands during 2014 only 4620 full electric vehicles (FEVs) and 24,370 Plug-in Hybrid Electric Vehicles (PHEVs) were sold. During 2018, these numbers increased to 21,840 FEVs and 97,270 PHEVs, which represents a growth of 373% and 299% over a period of four years, respectively (Rijksdienst voor Ondernemend Nederland 2019). These EVs can be charged at more than 7500

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public and more than 11,500 semipublic charging stations. These numbers will keep on rising in the upcoming few years. With the rise of the Internet of Things (IoT), i.e., the internetworking of physical devices, it is also possible to remotely control the charging of EVs. This has created the opportunity for a new business model, the charging aggregator, which remotely controls the charging of a "swarm" of distributed EV batteries in order to optimize supply and demand. Several companies, particularly utility companies, distribution system operators, or charging point providers have naturally spotted the opportunity to exploit this new business model. Increasingly, the electric grid exhibits large peaks and valleys depending on the time of day (Bancz-Chicharro et al. 2014). By timing the charging of EVs in a smart way, these peaks and valleys could be exploited, e.g., to smoothen the load curve, to reduce peaks or to balance grid imbalances. Despite the opportunity, at this moment, most charging infrastructure providers charge electric vehicles with maximum charging speed from the moment they are plugged into a charging point until the battery is fully charged or the EV is disconnected, i.e., the potential of the aggregator business model is not used. Next to technological challenges (i.e., having access to the charging unit in the car or charging point), this is due to the fact that requiring change in the consumer's behavior could reduce the attractiveness of EV charging services. Also, due to the niche status of the technology, large-scale data to calculate the effectiveness of this business model is not available.

To address the latter problem, a robust optimization strategy is developed which calculates charging strategies for charging sessions to reduce electricity costs for aggregators in cities with electric mobility (Girotra and Netessine 2013). More specifically, we assume that aggregators can adjust the charging pattern of the session by postponing the charging, varying the charging speed, or introducing charging breaks to optimize their profit function. For this study, the calculations are based on the day-ahead Amsterdam Power Exchange (APX) electricity prices on a quarterly basis and the electricity requirements of individual EV users, which are based on more than 360,000 charging sessions at public charging points in Amsterdam during the year 2015. In the context of public charging spots, it should be noted that such infrastructure is a scarce good. Many charging spot providers and municipalities struggle with over occupancy or "hogging" of charging spots, where drivers leave their vehicle connected long after charging has been completed. Although this behavior has negative effects for EV charging throughput, it provides an opportunity for smart charging, as will be demonstrated.

Our optimization strategy minimizes the costs of charging an EV (for an aggregator and for EV drivers) without violating the charging preferences of EV drivers. This includes the electricity costs and a penalty on the occupancy of a charging point. The developed optimization model calculates for each specific EV charging session the cheapest charging pattern given the 15-min day-ahead APX prices and the charging requirements specified for the session (i.e., the connection time, the required charging load, and the required disconnection time of the specific EV user). The principle of the optimization strategy is as follows: high electricity prices will be linked to low electricity demand of EV users, and low electricity prices will be linked to high electricity demand of EV users (Espey 1998; Sioshansi 2012).

What is more, in alternative scenarios we additionally consider the effect of EV drivers changing their behavior to charge at different times. In the former, the user makes use of smart charging without changing current charging preferences. In the latter, the smart charging approach is combined with the changed timing of charging of different user groups, e.g., as a response to an incentive from an aggregator. Given the charging requirements of the EV users and the day-ahead APX electricity prices, the optimization strategy will charge the EVs with minimal electricity costs.

We empirically evaluate the effects of deploying such an optimization for two key stakeholders, the aggregator and individual EV drivers. For the aggregator, the current total energy demand is compared to the modified, optimized one, as well as the resulting cost reduction is calculated. In addition, it is demonstrated which sessions are most suitable for optimizing. As a result, the suggested charging patterns reduce the electricity costs of EV charging substantially. Based on the model, an average reduction of electricity costs between 20% and 30% can be achieved, depending on the day of the week. We also show that changing EV owner's charging preferences such as starting earlier or later can benefit certain groups of EV drivers substantially and reduce electricity charging costs up to 35%. Moreover, we contribute in building a model that is based on actual charging sessions; we account for occupancy of charging points; and the model is straight forward to implement in practice. Most importantly, the developed optimization strategy does not violate the preferences of the EV users, which is critical for social acceptance.

In what follows we first provide background information on the definitions and principles of smart electricity grids, decentral and central EV charging approaches, and optimal smart EV charging approaches. Then an optimization model is formulated to reduce the charging costs of electrical vehicles. Next, the optimization model is tested based on 360,000 charging sessions at public charging points in Amsterdam during the year 2015. The empirical study will quantify two separate effects on EV charging: the cost reductions of EV charging due to the developed optimization model and the cost reductions due to the changes of the EV user charging behavior. Importantly, due to the relatively unique dataset, our empirical study provides a realistic assessment of the savings potentially resulting from optimized public charging, both in the case of an aggregator and for an individual EV driver. Finally, the implications of our findings are discussed.

2 Background and Relevant Literature

The term smart grid is used to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery, and consumption of electrical energy (Amin and Wollenberg 2015; Valogianni 2016; see Table 1). The smart grid is also different from the traditional grid due to the large-scale integration of renewable sources and the potential double role of electricity consumers also being producers. These

Table 1 Relevant literature related to definitions and principles of smart electricity grids, decentral and central EV charging approaches, and optimal smart EV charging approaches

Subject	Articles
Definitions and principles of smart electricity grids	Gottwalt et al. (2011), Verzijlbergh et al. (2012), De Creamer et al. (2014, 2015), Amin and Wollenberg (2015), Valogianni (2016), Helms et al. (2016)
Decentral and central EV charging approaches	Molderink et al. (2010), Mohsenian-Rad et al. (2010), Anderson et al. (2011), Xu and Wong (2011), Gottwalt et al. (2011), Vandael et al. (2013), Dias et al. (2011)
Optimal smart EV charging approaches	Espey (1998), Brons et al. (2008), Ahn et al. (2011), Hidrue et al. (2011), Wu et al. (2012), Sioshansi (2012), Hahn et al. (2013), Vandael et al. (2013, 2015), Valogianni (2016)

so-called "prosumers" for instance produce electricity using solar panels or store electricity in electric vehicle batteries. To orchestrate this on a larger scale to effectively exploit the combined flexibility of the users, an aggregator can be the agent (Helms et al. 2016). An aggregator is a demand side service provider, usually in a utility market such as the electricity market. Aggregators are relevant market newcomers in Europe with growing integration of smart systems (which enable quick contact with consumers, smart charging profiles) and add electricity generation from fluctuating renewable resources. Furthermore, aggregators can bundle energy from different retailers to provide independent offerings to consumers.

In the case of electric vehicles, an aggregator could optimize the electricity demand curves of the charging EV users to reduce the electricity costs of EV charging (Gottwalt et al. 2011; Verzijlbergh et al. 2012; De Creamer et al. 2014, 2015). Coordination mechanisms to lower the costs of EV charging can be decentralized (bottom-up) or centralized (top-down) (Vandael et al. 2013; Dias et al. 2011). Decentralized approaches (Molderink et al. 2010; Mohsenian-Rad et al. 2010) require no formal coordinating entity and assume that each individual electricity customer communicates with the electricity grid via pricing signals. These signals have the ultimate goal of incentivizing consumers to charge the car when demand is low (low price period) and provide counter-incentives for charging when there is a peak in the electricity demand (high price period). Bottom-up approaches assume that the customers have the freedom to schedule their power consumption based on their own individual preferences. Centralized mechanisms (Anderson et al. 2011; Xu and Wong 2011) assume an external coordinator, who is usually the grid operator. This grid operator is responsible for maintaining the stability and reliability on the grid and usually prevents non-urgent electricity consumption during periods when electricity demand is peaking.

Depending on the market, the above-mentioned approaches have advantages and disadvantages (Gottwalt et al. 2011; Vandael et al. 2013). Bottom-up approaches have the benefit that customers' individual comfort is not violated and the EV users have the freedom to schedule their EV charging based on their individual preferences. However, the main disadvantage is that since the same price signals are provided to all customer agents, the EV charging schedules could coincide.

Assuming that all EV users are cost minimizers, they tend to shift power demand to the cheaper time instants, creating new peaks. The benefits of the top-down coordination mechanisms are that they easily satisfy the constraints imposed by the smart grid operator. However, there are significant shortcomings in this approach. The most important challenge is that often the smart grid operator must intervene and may as a result violate the EV driver's comfort (for instance, by delaying charging or switching off charging points).

Wu et al. (2012) propose an operating framework for aggregators of plug-in EVs. First, a minimum-cost load scheduling algorithm is designed, which determines the purchase of energy in the day-ahead market based on the forecasted electricity prices and forecasted EV power demands. Second, a dynamic dispatch algorithm is developed, used for distributing the purchased energy to EVs on the operating day. In this algorithm, electricity prices and EV charging behavior are considered deterministic. The results of the empirical study of Wu et al. (2012) show that the dispatched load perfectly matches the purchased energy. However, the assumption of deterministic (i.e., known beforehand) charging behavior is likely not realistic and a disadvantage of their approach.

Vandael et al. (2013) present an approach for demand side management of EVs. Their approach consists of three steps: aggregation, optimization, and control. In the aggregation step, individual EV charging constraints are aggregated. In the optimization step, the aggregated constraints are used for computation of a collective charging plan, which minimizes costs for electricity supply. In the real-time control step, this charging plan is used to create an incentive signal for all individual EVs, determined by a market-based priority scheme. The most significant difference between this approach and centralized approaches is that the central part of this approach calculates a collective charging plan for each EV and does not calculate an individual charging plan for each EV. Next, this collective charging plan is translated to individual EV power set points through a market-based priority scheme. One limitation of this approach is the discrepancy between the derived individual charging plans and the charging requirements of the individual EV users. An individual EV user wants to connect his/her car at a specific time point, wants to charge a specific electricity load, and wants to finish the charging session on a specific moment (Hidrue et al. 2011; Sioshansi 2012). Often the approach of Vandael et al. (2013) does not meet these EV user requirements.

Vandael et al. (2015) address the problem of defining a day-ahead operational plan by the aggregator for charging a fleet of EVs. The decisions made by the aggregator are divided in two phases. In the first decision phase, the aggregator predicts the energy required for charging its EVs for the next day, and purchases this amount in the day-ahead market. During the second decision phase, the aggregator communicates with the EV users to control their charging, based on the amount of energy purchased in the day-ahead market during the first decision phase. EV charging is controlled during operation by a heuristic scheme, and the resulting charging behavior of the EV fleet is learned by using batch mode reinforcement learning. Based on this learned behavior, a cost-effective day-ahead consumption plan can be defined.

A shortcoming of the above-mentioned approach is the fact that it is not clear whether the individual EV users are willing to charge according to the constructed charging plans. In case the constructed charging plans (for instance, charging in the night) differ much from the initial charging plans (for instance, charging in the morning) of the individual EV users, not many individual EV users will change their initial charging plans. It is not clear to what extent the individual charging plans meet these individual EV user requirements. In fact, the approaches of Vandael et al. (2013, 2015) have the potential to achieve balance on the grid but most of the times they do not satisfy individual comfort and require direct control, which might not be easy to implement in practice.

Last, Valogianni (2016) proposes an EV charging coordination mechanism that combines benefits both from the decentralized and centralized approaches. The mechanism is capable of reducing peak demand, satisfying individual preferences as well as broadcasting the same price function to all customers in the market. However, the mechanism assumes that the day-ahead electricity price per hour (in Euro/kWh) depends linearly on the total charged electricity (in kWh) by the EV users of the aggregator's charging points during this hour. Maybe the EV users of the charging points of a specific aggregator could slightly influence the hourly electricity prices of the next day (depending on the amount of the charged electricity by the EV users), but these prices do likely not depend linearly on the expected total electricity charging load of the specific aggregator (Espey 1998; Brons et al. 2008).

Ahn et al. (2011) and Hahn et al. (2013) developed an algorithm for calculating load shift potentials defined as the range of all charging curves meeting the customer's required amount of electricity. They found that the charge curve reaches minimal costs and charges the minimal amount of required electricity (varying the charging speed continuously over the time). Based on these (theoretical) calculations, it turned out that the EV load shifting potential of EVs is significant.

As an extension of these papers, an optimization model is developed to reduce the electricity costs of EV charging in two scenarios, i.e., with and without requiring the user to change their charging preferences. Next, the consequences of the implementation of our model are calculated based on 360,000 charging sessions at public charging points in Amsterdam during the year 2015.

3 The Modelling of an EV User Charging Strategy

The day-ahead APX electricity prices (of quarters of an hour) vary over the day. An optimization model will be developed to obtain EV user charging strategies that reduce the aggregator's electricity costs (given the day-ahead APX electricity prices and the EV users' electricity demand). The entity in the model is an EV user. The principle of the model is as follows. The day-ahead electricity APX-prices (on a 15 min level) and the EV user electricity demand are known. These data will be used to calculate the optimal day-ahead demand curve of the individual EV user with minimal electricity costs: the optimal user charging strategy. To do so, we minimize

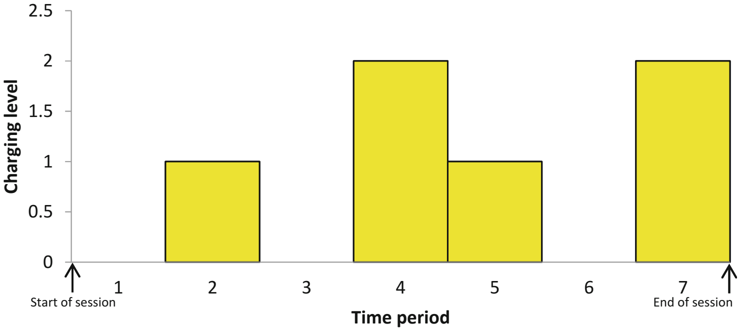

Fig. 1 An optimal charging strategy of an individual EV user

the differences between the cheapest electricity demand pattern and the optimal electricity demand pattern, i.e., user charging strategy. By doing this, the optimal electricity demand pattern depends on the APX-prices on a 15 min level, as well as the EV user electricity demand requirements. The result of the optimization model is an optimal electricity demand curve corresponding to the preferences of an individual user, i.e., user charging strategy, which will usually differ from the current (not optimized) demand curve (see Fig. 1).

Figure 1 shows a specific optimal charging strategy of an individual EV user with postponed charging, on–off charging, and two levels of charging speed. In our approach, the number of levels of charging speed can be raised (Schäuble et al. 2017). Charging in the current situation could be visualized by a simple horizontal straight line that starts at "start of session" (i.e., only one level of charging speed). The optimal charging strategies will depend on, among others, differences between weekdays and weekends, seasonal effects, day-ahead APX electricity prices (on a 15 min level), and user-specific requirements (i.e., required connection starting time point, required charging load, required disconnection time point).

As mentioned above, the entity in the optimization model is an EV user. In our model, the EV user can:

1. Use an on–off charging strategy (to postpone the continuation of the charging).
2. Use different charging speed levels (for instance, full speed level and half-speed level).
3. Choose the desired amount of electricity (kWh) to charge or a desired state of charge (SOC).
4. Combine the above strategies.

These assumptions regarding the possible user charging strategies will be included in the optimization model by adding model restrictions. The restrictions will shape the form of the optimal demand curve. With these user charging strategies, it is nearly impossible to get a complete alignment with the input electricity price curve, because perfect alignment requires continuous adjustment of the speed levels, which would render the optimization (in its current form) computationally intractable.

In fact, the electricity costs of a charging session can be reduced by applying the optimization model to get optimal charging strategies (corresponding to the EV user-specific requirements) and by changing the EV user charging behavior. Changes in the EV user behavior can be modelled, among others, by changing the connection starting time point, the disconnection time point, and the required load of a charging session of a specific EV user.

Observe that intuitively, the result of the optimization calculations could be that it is most profitable to start all charging sessions at, say, 2 am. This seems suboptimal for user engagement and might in addition result in a substantial shift of the usage peak, instead of its reduction. To alleviate the former concern while allowing the EV user to connect at his preferred times, the optimized charging session should be remotely controlled by using appropriate software. For the latter concern, it should be noted that shifting EV energy demand from current peak hours, even if it forms a new peak, is still an improvement in the context of the overall electricity grid.

Therefore, our algorithm calculates the optimal charging strategy of an individual EV user given his/her own preferences of a charging session (i.e., the required connection starting time point, required load, and required disconnection time point of the charging session), followed by addressing which sessions are most suitable for optimization. Next, the financial consequences of the behavioral changes (for instance, postponing the connection starting time point) will be calculated. Finally, based on the provided financial information the EV user can choose his/her preferred connection starting time point.

4 The Optimization Model

A Linear Programming model with discrete decision variables will be formulated to calculate the cheapest day-ahead charging strategy of a specific EV user charging session. To do this, we need values of the following user characteristics of a specific EV charging session as input of the optimization model: required connection time of charging session; required disconnection time of charging session: DT; different charging speed levels available, for instance: level Speed1 and level Speed1 + Speed2; state of charging: SOC; required total charging load: LOAD; total capacity of EV battery: CAP. The calculated cheapest charging strategy of a specific charging session includes the possibilities of postponed charging, on–off charging, and different levels of charging speed.

The following model parameters are needed as input of the optimization model:

- APX electricity prices for tomorrow every quarter of an hour i: P_i ($i = 1, 2, \ldots, 96$)
- Penalty Occupancy Period in quarter of an hour i: POP_i ($i = 1, 2, \ldots, 96$)
- Penalty Overflow 80% Threshold Battery: POTB.

The above model parameters will be expressed in terms of Euros. The penalties are proposed as an instrument that the exploiter of the charging infrastructure can use to nudge the charging behavior in a desired direction. For instance, $\text{POP}_1, \ldots, \text{POP}_{96}$ are induced to discourage undesirable charging strategies, i.e., these penalties will discourage periods of occupying without loading. POTB should discourage the lengthy occupancy period needed to charge the last 20%, since due to the physical properties of most EV batteries, charging the last piece of the battery goes slower than the first 80% (Yong et al. 2015).

4.1 Decision Variables

The following decision variables are used in the optimization model: $Y_{1i} = 0$ if not loading in time period i with Speed1 and $Y_{1i} = 1$ if loading in time period i with Speed1. Similarly, $Y_{2i} = 0$ if not loading in time period i with Speed1 + Speed2 and $Y_{2i} = 1$ if loading in time period i with Speed1 + Speed2. Here, $i = 1$ corresponds to the first quarter of an hour during the charging session and $i = 1, 2, \ldots, \text{DT}$, where DT is at most 96. The linear programming model searches for an optimal charging strategy within a maximum of 24 h (i.e., 96 quarters of an hour from the starting time of a charging session) by determining for which i's Y_{1i} and Y_{2i} are equal to 1.

4.2 Objective Function

For notation convenience, we introduce the variable "total electricity charged" (TEC), defined as

$$\text{TEC} \coloneqq \Sigma\, (\text{Speed1} * Y_{1i} + \text{Speed2} * Y_{2i}). \tag{1}$$

The costs of the EV charging session of one specific EV user will be minimized as follows:

Minimize

$$\begin{aligned} &\Sigma\, (\text{P}_i * \text{Speed1} * Y_{1i}) + \Sigma\, (\text{P}_i * \text{Speed2} * Y_{2i}) + \Sigma\, (\text{POP}_i * (1 - Y_{1i})) \\ &\quad + \text{POTB} * [\text{TEC} - 0.8 * \text{CAP}], \end{aligned} \tag{2}$$

where the summations are from $i = 1$ up to $i = \text{DT}$.

The first two terms correspond to the costs of electricity (based on the APX electricity prices). The third term corresponds to a penalty on a time period when connected without charging (i.e., occupancy costs). The value of this penalty, which is not charged to the user, could depend on i: occupancy without charging is less important during the night than during the day. Finally, the fourth term indicates a penalty on charging the battery more than 80% of the total capacity of the battery (i.e., slow charging costs). This is a different kind of cost to reflect the physics of batteries, i.e., slower charging when SOC is above 80%, but it is not a cost in euros to the user.

4.3 Restrictions

The optimization model uses the following restrictions:

$$Y_{1i} = 0 \text{ or } 1 \qquad \text{if } i = 1, \ldots, \mathrm{DT} \tag{3}$$

$$Y_{2i} = 0 \text{ or } 1 \qquad \text{if } i = 1, \ldots, \mathrm{DT} \tag{4}$$

$$\mathrm{TEC} \geq \mathrm{LOAD} \tag{5}$$

$$Y_{1i} = 0 \text{ and } Y_{2i} = 0 \qquad \text{if } i > \mathrm{DT} \tag{6}$$

$$Y_{1i} \geq Y_{2i} \qquad \text{if } i = 1, \ldots, \mathrm{DT} \tag{7}$$

$$Y_{2i} + (\mathrm{SOC} + \mathrm{TEC})/(0.8 * \mathrm{CAP}) \leq 2 \qquad \text{if } i = 1, \ldots, \mathrm{DT} \tag{8}$$

Restriction (5) guarantees that the total charged electricity is more than or equal to the required electricity load. Restriction (6) guarantees that after the required disconnection time point charging is not possible anymore. Restriction (7) guarantees that charging speed level “Speed1 + Speed2” is only possible if both Y_{1i} and Y_{2i} are equal to 1. Restriction (8) guarantees that high charging speed level “Speed1 + Speed2” is not possible if the charged electricity load is more than 80% of the capacity of the users EV, since charging the last 20% of the battery goes slower than the first 80%.

The model is a mixed integer linear programming model with “2 $*$ DT” 0–1 decision variables and “2 $*$ DT + 1” restrictions. For instance, if the connection duration is 6 h, then there are 48 0–1 decision variables and 49 restrictions.

As a result of the optimization algorithm values of the decision variables: Y_{11}, Y_{12},. . ., $Y_{1\,(96)}$, and Y_{21}, Y_{22},. . ., $Y_{2\,(96)}$ are obtained. Furthermore, we get values of the costs of electricity (related to the day-ahead APX prices); the costs related to the penalty on a time period when connected without charging (i.e., occupancy costs); and the costs related to a penalty on charging the battery more than 80% of the total capacity of the battery (i.e., slow charging costs).

5 Empirical Results

In this section, the empirical analysis of the effectiveness of the optimization algorithm will be described by comparing its output with data of real charging sessions. For the empirical analysis, data are used from the public charging stations of the city of Amsterdam (i.e., the CHIEF database of the University of Applied Sciences Amsterdam; references Van Montfort et al. 2016). During the year 2015, more than 363,000 sessions were logged of 17,626 unique user charge cards. Among others, for each charging session the following variables were registered: id-number of charging station, address of charging station, id-number of EV-user, the time of connecting and disconnecting, duration of charging (which is not the same as duration of connection), and energy (kWh) charged. By using the above-mentioned information, the capacities of the rechargeable EV batteries and the charging speed levels have been estimated (Wolbertus et al. 2016).

Observe that although three of the input parameters required for the optimization model are available through this database, namely the time of connecting and disconnecting, as well as kWh charged, the other three are not: charging speed, state of charge, and battery capacity. Whereas we chose to estimate each session's charging speed in a manner described below, we will not carry out empirical analysis using the part of the model that requires information about the state of charge and battery capacity, i.e., the penalty of passing the threshold of 80% of the battery.

The effect of the optimization algorithm developed in Sect. 4 is tested by comparing the costs it induces with the costs resulting from straightforward charging. To solve the linear program of the optimization algorithm, the lpSolve package was used with the R programming language. The optimization algorithm determines in which quarters of an hour an EV should or should not be charged, and with which speed. In this way, it results in a *smart charging profile* given the requirements of the specific EV user.

The input parameters for the algorithm are the connecting and disconnecting time of an individual charging session, as well as a *minimum required load*. These input parameters are obtained from a total of 363.093 real charging sessions that were carried out at the public charging infrastructure in Amsterdam in 2015. Whereas the connecting and disconnecting times are self-explanatory, the input referred to as *minimum required load* corresponds to the kWh that were charged in a given session.

The charging speed is estimated from the database based on the charging time and the kWh charged, both of which are measured and available in the database. The average charging speed is computed as: average speed = charged kWh/charging time. For the sake of enabling flexibility, the optimization algorithm uses two speed levels. The higher one equals the average speed, as defined above, the lower one is half of that. This allows the smart charging profile to make use of "second best" price slots, if needed. In theory, the model can be extended by including more than two speed levels (Schäuble et al. 2017). In practice, the values for the speed levels can be adjusted to what is suitable.

The aim of the penalties introduced in the theoretical model is to show the opportunities of our model. However, in this empirical study our optimization model is applied without penalties, because we want to make a “fair” comparison between the electricity costs based on our optimization model and the realized electricity costs based on straightforward charging (i.e., full speed charging starts at the moment the EV is connected). Our optimization algorithm chooses the cheapest quarters and breaks when the price is deemed too high, with the condition that a *minimum required load* should be reached before the user disconnects. The optimization algorithm then chooses which charging speed to apply to which quarters. Therefore, the total electricity charged (TEC) in an optimized session satisfies the form.

$$\mathrm{TEC} = \Sigma\ \mathrm{Speed1} * \mathrm{Qslow} + \Sigma\ (\mathrm{Speed1} + \mathrm{Speed2}) * \mathrm{Qfast}, \tag{9}$$

where Q_slow refers to the quarters that were chosen for slow charging, and Q_fast the quarters chosen for fast charging. As a result of this form, TEC $> =$ *minimum required load* from the real session, that is, additional load may have been charged,

$$\text{Extra load} = \mathrm{TEC} - \textit{minimum required load}. \tag{10}$$

If this extra load is non-zero, it must be accounted for in a comparison between the real session and the calculated optimal session. In order to compare the difference in costs, we create a so-called appended session on the basis of the original session, where the additional kWh are appended to the end of the real session. Note that the extra load is bounded, because the hypothetical potential extra load never takes more than 15 additional minutes to be charged. To summarize, this enables us to compare the costs for the same amount of electricity consumed within the same connection time period with only a minor adjustment to the real parameters.

The optimization model is run by using the historical data of all charging sessions (i.e., starting time points, disconnection time points, and charging loads) in Amsterdam for one year, 2015. This **first analysis** *quantifies the effect of the optimal charging algorithm compared to the realized straightforward charging method*: first, we calculate the electricity costs of all charging sessions during the year 2015 by using the realized current straightforward charging strategies (i.e., only one speed level, no breaks); next, we calculate the electricity costs of all charging sessions during the year 2015 by using the optimal charging strategies, which were calculated by applying our optimization model. The electricity costs are in both cases based on the quarterly APX prices for the year 2015.

The empirical results are evaluated for two stakeholders, the charging aggregator and the EV drivers. For the charging aggregator it is interesting to know (1) the total change in distribution of energy over the day and (2) the potential financial benefit as a consequence of modified charging patterns. Figure 2 illustrates the change in electricity demand when individual charging sessions have been optimized for price. The most prominent change is a major shift from the most expensive part of the day, between 5 pm and 8 pm, to the cheapest part of the day, between 2 am and

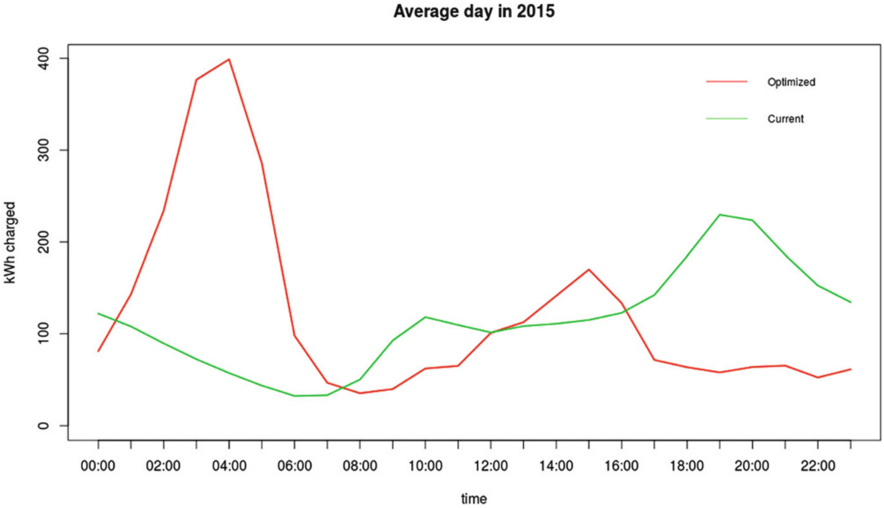

Fig. 2 Change in energy demand as a result of modified charging patterns

5 am. The total energy costs of all optimized charging sessions in the year of 2015 is 132,672.16 € instead of 166,643.27 €. This amounts to a 20.39% cost reduction for the same amount of energy, based on APX prices.

Table 2 describes the effects of the optimization model for the individual EV drivers on different days of the week. In the third column, we observe that the average electricity cost reduction per charging session is between 21.91% (Thursday) and 26.67% (Monday), where the only change in user behavior is enabling smart charging and the charging session requirements of the EV users do not change. With the problem of over occupancy of charging spots in mind, we report the average number of non-charging hours until completion of charging, which includes potential delay before starting a charging session as well as possible breaks therein. On average, the optimization algorithm thus chooses to complete charging almost 5 h later than in the current situation. After the charging has finished, many EVs stay connected without using the charging facilities, on average during 3 h. The difference between weekdays is negligible in all columns, also the difference between midweek days and weekends.

Around 41% of the charging sessions save less than 10% by optimizing charging. The remaining 59% sessions thus manage to cut more than 10% of costs by optimization, the distribution of their cost reduction can be seen in the left panel of Fig. 3. The length of the connection time is an important parameter of each session; a longer connection time provides more opportunities to optimize. This can be seen in the right panel of Fig. 3, which illustrates the sessions that manage to cut at least 10% of the costs in the context of all charging sessions. In fact, when only considering sessions with connection time of 4 h or longer, the average saving is 26.07%. In the case of 8 h or longer, the average costs reduction is 31.87%. Those cases amount for approximately half of all the charging sessions, implying that substantial savings can

Table 2 Effects of optimization model over the year 2015

	Average *costs* with *straightforward charging* per charging session (€)	Average *costs* with *optimal charging algorithm* per charging session (€)	Average cost reduction per charging session (%)	Average number of *non-charging* hours until completion of charging session with optimization model (h:mm)	Average *charging duration* with optimization model (h:mm)	Average *fraction* of charging duration with *speed 1* (%)	Average *time* connected *after charging is finished* with optimization model (h:mm)
Monday	0.44	0.32	26.67	4:41	1:24	38.39	3:55
Tuesday	0.50	0.38	24.36	4:54	1:23	38.57	3:07
Wednesday	0.48	0.37	23.08	4:42	1:22	38.36	3:00
Thursday	0.47	0.37	21.91	4:32	1:22	38.56	3:02
Friday	0.50	0.39	22.13	4:35	1:23	39.62	3:02
Saturday	0.48	0.37	22.55	4:54	1:21	38.97	3:17
Sunday	0.45	0.34	25.79	5:09	1:21	38.50	3:27
Average	0.47	0.36	23.73	4:47	1:22	38.71	3:16

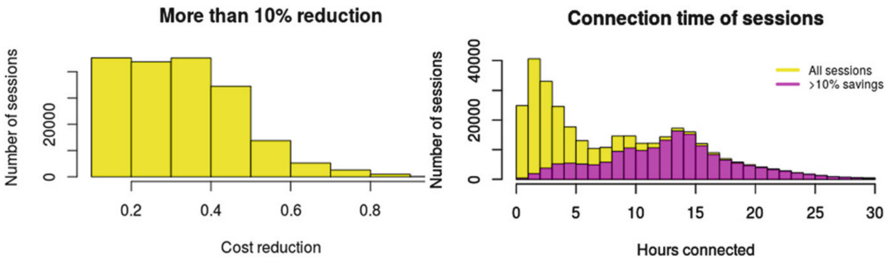

Fig. 3 (Left) Distribution of cost reduction of session with more than 10% cost reduction. (Right) Connection time of charging sessions

be reached by the optimization algorithm. Moreover, since the total savings amount to around 30,000 euros, it turns out that 88% of the overall cost reduction for the aggregator comes from optimizing these long sessions.

The **second analysis** *quantifies the effect of the changes in the user behavior* (combined with the application of the optimization model) for three different user groups. This is to evaluate if costs can be reduced even further by active participation of users, i.e., when users are willing to change their connection time according to an incentive from an aggregator. To do this analysis, we first identify three groups of EV users who typically start charging their EV in the morning (between 6.00 am and 12.00 am), the afternoon (between 12.00 am and 6.00 pm) or the evening/night (between 6.00 pm and 6.00 am). A user must have charged in a given time slot at least 50 times in the year 2015 to belong to the corresponding user group. From the original 360,000 sessions, this filtering process leaves 30,484 sessions of regular morning users (307 individual users, 47,492 sessions of regular afternoon users (637 individual users) and 78,258 sessions of regular evening users (912 individual users).

For each separate EV user group, a typical session is constructed with average charged energy and duration, and the median starting time. The median starting times of the three user groups are 8.00 am, 3.00 pm, and 7.00 pm, which are more representative for the typical users than the average starting times, particularly for the evening and night chargers. Next, for each user group, the charging costs are calculated resulting from applying average prices per quarter to our optimization model *and* by moving the starting time of the charging sessions with 1, 2,. . ., 12 h earlier or 1, 2,. . ., 12 h later. The results of these analyses are presented in Fig. 4.

Figure 4 shows for each EV user group (i.e., morning chargers, afternoon chargers, and evening/night chargers) the consequences of a behavioral change: moving the starting time of the charging sessions (i.e., the time at which to connect). In fact, the consequences are calculated in case the EV users have agreed to connect at a different time point. Note that the amount of electricity charged differs per user group, which is reflected in the different maximum and minimum costs. The electricity costs per charging sessions of the afternoon chargers (red line) reduce dramatically in case they start charging later. The minimum costs are achieved by starting between 5 and 12 h later (between 8 pm and 3 am). However, due to the

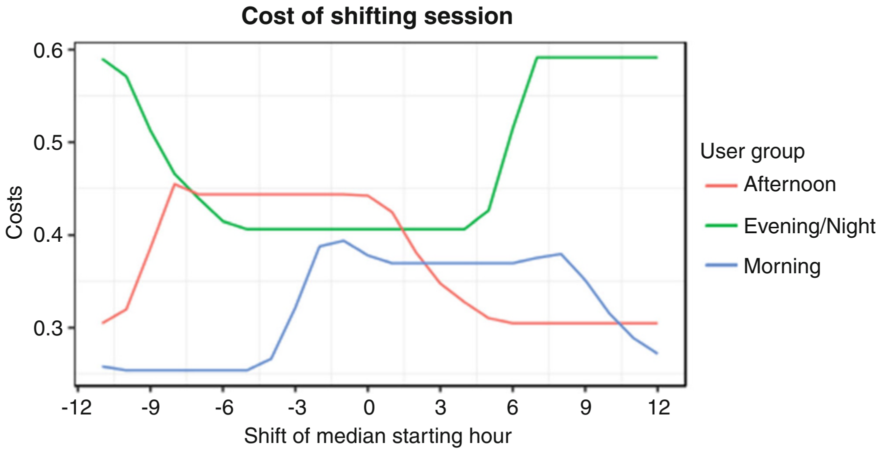

Fig. 4 Costs of shifting an average morning, afternoon, or evening session. The center represents each user group's median starting point; 8 am for morning chargers, 3 pm for afternoon chargers, and 7 pm for evening/night chargers

deployment of the optimized charging strategy, the evening/night chargers do not need to change the starting time point of their charging session, this will not reduce their average electricity costs of charging. Finally, it will be profitable for the morning chargers to connect some hours earlier. This behavioral change of the typical EV morning charger can reduce the electricity charging costs with up to 35%.

In the comparison of the straightforward charging pattern and our optimal charging pattern, the penalties of the occupancy and the slow charging are left behind for reasons listed above. The occupancy penalty stimulates a user to make the charging session as short as possible, whereas the slow charging penalty stimulates the user to stop the charging after 80% of the battery capacity is filled. Of course, the occupancy penalty reduces the cost benefit of our approach, because it demotivates the algorithm to postpone the charging to cheaper quarters.

6 Discussion, Conclusions, and Implications

In this chapter, an optimization model was developed that applies unobtrusive charging strategies (i.e., postponing, on–off charging, and two charging speed levels) for an electric vehicle charging aggregator. Our results show that applying such a model can significantly reduce energy costs for EV users. The analysis shows that the calculated charging patterns of a charging session will reduce the electricity costs on average about 25%. This is a significant saving and could benefit users and aggregators with regard to cost savings but also in terms of sustainability since this model uses resources more efficiently. Next, we empirically showed the consequences of a simple behavioral change: namely an EV user starts charging earlier or starts charging later. We found that especially for EV users who want to start their EV charging session in the morning or afternoon, it can be very profitable to start charging earlier or to postpone the charging session and result in between 20% and 30% additional electricity cost reduction. When new starting times are adapted in tandem with an optimized smart charging profile, they require only minor changes in user behavior. Encouraging changes in the charging behavior may thus be feasible even when smart charging is enabled.

Based on these findings, new business models for electric vehicles can be developed (Bohnsack and Pinkse 2017) and general guidelines may be offered to the EV users for optimal starting times of charging sessions (Gan et al. 2013; Wang et al. 2015). More concretely, we suggest that in order to communicate with the user and to provide the financial benefits of the optimization model an aggregator could develop an app. On the screen of the app, an EV user could fill in the preferred starting time point, the preferred disconnection time point, and the required electricity load of the intended charging session. By using this information, the app could present a curve like the curves in Fig. 4, based on which the EV user could decide whether it is attractive for him to change the initial starting time point, disconnection time point, or charged load of the forthcoming charging session.

The developed optimization model could be implemented by the aggregator in a multiperiod setting. It is not a one-shot decision, but rather a step-by-step rollout process. For each individual charging point, the operating software to control the charging speed level of a charging session has to be adapted. The operating software has to calculate the optimal charging pattern of a charging session given the starting time point, disconnection time point, and electricity load of the charging session, which was filled in on the app.

This chapter is the first attempt to study the emerging issues around aggregator business models for electric vehicles, providing a realistic empirical assessment of the financial benefits. This opens up significant research opportunities for operations researchers in this industry. Among the possible extensions of this work that we suggest would be the study of competition between aggregator business models, the application to other flexibility sources such as houses with smart meters or stationary battery storage, but also the influence of user-specific incentives and complementary market design decisions. With regard to business model competition, it would be worthwhile to study the effects of the competition of two or more aggregators on the cost reduction potential. The assumption would be that the competition reduces the cost savings. This would require an extension of the model. Thus, future research should study how this model could be applied in different settings such as the upcoming stationary battery market or smart devices at home. Last, this research could be enriched by studying the effect of complementary market design mechanisms. In the case of EV charging, the aggregator model could include some penalties to influence the calculated charging patterns of the charging sessions for the system as a whole, for instance via occupancy penalties or slow charging penalties. The occupancy penalty is a penalty on a time period when the EV is connected without charging, which can be imposed to discourage long occupancy of charging spots. The slow charging penalty indicates a penalty on charging the battery more than 80% of the total capacity of the battery, since the charging speed of the battery decreases radically when state of charging is more than 80%. By choosing appropriate values of the penalties, the aggregator can influence the occupancy and the slow charging of an EV charging session. These market design decisions can decrease costs even more and need to be studied further. Certainly, these can be different kinds of costs and are not necessarily costs in Euros to the user.

One additional advantage of EVs is that the batteries of the EV's can also be used for dispatch during peak demand for peak shaving. The infrastructure may have to be changed to allow for two-way up- and de-charging. But this particular type of flexibility could lead the EV owner to reduce costs further by selling during peak quarters and contribute to system flexibility.

This chapter and the suggested avenues for future research are clearly relevant in the age of the Internet of Things and artificial intelligence. We believe that understanding the optimized orchestration of user behavior and use of resources will open up great opportunities for a more sustainable future.

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