UNIVERSITY OF LJUBLJANA
FACULTY OF ECONOMICS

RENATA DOMBROVSKI

EFFECTIVENESS OF FINANCIAL AND FISCAL INSTRUMENTS FOR PROMOTING SUSTAINABLE RENEWABLE ENERGY TECHNOLOGIES

DOCTORAL DISSERTATION

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The undersigned Renata Dombrovski, a student at the University of Ljubljana, Faculty of Economics, (hereafter: FELU), declare that I am the author of the doctoral dissertation entitled Effectiveness of financial and fiscal instruments for promoting sustainable renewable energy technologies, written under supervision of Professor Jože Damijan, Ph.D.

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EFFECTIVENESS OF FINANCIAL AND FISCAL INSTRUMENTS FOR PROMOTING SUSTAINABLE RENEWABLE ENERGY TECHNOLOGIES

SUMMARY

It is generally recognized that countries should restructure their current renewable energy policies to have energy-efficient and low-carbon economies. This PhD dissertation is strongly motivated by the on-going debate, still without a consensus, on identifying the most effective pathways for countries' transitioning process towards renewables. It focuses on topics linked to energy policy instruments aimed to support sustainable renewable energy technologies (SRET), firms' productivity and productivity growth. It utilizes various subject-relevant, econometric methods, such as pooled ordinary least squares (OLS), fixed effects (FE), random effects (RE), panel corrected standard errors (PCSE) estimator, and system generalized method of moments (GMM), to improve the robustness of the results. This PhD dissertation is structured in the form of three interrelated chapters.

The first chapter presents a synthesis of the recent improvements in measuring the impact of financial and fiscal instruments on promoting technology changes. It focuses on all three stages of the technological change process: invention, innovation and diffusion of SRET. This is of particular importance because the degree of success of policy support instruments depends on their interactions, on the technological development stage and on the type of SRET. Electricity generation from SRET should increase, as should their cost–competitiveness in comparison with conventional alternatives. Therefore, identification of the most effective and efficient technology-specific policy instruments that will encourage technological innovations and diffusion is needed; otherwise, the new European Union target of achieving 80-95 % emission reductions by 2050 could not be met. The above-stated goal certainly calls for novel energy policy solutions by member countries.

Previous research has failed to evaluate the influence of all relevant elements of energy policy on technology-specific sustainable renewable energy (SRE) diffusion. To investigate this problem, the **second chapter** studies the effectiveness of financial and fiscal instruments in promoting SRET diffusion at the macro level. These drivers are analysed for 26 European Union countries over the period 1990 - 2011, additionally controlling for potential political, economic, social, and environmental drivers. The chapter adds to existing research by examining how patenting activities and perceived corruption in the energy sector affect actual renewable energy installations and electricity generation. The results show that fixed and premium feed-in tariffs, quotas, and tenders effectively promote wind technologies. Consistent with previous research, other explanatory variables have technology- and model-dependent impacts.

In addition, so far recent research provides inconsistent evidence of the effectiveness of the recent EU renewable energy policies. Therefore, the **third chapter** aims at empirically verifying the effectiveness of the three major EU renewable energy policies at the micro level. It first examines in what extent the Emission Trading Scheme (EU ETS) in combination with other renewable support instruments, such as Feed-in Tariff (FIT) and Renewable Portfolio Standard (RPS), contribute to the reduction of emissions by regulated firms. Second, as regulated firms switch to new and more energy-efficient technologies in order to meet the regulation, this chapter aims to estimate the impact of the EU ETS, together with the FIT and RPS instruments, on firms' productivity premia and productivity growth. The main results show that the EU ETS does not have a significant impact on firms' productivity (except in periods around the implementation phase, i.e. in years t_0 and t_1). Firms that are using the FIT support have been more productive already before the EU ETS implementation and continue to maintain the productivity premia over non-EU ETS firms also after the ETS implementation, while RPS is shown to boost firms' productivity after the EU ETS is implemented. The interactions between EU ETS and FIT-RPS measures do not seem to have an additional systematic impact on the productivity of firms affected.

It is expected that the results presented in this PhD dissertation will assist the policy decision-making process and encourage firm-level environmental decisions. These results should also spur the interest of the broader research community to continue with the research on energy policy instruments. For example, further research could focus more rigorously on country specific policy design elements of each policy instrument when more data become available.

Keywords: sustainability, renewable energy, financial and fiscal instruments, technology diffusion, firm productivity

UČINKOVITOST FINANČNIH IN FISKALNIH INSTRUMENTOV ZA SPODBUJANJE TRAJNOSTNIH TEHNOLOGIJ OBNOVLJIVIH VIROV ENERGIJE

POVZETEK

Splošno priznano dejstvo je, da morajo države svoje trenutne politike glede obnovljivih virov energije prestrukturirati, če želijo imeti energetsko učinkovito in nizkoogljično gospodarstvo. Pomemben povod za to doktorsko disertacijo so tekoče razprave o prepoznavanju najučinkovitejših poti za države, ki prehajajo na obnovljive vire, o čemer soglasje še ni bilo doseženo. Disertacija se osredotoča na teme v povezavi z instrumenti energetske politike za spodbujanje trajnostnih tehnologij za obnovljive vire energije (SRET), produktivnost podjetij in rast produktivnosti podjetij. Za izboljšanje zanesljivosti rezultatov so uporabljene različne zadevne ekonometrične metode, kot npr. združeno ocenjevanje po metodi navadnih najmanjših kvadratov (angl. pooled ordinary least squares, pooled OLS), metoda fiksnih učinkov (fixed effects, FE), metoda slučajnih vplivov (angl. random effects, RE), ocena panelno popravljenih standardnih napak (angl. panel corrected standard errors, PCSE) in sistemska posplošena metoda momentov (angl. system generalised method of moments, system GMM). Doktorsko disertacijo sestavljajo tri med seboj povezana poglavja.

Prvo poglavje podaja sintezni pregled nedavnih izboljšav pri merjenju učinka finančnih in fiskalnih instrumentov za spodbujanje sprememb v tehnologijah. Osredotoča se na vse tri stopnje procesa tehnoloških sprememb: izume, inovativnost in širjenje SRET. To je zelo pomembno, saj uspešnost instrumentov za podporo politiki temelji na njihovih medsebojnih odnosih, na stopnji tehnološkega razvoja in vrsti SRET. Proizvodnja električne energije ob uporabi SRET in njena stroškovna konkurenčnost bi se morali povečati v primerjavi s konvencionalnimi alternativami. Zato je potrebno prepoznavanje najučinkovitejših in najuspešnejših instrumentov politike, specifičnih za te tehnologije, ki bodo spodbujali tehnološke inovacije in širjenje; v nasprotnem primeru novega cilja Evropske unije za 80–95 % zmanjšanje emisij do 2050 ne bo mogoče izpolniti. Za izpolnitev tega cilja bodo vsekakor potrebne nove rešitve v energetski politiki držav članic.

Prejšnje raziskave niso ustrezno ocenile vpliva vseh pomembnih elementov energetske politike na tehnološko specifično širjenje obnovljivih virov energije (SRE). Kot doprinos k reševanju tega problema **drugo poglavje** preučuje učinkovitost finančnih in fiskalnih instrumentov pri širjenju SRET na makro ravni. Te spodbude so analizirane za 26 držav Evropske unije za obdobje 1990–2011, kot dodaten nadzor potencialnih političnih, gospodarskih, socialnih in okoljskih spodbud. Poglavje dodatno prispeva k obstoječim raziskavam in preučuje, kako dejavnosti patentiranja in zaznava korupcije v energetskem sektorju vplivajo na obstoječe naprave za obnovljive vire energije in proizvodnjo električne energije. Rezultati kažejo, da fiksne zagotovljene odkupne cene, premije, kvote

in razpisi učinkovito spodbujajo vetrno tehnologijo. V skladu s predhodnimi raziskavami ugotavljamo, da imajo tudi druge odvisne spremenljivke tehnološko in modelsko odvisne učinke.

Poleg tega so ugotovitve nedavnih raziskav neskladne glede učinkovitosti novejših politik EU glede obnovljivih virov energije. Zato je cilj **tretjega poglavja** empirično preveriti učinkovitost treh glavnih politik EU glede obnovljivih virov energije na mikro ravni. V tem poglavju najprej preučujemo, v kakšnem obsegu sistem EU za trgovanje z emisijami (EU ETS), v kombinaciji z drugimi instrumenti, ki podpirajo uporabo obnovljivih virov, kot sta npr. sistem zagotovljenih odkupnih cen (FIT) in standard portfelja obnovljivih virov energije (RPS), vpliva na zmanjšanje emisij s strani reguliranih podjetij. Drugič, ob prehodu reguliranih podjetij na nove, energetsko učinkovitejše tehnologije, da bi izpolnjevala zahteve predpisov, je namen tega poglavja oceniti vpliv sistema EU ETS, skupaj z instrumentoma FIT in RPS, na produktivnostne premije podjetij in rast produktivnosti. Glavni rezultati kažejo, da sistem EU ETS nima znatnega vpliva na produktivnost podjetij (razen v obdobjih v izvedbeni fazi, tj. v letih t_0 in t_1). Podjetja, ki uporabljajo podporo instrumenta FIT, so bila že pred izvajanjem EU ETS produktivnejša in tudi po vključitvi v sistem EU ETS ohranjajo produktivnostne premije v primerjavi s podjetji, ki niso vključena v sistem EU ETS, medtem ko se je za instrument RPS izkazalo, da povečuje produktivnost podjetij po uvedbi EU ETS. Zdi se, da medsebojni vplivi med ukrepi EU ETS ter FIT in RPS nimajo dodatnega sistematičnega vpliva na produktivnost zadevnih podjetij.

Pričakujemo, da bodo rezultati, prikazani v tej doktorski disertaciji, pomagali v postopkih odločanja glede politik in spodbujali odločanje o okoljskih zadevah na ravni podjetij. Rezultati bi morali spodbuditi interes širše raziskovalne skupnosti, da bi se raziskave o instrumentih energetske politike nadaljevale. Nadaljnje raziskave bi se lahko dosledneje osredotočale na elemente oblikovanja politik po posameznih državah, za vsak instrument politike posebej, in sicer ko bo na voljo več podatkov.

Ključne besede: trajnost, obnovljiva energija, finančni in fiskalni instrumenti, širjenje tehnologije, produktivnost podjetij

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ABBREVIATION	DEFINITION
AEA	Allocated emission allowances
AF	Allocation factor
BRICS	Brazil, Russia, India, China, and South Africa
CDM	CDM (Clean development mechanism) allows a country with commitment targets under the Kyoto Protocol to implement an emission reduction project in developing countries. Such projects can earn CER credits.
CER	CER (certified emission reduction) credits. Each CER credit is equivalent to one tonne of CO_2. CER credits can be traded to help industrialized countries in meeting their Kyoto targets.
CO_2	Carbon Dioxide
CPI	Corruption Perception Index
E3ME	Cambridge Econometrics energy-environment-economy model of Europe
EC	European Commission
ECO-INNOVATION	The eco-innovation process includes three stages: invention, innovation, and diffusion of technology. The terms eco-innovation, technological change process, and SRE transition are used interchangeably.
EEA	European Environment Agency
EIA	Energy Information Administration
EPO	European Patent Office
ERU	ERU (emission reduction unit) that is equivalent to one tonne of CO_2.
ET	Emission trading allows countries that are above their Kyoto targets to buy emission allowances from other countries that are under their Kyoto targets.
ETR	Environmental Tax Reform
EU	European Union
EU ETS	The EU ETS (European Union Emission Trading System) is the first and the biggest international system for trading EUAs. It covers more than 11,000 power stations and industrial plants in 31 countries, as well as airlines.
EUA	Each EUA (European Union allowance) gives the holder the right to emit one tonne of carbon dioxide or its equivalent.

ABBREVIATION	DEFINITION
EUTL	The EUTL (European Union Transaction Log), successor of the CITL (Community Independent Transaction Log) is a central transaction log, run by the European Commission. It checks, records and authorizes all transactions taking place within the EU ETS.
FE	Fixed Effects
FEVD	Fixed Effects Vector Decomposition
FGLS	Feasible Generalized Least Squares
FIT	A FIT (Feed in Tariff) offers long-term contracts, usually for a period of 15-20 years to guarantee payments to renewable electricity producers for each kilowatt-hour generated.
GDP	Gross Domestic Product
GHG	Greenhouse gasses: water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), chlorofluorocarbon
GMM	Generalized Method of Moments
GRANDFATHERING	Free of charge allocation of EU ETS CO_2 emission allowances
IEA	International Energy Agency
INSTALLATION	A factory or power plant
IPC	International Patent Classification
JI	JI (Joint implementation) permits countries that implemented the Kyoto Protocol to earn ERUs from an emission reduction or limitation projects in any other country with commitments under the Protocol.
kWh	Kilowatt hour
KYOTO PROTOCOL INSTRUMENTS	The Kyoto Protocol introduced the following market based instruments: ET, CDM, and JI to assist countries to achieve their emission targets set by the Protocol.
LSDV ESTIMATOR	Least Square Dummy Variable Estimator
OECD	The Organisation for Economic Co-operation and Development
OHA / PHA	Each installation covered by the EU ETS owns just one OHA (Operator Holding Account) or PHA (Person Holding Account). OHA and PHA can be used for trading EUAs under the EU ETS.
OLS	Ordinary Least Squares Regression
PCSE	Panel Corrected Standard Errors

ABBREVIATION	DEFINITION
R&D	Research and Development
RE	Random Effects
REN21	Renewable Energy Policy Network for the 21^{st} Century
RES-LEGAL	Legal Sources on Renewable Energy; The website on European regulations on renewable energy generation
RPS	RPS (Renewable Portfolio Standard) or Quota requires from suppliers to produce a certain percentage of their electricity from renewable energy sources.
SRE	Sustainable renewable energy
SRET	Sustainable renewable energy technologies
TGC	Tradable Green Certificate is market-based instrument used to encourage electricity production from SRE sources and thus to facilitate meeting the SRE electricity quota.
TFP	Total factor productivity
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VE	Verified emissions
VIF TEST	Variance Inflation Factor test
WWEA	World Wind Energy Association

INTRODUCTION

Description of the research problem area

The main inspiration for this doctoral dissertation is the commitment of the EU to reach climate change targets. One of the major global environmental concerns is how to reduce reliance on non-sustainable energy sources, such as oil, coal, natural gas and uranium. Within this context, the EU sets several key targets that member countries should meet. First, GHG emissions should be reduced by 20 % in 2020, by at least 40 % in 2030 and by 80-90 % in 2050 compared to 1990 levels. Second, the share of energy consumption from renewables should increase by 20 % in 2020 and by at least 27 % in 2030 compared to 1990 levels. Third, energy efficiency should increase by 20 % in 2020 and by 30 % in 2030 compared to 1990 levels (European Commission, 2009b; 2011; 2014b). Reaching these targets would be impossible without more effective and efficient renewable energy policies in force (European Commission, 2014b). Debates on policy support instruments for promoting sustainable renewable energy technologies (SRET) have been intensified in recent years. Although the results indicate that policy support instruments promote new technologies (OECD, 2010), these results should be taken with caution. Previous research fails to evaluate the influence of all of the relevant elements of the energy policy on the technological change process and its consequent impact on firms' productivity (see, e.g., Gagelmann & Frondel, 2005; Butler & Neuhoff, 2008; Coria, 2009; Rogge & Hoffmann, 2010; Antoci, Borghesi, & Sodini, 2012). In many cases, when assessing the impact of policy instruments, researchers do not separately address technological innovations and technological diffusion. Distinguishing between the two phases is highly important because different instruments are not designed to equally promote each eco-innovation phase or technology type. Often, researchers ignore the difference between SRET types, such as wind, solar, biomass and geothermal (see, e.g., Marques & Fuinhas, 2011; Bodas–-Freitas, Dantas, & Iizuka, 2012). In such cases, they measure the impact of policy instruments on total renewables. Other shortages detected in previous studies include a higher research interest for the United States or a focus on the OECD countries for which more data are available (Huang, Alavalapati, Carter, & Langholtz, 2007; Carley, 2009; Yin & Powers, 2010; Shrimali & Kniefel, 2011). Moreover, relevant studies are predominately based on a shorter time series that prevents them from controlling for major recent changes in the business environment (see Marques, Fuinhas, & Manso, 2010, and Laing, Sato, Grubb, & Comberti, 2013 for a detailed overview). Some of the changes include the global financial crisis, recent increasing oil prices, and increasing public environmental awareness. The changes addressed could significantly affect the technological change process, firms' CO_2 emissions and firms' productivity. Moreover, researchers trying to provide solutions for meeting the EU climate change targets are finding conflicting results on policy instruments effectiveness (e.g., Coria, 2009; Johanstone, Haščič, & Popp, 2010; Anderson, Convery, & Di Maria, 2011; Czarnitzki, Hanel, & Rosa, 2011; Antoci et al., 2012; Bodas–Freitas et al. 2012; Calel & Dechezlepretre, 2012; Noailly, 2012; Jaraitė & Kažukauskas, 2013; Aguirre & Ibikunle, 2014). Considering all of the above-mentioned facts, policymakers are left with an insufficient amount of significantly important information on how to transform countries' energy policies.

Research purpose and objectives

This doctoral dissertation aims to contribute to the debate on SRE policy support instruments by clarifying current conflicting results and by overcoming the problems identified above. In general, it intends to assess the effectiveness of countries' policy support instruments mix on technological diffusion, on firms' CO_2 emissions and on firms' productivity / productivity growth. In particular, it intends to provide answers to the following key research questions:

- What are the major recent methodological improvements in measuring the impact of policy support instruments on the process of technological change?
- What are the most effective country- and technology-specific policy instruments that can be used to promote diffusion of a particular type of SRET?
- What is the impact of the EU ETS and other main policy support instruments on firms' harmful CO_2 emissions and their productivity / productivity growth?

It is expected that results will confirm the main research hypothesis that states that the current mix of energy technologies and instruments is inconsistent with the EU policy for renewable energy. This hypothesis is defined to serve as a basis for identification of the most effective policy mix intended to promote SRET, to motivate CO_2 emission reductions and to increase firms' productivity / productivity growth.

Research methods and data

This doctoral dissertation provides a more comprehensive analytical framework and a more rigorous econometric analysis than other current studies. In doing so, it offers novel empirical results that contribute to the policy and firm level decision-making process. In this doctoral dissertation, four main models are estimated. The first model extends standard econometric models (used by e.g., Groba, Indvik, & Jenner, 2011; Marques, Fuinhas, & Manso, 2011; Dong, 2012) for testing the effectiveness of policy elements in promoting a particular type of SRET. The second model (based on the model by Abrell et al. (2011)) is further employed to identify factors contributing to CO_2 emission reductions of the EU ETS firms. The third model, based on the models developed by Wagner (2007), Commins et al. (2011) and Jaraite & Kažukauskas (2013), is employed to assess whether firms in the EU ETS scheme experience a significant productivity premia over the non-EU ETS firms, whereby controlling for the country-specific policy instruments (FITs or RPSs). The fourth model is a standard growth accounting model used to examine the impact of policy instruments on firms' productivity growth. The first model is estimated using pooled OLS, FE and PCSE estimators; the second model is estimated using pooled OLS and RE; the third model is estimated using pooled OLS, FE, while the fourth model is analysed using pooled OLS, FE and system GMM. The analysis uses different econometric techniques to increase the robustness of the results. The estimation methods are chosen according to the type of data and analysis and are based on the results of relevant econometric tests (e.g., Hausman, modified Wald test for groupwise heteroscedasticity, Pesaran cross-sectional dependence test, Wooldridge test for autocorrelation in panel data, Arellano-Bond test for autocorrelation, etc.).

This doctoral dissertation analyses panel data for EU countries in the years between 1990 and 2011 (the first model), between 2005 and 2012 (the second model), and between 1992 and 2012 (the third and the fourth model). The **macro-level data** are collected from the following statistical data sources: the Energy Information Administration (EIA), International Energy Agency (IEA), EUROSTAT, Haas et al. (2011), Res-legal, REN21, the United Nations Environment Programme (UNEP), the World Bank's World Development Indicators, Transparency International, and PATSTAT. The **micro-level data** are gathered from the relevant statistical source: AMADEUS (Bureau van Dijk). The **installation-level** data are collected from the European Union Transaction Log (EUTL) and aggregated to the firm level.

Original scientific contribution

The original contribution of the doctoral dissertation compared to previous research is extensive. The results presented in this thesis should be of relevance for theory, energy policy, firms, society, and researchers interested in policy instruments for promoting SRET. First, the results add value to energy and environmental economic literature because the analysis takes an innovative approach. Such an approach links different policy instruments with different stages of the technological change process[1] and with different types of SRET. Second, it extends the models used in previous studies on SRE policy instruments (e.g., Groba et al., 2011; Marques et al., 2011; Dong, 2012) to incorporate several crucial policy instruments (i.e., technology-specific fixed FITs, technology specific premium FITs, RPSs or quotas, caps, tenders, tax incentives and investment grants). It applies these modified and improved models to a sample of EU countries. Third, it extends the analysis to several types of SRET (i.e., wind, solar, geothermal, and biomass). Fourth, it includes other policy elements, in addition to financial and fiscal, to control for their effectiveness on capacity installations and electricity generation. In particular, other

[1] The technological change process includes three phases for SRET: invention, innovation and diffusion. Different financial and fiscal instruments are implemented to support a particular phase. Here, the terms technological change process, eco-innovation, and SRE transition are used interchangeably.

elements are grouped in three categories: political, socioeconomic, and environmental. Fifth, when focused on the micro level, it investigates the impact of the EU ETS and other support instruments (highly neglected in previous studies) on firms' economic and environmental performance. Sixth, it uses a longer time span than a majority of the previous studies. Finally, it utilizes different econometric methods to increase the robustness of the results (pooled OLS, PCSE, FE, RE and system GMM). The results based on the comprehensive analysis of renewable support instruments should facilitate the decision-making process on both the policy and firm levels. It is expected that the results will contribute to the policy decision-making process in the EU, in addition to outside the EU borders. This expectation is based on the fact that SRE policy instruments and carbon pricing policies are emerging worldwide.

Thesis outline

The thesis begins with an introduction to the research area that is followed by three chapters: 1. Policy Instruments for Eco-Innovation, 2. Macroeconomic Analysis of the Effectiveness of Policy Instruments in Promoting Technological Diffusion, 3. Energy Policy Instruments and Firm Productivity, and Conclusion.

The **Introduction** describes the broader research area and identifies the research topic, purpose and objectives. In general, it provides a concise answer to the following question: Why is this research needed? It further presents an overview of the research methods used in the thesis and assesses its original scientific contribution.

The **first chapter** includes six subsections. The Introduction provides an overview of the research area. The second subsection addresses the most significant climate change conventions and legislation introduced to encourage SRET development. The third subsection discusses the relationship between financial and fiscal instruments and source-specific SRET innovation and SRET diffusion. The fourth subsection assesses the effectiveness and efficiency of policy instruments in supporting the technology changes. The fifth subsection suggests further research directions and presents policy implications. The final subsection concludes the first chapter of the doctoral dissertation.

The **second chapter** comprises six subsections. The first subsection presents a general introduction to this part of the research. The second subsection provides a literature review on the effectiveness of policy support instruments in supporting SRET diffusion. It stresses the importance of SRET diffusion for reaching the EU's '20-20-20', '2030', and '2050' renewable energy targets. It also details the empirical approach and econometric strategy developed. The third subsection presents the data and descriptive statistics. The results are provided in the fourth subsection and discussed in the fifth subsection. The sixth subsection concludes this chapter and considers further research possibilities.

The **third chapter** consists of six subsections. The first subsection addresses the research problem area. The second subsection develops the research framework. It provides a review of the relevant empirical literature and a conceptual framework on the impact of SRE policy instruments on firms' performance. The third subsection identifies the empirical approach and econometric issues. The fourth subsection describes the data used for analysis and provides descriptive statistics. The fifth subsection presents and discusses the obtained results. The sixth subsection concludes this chapter, stresses its limitations and discusses new relevant topics for further research.

The **fourth chapter** concludes the thesis by summarizing the main research findings and by emphasizing its scientific contribution. Based on these findings, it offers recommendations for the EU Energy Policy and firms' management. Moreover, the final chapter of the doctoral dissertation presents its research limitations and develops some ideas that call for further research in this area.

1. POLICY INSTRUMENTS FOR ECO-INNOVATION

1.1. Introduction

It is well known that the pressure on energy resources is high. However, the share of renewables in total electricity net generation is still low, only 24.6 % according to the European Union (EU) data for 2012 (EIA, 2014). A major potential solution to this problem is that the current climate policy adopts financial and fiscal instruments that would make sustainable renewable energy technologies (SRET) more affordable (Commission of the European Communities, 2008). It is important to emphasize that not all policy support instruments are equally effective and efficient. Their achievements depend on their interactions, on the eco-innovation stage and on the type of SRET to which they relate. With consideration to these issues, this chapter summarizes recent approaches for evaluating the effectiveness and efficiency of policy instruments used to promote eco-innovations. The term ‘effective’ denotes the extent to which a policy instrument achieves policy objectives (i.e., achieves an increase in the number of SRET innovations or/and SRET installations). The term ‘efficient’ refers to the ability of a policy instrument to reduce generation costs (Commission of the European Communities, 2008). The eco-innovation process includes three stages for SRET: invention, innovation, and diffusion (European Environment Agency, 2011). However, researchers usually only differentiate between innovation and diffusion.

This chapter also reveals the possible avenues for relevant theoretical or empirical (econometric or case study) research. Its contribution is in linking all of these research approaches with various financial and fiscal support instruments and with both technological innovations and their diffusion. To date, policy support instruments are usually examined separately, or comparisons between two or three different instruments are included (Morris & Read, 2001; Gagelmann & Frondel, 2005; Butler & Neuhoff, 2008; Oikonomou, Jepma, Becchis, & Russolillo, 2008; Commins, Lyons, Schiffbauer, & Tol, 2009; Coria, 2009; Markandya, Ortiz, Mudgal, & Tinetti, 2009; Peretto, 2009; Falconett & Nagasaka, 2010; OECD, 2010; Rogge & Hoffmann, 2010; Kažukauskas & Jaraite, 2011; Antoci et al., 2012; Bodas–Freitas et al., 2012; Dong, 2012; Noailly, 2012). Thus, the comprehensive overview of multiple instruments’ impacts is needed to provide a broader picture. This is of significant importance for facilitating the policy-making decisions in the field of renewable energy.

The general finding is that sustainable renewable energy (SRE) support instruments promote new technologies (OECD, 2010). However, different instruments do not equally promote hydro, geothermal, solar, wind and biomass technologies (Falconett & Nagasaka, 2010; Johnstone et al., 2010; European Environment Agency, 2011; Dong, 2012). While trying to determine why one instrument is better than another, many papers do not exclusively focus on one particular type of SRET (Dinica, 2006; Marques & Fuinhas, 2011; Bodas–Freitas et al., 2012). However, if a distinction between SRET types is made, the research focus is typically solely on wind or solar technologies (Groba et al., 2011; Dong, 2012). Moreover, the majority of studies that focused on various support instruments do not cover all 27 EU countries. The lack of empirical analysis, especially on a micro level, in addressing this emergent topic is also identified. Further research should provide a new methodological framework to include all main SRE policy support instruments while identifying their impact on eco-innovations.

The chapter 1 is structured as follows. Section 1.2 documents the main steps towards the development of SRET referring to related legislation. Section 1.3 discusses the link between financial and fiscal instruments and different stages and types of technology. Section 1.4 addresses the key characteristics of main policy instruments with respect to promotion of the technology changes. Section 1.5 identifies further research opportunities and policy implications. Section 1.6 concludes this chapter 1.

1.2. Main steps toward the promotion of the technology changes

The SRE debate has attracted attention for decades, and it continues to grow. The process towards clean technology development and its diffusion started with *The Vienna Convention for the Protection of the Ozone Layer from 1985* (UNEP, 2001) and *The United Nations Framework Convention on Climate Change*, 1992 (UNFCCC, 1992). These conventions recognized that countries, especially developing ones, need to achieve sustainable social and economic progress. To fulfil the specified requirements, countries must implement new technologies. New technologies are expected to achieve greater energy efficiency and to reduce greenhouse gasses (GHG) emissions. The next important step was *The Montreal Protocol on Substances That Deplete the Ozone Layer from 1987* (UNEP, 2000). A few years later, by signing *The Kyoto Protocol* (UNFCCC, 1998), countries agreed to reduce their emissions by at least 5 % from the 1990 level during the period from 2008 to 2012. The Kyoto Protocol was adopted in 1997 and entered into force in 2005. To help countries meet their targets of efficiently reducing emissions, the Kyoto Protocol introduced three market–based mechanisms. These mechanisms are Emissions Trading (ET), The Clean Development Mechanism (CDM) and Joint Implementation (JI). Furthermore, the 2007 United Nations Climate Change Conference held in Bali (UNFCCC, 2007), the 2009 United Nations Climate Change Conference held in Copenhagen, Denmark (UNFCCC, 2009) and the 2010 United Nations Climate Change Conference, which took place in Cancun, Mexico (UNFCCC, 2010), delivered important decisions toward a cleaner environment in the future. All of these conferences significantly contribute to the climate change debate. However, some EU countries need to revise their SRE policies in order to foster the SRET change process. Innovative solutions are required in order to meet the EU SRE targets by 2020 and 2030. The EU is currently on target to accomplish two of three proposed objectives. These objectives are GHG emission reductions by 20 % and increasing the renewable energy share by the same percentage by 2020. The third EU target, achieving a 20 % increase in energy efficiency by 2020, will not be accomplished unless additional fiscal policy solutions are established. The 2030 targets go a step further and require that countries, in comparison to 1990 levels, reduce GHG emissions by at least 40 % in 2030, increase the share of energy consumption from renewables by at least 27 % in 2030, and increase energy efficiency by 30 % in 2030 (European Commission, 2014b). Furthermore, in March 2011, the European Commission (EC) adopted 'A Roadmap for Moving to a Competitive Low Carbon Economy in 2050'. Its goal is to keep the climate change below 2 degrees Celsius. Another accepted target is to obtain between 80 and 95 % of GHG emission reductions by 2050 from a 1990 baseline. With the aim of reaching this target, the EC report (European Commission, 2011) notes that more focus is needed on energy efficiency policies.

According to the EC, increased energy efficiency is the most cost effective and quickest way to reduce GHG emissions. Therefore, examining and implementing the most effective and efficient policy instruments that would increase energy efficiency has become one of the greatest challenges. This challenging task is of interest and importance for both researchers and policymakers worldwide. The spread of SRE policy instruments throughout the years (see Table 1.1) indicates the emerging need for facing environmental and economic challenges (Busch & Jörgens, 2005).

FIT is a long-term fixed or premium financial support provided for SRE electricity producers. RPS or quota requires a certain amount of electricity to be produced from SRE sources. The cap and trade scheme denotes a limit on CO_2 emissions. Firms that are below the limit could sell their unused emission allowances to higher emitters. Tender can be investment or generation based. The investment based tender works in such a way that a fixed number of technologies that should be installed is announced, and the firm with the most competitive tender receives the investment support. The generation based tender works in a similar way, however, by providing a bid price subsidy for generated SRE electricity. The tax incentive or investment grant denotes various types of incentives for SRET implementation and use that is in force in a particular EU country (e.g. electricity tax exemption, other tax reductions or exemptions).

Table 1.1: Year of implementation of policy instruments for supporting SRE electricity generation in 27 EU countries from 1990 to 2011

	FIT WIND	FIT PV	FIT BIO	FIT GEO	FIRST CAP INTRODUCED	QUOTA	TENDER	TAX INCENTIVE/ INVESTMENT GRANT
1990	(DE)	(DE)	(DE)	(DE)			(UK)	
1991								
1992	(IT)	(IT)						
1993	(LU), *(DK)*	(LU), *(DK)*	(LU), *(DK)*					
1994	(ES), (GR)	(ES), (GR)	(ES), (GR)	(ES), (GR)				(SE)
1995							(IE)	
1996								
1997							(FR)	(FI), (NL)
1998	(AT)	(AT)	(AT)	(AT)				
1999								
2000						(PL)		(PL)
2001	(FR), (PT)	(FR), (PT)	(FR), (PT)	(FR), (PT)		(IT)		
2002	(CZ), (HU), (LT)	(CZ), (HU), (LT)	(CZ), (HU)	(CZ), (HU)		(BE), (UK)		
2003	(BG), *(EE)*, (NL)	(BG), *(EE)*, (NL)	*(CY)*, *(EE)*, (NL)	*(EE)*, (NL)		(SE)		(SK)
2004	(SI)	(MT), (SI)	(BG), (SI)	(SI)				(CY)
2005	*(IE)*, (SK)	(SK)	*(IE)*, (SK)	(SK)		(RO)	(PT)	
2006	*(CY)*	*(CY)*			(AT), (IE), (PT)			(MT)
2007			(IT)	(IT)	(EE), (NL)			
2008					(CY), (ES)			
2009					(LV)		(LV)	
2010	(LV), (UK)	(LV), (UK)	(LV)	(LV)				
2011	*(FI)*	*(FI)*						

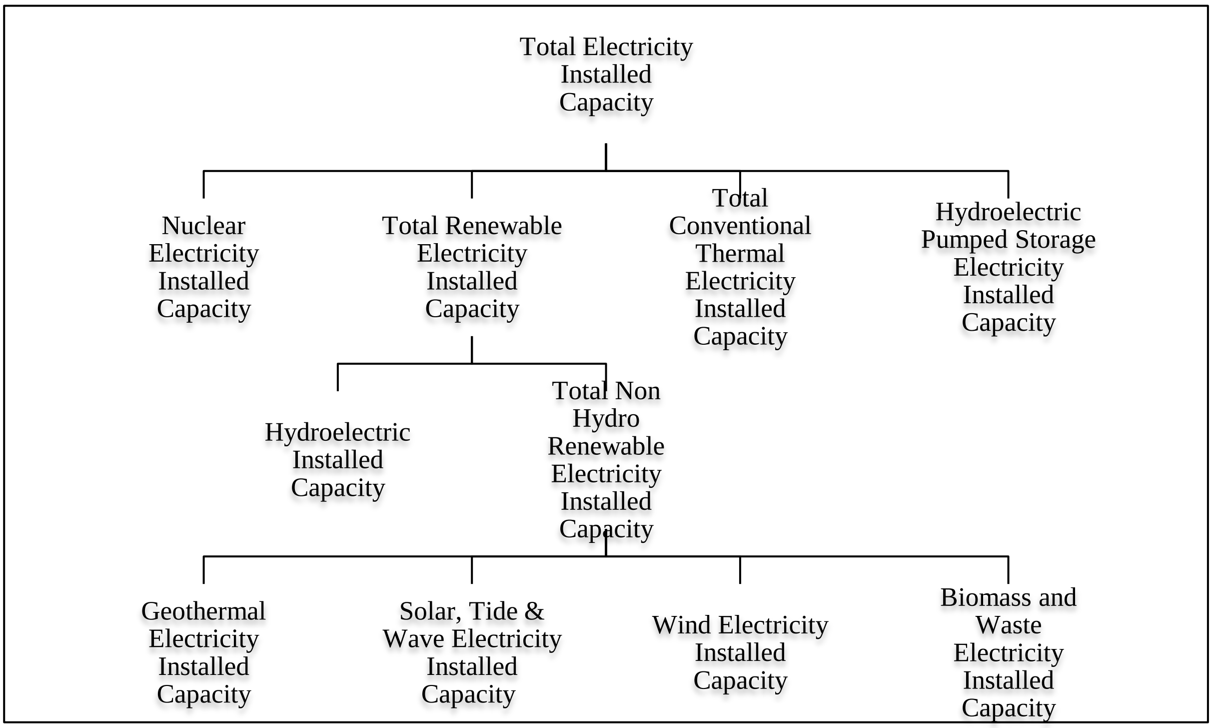
Note. Each row represents a policy type. *Italics* denote premium FIT policies. AT, Austria; BE, Belgium; BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DK, Denmark; EE, Estonia; FI, Finland; FR, France; DE, Germany; GR, Greece; HU, Hungary; IE, Ireland; IT, Italy; LV, Latvia; LT, Lithuania; LU, Luxembourg; MT, Malta; NL, Netherlands; PL, Poland; PT, Portugal; RO, Romania; SK, Slovakia; SI, Slovenia; ES, Spain; SE, Sweden; UK, United Kingdom; HR, Croatia; NO, Norway; CH, Switzerland.

Source: R. Haas et al., *A historical review of promotion strategies for electricity from renewable energy sources in EU countries*, 2011; REN21, *Renewable Energy Policy Network for the 21st Century*, 2012; Res-legal, *Legal sources on renewable energy*, 2012; and IEA/IRENA, *Joint Policies and Measures database*, 2014.

Table 1.1 indicates the year when different SRET support instruments were implemented in a particular EU country. Technology specific fixed FITs were implemented before 1990 in Germany. Premium FITs for wind, solar and biomass technologies were first implemented in Denmark in 1993. Premium FIT for supporting the electricity generation from geothermal technologies was first implemented in Estonia in 2003. The first CAP was introduced in Austria, Ireland and Portugal in 2006. Quota was first implemented in Poland in 2000. Tenders were first introduced in UK (before 1990). Tax incentives / investment grants aimed at supporting SRET were first implemented in Sweden in 1994.

Before addressing the barriers and opportunities for finding an effective and efficient financial and fiscal policy framework, it is necessary to understand the relationship between policy instruments and technological change. Therefore, section 1.3 will contribute to a deeper understanding of these instruments with respect to different stages and types of SRET. The subsequent figure 1.1 presents the different types of electricity generating technologies according to the U.S. Energy Information Administration classification.

Figure 1.1: Total electricity capacity - EIA classification

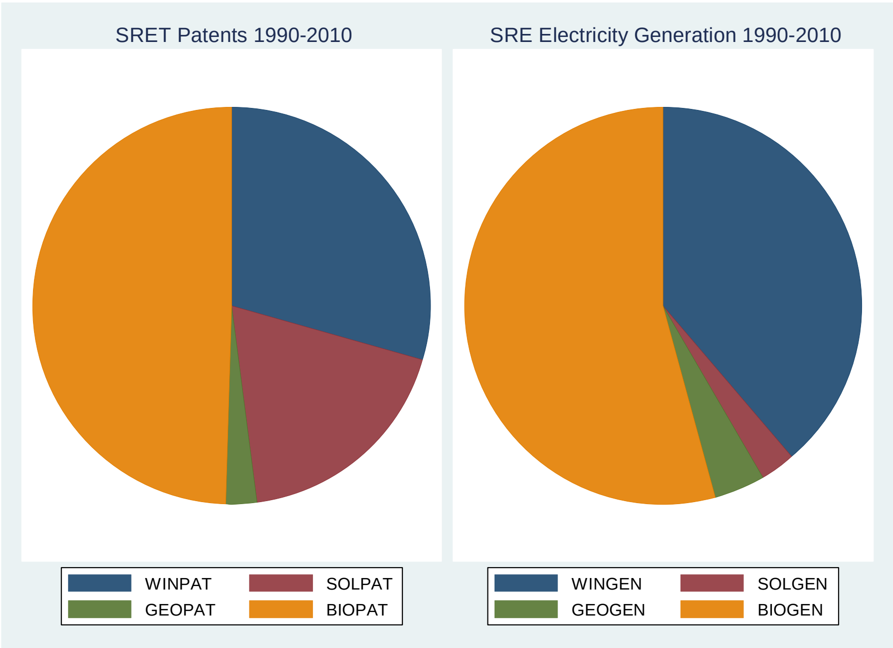


Source: According to the EIA, *International Energy Statistics*, 2014.

1.3. Analysis of the link between policy instruments and technological change

Research findings reveal that is very important for countries to develop and implement SRET and to use cleaner energy by reducing GHG emissions (Gerlagh, 2008; Zhai, Wang, Dai, Wu, & Ma, 2008; Peretto, 2009; Nixon, Dey, & Davies, 2010; Popp, Newell, & Jaffe, 2010; Schmidt, Schneider, & Hoffmann, 2012). Therefore, a large number of financial and fiscal instruments have been introduced to promote eco–innovation. As indicated, according to the European Environment Agency (2011), the term *eco–innovation* includes all three stages of the technological change process: invention, innovation and diffusion. The distinction between these three stages of technological changes in economic theory is credited to Schumpeter (1942). Following his classification, *invention* encompasses the development of new products or processes, *innovation* relates to their commercialization, and *diffusion* implies the spread of new products and processes across the market. However, researchers primarily only make a distinction between innovation and implementation of emerging technologies. At this point, the link between technological innovation and diffusion becomes clear. Innovations are a precondition for implementation activities and are a counterpart of the climate change debate. Optimal fiscal solutions are needed in both cases. The majority of studies have confirmed that successful SRE policies foster eco-innovations. However, the level of success of policy instruments varies across the different types of SRET (Markandya et al., 2009; Falconett & Nagasaka, 2010; Johnstone, et al., 2010). In addition, various instruments are more or less effective / efficient for different technological development stages (European Environment Agency, 2011). The figure 1.2 shows the number of SRET specific patents and electricity generation from different SRET types in total renewables. Biomass patents and electricity generation from biomass sources have the highest share in total SRE patents / SRE electricity generation.

Figure 1.2: Wind, solar, geothermal, and biomass patents and electricity generation from SRET in the EU



Source: According to the PATSTAT; EIA, *International Energy Statistics*, 2014.

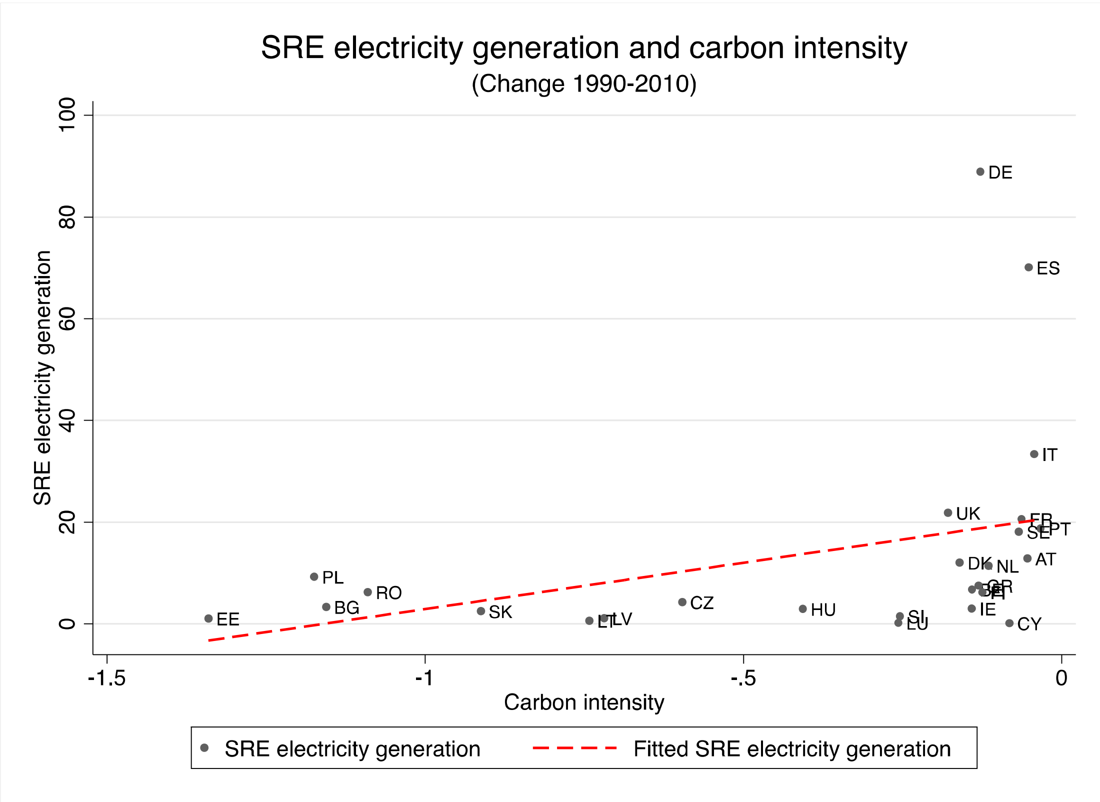
The main problem identified is that the literature does not provide unique conclusions regarding the impact of policy specific instruments on technological innovation and diffusion. The emerging debate on the role of energy taxes in the technological change process yields mixed results. While a group of studies (Johanstone et al., 2010; Næss–Schmidt, Hansen, Tops, Jensen, & Jespersen, 2010; OECD, 2010) confirm that energy taxation drives technological innovation, Noailly (2012) does not find a significant impact of energy taxes (captured by energy prices) on innovations. In the case of technological diffusion, researchers (Coria, 2009; Liu & Espínola-Arredondo, 2013) determine scenarios under which environmental taxes promote diffusion processes. Research by Johanstone et al. (2010) on fiscal incentives shows, e.g., that targeted tax credits do not have an impact on innovation in renewable technologies. Later, focusing on R&D tax credits, Czarnitzki et al. (2011) identify their positive effect on the innovation output. Regarding the EU ETS, Anderson et al. (2011) show that emission trading encourages moderate technological change. Later, Calel & Dechezlepretre (2012) do not find that the EU ETS impacted the direction of technological change at all. Focusing on innovations, limited innovation effects of the pilot phase of the EU ETS are acknowledged in the research by Gagelmann and Frondel (2005). In contrast, Rogge and Hoffmann (2010) argue that the EU Emission Trading Scheme (ETS) influenced the sectoral innovation system of power generation technologies in Germany. When examining the impact of Kyoto instruments on technological diffusion, Bodas–Freitas et al. (2012) emphasize that these instruments are not encouraging SRET in BRICS (Brasil, Russia, India, China and South Africa). However, Antoci et al. (2012) identify how the EU ETS can promote the diffusion of new clean technologies. Focusing on comparisons between feed in tariff (FIT) and renewable portfolio standard (RPS), Johnstone et al. (2010) emphasize that FITs better promote innovations in solar technologies, while obligations and tradable certificates more effectively induce innovations in wind technologies. A different scenario is documented in the case of technological diffusion, where FITs increase wind capacity more than RPS (Dong, 2012).

It should be noted that one group of studies more explicitly analyses the effectiveness and / or efficiency of policy instruments in promoting technological innovation. Other researchers link the instruments with technological diffusion. Studies have been elaborated more in depth in section 1.4. Further research efforts are needed in order to clarify the identified mixed results.

Emerging clean energy technologies' development demands SRE policy systems in countries (Dinica, 2006; Lipp, 2007; Siriwardena, Wijayatunga, Fernando, Shrestha, & Attalage, 2007; Strand, 2007; Hart, 2008; Vollebergh, 2008; Delucchi & Jacobson, 2011). According to the European Commission (2007), the EU has a commitment to reduce GHG emissions to a level that would limit the global temperature increase to 2 degrees Celsius compared to pre–industrial levels.

Figure 1.3 reveals that, when observing long differences between 1990 and 2010, countries increasing overall electricity generation from SRET tend to be less carbon intensive.

Figure 1.3: SRE electricity generation and carbon intensity



Note: SRE electricity generation is measured in Billion Kilowatthours; Carbon intensity is measured in Metric Tons of Carbon Dioxide per Thousand Year 2005 U.S. Dollars.

Source: According to the EIA, *International Energy Statistics*, 2014, own calculations.

However, as is emphasized in the EC Report (Commission of the European Communities, 2007), with the energy and transport policies that are currently in force, European carbon dioxide (CO_2) emissions would not sufficiently decrease to ensure environmental sustainability. It is estimated that CO_2 emissions would increase by approximately 5 % by 2030 and global emissions would rise by 55 %. That further implies that the present system of renewable energy policies within the EU is not sustainable. The Ministry of Economic Affairs, Agriculture and Innovation (2011) noted that achieving a more sustainable energy system is a huge challenge but also an opportunity for energy policy to reduce the dependence on fossil fuels and to make a step towards low–carbon economy targets by 2050.

Overall, renewable energy policies differ in their degree of success. Their success is highly dependent on their SRE support instrument choice. If effective and efficient in promoting SRET, they are also a driving force in reaching environmental and economic goals. Therefore, the impact of financial and fiscal instruments on innovation and diffusion of clean technologies should be assessed.

1.4. Literature review of policy instruments intended to promote technological changes

A literature review identified two relevant groups of papers: theoretical analyses of the impact of SRE polices on eco–innovation and empirical studies of the relationship. This section first presents key characteristics of policy instruments that support innovation and implementation of SRET. It then focuses on the stage of technological development process to which they relate, on the methodology used, on the main findings and on the further research implications necessary to foster technological change. The most relevant recent studies are examined in more detail (see Table 1.2). Selected studies include comprehensive econometric analyses of the impacts of policy instruments on innovation and diffusion of SRET.

Table 1.2: Overview of the studies focused on policy instruments for eco-innovations

Study	**Type of analysis**	**Financial and fiscal instrument types addressed**	**Technologies addressed**	**Level of analysis**	**Level of eco–innovation process**
Anderson et al. (2011)	Case study	EU ETS	Low carbon technologies	Micro analysis	Technological change process
Antoci et al. (2012)	Theoretical model	EU ETS	Pollution free vs. polluting technologies	Micro analysis	Technological diffusion
Bodas–Freitas et al. (2012)	Econometric analysis	Kyoto Protocol instruments	Renewable energy technologies (not specified by source of RE)	Macro analysis	Technological diffusion
Calel & Dechezlepretre (2012)	Econometric analysis	EU ETS	Low carbon technologies	Micro analysis	Technological change process
Cansino et al. (2010)	Comprehensive overview	Tax incentives	Technology specific renewable energy	Macro analysis	Technological diffusion
Commins et al. (2009)	Econometric analysis	Energy taxes and the EU ETS	Not specified	Micro analysis	Investments (potential technological innovation and diffusion impacts)
Corria (2009)	Theoretical model	Environmental taxes and permits	Clean technologies	Micro analysis	Technological diffusion
Czarnitzki et al. (2011)	Econometric analysis	R&D tax credits	Not specified	Micro analysis	Technological innovation
Dong (2012)	Econometric analysis	FIT and RPS	Wind	Macro analysis	Technological diffusion
European Environment Agency (2011)	Econometric analysis	Carbon taxes	Renewable energy technologies	Macro analysis	Technological innovation

(table continues)

(continued)

Study	**Type of analysis**	**Financial and fiscal instrument types addressed**	**Technologies addressed**	**Level of analysis**	**Level of eco–innovation process**
Falconett & Nagasaka (2010)	Theoretical model	Governmental grants, carbon credits, FITs and renewable energy certificates	Small–scale hydroelectric, wind energy and solar PV systems	Macro analysis	Technological diffusion
Gagelmann & Frondel (2005)	Critical literature review analysis	EU ETS, command and control instruments	Clean technologies	Overview of different studies	Technological innovation
Johnstone et al. (2010)	Econometric analysis	R&D, investment incentives, tax incentives, tariff incentives, voluntary programs, obligations, and, tradable certificates	Wind, solar, ocean, geothermal, biomass, waste to energy	Macro analysis	Technological innovation
Kažukauskas & Jaraite (2011)	Econometric analysis	Tradable green certificates and Feed in Tariffs	Electricity generating conventional and renewable technologies	Micro analysis	The profitability of power generating firms and policies promoting renewable energy
Liu & Espinola Arredondo (2013)	Theoretical model	Environmental taxes	Green vs. polluting technologies	Micro analysis	Technological diffusion
Markandya et al. (2009)	Case studies	Tax incentives, energy tax	Energy efficient appliances	Macro analysis	Technological diffusion
Morris & Read (2001)	Case study	Landfill tax	Sustainable waste management and related renewable energy conversion technologies	Macro analysis	Technological innovation
Næss–Schmidt et al. (2010)	Econometric analysis	Government R&D in the technology of interest, energy prices and taxes	Biomass for heating in buildings, boilers, ventilation in buildings, lighting, light emitting diodes, motor vehicle fuel efficiency, paper and pulp production	Macro analysis	Technological innovation

(table continues)

(continued)

Study	Type of analysis	Financial and fiscal instrument types addressed	Technologies addressed	Level of analysis	Level of eco–innovation process
Noailly (2012)	Econometric analysis	Regulatory energy standards in building codes, energy taxes captured by energy prices and technology specific governmental energy R&D	Insulation, high-efficiency boilers, heat and cold distribution, ventilation technologies, solar boilers, energy saving lightings, buildings materials and climate control technologies	Sector analysis–buildings	Technological innovation
Oikonomou et al. (2008)	Theoretical model	White Certificates and energy taxes	Conventional electricity sector	Micro analysis	Technological change process
Rogge & Hoffmann (2010)	Case study	EU ETS	Power generation technologies	Sector analysis	Technological innovation
Schneider et el. (2008)	Review of empirical studies and expert interviews	CDM	Low carbon technologies	Analysis of the private sector technology transfer	Technological transfer

Source: Own compilation according to the studies cited.

This analysis addresses the following key market-based instruments: environmental taxes, fiscal incentives, emission trading, clean development mechanism, joint implementation, feed-in tariff, renewable energy portfolio standard, government grants and carbon credits. In the process of examining the link between policy instruments and eco-innovation, policies can be classified as those that regulate either the SRE electricity price or the quantity produced (Weitzman, 1974).

Price-based policy instruments, such as fiscal incentives (R&D tax incentives / tax credits), and quantity-based Kyoto instruments can directly support investments in SRET. In contrast, other price-based policy instruments, FITs, and quantity-based instruments, RPSs, can directly support electricity generation from SRET. Apart from policy instruments that directly promote SRET, there are other instruments, such as environmental taxes, that may have an indirect impact on technological change (Haas et al., 2004; Held, Haas, & Ragwitz, 2006). However, all of these energy policy instruments could influence all stages of the technological change process (detailed innovation / diffusion analyses are provided in section 1.4). Along with those market-based instruments, command and control approaches address the technological change. Such approaches include emission standards, process or equipment specifications, etc. The link between policy instruments and the eco-innovation process is graphically presented in the Figure 1.4.

Figure 1.4: The link between policy instruments and the eco-innovation process

POLICY INSTRUMENTS **Market based vs. Command and Control**	**IMPACT** **Direct vs. Indirect**	**ECCO-INNOVATION PHASE** **Invention vs. Innovation vs. Diffusion: Implementation of SRET / SRE electricity generation**
MARKET BASED (Price vs. Quantity)		
• **PRICE BASED**		
R&D incentives	**DIRECT**	Innovation
Tax incentives / Investment grants	**DIRECT**	Diffusion: Implementation of SRET
Premium and Fixed Feed in tariffs	**DIRECT**	Diffusion: SRE electricity generation
Environmental taxes	INDIRECT	Invention, innovation, diffusion
• **QUANTITY BASED**		
EU Emission Trading Scheme	**DIRECT**	GHG emission reductions
	INDIRECT	Invention, innovation, diffusion
Clean Development Mechanism	**DIRECT**	GHG emission reductions
	INDIRECT	Diffusion
Joint Implementation	**DIRECT**	GHG emission reductions
	INDIRECT	Diffusion
Tendering schemes	**DIRECT**	Diffusion: Implementation of SRET / SRE electricity generation
Renewable Portfolio Standard	**DIRECT**	Diffusion: SRE electricity generation
COMMAND AND CONTROL		
Technology and Performance Standards	**DIRECT**	Diffusion

Source: According to R. Haas et al., *How to promote renewable energy systems successfully and effectively*, 2004; A. Held et al., *On the success of policy strategies for the promotion of electricity from renewable energy sources in the EU*, 2006; European Environment Agency, *Environmental tax reform in Europe: opportunities for eco-innovation*, 2011; and extended by the author.

Renewable energy policies should be carefully designed to foster the innovation process and the diffusion of new technologies. Supported by a number of existing findings, taxation of non-renewable technologies is a good starting point.

1.4.1. Environmental taxes and fiscal incentives

The economic rationale behind environmental taxes is that these taxes raise the price of environmentally non–friendly activities. At the same time, they provide incentives to mitigate the effects of pollution. More precisely, the studies confirmed that environmental taxes and investment subsidies increase innovation and diffusion of SRET (for detailed review see European Environment Agency, 2011). However, their effect varies across sectors, technologies and innovation types. The studies also reveal that the impact of these taxes cannot be examined without taking into consideration different design characteristics of country-specific SRE policies. In subsequent paragraphs (in subsection 1.4.1), these studies are examined in more detail.

The four different types of environmental taxes are energy, transport, pollution and resource. Environmental taxes should be examined and implemented carefully. If they are too rigid in a certain country, they can become counterproductive, causing a carbon leakage effect (Babiker, 2005; Barker, Junankar, Pollitt, & Summerton, 2007; Næss–Schmidt et al., 2010). This means that firms can change location to countries with lower taxes. They can also use non–renewable technologies instead of making the decision to innovate or implement clean alternatives. Barker et al. (2007) examine potential carbon leakage from six EU countries that implemented Environmental Tax Reform from 1995 to 2005. Their study contributes to the literature by measuring potential leakage from historical actions using the (E3ME)[2] econometric dynamic model. Their results show that carbon leakage is small or negative as a result of technological spill–over effects.

The analysis of different environmental taxes and their impacts on technological changes has been studied. The first group of studies (Næss–Schmidt et al., 2010; European Environment Agency, 2011; Noailly, 2012) assesses the impact of these taxes on technological innovation. The second group (Commins et al., 2009; Coria, 2009) assesses their impact on diffusion of SRET.

Næss–Schmidt et al. (2010) focus on the role of taxes in innovation of energy technologies. They conduct econometric analysis using European patent data from 1978 to 2007. Their study covers 33 countries, 13 energy products and seven technologies. The authors use the Copenhagen Economics Renewables Innovation Model to find the link between energy taxes, prices and patents. The model is estimated by quasi-static panel regression with country fixed effects (FE) and dynamic panel regression. Their main findings indicate that energy taxation is an efficient driver of innovation. R&D policies that support long-term innovation need to be a supplement to energy taxation.

[2] Cambridge Econometrics energy-environment-economy model of Europe

One of the major findings of a recent OECD study of taxation, innovation and environment (OECD, 2010) is that environmental taxes can stimulate innovation. The European Environment Agency (2011) report examines various options under which the revenues collected from carbon taxes can be redirected back to the economy. The results based on macro–econometric models show that using some of the revenues to support SRE would have positive impacts on the economy. However, further research is needed in considering country-specific factors that could not be fully examined by the modelling framework presented in the study. In addition, CDM/JI measures were not analysed. Therefore, the report concludes noting that the discussion on market-based instruments should be intensified. That is crucially important because the EU needs to implement a mix of policy instruments that will enable reaching GHG emission targets and maximizing prosperity.

Noailly (2012) examines the influences of multiple SRE policy instruments on technological innovation, especially in the buildings sector. In particular, these instruments include regulatory energy standards for buildings, energy taxes, and governmental energy R&D support. The econometric analysis of patent data estimates the impact of different policy instruments on technological innovation for seven EU countries from 1989 to 2004. A conditional fixed-effect Poisson model with robust standard errors clustered at the country level is used. The main result reveals that strengthening the wall insulation standards would have significant positive impact on new patents. The study finds that energy prices have no significant impact on patenting activities, while the effect of governmental energy R&D support is small but positive. The author also highlights future research possibilities. Further work should use technology specific firm-level patent data to examine how SRE policy elements could influence firm behaviour. Second, factors, such as stability and flexibility of the policy elements, should be assessed. Third, how innovations contribute to GHG emission reductions should be empirically examined. Finally, the author suggests that it should also be examined how different policy instruments increase energy efficiency through SRET diffusion.

Commins et al. (2009) examine the effects of the EU ETS and energy taxes on employment, investments, productivity, and profitability of EU firms across various sectors using firm–level panel data for the period from 1996 to 2007. The main results of their study indicate that energy taxes have a positive impact on firms' productivity and profitability but a negative impact on employment. The effects on investments are mixed. Additionally, findings show a negative effect of the EU ETS on productivity and profitability. The EU ETS impact on employment and investment proved to be insignificant. The results of analysis by Commins et al. (2009) also reveal large variations between sectors, both in size and in estimated coefficient signs. It should be noted that the dataset used in their analysis only covers the first EU ETS phase. Therefore, further research is needed to employ the data for the second EU ETS trading period and to re-estimate these issues.

Coria (2009) develops the adoption model in a dynamic setting to test how the policy instrument choice influences SRET diffusion. The analysis by Coria (2009) is restricted to firms engaged in an imperfect market competition. Moreover, the analysis assumes that the regulator sets an ex-post optimal level of emissions before firms initiate technological adoption. The results show that in the case of higher output demand elasticity, auctioned permits dominate over emission taxes in quickening SRET diffusion. Further relevant analyses on technological diffusion should consider different settings than were used in this study.

Additionally, *fiscal incentives* (R&D tax incentives, tax credits, tax exemptions or reductions) are also used to promote technological innovations and diffusion of SRET. In some countries, they are the main support instrument, while others most often apply them in combination with other SRE policy instruments. Fiscal incentives could be sufficient to stimulate SRET in countries with higher energy tax rates; otherwise, a mix of instruments is needed (Commission of the European Communities, 2008). The first group of studies (Johnstone et al., 2010; Czarnitzki et al., 2011) link fiscal incentives with technological innovations, while the second group (Markandya et al., 2009; Cansino, Pablo-Romero, Román, & Yñiguez, 2010) examine their impact on SRET diffusion.

Johnstone et al. (2010) find that investment incentives support all SRET excluding wind. However, a significant positive link is determined between investment incentives and geothermal and biomass technologies. Targeted tax credits and voluntary programs do not have an impact on technological innovations (detailed analysis of their research is provided under subsection 1.4.3: Feed-in tariff and renewable energy portfolio standards). In contrast, Czarnitzki et al. (2011) find that R&D tax credits increase the innovation output of Canadian manufacturing firms. The authors conduct analysis employing cross-sectional data, based on the Canadian 1999 Survey of Innovation, and use a non-parametric matching approach. For future research, the use of panel data and objectively measured performance indicators instead of self-reported is suggested.

Markandya et al. (2009) develop the economic-engineering-type model of consumers' behaviour. Its purpose is to analyse the impact of tax incentives on the process of production and commercialization of energy efficient appliances. Based on the countries and appliances considered, Markandya et al. (2009) find that, e.g., Denmark and Italy should provide tax credits on boilers. CFLi bulb subsidies proved to be an efficient choice for France and Poland. Both types of incentives are assessed in terms of cost and emission reductions they impose. In addition, Markandya et al. (2009) identify that, in most cases, energy taxes are more cost-effective than subsidies. As suggested, further research should take distributional factors into account because of the concern that energy tax increases might seriously hurt economically vulnerable groups. Second, the model should be extended to fully account for spillover effects of the incentives. Finally, a dynamic modelling approach would be a valuable extension for the model presented.

Cansino et al. (2010) presents the main tax incentives aiming to promote SRE electricity within European Union countries. They find that 16 EU countries use tax incentives together with other instruments, mainly with quotas and price regulations. However, the problem lies in the fact that not all available technologies are promoted. The authors also identify that an exemption on the payments of excise duties for SRE electricity generation is the most widely used tax incentive type. The goal of the EU is to provide an SRE policy framework. This goal is challenging to achieve because of the great diversity of tax incentives used to promote electricity from SRET. Despite this problem, the authors argue that multiple case studies on country- and SRET-specific tax incentives can be used to better inform the EU energy policy.

1.4.2. Emission trading, clean development mechanism and joint implementation

The Kyoto Protocol introduced three market-based instruments, ET, CDM and JI, to help countries achieve their emission requirements under the Protocol. ET, as determined in Article 17 of the Kyoto protocol, allows countries that exceed their emission reduction commitments under the Protocol to buy emission units from other countries that are under their Kyoto targets. The CDM, as defined in Article 12 of the Protocol, allows a country with an emission reduction or limitation targets under the Kyoto to implement an emission reduction project in developing countries. Such projects can earn certified emission reduction (CER) credits, each equivalent to one tonne of CO_2. CERs can be traded or sold and can give industrialized countries some flexibility in meeting their Kyoto targets. JI, as defined in Article 6 of the Kyoto Protocol, allows a country with an emission reduction or limitation commitment under the Protocol to earn emission reduction units (ERUs) from an emission-reduction or emission-removal project in any other country with targets under the Protocol. An ERU is equivalent to one tonne of CO_2.

In general, the underpinning economic rationale of the Kyoto instruments is that emission reductions and low-carbon technology diffusion should be achieved in a cost-effective way (see Appendix A and B for an overview of verified emissions and SRE electricity generation in 27 EU countries since the introduction of the EU ETS). However, it was argued (Gagelmann & Frondel, 2005; European Commission, 2014a) that during the first EU ETS trading period (2005–2007), too many emission allowances were issued and distributed free of charge. Another reason for the limited impact of the EU ETS was the lenient cap on emissions and the unlimited usage of CDM and JI credits. Consequently, the price of first-period allowances decreased to zero in 2007, and firms did not have enough incentives to reduce emissions and to implement SRET. According to the European

Commission (2014a), based on 'learning by doing', the number of allowances was reduced by 6.5 % in the second trading period (2008–2012). Major reform will affect the third EU ETS trading period (2013–2020). The reform will introduce the EU wide cap on emissions and auctioning of allowances. Despite these improvements, researchers emphasize that further research on preventing the carbon leakage caused by Kyoto should be intensified (Antimiani, Costantini, Martini, Salvatici, & Tommasino, 2013).

Recent studies have begun to examine the impact of Kyoto instruments on technological innovation (Gagelmann & Frondel, 2005; Rogge & Hoffmann, 2010) and diffusion processes (Schneider, Holzer, & Hoffmann, 2008; Antoci et al., 2012; Bodas–Freitas et al., 2012).

Gagelmann & Frondel (2005) emphasize that the literature does not provide a unique answer to the question of whether the ETS causes more innovation than other policy instruments, such as command and control. Based on the studies reviewed, the authors conclude that the innovation effects of the EU ETS in its pilot phase were limited, especially as a result of lenient emission targets in that period. Later, Rogge & Hoffmann (2010) empirically investigate the actual innovation impacts of the EU ETS in the initial years after its implementation. The authors conduct analyses for Germany based on 42 interviews with experts in the power sector. Regardless of the low expectations of the EU ETS impact on innovations, triggered by Gagelmann & Frondel's (2005) findings, the authors argue that the EU ETS has limited influence on the technological innovation system. However, based on the research results by Rogge & Hoffmann (2010), it is not expected that the revised EU ETS will be sufficient for achieving a low-carbon power sector. This finding again confirms the need for identifying the most effective and efficient policy instrument mix for reaching the EU environmental targets. Future research should also address the next several essential issues. First, Rogge's and Hoffmann's (2010) findings for Germany should be compared with relevant results from other EU countries. Second, future analysis should be extended to include other industrial sectors operating under the EU ETS. Third, in-depth country specific company case studies are needed to identify the extent of innovation effects triggered by the EU ETS.

By assessing empirical studies and conducting expert interviews, Schneider et al. (2008) find that the CDM contributes to low-carbon technology transfer. However, its performance is affected by geography, technology and project size. The impact of firm size and other firm characteristics still need to be analysed.

Bodas–Freitas et al. (2012) conduct an empirical analysis to examine if the Kyoto incentives have stimulated the diffusion of SRET in BRICS. Their results suggest that the Kyoto mechanisms are not providing incentives that facilitate the SRET implementation and utilization in BRICS. Instead, these mechanisms are encouraging installed technological capacity. It should be noted that the analysis conducted by Bodas–Freitas et al. (2012) uses the secondary macro-level data. Further research on these issues requires hard data at the project level supported by in-depth interviews with project participants. Constructing such a database would enable researchers to examine the differences in the sustainability levels of the different types of SRET. Moreover, a newly constructed dataset could be used for determining the crucial factors that attract private buyers or governments to invest in CDM and JI projects.

Antoci et al. (2012) examine the impact of EU ETS on the diffusion of new clean technologies, taking into account firms' strategic behaviours and penalties for firms that exceed their emission targets. The authors analyse the evolutionary game model with pairwise random matching. They assume that each firm has to decide if it will adopt new clean technology or meet the emission targets using old technology and EU ETS allowances. The results show that properly defined penalties for non–compliant firms and an increase in permit trades can promote non-polluting scenarios and the diffusion of new clean technologies. To strengthen the realism of the model, the evolutionary game should be extended to possible matching in the case of *n* firms.

Further research on the impact of Kyoto instruments on technological diffusion should be intensified in order to clarify the dilemma of whether these instruments actually stimulate SRET diffusion.

1.4.3. Feed-in tariff and renewable energy portfolio standards

FIT refers to a policy instrument that reduces the risk of long-term investments in SRET. Under a FIT, SRE electricity producers are paid a fixed or premium amount of money for each kilowatt-hour generated and prices are guaranteed for a certain period of time. **Quota obligations**, also known as **RPS**, oblige suppliers to produce a certain percentage of their electricity from SRE sources. Certified renewable energy generators get certificates for units of electricity they produce (**Renewable energy certificates – RECs**). Renewable energy producers can sell RECs that prove the SRE source of electricity.

The basic economic rationale behind FITs and RPSs is to reduce the costs of SRE electricity production. The pros and cons of these instruments related to technology change are identified in a research paper by Johnstone et al. (2010). The authors conduct panel analysis using patent data for 25 countries over the period from 1978 to 2003 to examine the effect of environmental policies on SRET innovation. The contribution of their paper is twofold: (1) the cross-country focus allows them to examine the effects of FITs, production quotas and investment subsidies, and (2) they study patent activity with respect to different SRE sources. The results of Johnstone et al. (2010) indicate that different support instruments are effective for different SRE sources. Thus, all research conclusions and policy recommendations provided in studies that do not differentiate between SRET support instruments, SRET type or phase of development, should be taken with caution. In particular, Johnstone et al. (2010) find that FITs are effective in promoting innovation in more costly SRET, such as solar power technologies. On the contrary, obligations and tradable certificates are effective in inducing additional innovations in SRET that can almost compete with fossil fuels, such as wind power technologies. The authors also draw attention to further research possibilities, e.g., to consider other determinants of SRET patenting such as changes in natural conditions. The second research suggestion is to examine the role of country- and technology-specific patents in SRET diffusion and in CO_2 emission reductions. The findings by Johnstone et al. (2010) differ from a recent study (Boehringer, Cuntz, Harhoff, & Asane-Otoo, 2014) that identifies an insignificant impact of FITs on all types of SRET innovations. The econometric analysis by Boehringer et al. (2014) employs a negative binomial model with time and technology FE and focuses on Germany. Further research should extend the analysis by Boehringer et al. (2014) to other EU countries. The purpose of such an approach is to increase the robustness and generalizability of results on FIT effectiveness in triggering SRET innovations. In addition, by using this setting, the impact of other SRET supporting policy instruments should be addressed.

While the first two reviewed studies (Johnstone et al., 2010 and Boehringer et al., 2014) evaluate the impacts of FITs and RPSs on SRET innovations, studies by Falconett and Nagasaka (2010), Kažukauskas & Jaraite (2011), and Dong (2012) focus on the link between FITs, RPSs, governmental grants, carbon credits and SRET diffusion.

Dong (2012) examines the effectiveness of FIT and RPS standards in encouraging development of wind technologies. The author designs four different scenarios of modelling and conducts regression analysis using a panel data set for 53 countries for the period from 2005 to 2009. The main findings indicate that FIT increases total wind capacity more than RPS across countries. Dong (2012) does not find a significant difference in annual wind capacity installations supported either by FIT or RPS since 2005. The analysis also reveals that wind energy development is associated with high electricity demand and with high oil reliance. Further research should, among other issues, investigate how wind energy capacity development impacts other renewable energy industries.

Falconett & Nagasaka (2010) develop a probabilistic model to calculate the effects of government grants, feed-in tariffs and renewable energy certificates on the financial return of small hydro, wind energy and solar PV systems. The authors also examine the carbon credit impacts on the net present value of renewable projects and compare it with other instruments. A *carbon credit* is a permit that gives the right to the holder to emit one tonne of carbon dioxide. If countries or groups reduce the GHG below their emission allowances, they receive the credit. Others that pollute above their emission targets have to buy it. A carbon credit is a tradable financial instrument; a carbon credit's purpose is to reduce harmful emissions. The results of the Falconett & Nagasaka (2010) study indicate that the FIT is the most efficient instrument for supporting solar PV systems and wind SRE projects. The green certificate mechanism is the most suitable to increase the profitability of hydroelectric projects. In addition, Falconett & Nagasaka (2010) find that government grants and carbon credits are secondary support instruments in comparison with FIT and RECs. In conclusion, their study reveals that the efficiency of the policy support instruments depends on the stage of implemented SRET technologies. Within this context, further research should focus more on the design of policy instruments to enable them to increase SRET competitiveness on the electricity market.

One of the few micro-empirical analyses is the research paper by Kažukauskas & Jaraite (2011), who investigate how tradable green certificates (TGC) and FIT affect electricity generating firms. The authors use cross–country micro-level data for 27 EU countries in the period from 2002 to 2007. The main finding indicates that electricity generating firms operating in TGC countries were more profitable than firms operating in countries that implemented FIT. However, the exact sources of the higher profitability of firms in TGC environment are not identified and further research attention is required. Additionally, Kažukauskas & Jaraite (2011) find that the EU ETS does not have an impact on electricity-generating firms in countries with TGC policies in force. Future analyses should use the data from the second phase of the EU ETS to reinvestigate these issues.

1.5. Importance of further research for the renewable policy decision–making process

Different researchers might utilize insights from this review in order to contribute to the process of technology changes. Detailed gaps in the theoretical, econometric and case study literature are provided in section 1.4, organized according to the policy instruments used to support eco-innovations. However, major possible research opportunities can be summarized as follows.

In a frequently cited research paper, Jaffe, Newell, & Stavins (2002) emphasize that empirical evidence generally supports theoretical findings that market-based instruments have a greater significant positive impact on eco-innovation than command and control approaches. However, these authors also identify the empirical studies that are not consistent with the theory. Therefore, further work is needed in order to resolve the obvious dilemma.

In general, further research should include all main financial and fiscal policy support instruments in the analysis to empirically identify the most effective and efficient ones for fostering technological innovation and diffusion. In addition, other elements of country-specific SRE policy, such as political, economic, social, environmental and technical elements, should be evaluated. All of these renewable policy elements should be examined more thoroughly through different case studies and then used to support comprehensive and more general econometric findings. Despite various approaches to this emerging topic, there is a lack of evidence that focuses on SRE policy design.

Current research reveals that further efforts are needed to examine the stability and flexibility of country- and technology-specific instruments. Moreover, the impact of multiple support instruments on innovations and on consequent GHG emission reductions at the micro level should be further analysed. This analysis should control for technology- and firm-specific patents and use a longer series. Another interesting task would be to test how policy instruments increase energy efficiency through technological diffusion. Theoretical models should consider different settings (see, e.g., Liu & Espinola–Arredondo, 2013 for more detailed recommendations) when examining the impacts of policy instruments on technological change. In addition, they should fully account for spillover impacts of the incentives.

Focusing on Kyoto Protocol instruments, the EU ETS is the correct tool for GHG emission reductions because this is the primary goal of emission trading. The theoretical and empirical findings, although they are primarily case studies, confirm that the emission trading system can trigger innovation as well. The strength of its impact on technological change should be further examined, incorporating changes in the EU ETS design that are or will be included in the second (2008–2012), third (2013–2020), and fourth (2021–2028) trading periods (European Commission, 2014a). Studies to date have focused primarily on its pilot phase (2005–2007). Because the amounts of emission allowances issued under the EU ETS, free allocations and innovation patterns differ across sectors, further analyses should address different sectors covered by the scheme. In addition, further research should combine historical patents, environmental R&D, the EU ETS and firm financial data in order to conduct econometric analyses and provide more comprehensive results that cannot be obtained by only using case studies. However, in-depth case studies at the firm level focused on technological and firm-level differences in EU countries could significantly contribute to conclusions on the effects of the EU ETS. Comprehensive analyses of the impact of Kyoto instruments on technological diffusion should use project level data to clarify the unsolved dilemma: Do these instruments really promote diffusion of clean technologies?

The policy decision–making process requires all of these findings in order to secure sustainable renewable energy policies within countries.

1.6. Concluding remarks

This chapter provides a current literature review that considers the overall promotion of technology changes and determines further research suggestions. It takes an innovative approach in preparing crucial information for the SRE policy. In particular, it links multiple different support instruments with different SRET types and stages of the technological change process. Previous relevant review studies failed to systematically address this instrument specific – technology type specific – technology stage specific relationship.

It can be summarized that policy support instruments have a positive influence on technological innovation and implementation in the area of SRE. However, technology-specific analyses emphasize the importance of instrument choice pointing to differences in the effectiveness and efficiency of instrument types when promoting different renewables. Moreover, when examining their impact on eco–innovation, researchers predominantly compared two policy support instruments, e.g., FIT vs. RPS or energy taxes vs. incentives. When referring to a specific technology, especially when using the number of capacity installations as the dependent variable, they most often solely focus on wind or solar SRE sources. However, a summary of existing findings and identification of the gaps in the literature are valuable steps for further research contributions to this field.

Thus, addressing the further empirical challenges in identifying the most effective and efficient policy instrument mix to promote SRET has been the main purpose of this chapter. Among the proposed topics that require further research attention, this dissertation focuses on the following two topics: (1) macroeconomic analysis of the effectiveness of policy instruments in promoting technological diffusion and (2) energy policy instruments, firm's CO_2 emissions and firm's productivity / productivity growth. These topics urgently call for research attention to face harmful climate changes and global warming. One potential solution for climate change is identification of the most effective financial, fiscal, political, economic, social, and environmental drivers of SRET diffusion. Electricity generation from SRET does not have a negative effect on the environment compared to electricity generated from non-SRE sources. Additionally, in addition to positive environmental impacts, implementation of SRET technologies is expected to consequently increase firms' productivity growth. The next two chapters provide detailed empirical analyses of the above-mentioned topics.

2. MACROECONOMIC ANALYSIS OF THE EFFECTIVENESS OF POLICY INSTRUMENTS IN PROMOTING TECHNOLOGICAL DIFFUSION

2.1. Introduction

Sustainable renewable energy technologies (SRET) play a critical role in powering national economies, satisfying increasing energy needs, and reducing harmful emissions. Identifying potential strategies for accelerating the process of SRET diffusion is a crucial policy topic. Policymakers must choose the financial and fiscal instruments that are most effective at encouraging installation of renewable technologies and related electricity generation. The ultimate goal is to achieve the European Union's key "20-20-20", "2030", and "2050" targets. The "20-20-20" targets include reducing greenhouse gas (GHG) emissions, increasing energy consumption from renewables, and reducing primary energy use by 20 % compared to 1990 levels. The "2030" targets imply that GHG emissions should be reduced by at least 40 %, the share of energy consumption from sustainable renewable energy (SRE) sources should increase by at least 27 %, and energy efficiency should increase by 30 % by 2030 compared to 1990 levels. The "2050" target requires reducing GHG emissions by 80-90 % of 1990 levels by 2050. As argued by Sawin (2004) and Ragwitz et al. (2006) and later empirically confirmed by Dong (2012), effective SRE policies exist only in a limited set of countries. However, there is clear disagreement in the literature about the most effective policies to drive diffusion of SRET.

As such, the aim of this chapter is to bring clarity to the mixed findings in the literature by examining the effectiveness of the whole spectrum of source-specific financial and fiscal, political, socioeconomic, and environmental elements at promoting SRET diffusion. Determining the effectiveness of these elements will provide additional support for countries in their design of renewable energy policies. In this chapter, the term "most effective" refers to the policy instruments that achieve SRE policy objectives to the greatest extent. The source-specific financial and fiscal support instruments examined include technology-specific feed-in tariffs (FITs), renewable portfolio standards (RPSs) or quotas, caps, tenders, tax incentives, and investment grants. Political elements examined include corruption and energy import dependence. Socioeconomic elements examined include GDP; prices of coal, natural gas, and oil; electricity production from coal, oil, natural gas, and nuclear sources; energy consumption per capita, and technology-specific patents. The environmental element included is carbon intensity. Recent research (e.g., Johnstone et al., 2010) that focuses on patenting activity (the innovation phase) to study development of renewables[3] finds that the effect of SRE policies depends highly on the

[3] According to the European Environment Agency (European Environment Agency, 2011), development of renewables (i.e., the eco-innovation process) encompasses three stages: invention, innovation, and diffusion of technology. However, researchers usually differentiante only between innovation and diffusion.

type of SRE source. To validate this finding, this chapter's analysis of technological diffusion differentiates between four different renewable energy sources: wind, solar, biomass, and geothermal.

The impact of the SRE policy elements on technological diffusion is studied by using panel data for 26 EU countries during the period from 1990 to 2011. Two different measures of SRET diffusion—installed capacity of renewable sources and related actual electricity generation—are used to verify the robustness of the results. The results confirm that the impact of policy elements on technological diffusion varies across different renewable energy sources.

This chapter contributes to existing research in several ways. First, it expands the literature by providing a comprehensive and up-to-date review of relevant empirical studies, focusing on their methodological aspects. Second, it considers the impact of financial and fiscal, political, economic, environmental, and social elements on countries' source-specific SRE installed capacity and electricity generation. These elements have not yet been systematically addressed in the literature. Third, the analysis controls for the effects of the political environment, as measured by perceived corruption, and the socioeconomic environment, as measured by technology-specific patents. Fourth, it uses the latest International Energy Agency (IEA) data to test the impact of prices of non-renewable sources on the diffusion of renewables. Finally, it examines a longer time period, which allows for improving the precision of the estimates. The novel results, based on empirical research, aim to inform (perhaps even alarm) European Union (EU) policymakers that rapid reorganization of the existing SRE-supporting policy instrument mix is needed. Only by doing so can the EU climate change mitigation targets be met.

The chapter is organized as follows. Section 2.2 provides a current overview of the literature on effectiveness of renewable policy instruments in terms of reaching the EU's "20-20-20" and "2050" renewable energy targets. It also describes the chapter's empirical approach and econometric strategy. Section 2.3 describes the data and offers descriptive statistics. Section 2.4 presents results, which are discussed in Section 2.5. Section 2.6 concludes, considering further research avenues.

2.2. Methods

This section includes a survey of the relevant literature followed by a detailed description of the empirical approach and econometric issues.

2.2.1. Literature review of policy instruments aimed to facilitate the process of technological diffusion

Most papers dealing with renewable energy issues have taken an informative and qualitative approach (see Marques & Fuinhas (2011) for an overview). Ragwitz et al. (2006), Klessmann, Held, Rathmann, & Ragwitz (2011), and Winkel et al. (2011) provide comprehensive and informative country-, policy-, source-, technology-, and instrument-specific analyses for the EU countries, forming an excellent foundation for conducting further empirical investigations of SRE. Additionally, case studies (Lipp, 2007; Mabee, Mannion, & Carpenter, 2012) and other qualitatively oriented investigations have demonstrated that SRE-supporting policies are important drivers of SRET. However, econometric examinations of the impact of public policy instruments on the implementation of SRET are rare, although they have increased in the last two years. The summary of the relevant studies is provided in the Appendix D.

A few empirical studies have evaluated the effectiveness of the FITs and RPSs that are widely used to support renewable energy (see Dong (2012) for a review). However, these studies have failed to consider other support instruments, such as cap and trade schemes, tenders, tax incentives, and investment grants, which are included in this analysis. Most empirical papers dealing with renewable electricity technologies focus on the United States, mainly examining RPS (Huang et al., 2007; Carley, 2009; Yin & Powers, 2010; Shrimali & Kniefel, 2011). Another group of papers has focused mostly on total renewable sources, not any particular type of SRET or support instrument (e.g. Marques et al., 2010; Marques & Fuinhas, 2011; Marques et al., 2011; Marques & Fuinhas 2012a; Salim & Rafiq, 2012; Aguirre & Ibikunle, 2014). If researchers differentiate between renewable energy sources, they usually do not address all relevant sources (i.e., wind, solar, biomass, and geothermal). Wind is considered most frequently since data on wind technology installation is more comprehensive than that for other SRE sources (e.g., Bird et al., 2005; Menz & Vachon, 2006; Dong, 2012). Moreover, wind technologies have the greatest installed base among SRET (WWEA, 2010). The following sections review each of these literatures in turn. In addition, I review studies that focus on SRE innovations (Popp, Haščič, & Medhi, 2011; Bayer, Dolan, & Urpelainen, 2013) because they cover some variables (e.g., corruption) that should be included in the diffusion framework.

Among studies focused on US states and RPS, Carley (2009) applies a fixed effects vector decomposition (FEVD) model to panel data from 50 US states, 1998-2006. She finds that RPS has no significant impact on SRE electricity generation across states. Shrimali & Kniefel (2011), using panel data for the 50 states from 1991-2007, employ a state fixed effect model with state-specific time trends to estimate the impact of state policies on the diffusion of SRE sources. They find that RPS with capacity/sales requirements has a significant positive impact on geothermal and solar capacities. However, it has a significant negative impact on diffusion of wind and biomass SRE. Voluntary RPSs are found to be ineffective in supporting any type of renewable capacity.

Considering studies examining total renewables, Marques et al. (2010) conduct the first econometric analysis of SRET using EU countries' data. Marques & Fuinhas (2011) were first to apply the quintile regression approach to studying SRE, observing the 21 EU countries during two time spans: 1990 to 1998 and 1999 to 2006. They find that energy efficiency measures effectively promote renewables during the second period. However, these measures are not statistically significant in explaining SRE use in the first period. Salim & Rafiq (2012) use panel data and time series analysis to examine the determinants of SRE consumption in six major emerging economies: Brazil, China, India, Indonesia, the Philippines, and Turkey. Their results show that income and carbon emissions have been significant long-term drivers of SRE consumption in four countries; in the Philippines and Turkey, income is the main determinant of SRE consumption. Additionally, they find that oil prices have the smallest impact on SRE consumption. For Brazil and China, there is a significant short-term causal relationship between SRE consumption and income as well as between SRE consumption and carbon emissions. Aguirre & Ibikunle (2014) apply fixed effects vector decomposition and panel-corrected standard error (PCSE) estimators to panel data from the EU, OECD, and BRICS countries. Observing the period from 1990 until 2010, they examine which elements might impact macro-level growth in SRE. Among other findings, they note that some SRE policies slow down SRE investments, implying failures in their design.

Among studies that focus on source-specific technology, Dong (2012) uses panel data for 53 countries, covering five years starting from 2005. He finds that FITs promote total wind capacity better than RPS. For annual wind capacity installations, however, there is no significant difference between the two policies. His research also showed that wind energy development responds to high electricity demand and high oil dependence. Dong's paper has two main limitations: longer time series are needed to confirm that there is no multicollinearity when lags are included, and, with a larger sample size, the different policy designs should be tested for all included countries. Gan & Smith (2011) conduct one of the few empirical studies focused on bioenergy. The authors find that GDP, SRE, and bioenergy market-deployment policies significantly and positively affected the supply of SRE and bioenergy in OECD countries between 1994 and 2003; R&D expenditures, energy prices, CO_2 emissions, and other energy policies do not have significant impacts. The authors note that the magnitudes of these non-statistically significant variables were too small to significantly influence energy supply in the period observed, but longer series should be used to re-examine their impact before making final conclusions or policy recommendations.

Among studies that focus on technological innovations, Popp et al. (2011) assess the impact of technological change on technology-specific SRE capacity investments in 26

OECD countries from 1991 to 2004. The authors find that technological advances lead to increased investments, although the effect is small. Bayer et al. (2013) study the economic and political determinants of energy innovation in 74 countries from 1990 to 2009. Testing the impact of corruption within the technological innovation framework, they find that it does not have large effects on a country's production of international SRE patents. However, their results also suggest that democratic institutions contribute to innovation.

Taking a broader view than these studies, three recent analyses empirically examined the effect of multiple policy instruments in promoting SRET (Yin & Powers, 2010; Groba et al., 2011; Jenner, 2012). By introducing a new quantitative measure for RPS stringency that accounts for differences in RPS policy design among countries, Yin & Powers (2010) make a significant contribution to the SRE field. Focusing on US states and applying fixed effects estimation techniques, the authors find that RPS policies significantly and positively affect total in-state SRE development—a finding opposite that of Carley (2009). Moreover, the authors verify that this result is masked when RPS design characteristics are not taken into account. Groba et al. (2011) use panel data for 26 EU countries for the period from 1992 to 2008 and find that FIT policies are drivers of solar photovoltaic (PV) and onshore wind capacity development in the EU. They develop a new indicator for FIT strength to estimate the resulting return on investment, taking into account variability in tariff size, contract duration, digression rate, price of electricity, and electricity generation cost. Jenner (2012) develops an investment decision model to explain how diverse FIT policy designs affect the incentive to invest in SRET. The analysis, including 26 EU countries from 1990 to 2010, reveals that FITs effectively support geothermal, solar PV, and biomass electricity generation. No such link is found in the case of onshore wind, however. When using binary variables to test the impact of FITs on SRE generation, a significant positive impact is found only in the case of SRE generation from solar PV technologies; replacing these binary variables with the tariff amount produces similar results. Yin & Powers (2010) and Jenner (2012) argue that design of RPS and FIT policies might affect results but do not control for the design of other supporting policy instruments. However, they do draw conclusions about the instruments' effectiveness.

In summary, existing literature shows that financial and fiscal instruments promote SRET. However, recent empirical research has lacked sufficiently comprehensive analysis including, among other policy elements, examination of technology-specific support instruments used in particular EU countries. Only the most popular ones, such as FITs and RPS, have been studied in depth. In addition, the impact of these policy instruments on geothermal, solar, wind, and biomass technology implementation and resulting electricity generation should be tested. This is needed to capture both the actual and expected returns on investment. Another concern is that in an ideal setup, when policy and market uncertainties are taken into account, price- and quantity-based instruments could have similar impacts on the diffusion of SRE (see Menanteau, Finon, & Lamy, 2003). In practice, however, the evidence is mixed regarding the performance of policy instruments under the same or similar conditions. Mostly comparative case studies (Lipp, 2007; Butler & Neuhoff, 2008; Mabee et al., 2012) find that FITs are more effective than RPS in terms of promoting wind capacity development. Moreover, theoretical research that accounts for policy design of FITs and RPS (Sawin, 2004; Mitchell, Bauknecht, & Connor, 2006) concludes that FITs generally outperform RPS in terms of effectiveness for promoting SRET. Dong (2012) confirms these findings using total wind capacity as a dependent variable. With regard to annual wind capacity, no significant difference between FITs and RPS is found.

Another group of environmental economists (Jaffe, Newell, & Stavins, 2003; Fischer & Newell, 2008) argue that the RPS approach is superior to FITs at promoting wind development. The results of Jenner's (2012) econometric study show that FITs have positive and significant impacts on electricity generation from all technologies except for onshore wind. In addition, Jenner (2012) finds that biomass energy is not affected by a quota system, whereas energy from solar PV, geothermal, and onshore wind sources decreases significantly with a tighter quota. Furthermore, a Nordic wind power case study (Boomsma, Meade, & Fleten, 2012) finds that FITs support earlier investments, whereas renewable energy certificate trading after investment is undertaken generates incentives for larger projects. Given this diversity of results, some clarification is needed. This can be obtained by using a more comprehensive approach and controlling for additional factors.

Considering the gaps in the literature and the different conclusions obtained thus far, this research thus intends to provide a more comprehensive analysis in order to provide reliable guidance to policymakers to help them to revise SRE policies and programs. The next section details the empirical approach used to do so.

2.2.2. Empirical approach and econometric issues

The analysis examines the effectiveness of 26 EU countries' energy policy instruments. Different modeling scenarios are used to test the impact of financial and fiscal instruments on the diffusion of technology-specific renewable energy sources. I also control for political, socioeconomic, and environmental factors that could affect diffusion of SRE capacity. To make the results more robust, I employ two different measures of SRE diffusion, namely annual installation of renewable capacity and related annual electricity generation. Following Dong's (2012) approach, I consider the added technology-specific capacities and related electricity generation to be the appropriate proxies for the instruments' effectiveness. The model is estimated using a larger panel of data (from 1990 to 2011) than used in most previous studies. This helps improve the precision of the estimates, generate more reliable standard errors, and control for unobserved heterogeneity across states and years.

Based on past research, the following model is estimated:

$$\Delta X_{ijt} = \alpha_0 + \beta_1 FFIT_{ijt-1} + \beta_2 PFIT_{ijt-1} + \beta_3 RPS_{it-1} + \beta_4 CAP_{it-1} + \beta_5 TENDER_{it-1} + \beta_6 TIIG_{it-1} + \beta_n lnN_{it-1} + \delta T + u_{it} + \varepsilon_{it} \tag{2.1}$$

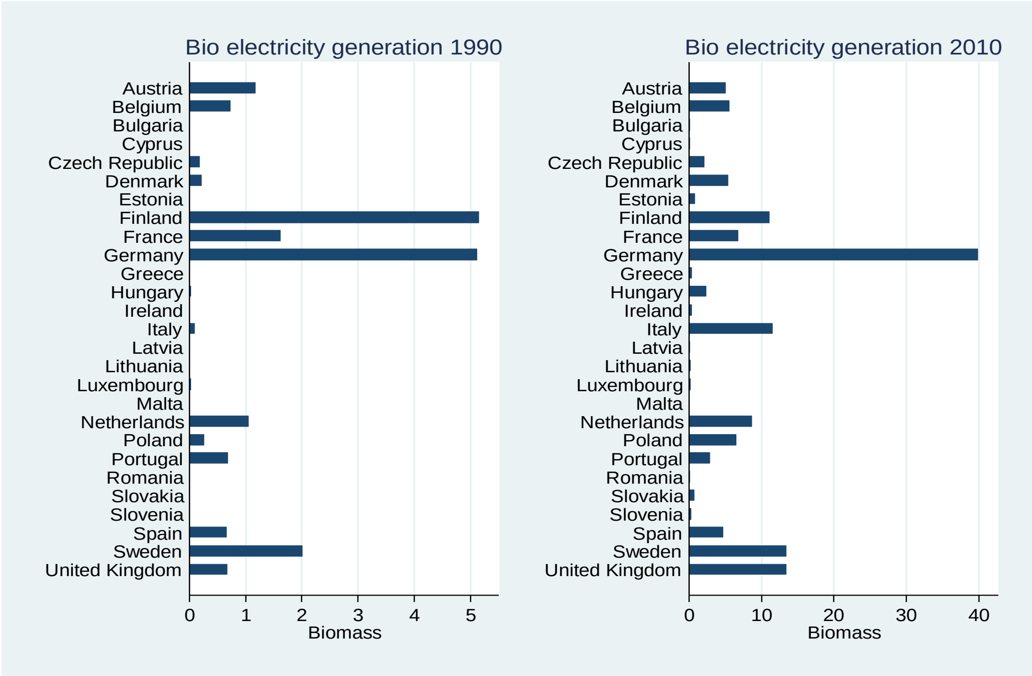
where *i* denotes a country, *j* denotes a particular SRE source, and *t* is time in years. ΔX_{ijt}, defined as $\Delta X_{ijt} = lnX_{ijt} - lnX_{ijt-1}$, indicates two different sets of dependent variables: installed source-specific SRE capacity and source-specific SRE generation. Financial and fiscal variables $FFIT_{ijt}$, $PFIT_{ijt}$, RPS_{it}, CAP_{it}, $TENDER_{it}$, and $TIIG_{it}$ denote fixed feed-in tariffs, premium feed-in tariffs, renewable portfolio standards, cap and trade schemes, tendering schemes, and fiscal incentives (tax incentives or grants), respectively. N_{it} is a vector of socioeconomic, political, and environmental control variables. Socioeconomic variables included are as follows: GDP; oil, coal, and natural gas prices; electricity production from oil, coal, natural gas, and nuclear sources; energy consumption per capita; and technology-specific patents. Political variables include corruption perception and energy import dependence. The environmental variable included is carbon intensity. δT denotes time dummies, u_{it} is a fixed effects term, and ε_{it} is the usual standard error. In order to reduce variability, all variables are expressed in natural logarithms. In the models considering the annual change in the dependent variable, all explanatory variables are time-lagged by *s* years (*s*=1).

The two types of dependent variables used indicate promotion of SRET, namely in terms of added geothermal, wind, and solar installed capacity and added geothermal, wind, solar, and biomass electricity generation. Added installed capacity is defined as the difference between cumulative SRE capacities in adjacent years. I choose installed capacity to capture the maximum potential effect of investment on a particular SRET under the different support schemes. Examining electricity generation allows for testing the investments' real effects. By using capacity added in a given year, I am able to separate out the effect of the overall trend in total capacity installation. The subsequent figures (2.1, 2.2, 2.3, and 2.4) compare the level of electricity generation from a particular SRET in the EU countries in 1990 and 2010. In most countries, electricity generation from SRET increased over the years. Additionally, the figures reveal that countries that are well known for strong technology-specific SRE potential and successful policy design actually do lead in generating electricity from those SRE sources.

Figure 2.1 shows that, among EU countries, Germany generated the highest amount of electricity from biomass sources in both 1990 and 2010. Figure 2.2 then reveals that France was the leading EU country with respect to solar electricity generation in 1990, while Germany occupied that position in 2010. Figure 2.3 indicates that the highest amount of electricity from wind sources in the EU was produced by Denmark in 1990 and Spain in

2010. The final figure (Figure 2.4) demonstrates that Italy, one of the few EU countries to generate electricity from geothermal sources, is also the most successful at doing so.

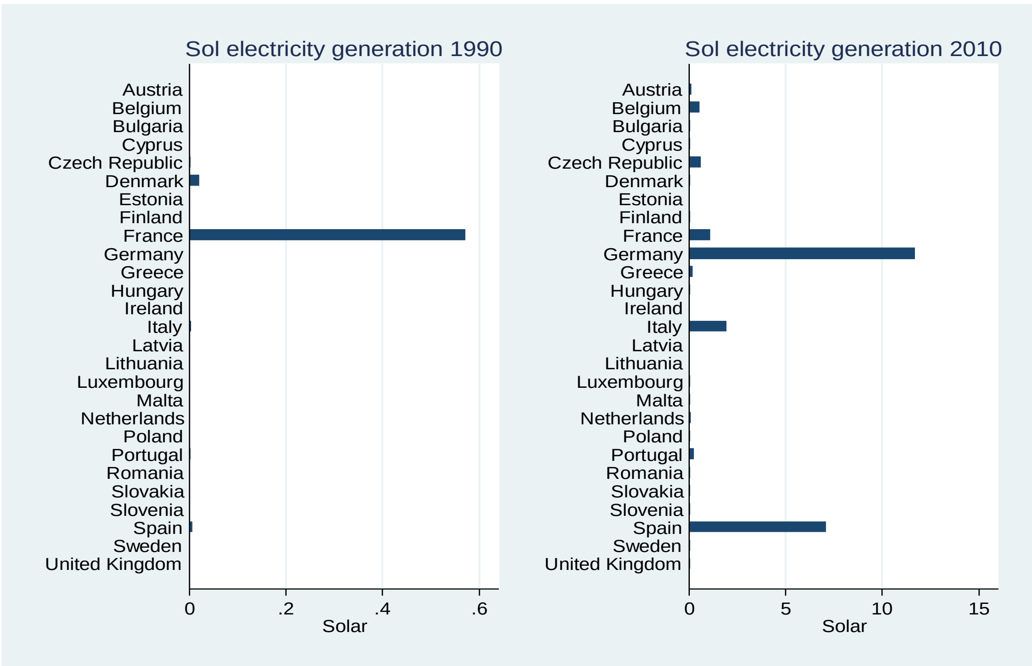
Figure 2.1: Electricity generation from biomass technologies (1990 vs. 2010)



Note. Values are expressed in million kilowatts.

Source: According to the EIA, *International Energy Statistics*, 2014.

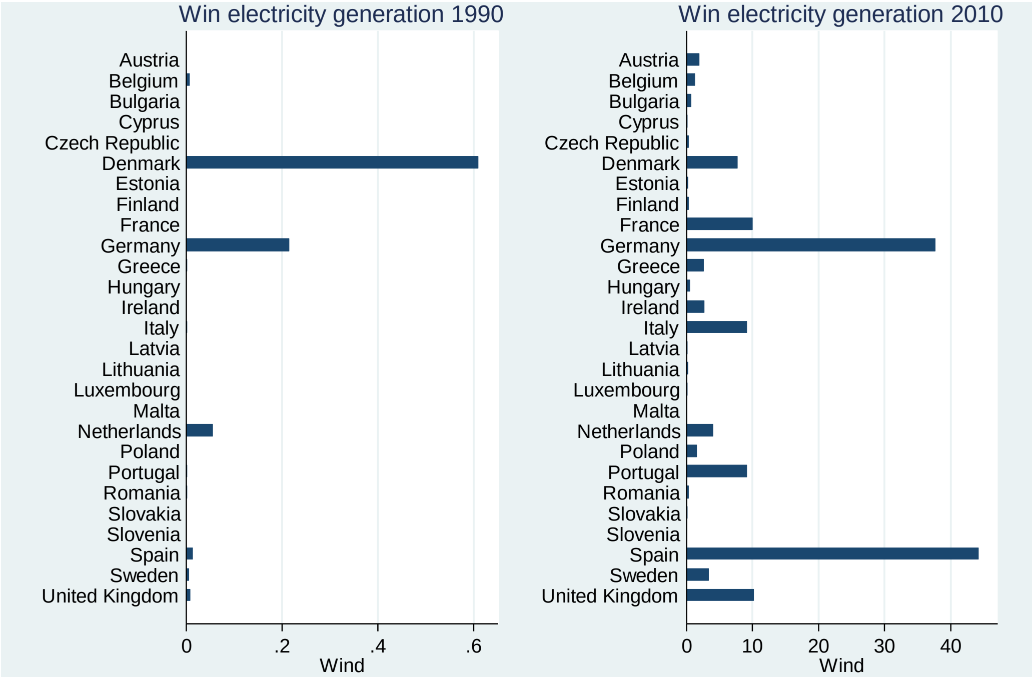
Figure 2.2: Electricity generation from solar technologies (1990 vs. 2010)



Note. Values are expressed in million kilowatts.

Source: According to the EIA, *International Energy Statistics*, 2014.

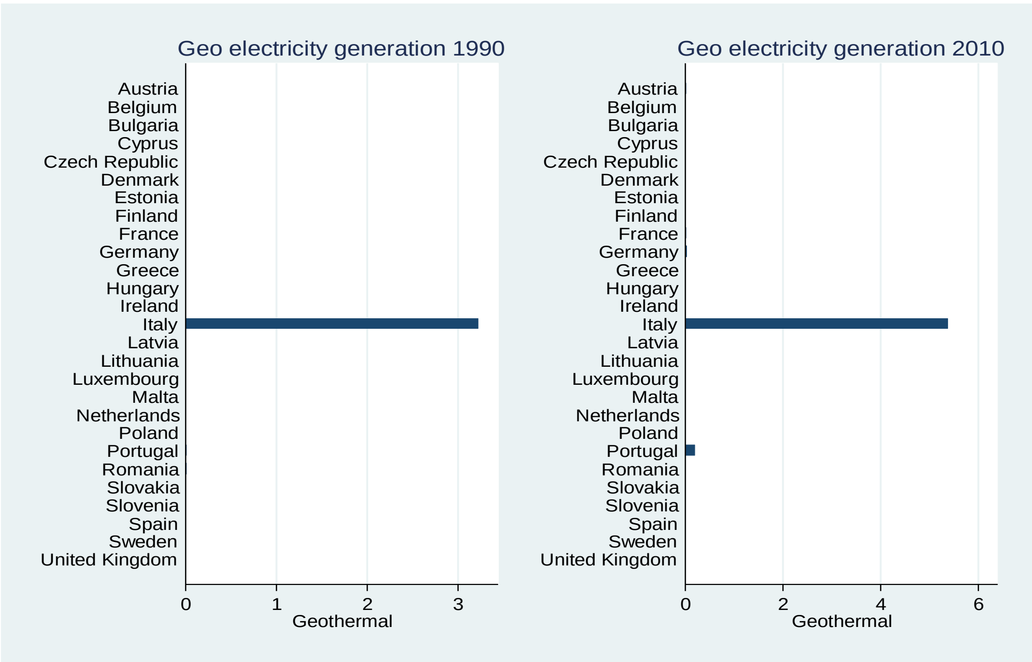
Figure 2.3: Electricity generation from wind technologies (1990 vs. 2010)



Note. Values are expressed in million kilowatts.

Source: According to the EIA, *International Energy Statistics*, 2014.

Figure 2.4: Electricity generation from geothermal technologies (1990 vs. 2010)



Note. Values are expressed in million kilowatts.

Source: According to the EIA, *International Energy Statistics*, 2014.

The explanatory variables included in the analysis are factors that might influence country-specific SRE policies and, consequently, achievements in installed capacity and SRE electricity generation. The explanatory variables are grouped into four categories: financial and fiscal, socioeconomic, environmental, and political. The respective data sources and measurement units for the variables are given in Table 2.1.

Table 2.1: Variables description

Variables of interest (independent)	**Description of the variable**	**Unit of measurement**	**Data source**	**Period**
GEO I.	Added geothermal electricity installed capacity	Thousand Kilowatts	UNEP/EIA	1991-2009
SOL I.	Added solar, tide & wave electricity installed capacity	Thousand Kilowatts	UNEP/EIA	1991-2009
WIN I.	Added wind electricity installed capacity	Thousand Kilowatts	UNEP/EIA	1991-2009
GEO G.	Added geothermal electricity net generation	Billion Kilowatthours	EIA	1990-2011
WIN G.	Added wind electricity net generation	Billion Kilowatthours	EIA	1990-2011
SOL G.	Added solar, tide & wave electricity net generation	Billion Kilowatthours	EIA	1990-2011
BIO G.	Added biomass and waste electricity net generation	Billion Kilowatthours	EIA	1990-2011
FIT	Feed In Tariff - prefix ‘f’ indicates fixed, and ‘p’ premium tariff - suffix w, s, b and g denotes wind, solar, tide & wave, biomass & waste, and geothermal, respectively	Binary	IEA/IRENA, Res-legal, REN21, Haas et al. (2011)	1990-2011
CAP	CAP	Binary	IEA/IRENA, Res-legal, REN21, Haas et al. (2011)	1990-2011
RPS	Renewable portfolio standard or quota obligation	Binary	IEA/IRENA, Res-legal, REN21, Haas et al. (2011)	1990-2011
TENDER	Tendering scheme	Binary	IEA/IRENA, Res-legal, REN21, Haas et al. (2011)	1990-2011
TI/IG	Tax incentives / investment grants	Binary	IEA/IRENA, Res-legal, REN21, Haas et al. (2011)	1990-2011
GDP	GDP based on purchasing power parity (PPP)	Constant 2005 int. dollars	World Bank	1990-2011
COALNEW	Coal prices	Indices of Energy End-Use Prices	Energy Prices and Taxes - IEA	1990-2011
OILNEW	Oil prices	Indices of Energy End-Use Prices	Energy Prices and Taxes - IEA	1990-2011
NGNEW	Natural gas prices	Indices of Energy End-Use Prices	Energy Prices and Taxes - IEA	1990-2011
EPCP	Electricity production from coal	% of total	The World bank	1990-2011
EPNGP	Electricity production from natural gas	% of total	The World bank	1990-2011
EPNUP	Electricity production from nuclear	% of total	The World bank	1990-2011
EPOP	Electricity production from oil	% of total	The World bank	1990-2011
ECpc	Energy consumption per capita	million BTU per person	EIA	1990-2011

(table continues)

(continued)

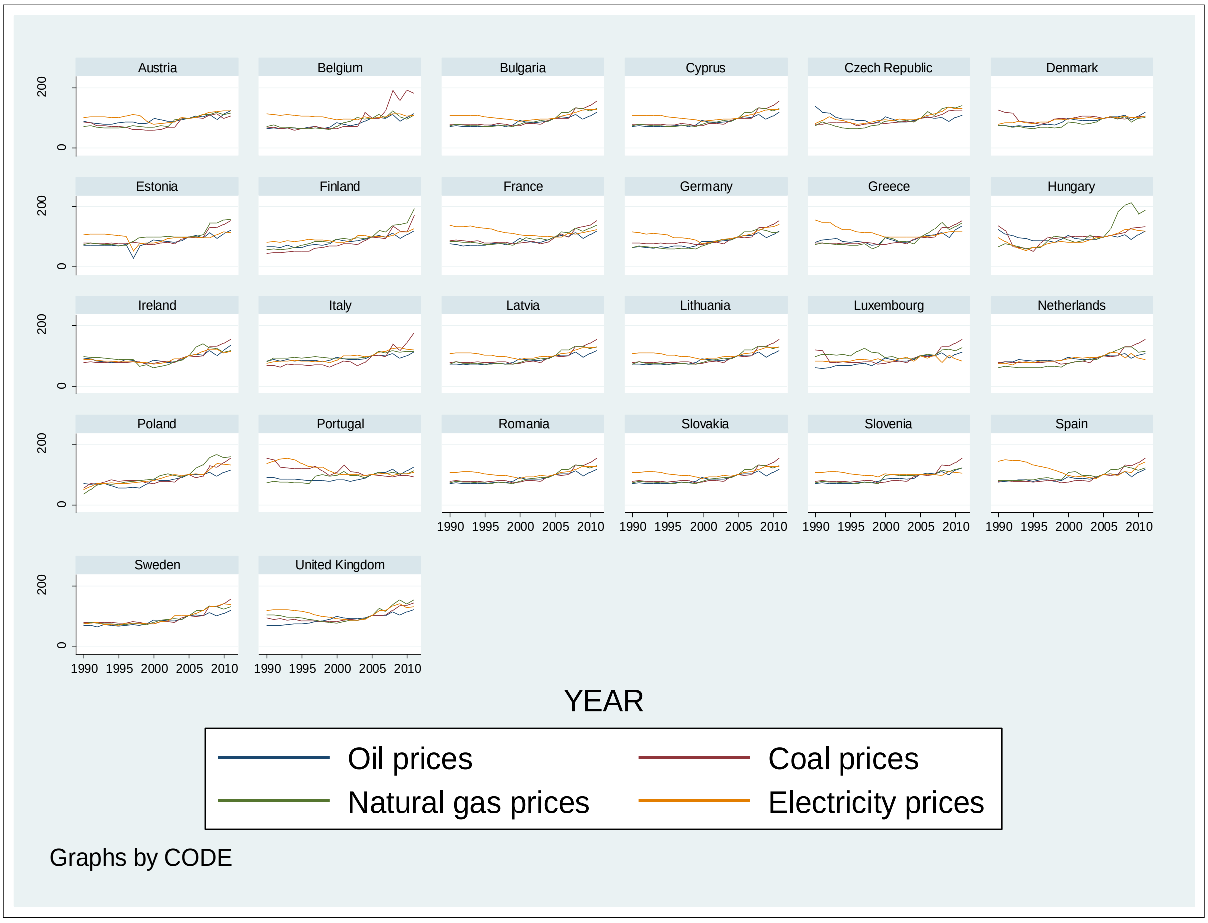
Variables of interest (independent)	Description of the variable	Unit of measurement	Data source	Period
SOLPAT	Solar patents	Integer	PATSTAT	1990-2011
WINPAT	Wind patents	Integer	PATSTAT	1990-2011
GEOPAT	Geothermal patents	Integer	PATSTAT	1990-2011
BIOPAT	Biomass & waste patents	Integer	PATSTAT	1990-2011
CPI	Corruption perception index	Score 0 (highly corrupt) – 100 (very clean)	Transparency International	1990-2011
EID	Energy import dependence	% of total	Eurostat	1990-2011
CI	Carbon intensity	Metric Tons of Carbon Dioxide per Thousand Year 2005 U.S. Dollars	EIA	1990-2011

The main variables of interest are dichotomous variables accounting for the impact of **financial and fiscal SRE policy instruments** (technology-specific fixed and premium FIT, RPS, cap, tender, and tax incentive or investment grant) on dependent variables. Each dummy variable equals 1 if the given policy instrument is in place and 0 otherwise; they are time variant, indicating the year the given policy instrument was adopted. The analysis accounts for different FITs for four SRET: geothermal, wind, solar, and biomass. Following the logic behind the support instruments, the estimated coefficients on these dummy variables should be positive and significant. However, taking into account the less positive and also non-unique findings of some relevant empirical studies (e.g., Carley, 2009; Marques et al., 2010; Groba et al., 2011), we might expect different instruments to have different impacts on different SRET. Moreover, other relevant SRE policy elements might impact the significance of the effect of financial and fiscal support for deployment of renewables. This more comprehensive approach should thus help clarify previous results. The **socioeconomic elements** considered are as follows: GDP; prices of coal, natural gas, and oil; electricity production from coal, oil, natural gas, and nuclear sources; energy consumption per capita; and technology-specific patents. As established in the literature (e.g., Carley, 2009; Groba et al., 2011), countries with higher **GDPs** should be more easily able to afford the costs of the SRET diffusion process. On the other hand, as explained by Marques & Fuinhas (2011), higher GDP might be associated with considerable existing infrastructure for traditional energy sources. Transitioning this to renewable infrastructure is expensive; therefore, a negative effect could also be expected. In line with the literature (Bird et al., 2005; Van Ruijven & van Vuuen, 2009; Marques et al., 2010; Marques & Fuinhas, 2011), I include **prices of coal, natural gas, and oil**[4] in the regressions. In countries without strong environmental policies, higher prices could lead consumers to decide to further rely on conventional sources. On the other hand, higher prices for electricity generated from non-SRE sources could make SRE more economically

[4] For non-OECD countries, indexes for OECD Total serve as a proxy.

feasible and competitive. Insignificant results could also be seen, potentially because small price increases are insufficient to encourage a shift towards renewables. Energy price movements (1990-2011) are presented in Figure 2.5, with the last decade seeing price increases for the majority of countries in the sample. Price increases are a consequence of energy crisis, higher demand (except in the period from the late 2008 to the early 2010), and of increased environmental awareness. The detailed data on oil, coal, natural gas and electricity prices is presented in the Appendix C.

Figure 2.5: Energy prices movements 1990 - 2011



Source: According to the IEA, *Energy Prices and Taxes Database*, 2014.

Following Huang et al. (2007), Marques et al. (2010), and Groba et al. (2011), I include **electricity production from coal, oil, natural gas, and nuclear sources** in the regressions. The traditional energy industry lobbies are expected to be barriers to SRE capacity diffusion. Carley (2009), Marques & Fuinhas (2011), and Marques et al. (2010; 2011) suggest using **energy consumption per capita** as a development indicator and a proxy for a country's energy needs; it is also used as an energy efficiency indicator (e.g. Toklu, Guney, Isık, Comaklı, & Kaygusuz, 2010; Marques & Fuinhas, 2011). The effect of this variable on SRE capacity could be positive if SRE sources meet additional energy needs or negative if conventional technologies dominate in doing so. I also include cumulative counts of **renewable energy patent applications** filed through the European

Patent Office (EPO)[5]. The patent search is conducted using the International Patent Classification (IPC) codes (Table 2.2), as determined by Popp et al. (2011). These codes relate directly to SRE in the areas of wind, solar PV, geothermal, and biomass and waste.

Table 2.2: IPC classes used in the research

Technology	Class and sub-classes
Wind	
Wind motors with rotation axis substantially in wind direction	F03D 1/00-06
Wind motors with rotation axis substantially at right angle to wind direction	F03D 3/00-06
Other wind motors	F03D 5/00-06
Controlling wind motors	F03D 7/00-06
Adaptations of wind motors for special use	F03D 9/00-02
Details, component parts or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D 11/00-04
Solar photovoltaic	
Devices consisting of a plurality of semiconductor components sensitive to infrared radiation, light - specially adapted for the conversion of the energy of such radiation into electrical energy	H01L 27/142
Semiconductor devices sensitive to infrared radiation, light - adapted as conversion devices	H01L 31/042-058
Generators in which light radiation is directly converted into electrical energy	H02N 6/00
Geothermal	
Production or use of heat, not derived from combustion - using natural or geothermal heat	F24J 3/00-08
Devices for producing mechanical power from geothermal energy	F03G 4/00-06
Biomass and waste	
Solid fuels essentially based on materials of non-mineral origin - animal or vegetable substances; sewage, town, or house refuse; industrial residues or waste materials	C10L 5/40-48
Engines or plants operating on gaseous fuel generated from solid fuel, e.g. wood	F02B 43/08
Liquid carbonaceous fuels	(C10L1
Gaseous fuels	or C10L3
Solid fuels	or C10L5)
AND	and
Dumping solid waste	(B09B1
Destroying solid waste or transforming solid waste into something useful or harmless	or B09B3
Incineration of waste; Incinerator constructions	or F23G5
Incinerators or other apparatus specially adapted for consuming specific waste or low grade fuels, e.g. chemicals	or F23G7)
Plants or engines characterized by use of industrial or other waste gases	F01K 25/14
Incineration of waste - recuperation of heat	F23G 5/46
Plants for converting heat or fluid energy into mechanical energy; use of waste heat	(F01K 27
Profiting from waste heat of combustion engines	or F02G 5/00-04
Machines, plant, or systems, using particular sources of energy - using waste heat, e.g. from internal-combustion engines	or F25B 27/02)

Source: Popp et al., *Technology and the diffusion of renewable energy*, 2011; Johnstone et al., *Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts*, 2010.

[5] EPO filings mainly include valuable innovations with high commercial value. I take counts based on the inventor country, looking at the priority date, which denotes the date of the first application in any country worldwide. These criteria are chosen because, for measuring a country's innovation performance, a count of resident inventors is more meaningful then a count of applicants. In addition, the only clearly meaningful date from a technological or economic point of view is the priority date, which is closest to the date of invention (OECD, 2001). In order to avoid double counting I use fractional counting if multiple inventors or IPC classes are provided.

Ideally, increased patenting activity should have a positive and significant impact on SRET development. However, as noted by Popp et al. (2011), policy-induced substitution might overwhelm this induced technological change.

Following basic logic, also supported by the literature (e.g., Van Ruijven & van Vuuen, 2009), higher **CO_2 intensity** should prompt investments in SRET. However, the effect might be different if countries show less environmental concern and consequently continue using fossil fuels.

Under **political elements,** I emphasize the potential impacts of perceived corruption and energy import dependence on the promotion of renewables. To the best of my knowledge, testing the effect of **perceived corruption** on technology-specific renewables deployment, together with other drivers of SRE diffusion, is a new contribution to the literature. As indicated by Bayer et al. (2013), corruption could negatively impact the process of transitioning to renewables if SRET opponents, such as power plant owners, bribe officials to raise barriers to SRE innovations. The same problem could occur in the case of technological diffusion. Following Marques et al. (2010), I focus on **import dependency in energy** as a proxy for energy security; higher reliance on foreign energy is expected to motivate domestic SRE development.

In order to further verify the robustness of the results, I follow Marques et al. (2010) and include a control variable for EU Directive 2001/77, which requires EU countries to implement policies supporting SRE development. This binary variable indicates the ratification year of the directive and applies to countries that were EU member states at that time. This variable should control for changes in the process of SRE development after the directive was implemented, as its implementation should motivate installation of SRE capacity and greater generation of related electricity. Moreover, I re-estimate the main model after excluding three countries (Italy, Germany, and Spain) that might be driving the results through their strong environmental achievements. Additionally, I test the adequacy of using a panel data structure via the Breusch and Pagan Lagrangian multiplier test (see Table 2.3). The null hypothesis of this test is rejected for six of the model specifications, confirming significant differences across entities—i.e., a panel effect.

Table 2.3: Breusch and Pagan Lagrangian multiplier test for random effects

	LM test1	LM test 2	LM test 3	LM test 4	LM test 5	LM test 6	LM test 7
χ^2	38.83	5.50	202.90	294.75	36.00	1399.90	0.00
Prob > χ^2	0.0000	0.0095	0.0000	0.0000	0.0000	0.0000	1.0000

Note: The results of the Breusch and Pagan Lagrangian multiplier test for random effects are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

I first perform estimations using the most common panel data techniques: ordinary least squares (OLS), random effects, and fixed effects. I then run the Hausman test (Hausman, 1978) to examine if, given the nature of the data, the fixed effects model is superior to the random effects one (see Table 2.4).

Table 2.4: The Hausman test results

	Hausman test1	Hausman test 2	Hausman test 3	Hausman test 4	Hausman test 5	Hausman test 6	Hausman test 7
χ^2	93.40	47.76	48.33	35.96	71.60	34.58	96.65
Prob > χ^2	0.0000	0.0003	0.0002	0.0107	0.0000	0.0107	0.0000

Note: The Hausman test results are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

The Hausman test rejects the null hypothesis that the unique errors are not correlated with the regressors; this validates the use of fixed effects to remove the time-invariant biases from the error term.

Furthermore, macro panels with long time series (longer than 20 years) usually face problems of heteroscedasticity, contemporaneous correlation (or cross-sectional correlation), and serial correlation (or first-order autocorrelation). To examine these issues, I first employ the modified Wald test for groupwise heteroscedasticity, which confirms the presence of heteroscedasticity (see Table 2.5).

Table 2.5: Modified Wald test for groupwise heteroskedasticity in fixed effect regression model

	Modified Wald test1	Modified Wald test 2	Modified Wald test 3	Modified Wald test 4	Modified Wald test 5	Modified Wald test 6	Modified Wald test 7
χ^2	2003.84	8169.94	50172.34	209.92	226.02	27962.53	992.65
Prob > χ^2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note: The results of the modified Wald test for groupwise heteroskedasticity are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

In order to test for cross-sectional dependence, I run the Pesaran cross-sectional dependence test, which confirms that the residuals are correlated among entities under six model specifications (see Table 2.6).

Table 2.6: Pesaran's test of cross sectional independence

	Pesaran's test1	Pesaran's test 2	Pesaran's test 3	Pesaran's test 4	Pesaran's test 5	Pesaran's test 6	Pesaran's test 7
Prob	0.0436	0.1910	0.0000	0.0011	0.0027	0.0000	0.0676

Note: The results of the Pesaran's test of cross sectional independence are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

To test for serial correlation, which deflates coefficients' standard errors and inflates the R^2, I run the Wooldridge test for autocorrelation in panel data (see Table 2.7). This confirms that, for four model specifications, the data is characterized by first-order autocorrelation.

Table 2.7: Wooldridge test for autocorrelation in panel data

	Wooldridge test 1	Wooldridge test 2	Wooldridge test 3	Wooldridge test 4	Wooldridge test 5	Wooldridge test 6	Wooldridge test 7
Prob > F	0.5144	0.9837	0.0008	0.0000	0.0031	0.5407	0.0332

Note: The results of the Wooldridge test for autocorrelation in panel data are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

The link between capacity installations/related electricity generation and policy, as determined by simple OLS regression, cannot be interpreted as causal due to the potential bias of omitted variables, such as country-specific characteristics. Moreover, basic OLS does not correctly estimate the standard errors in the presence of panel heteroscedasticity, cross-sectional correlation, or serial correlation of the errors, as present in this dataset. Therefore, the main model is estimated using fixed effects with year dummies (equivalent to OLS with country and time dummies) included to control for unobserved, time-invariant state-level characteristics. These characteristics, such as source-specific potential and pre-existing renewable capacity, could impact countries' energy policies and their subsequent development of SRET. Prior to the inclusion of the year fixed effects, I test to verify that they are required; as all years' coefficients are not jointly equal to zero (in four model specifications), it is necessary to include time fixed effects when running the fixed effects model (see Table 2.8).

Table 2.8: Testing for time-fixed effects

	Testparm 1	Testparm 2	Testparm 3	Testparm 4	Testparm 5	Testparm 6	Testparm 7
Prob > F	0.3934	0.0638	0.7001	0.0076	0.0000	0.2719	0.0411

Note: The results of the test for time-fixed effects are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

The use of the common fixed effects and random effects models with robust standard errors that control for heteroskedasticity but not for contemporaneous or serial correlation could lead to biased estimated standard errors. In order to solve this problem, Parks (1967) suggests using a feasible generalized least squares (FGLS) estimator. However, FGLS tends to produce inaccurate estimates of standard errors and can only be used when T is greater than N (Beck & Katz, 1995). Given this, Beck & Katz (1995) develop the PCSE, an alternative estimator that provides more accurate standard error estimates than FGLS with no or little efficiency loss. Therefore, following Shrimali & Kniefel (2011), Jenner (2012), and Marques & Fuinhas (2012a), I use the panel-corrected standard errors estimator to correct for heteroscedasticity and serial and contemporaneous correlation.

2.3. Data and Descriptive Statistics

The analysis is conducted using panel data for 26 EU countries and considering two time spans. One EU country, Malta, is excluded due to incomplete data. Data on wind, solar, geothermal, and biomass electricity generation covers a period of 22 years, from 1990 to 2011. 1990 is chosen as the starting year because most of the relevant policy instruments were adopted in the late 1990s. In addition, data by Johnstone et al. (2010) reveals that growth in wind and solar energy patenting activity was especially fast from the mid-1990s. Data on installed capacity is available from 1991 to 2009 and is provided only for wind, solar, and geothermal technologies. Data is derived from the relevant statistical sources: the Energy Information Administration (EIA), EUROSTAT, International Energy Agency (IEA), Res-legal, REN21, the United Nations Environment Programme (UNEP), the World Bank's World Development Indicators, Transparency International, and PATSTAT. Data is then merged to form a balanced panel. Table 2.9 provides summary statistics.

Table 2.9: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Added geothermal capacity installed	468	0.2906077	7.62399	-91	93
Added solar, tide & wave capacity installed	468	34.81411	266.9627	-39	4467
Added wind capacity installed	468	157.6774	444.7475	-352	3247
Added wind electricity generation	546	0.3170644	0.9908431	-1.935001	9.003002
Added solar electricity generation	546	0.0840221	0.5935326	-0.029	8.823999
Added biomass and waste electricity generation	546	0.2404192	0.6965191	-1.618	7.739
Added geothermal electricity generation	546	0.0048497	0.0476912	-0.25	0.6789999
Fixed feed in tariff for wind	572	0.3496503	0.4772769	0	1
Premium feed in tariff for wind	572	0.0734266	0.2610637	0	1
Fixed feed in tariff for solar	572	0.3496503	0.4772769	0	1
Premium feed in tariff for solar	572	0.0611888	0.2398861	0	1
Fixed feed in tariff for biomass	572	0.3006993	0.4589635	0	1
Premium feed in tariff for biomass	572	0.0769231	0.2667026	0	1
Fixed feed in tariff for geothermal	572	0.2534965	0.4353934	0	1
Premium feed in tariff for geothermal	572	0.0157343	0.1245545	0	1
First cap introduced	572	0.0681818	0.2522783	0	1
Renewable portfolio standard / quota obligation	572	0.1031469	0.3044168	0	1
Tendering scheme	572	0.1118881	0.3155047	0	1
Tax incentive / investment grant	572	0.1346154	0.341611	0	1
GDP	572	4.59E+11	6.53E+11	7.29E+09	2.83E+12
Coal prices	572	93.65844	24.765	46.19342	192.573
Oil prices	572	88.47796	15.30759	27.62831	139.2245
Natural gas prices	572	93.89317	24.31737	37.62953	211.6287
Electricity production from coal, %	572	32.39609	27.37131	1.00E-05	97.49284
Electricity production from natural gas, %	572	17.44163	19.16968	1.00E-05	93.90462
Electricity production from nuclear, %	572	21.63645	24.49528	1.00E-05	87.98622
Electricity production from oil, %	572	9.655245	19.97473	1.00E-05	100
Energy consumption per capita	572	157.4077	68.82126	61.82684	439.5631
Wind patents	572	2.015712	9.37446	1.00E-05	131
Solar patents	572	1.252487	5.234898	1.00E-05	64
Geothermal patents	572	0.176033	0.7436238	1.00E-05	8
Biomass patents	572	3.327464	8.532733	1.00E-05	82
Corruption perception index	572	6.201066	2.086322	2.15	10
Energy import dependence	572	53.87881	28.64878	-50.92	103.63
Carbon intensity	572	0.6405603	0.5655682	0.12837	3.44926

Table 2.11 presents the correlations among the variables examined here; the Variance Inflation Factor (VIF) test indicates that multicollinearity is not a concern, as the highest mean VIF among all models is 3 (see Table 2.10).

Table 2.10: The Variance Inflation Factor test

	VIF test 1	VIF test 2	VIF test 3	VIF test 4	VIF test 5	VIF test 6	VIF test 7
Mean VIF	3.02	3.05	2.83	3.07	3.07	2.87	3.11

Note: The VIF test results are reported for model specifications with different dependent variables. The dependent variables are added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively.

Table 2.11: Correlation matrix

	Ln added wind capacity installed	Ln added solar capacity installed	Ln added geo capacity installed	Ln added wind electricity generation	Ln added solar electricity generation	Ln added geo electricity generation	Ln added biomass electricity generation
Ln added wind capacity installed *t*	1.0000						
Ln added solar capacity installed *t*	0.5253*	1.0000					
Ln added geo capacity installed *t*	0.1688*	0.1608*	1.0000				
Ln added wind electricity generation *t*	0.8882*	0.5814*	0.1783*	1.0000			
Ln added solar electricity generation *t*	0.4651*	0.7016*	0.2202*	0.5359*	1.0000		
Ln added geo electricity generation *t*	0.1794*	0.2022*	0.7228*	0.1971*	0.2780*	1.0000	
Ln added biomass electricity generation *t*	0.6757*	0.4836*	0.1352*	0.6978*	0.4477*	0.1887*	1.0000
Fixed FIT for wind *t*-1	0.3731*	0.3950*	0.2171*	0.4297*	0.5098*	0.2462*	0.3325*
Premium FIT for wind *t*-1	0.1194*	-0.0444	-0.0536	0.1636*	-0.0805	-0.0704	0.0642
Fixed FIT for solar *t*-1	0.3731*	0.3950*	0.2171*	0.4297*	0.5098*	0.2462*	0.3325*
Premium FIT for solar *t*-1	0.0900	-0.0214	-0.0495	0.1292*	-0.0559	-0.0640	0.0612
Fixed FIT for geo *t*-1	0.3931*	0.4360*	0.0366	0.4258*	0.5450*	0.0657	0.3377*
Premium FIT for geo *t*-1	0.0416	-0.0775	-0.0237	0.0554	-0.0804	-0.0318	-0.0274
Fixed FIT for bio *t*-1	0.3451*	0.3810*	0.0132	0.3984*	0.5033*	0.0344	0.2979*
Premium FIT for bio *t*-1	0.0810	-0.0599	-0.0565	0.1261*	-0.0820	-0.0734	0.0119
First cap introduced *t*-1	0.1416*	0.0762	-0.0366	0.1908*	0.2003*	0.0142	0.1323*
RPS *t*-1	0.2581*	0.1697*	0.1092*	0.2860*	0.2118*	0.1330*	0.2894*
Tendering scheme *t*-1	0.2838*	0.1441*	-0.0329	0.3103*	0.1096*	0.0233	0.1778*
Tax incentive / investment grant *t*-1	0.1346*	0.0580	-0.0792	0.1603*	0.0274	-0.1010*	0.2133*
Ln GDP *t*-1	0.6451*	0.5984*	0.2304*	0.6451*	0.5780*	0.2827*	0.7163*
Ln coal prices *t*-1	0.2131*	0.1494*	0.0038	0.3438*	0.3641*	0.0469	0.2528*
Ln natural gas prices *t*-1	0.2727*	0.1294*	0.1056*	0.3851*	0.3576*	0.0904*	0.2631*
Ln oil prices *t*-1	0.2511*	0.2288*	0.0698	0.3536*	0.3684*	0.0954*	0.3190*
Electricity production from oil *t*-1	-0.1900*	-0.1150*	0.1705*	-0.2107*	-0.0651	0.1944*	-0.3593*
Electricity production from coal *t*-1	0.0489	-0.0943*	-0.0699	-0.0085	-0.1374*	-0.1028*	0.1120*
Electricity production from natural gas *t*-1	0.2323*	0.2235*	0.0800	0.3196*	0.1882*	0.0806	0.1672*
Electricity production from nuclear *t*-1	-0.1176*	0.0211	-0.1561*	-0.1077*	0.0369	-0.1735*	0.0309
Energy consumption per capita *t*-1	0.1761*	0.2320*	-0.0866	0.2144*	0.1351*	-0.1209*	0.3165*
Ln wind patents *t*-1	0.4818*	0.5773*	0.1543*	0.5614*	0.5763*	0.1819*	0.4726*
Ln solar patents *t*-1	0.4308*	0.5722*	0.1498*	0.4360*	0.5793*	0.1762*	0.4376*
Ln biomass patents *t*-1	0.4537*	0.5516*	0.1743*	0.4823*	0.4490*	0.1967*	0.5647*
Ln geo patents *t*-1	0.2904*	0.4518*	0.2192*	0.3174*	0.4507*	0.2098*	0.2772*
Ln corruption perception index *t*-1	0.4811*	0.4118*	-0.0250	0.5241*	0.2488*	-0.0447	0.5401*
Energy import dependence *t*-1	-0.0845	0.0257	0.1807*	-0.0714	0.1111*	0.2321*	-0.2394*
Ln carbon intensity *t*-1	-0.5709*	-0.4854*	-0.1687*	-0.6265*	-0.4309*	-0.2146*	-0.5638*

	Fixed FIT for wind *t*-1	Premium FIT for wind *t*-1	Fixed FIT for solar *t*-1	Premium FIT for solar *t*-1	Fixed FIT for geo *t*-1	Premium FIT for geo *t*-1	Fixed FIT for bio *t*-1
Fixed FIT for wind *t*-1	1.0000						
Premium FIT for wind *t*-1	-0.1914*	1.0000					
Fixed FIT for solar *t*-1	1.0000*	-0.1914*	1.0000				
Premium FIT for solar *t*-1	-0.1742*	0.9100*	-0.1742*	1.0000			
Fixed FIT for geo *t*-1	0.7953*	-0.1522*	0.7953*	-0.1385*	1.0000		
Premium FIT for geo *t*-1	-0.0866*	0.4523*	-0.0866*	0.4970*	-0.0689	1.0000	
Fixed FIT for bio *t*-1	0.8948*	-0.1713*	0.8948*	-0.1559*	0.8888*	-0.0775	1.0000
Premium FIT for bio *t*-1	-0.1996*	0.9589*	-0.1996*	0.8726*	-0.1588*	0.4337*	-0.1786*
First cap introduced *t*-1	0.1276*	0.3117*	0.1276*	0.1792*	0.1942*	0.2336*	0.1589*
RPS *t*-1	-0.0886*	-0.0884*	-0.0886*	-0.0804	-0.1273*	-0.0400	-0.1536*
Tendering scheme *t*-1	-0.0222	0.0470	-0.0222	-0.0854*	0.0377	-0.0424	0.0005
Tax incentive / investment grant *t*-1	-0.1130*	0.0041	-0.1130*	0.0228	-0.0403	-0.0471	-0.0772
Ln GDP *t*-1	0.2999*	-0.1423*	0.2999*	-0.1531*	0.3801*	-0.1718*	0.2505*
Ln coal prices *t*-1	0.2318*	0.1967*	0.2318*	0.1568*	0.2354*	0.1035*	0.2573*
Ln natural gas prices *t*-1	0.3735*	0.1241*	0.3735*	0.0726	0.2688*	0.1427*	0.3349*
Ln oil prices *t*-1	0.3161*	0.1769*	0.3161*	0.1283*	0.2777*	0.1001*	0.2849*
Electricity production from oil *t*-1	-0.0906*	0.0872*	-0.0906*	0.1016*	-0.1223*	-0.0578	-0.1605*
Electricity production from coal *t*-1	-0.0915*	0.1765*	-0.0915*	0.2158*	0.0297	0.2674*	-0.0090
Electricity production from natural gas *t*-1	0.2323*	0.0213	0.2323*	-0.0714	0.0133	-0.0856*	0.1832*
Electricity production from nuclear *t*-1	-0.0029	-0.2388*	-0.0029	-0.2173*	0.0279	-0.1080*	-0.0197
Energy consumption per capita *t*-1	0.1159*	-0.0021	0.1159*	0.0023	-0.0381	0.0214	0.1823*
Ln wind patents *t*-1	0.3035*	0.0824	0.3035*	0.0846*	0.3145*	-0.0428	0.2950*

	Ln added wind capacity installed	Ln added solar capacity installed	Ln added geo capacity installed	Ln added wind electricity generation	Ln added solar electricity generation	Ln added geo electricity generation	Ln added biomass electricity generation
Ln solar patents *t*-1	0.3300*	-0.0795	0.3300*	-0.0787	0.3613*	-0.0644	0.3063*
Ln biomass patents *t*-1	0.1837*	-0.0044	0.1837*	-0.0064	0.2104*	-0.1072*	0.1484*
Ln geo patents *t*-1	0.2781*	-0.0611	0.2781*	-0.0514	0.3321*	-0.0387	0.2820*
Ln corruption perception index *t*-1	0.0577	0.2303*	0.0577	0.2141*	0.0873*	0.0285	0.1222*
Energy import dependence *t*-1	0.2956*	-0.2583*	0.2956*	-0.3377*	0.1501*	-0.1272*	0.2476*
Ln carbon intensity *t*-1	-0.2547*	-0.1003*	-0.2547*	-0.0521	-0.2462*	0.1723*	-0.2249*

	Premium FIT for bio *t*-1	First cap introduced *t*-1	RPS *t*-1	Tendering scheme *t*-1	Tax incentive / investment grant *t*-1	Ln GDP *t*-1	Ln coal prices *t*-1
Premium FIT for bio *t*-1	1.0000						
First cap introduced *t*-1	0.2955*	1.0000					
RPS *t*-1	-0.0922*	-0.0804	1.0000				
Tendering scheme *t*-1	0.0380	0.2205*	0.0652	1.0000			
Tax incentive / investment grant *t*-1	0.0376	0.0699	0.2227*	-0.1346*	1.0000		
Ln GDP *t*-1	-0.1705*	-0.0180	0.2910*	0.2987*	0.0500	1.0000	
Ln coal prices *t*-1	0.1908*	0.3154*	0.2518*	0.1070*	0.1196*	0.0731	1.0000
Ln natural gas prices *t*-1	0.1238*	0.3166*	0.2966*	0.1298*	0.2155*	0.0663	0.7044*
Ln oil prices *t*-1	0.1791*	0.3005*	0.2391*	0.1343*	0.1664*	0.1533*	0.6040*
Electricity production from oil *t*-1	0.1792*	0.0391	-0.0882*	-0.0611	0.0312	-0.2451*	-0.0533
Electricity production from coal *t*-1	0.1451*	-0.0713	0.0180	-0.0937*	-0.0998*	0.0477	-0.0170
Electricity production from natural gas *t*-1	0.0014	0.1789*	0.1033*	0.1958*	-0.0310	0.0954*	0.1658*
Electricity production from nuclear *t*-1	-0.2490*	-0.1939*	-0.0105	0.0668	0.0352	0.1417*	-0.0492
Energy consumption per capita *t*-1	-0.0142	-0.0110	0.0225	-0.0254	0.2434*	0.0526	-0.0275
Ln wind patents *t*-1	0.0664	0.1631*	0.2512*	0.1379*	0.0997*	0.5333*	0.2551*
Ln solar patents *t*-1	-0.0878*	0.1384*	0.1607*	0.2028*	0.0045	0.5917*	0.1435*
Ln biomass patents *t*-1	-0.0102	0.0329	0.1691*	0.1968*	0.1043*	0.6436*	-0.0341
Ln geo patents *t*-1	-0.0657	0.0304	0.1671*	0.0681	0.0439	0.3970*	0.1481*
Ln corruption perception index *t*-1	0.2212*	0.1199*	0.0023	0.2397*	0.2199*	0.3094*	0.0967*
Energy import dependence *t*-1	-0.2173*	0.1015*	-0.1081*	-0.1039*	-0.0981*	-0.2208*	-0.0058
Ln carbon intensity *t*-1	-0.0950*	-0.1130*	-0.1294*	-0.3158*	-0.1301*	-0.5105*	-0.1762*

	Ln natural gas prices *t*-1	Ln oil prices *t*-1	Electricity production from oil *t*-1	Electricity production from coal *t*-1	Electricity production from natural gas *t*-1	Electricity production from nuclear *t*-1	Energy consumption per capita *t*-1
Ln natural gas prices *t*-1	1.0000						
Ln oil prices *t*-1	0.6445*	1.0000					
Electricity production from oil *t*-1	-0.0573	-0.0452	1.0000				
Electricity production from coal *t*-1	-0.0847*	-0.1374*	-0.2490*	1.0000			
Electricity production from natural gas *t*-1	0.1972*	0.2677*	-0.1534*	-0.3133*	1.0000		
Electricity production from nuclear *t*-1	-0.0331	-0.0631	-0.2827*	-0.3337*	-0.3228*	1.0000	
Energy consumption per capita *t*-1	0.0486	-0.0587	-0.2612*	-0.1532*	0.3673*	0.0811	1.0000
Ln wind patents *t*-1	0.2480*	0.2908*	-0.1560*	-0.1245*	0.2798*	0.0154	0.2829*
Ln solar patents *t*-1	0.0994*	0.1308*	-0.1280*	-0.1091*	0.2286*	0.0849*	0.2123*
Ln biomass patents *t*-1	0.0173	0.0284	-0.1393*	-0.0983*	0.1649*	0.0682	0.3377*
Ln geo patents *t*-1	0.1407*	0.1407*	-0.0635	-0.0304	0.0531	0.0534	0.0624
Ln corruption perception index *t*-1	0.0709	0.0871*	-0.1440*	-0.0821	0.2310*	-0.0432	0.6438*
Energy import dependence *t*-1	0.0851*	-0.0157	0.4262*	-0.4828*	0.1519*	-0.0301	0.1143*
Ln carbon intensity *t*-1	-0.1939*	-0.2511*	-0.0261	0.4441*	-0.2732*	-0.0023	-0.3910*

	Ln wind patents *t*-1	Ln solar patents *t*-1	Ln biomass patents *t*-1	Ln geo patents *t*-1	Ln corruption perception index *t*-1	Energy import dependence *t*-1	Ln carbon intensity *t*-1
Ln wind patents *t*-1	1.0000						
Ln solar patents *t*-1	0.5584*	1.0000					
Ln biomass patents *t*-1	0.5145*	0.5332*	1.0000				
Ln geo patents *t*-1	0.3887*	0.4874*	0.3348*	1.0000			
Ln corruption perception index *t*-1	0.4143*	0.3280*	0.4804*	0.1538*	1.0000		
Energy import dependence *t*-1	-0.0767	0.0120	-0.0985*	0.0569	-0.0919*	1.0000	

	Ln added wind capacity installed	Ln added solar capacity installed	Ln added geo capacity installed	Ln added wind electricity generation	Ln added solar electricity generation	Ln added geo electricity generation	Ln added biomass electricity generation
Ln carbon intensity *t*-1	-0.4710*	-0.3940*	-0.5243*	-0.2297*	-0.7253*	-0.1707*	1.0000

Note. Variables written with *t*-1 are lagged by one year, while other variables are contemporaneous.

2.4. Results

The results of this analysis contribute to the current debate on the effectiveness of renewable energy policies by identifying the most effective instruments (financial and fiscal, socioeconomic, political, and environmental). In interpreting the regression results, the instruments with the largest estimated coefficients are the most effective at achieving policy objectives with respect to SRE diffusion. All tables show regression results with different variable specifications.

Table 2.12 presents the results of models in which the dependent variables are added wind, solar, and geothermal installed capacity. Table 2.13 shows the results when the dependent variables are added wind, solar, geothermal, and biomass renewable electricity generation. In both tables, OLS results are presented next to fixed effect results with year dummies (equivalent to OLS with country and year dummies) and PCSE included for each dependent variable.

The Table 2.14 documents the differences arising when using robust standard errors instead of PCSE by presenting the results of FE regressions with year dummies and robust standard errors.

To additionally demonstrate the robustness of findings, the results with the control variable for EU Directive 2001/77 are presented in Table 2.15. The results obtained after excluding Italy, Germany, and Spain are presented in Table 2.16.

Table 2.12: Impact of policy elements on added SRE installed capacity (1990 - 2009) in 26 EU countries

Estimation technique	OLS	FE	OLS	FE	OLS	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)	WIN I.	WIN I.	SOL I.	SOL I.	GEO I.	GEO I.
Fixed feed in tariff *t*-1	3.404***	3.520***	2.435***	0.164	-1.687***	-0.271
	[4.93]	[4.19]	[3.79]	[0.22]	[-4.67]	[-0.49]
Premium feed in tariff *t*-1	4.669***	3.851**	1.916	0.537	1.345	0.423
	[3.84]	[2.46]	[1.55]	[0.35]	[1.25]	[0.65]
Cap *t*-1	-0.515	-1.037	-1.063	-2.140*	-0.965	-1.069
	[-0.36]	[-0.93]	[-0.80]	[-1.86]	[-1.33]	[-1.32]
Quota *t*-1	3.047***	2.399**	1.445	1.173	-0.622	-0.745
	[3.18]	[1.98]	[1.60]	[1.07]	[-1.28]	[-1.29]
Tender *t*-1	1.839**	1.575	-0.984	-0.500	-1.510***	0.026
	[2.00]	[1.27]	[-1.12]	[-0.31]	[-3.37]	[0.02]
Tax incentive/investment grant *t*-1	2.608***	-1.633	-0.323	0.763	-0.855**	-0.456
	[3.24]	[-1.35]	[-0.42]	[0.69]	[-2.16]	[-1.32]
Ln GDP *t*-1	1.936***	-2.398	1.918***	-6.045**	0.846***	-3.216**
	[6.60]	[-0.49]	[6.65]	[-2.13]	[6.00]	[-2.19]
Ln oil prices *t*-1	-4.735**	-5.310	3.451*	-0.106	-0.116	2.087**
	[-2.32]	[-1.50]	[1.81]	[-0.05]	[-0.11]	[2.08]
Ln coal prices *t*-1	-0.127	-0.288	2.184	-1.424	-2.140**	-2.157
	[-0.07]	[-0.10]	[1.36]	[-0.53]	[-2.48]	[-1.24]
Ln natural gas prices *t*-1	3.917**	4.788*	-2.615	-1.809	3.412***	3.771***
	[2.27]	[1.82]	[-1.58]	[-0.77]	[4.00]	[2.60]
Electricity production from oil *t*-1	-0.062***	0.081	-0.012	0.023	0.011	0.085
	[-3.73]	[0.99]	[-0.77]	[0.27]	[1.31]	[1.12]
Electricity production from coal *t*-1	0.014	0.071	-0.038**	0.035	-0.003	-0.011
	[0.72]	[0.96]	[-2.13]	[0.51]	[-0.32]	[-0.30]
Electricity production from natural gas *t*-1	0.013	0.087	-0.012	0.123*	-0.000	-0.009
	[0.62]	[1.23]	[-0.59]	[1.79]	[-0.03]	[-0.23]
Electricity production from nuclear *t*-1	-0.039**	0.061	-0.024	0.087	-0.022**	-0.027
	[-2.29]	[0.61]	[-1.53]	[1.06]	[-2.56]	[-0.66]
Energy consumption pc *t*-1	-0.023***	-0.018	-0.000	-0.019	-0.004	0.012
	[-4.07]	[-0.49]	[-0.01]	[-0.68]	[-1.43]	[1.13]
Ln patents *t*-1	0.045	-0.041	0.268***	0.033	0.114***	0.050
	[0.82]	[-0.88]	[4.83]	[0.46]	[2.99]	[1.15]
Ln corruption perception index *t*-1	5.541***	-2.067	5.349***	4.273*	-0.851	0.203
	[3.86]	[-0.98]	[3.97]	[1.95]	[-1.20]	[0.19]
Energy import dependence *t*-1	0.027**	0.046	0.022*	0.080**	0.019***	0.011
	[2.22]	[1.51]	[1.85]	[1.97]	[3.23]	[1.11]
Ln carbon intensity *t*-1	-1.541*	-3.131	1.674*	5.799**	-0.496	-1.528
	[-1.69]	[-0.88]	[1.95]	[2.27]	[-1.14]	[-0.97]
Constant	-57.708***	64.728	-76.008***	161.132**	-34.821***	52.579*
	[-4.42]	[0.54]	[-6.20]	[2.23]	[-5.42]	[1.43]
Observations	457	457	462	462	460	460
R-squared	0.637	0.619	0.528	0.534	0.275	0.472

Note. The dependent variable is added wind / solar / geothermal installed capacity. The dependent variable is defined as a rate of change. OLS results are presented before fixed effects (FE) results for each dependent variable. FE regressions control for time fixed effects. Panel corrected standard errors are in brackets. ***, **, *, denote significance at 1%, 5% and 10% significance levels, respectively. Ln represents logarithm, and *t*-1 indicates the one-year lag.

Table 2.13: Impact of policy elements on added SRE electricity generation (1990 - 2011) in 26 EU countries

Estimation technique	OLS	FE	OLS	FE	OLS	FE	OLS	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal, biomass electricity generation)	WIN G.	WIN G.	SOL G.	SOL G.	GEO G.	GEO G.	BIO G.	BIO G.
Fixed feed in tariff *t*-1	2.322***	1.174***	1.622***	0.389	-1.022***	-0.054	0.057	0.310
	[7.02]	[3.06]	[5.49]	[1.07]	[-4.39]	[-0.36]	[0.17]	[0.65]
Premium feed in tariff *t*-1	3.398***	0.707	1.052*	0.369	1.358**	0.145	0.031	0.046
	[5.91]	[1.06]	[1.87]	[0.58]	[2.01]	[0.51]	[0.06]	[0.07]
Cap *t*-1	-0.352	-0.389	0.704	-0.595	-0.378	-0.258	0.699	0.531
	[-0.57]	[-0.86]	[1.40]	[-1.08]	[-0.95]	[-0.82]	[1.29]	[0.51]
Quota *t*-1	1.476***	0.872*	0.535	0.648	-0.182	-0.370***	0.555	-0.454
	[3.28]	[1.90]	[1.33]	[1.14]	[-0.59]	[-3.25]	[1.23]	[-1.40]
Tender *t*-1	1.036**	1.394***	-0.483	-0.288	-0.633**	0.641	-1.026**	0.018
	[2.40]	[3.07]	[-1.17]	[-0.44]	[-2.22]	[1.38]	[-2.53]	[0.05]
Tax incentive/investment grant *t*-1	1.713***	-0.914*	-0.853**	0.247	-0.688***	-0.187	0.845**	-0.114
	[4.28]	[-1.95]	[-2.45]	[0.51]	[-2.69]	[-1.34]	[2.25]	[-0.17]
Ln GDP *t*-1	0.992***	2.245	1.210***	-1.720*	0.723***	-0.568	1.299***	2.700
	[6.93]	[1.17]	[8.95]	[-1.79]	[7.95]	[-1.28]	[8.78]	[1.26]
Ln oil prices *t*-1	-2.042**	-2.060*	1.621*	-0.879	0.266	0.662*	2.322**	0.610
	[-2.16]	[-1.71]	[1.87]	[-1.13]	[0.41]	[1.92]	[2.46]	[0.37]
Ln coal prices *t*-1	0.985	0.650	2.702***	-0.265	-0.173	-0.618	0.047	0.623
	[1.33]	[0.95]	[4.05]	[-0.28]	[-0.34]	[-0.92]	[0.06]	[0.92]
Ln natural gas prices *t*-1	2.360***	2.466***	0.787	-1.438	1.067**	0.387	0.949	-0.910
	[3.06]	[2.62]	[1.11]	[-1.47]	[2.10]	[0.85]	[1.27]	[-1.32]
Electricity production from oil *t*-1	-0.034***	0.013	-0.001	-0.017	0.003	-0.016	-0.030***	-0.032**
	[-4.13]	[0.45]	[-0.08]	[-0.65]	[0.59]	[-0.60]	[-3.84]	[-2.08]
Electricity production from coal *t*-1	0.010	0.027	-0.031***	-0.046*	-0.009	-0.013	0.011	0.060***
	[1.07]	[1.15]	[-3.77]	[-1.80]	[-1.52]	[-0.89]	[1.21]	[2.82]
Electricity production from natural gas *t*-1	0.023**	0.027	-0.032***	-0.026	-0.009	-0.019	-0.011	0.010
	[2.16]	[1.24]	[-3.46]	[-1.07]	[-1.35]	[-1.23]	[-1.08]	[0.56]
Electricity production from nuclear *t*-1	-0.015*	0.055	-0.017**	-0.010	-0.025***	-0.018	-0.008	-0.023
	[-1.82]	[1.55]	[-2.20]	[-0.46]	[-4.44]	[-1.25]	[-1.01]	[-1.06]
Energy consumption pc *t*-1	-0.013***	0.009	0.005**	-0.005	-0.002	-0.005	0.004	0.003
	[-4.79]	[0.82]	[2.12]	[-0.39]	[-1.06]	[-1.56]	[1.47]	[0.23]
Ln patents *t*-1	0.064**	0.011	0.142***	-0.019	0.057**	0.008	0.013	0.048**
	[2.45]	[0.66]	[5.50]	[-0.75]	[2.32]	[0.81]	[0.53]	[2.32]
Ln corruption perception index *t*-1	3.441***	-1.338*	0.936	-0.107	-0.982**	-0.238	2.010***	1.970*
	[5.03]	[-1.75]	[1.49]	[-0.14]	[-2.12]	[-0.98]	[3.01]	[1.78]
Energy import dependence *t*-1	0.016***	0.027**	0.012**	0.019	0.019***	0.000	-0.002	-0.004
	[2.66]	[2.55]	[2.24]	[1.43]	[5.16]	[0.09]	[-0.33]	[-0.36]
Ln carbon intensity *t*-1	-0.967**	-1.856	1.036***	3.495***	-0.318	1.145**	-0.789*	-2.921**
	[-2.22]	[-1.26]	[2.60]	[2.63]	[-1.12]	[2.13]	[-1.85]	[-2.31]
Constant	-43.543***	-75.738*	-63.168***	51.757**	-32.107***	-84.941*	-56.696***	-84.197
	[-6.93]	[-1.57]	[-11.20]	[2.13]	[-7.88]	[-1.60]	[-9.52]	[-1.58]
Observations	502	502	526	526	527	527	442	442
R-squared	0.741	0.787	0.603	0.643	0.341	0.775	0.701	0.751

Notes. The dependent variable is added wind / solar / geothermal / biomass electricity generation. The dependent variable is defined as a rate of change. OLS results are presented before FE results for each dependent variable. FE regressions control for time fixed effects. Panel corrected standard errors are in brackets. ***, **, *, denote significance at 1%, 5% and 10% significance levels, respectively. Ln represents logarithm, and *t*-1 indicates the one-year lag.

The results will be discussed for each of the four relevant variable categories: financial and fiscal, socioeconomic, political, and environmental.

To begin with the effectiveness of financial and fiscal instruments in promoting installation of SRE capacity (Table 2.12), fixed FITs, premium FITs, and quotas have positive and significant impacts on installed wind capacity. In particular, implementing a fixed FIT would stimulate installation of around 3,520 thousand kilowatts of additional wind capacity. Implementing a premium FIT would support an additional 3,851 thousand kilowatts of wind installations, and implementing quotas would support an additional 2,399 kilowatts of wind installations (after controlling for other factors in all cases). Tendering schemes also positively affect installed wind capacity, although this impact is not significant. Considering solar capacity, fixed and premium FITs, quotas, tax incentives, and investment grants all have positive but insignificant impacts on the implementation of solar technology. The models with added geothermal capacity as the dependent variable also identify positive but insignificant effects of premium FITs and tendering schemes. From Table 2.13, which displays the set of regressions with added electricity generation as the dependent variable, it is clear that FITs, quotas, and tenders effectively promote wind electricity production. When the dependent variables are added solar, geothermal, and biomass electricity generation, there are predominantly positive, although insignificant, links between financial and fiscal instruments and SRE electricity generation.

Next, we consider the effectiveness of socioeconomic elements in promoting renewables. As presented in Tables 2.12 and 2.13, there is a significant negative impact of GDP on solar and geothermal SRE installation and related electricity generation. An increase in oil prices leads to a significant increase in geothermal capacity installations and use, whereas an increase in natural gas prices contributes significantly to greater achievements in wind and geothermal capacity and electricity generation. The signs and significances of the impacts of electricity production from oil, coal, natural gas, and nuclear depend on the source, but the effect of energy consumption per capita on SRE capacity and electricity generation is insignificant. Finally there is a positive and significant impact of biomass innovations on electricity generation from biomass technologies.

Turning to the effectiveness of political elements in promoting SRE sources, the results presented in Tables 2.12 and 2.13 reveal a significant positive relationship between perceived corruption and both solar capacity installations and biomass electricity generation. However, there is a significant negative relationship between perceived corruption and electricity production from wind technologies. Moreover, higher energy import dependence significantly stimulates installation of solar technologies and generation of electricity from wind technologies. Considering the environmental factor examined, the results presented in Tables 2.12 and 2.13 show that increased carbon intensity motivates installation of solar capacity and related electricity generation. It has a negative impact, however, on installed capacity and energy generation using biomass. The

Table 2.14 presents the results of FE regressions with year dummies and robust standard errors to reveal the differences arising when using robust standard errors instead of PCSE.

Table 2.14: Regression with robust standard errors (instead with PCSE)

Estimation technique	FE	FE	FE	FE	FE	FE	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)/ Ln (added wind, solar, geothermal, biomass electricity generation)	WIN I.	SOL I.	GEO I.	WIN G.	SOL G.	GEO G.	BIO G.
Fixed feed in tariff *t*-1	3.922***	0.284	-0.332	1.811***	0.306	-0.022	0.398
	[4.01]	[0.35]	[-0.62]	[4.72]	[0.93]	[-0.12]	[0.86]
Premium feed in tariff *t*-1	3.618**	0.171	0.119	1.365*	0.171	0.254	0.130
	[2.06]	[0.10]	[0.15]	[1.89]	[0.32]	[1.31]	[0.17]
Cap *t*-1	-1.303	-1.841	-0.744	-0.613	-0.980*	-0.383	0.449
	[-1.00]	[-1.08]	[-1.11]	[-1.09]	[-1.90]	[-1.59]	[0.82]
Quota *t*-1	2.799***	1.512	-1.008**	1.311***	0.923**	-0.446**	-0.446
	[2.61]	[1.34]	[-2.13]	[2.65]	[2.15]	[-2.55]	[-1.10]
Tender *t*-1	2.205	-0.441	-0.421	1.938***	-0.288	0.683**	0.056
	[1.42]	[-0.22]	[-0.30]	[2.81]	[-0.46]	[2.04]	[0.08]
Tax incentive/investment grant *t*-1	-1.315	0.480	-0.665**	-1.040*	0.088	-0.244*	-0.110
	[-0.95]	[0.45]	[-1.99]	[-1.80]	[0.20]	[-1.91]	[-0.18]
Ln GDP *t*-1	-2.390	-6.459**	-3.073	1.365	-2.401**	-0.693	2.421*
	[-0.63]	[-1.97]	[-1.58]	[0.97]	[-2.13]	[-1.64]	[1.88]
Ln oil prices *t*-1	-6.119	0.308	2.846*	-1.720*	-0.641	1.127**	1.096
	[-1.44]	[0.14]	[1.74]	[-1.72]	[-0.71]	[1.98]	[0.69]
Ln coal prices *t*-1	0.118	-1.155	-2.486*	0.626	-0.388	-0.624	0.557
	[0.06]	[-0.44]	[-1.74]	[0.78]	[-0.38]	[-1.17]	[0.74]
Ln natural gas prices *t*-1	6.175***	-2.690	3.843***	3.495***	-1.768*	0.451	-0.725
	[3.04]	[-1.23]	[2.67]	[4.41]	[-1.84]	[0.91]	[-0.68]
Electricity production from oil *t*-1	0.067	0.021	0.099	0.012	-0.017	-0.008	-0.034
	[0.89]	[0.25]	[1.54]	[0.39]	[-0.56]	[-0.41]	[-1.25]
Electricity production from coal *t*-1	0.056	0.025	-0.016	0.024	-0.060**	-0.005	0.058**
	[0.84]	[0.42]	[-0.45]	[0.83]	[-2.50]	[-0.37]	[2.49]
Electricity production from natural gas *t*-1	0.071	0.110*	-0.013	0.034	-0.029	-0.010	0.009
	[1.04]	[1.69]	[-0.35]	[1.30]	[-1.05]	[-0.73]	[0.38]
Electricity production from nuclear *t*-1	0.057	0.057	-0.033	0.045	-0.010	-0.011	-0.031
	[0.67]	[0.63]	[-0.92]	[1.38]	[-0.31]	[-0.82]	[-0.80]
Energy consumption pc *t*-1	-0.003	-0.020	0.013	0.015	0.005	-0.006	0.009
	[-0.10]	[-0.70]	[1.17]	[1.17]	[0.48]	[-1.40]	[0.72]
Ln patents *t*-1	-0.036	0.024	0.064	0.017	-0.021	0.018	0.047*
	[-0.60]	[0.31]	[1.15]	[0.76]	[-0.75]	[1.10]	[1.78]
Ln corruption perception index *t*-1	-3.118	4.509**	0.170	-1.149	0.258	-0.087	2.060
	[-1.44]	[2.06]	[0.24]	[-1.17]	[0.32]	[-0.44]	[1.51]
Energy import dependence *t*-1	0.032	0.082**	0.016*	0.019	0.019*	0.003	-0.003
	[0.85]	[2.33]	[1.65]	[1.48]	[1.79]	[0.82]	[-0.24]
Ln carbon intensity *t*-1	-4.270	5.676*	-1.785	-3.122**	3.748***	1.102*	-3.432**
	[-1.32]	[1.94]	[-1.25]	[-2.32]	[3.77]	[1.84]	[-2.52]
Constant	56.768	183.654**	45.305	-58.446	68.875**	6.412	-82.002**
	[0.60]	[2.27]	[0.94]	[-1.64]	[2.48]	[0.65]	[-2.48]
Observations	457	462	460	502	526	527	442
R-squared	0.733	0.637	0.574	0.864	0.765	0.862	0.790

Notes. The dependent variable is added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively. The dependent variable is defined as a rate of change. FE regressions control for time fixed effects. Robust standard errors are in brackets. ***, **, *, denote significance at 1%, 5% and 10% significance levels, respectively. Ln represents logarithm, and *t*-1 indicates the one-year lag.

The results of models that include the additional control variable (EU 2001/77 Directive), presented in Table 2.15, strongly support the robustness of the main results. Implementation of the directive significantly contributes to increases in installed capacity and electricity generation using solar technology. On the other hand, it has significant negative impact on installed wind capacity and biomass electricity generation. Moreover, variables' signs and significance remain largely the same after excluding Italy, Germany, and Spain from the sample, offering additional confirmation of the robustness of the results (Table 2.16).

Table 2.15: Robustness check 1: Impact of policy elements on added SRE installed capacity / electricity generation (1990 - 2011) in 26 EU countries after including additional variable

Estimation technique	FE	FE	FE	FE	FE	FE	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)/ Ln (added wind, solar, geothermal, biomass electricity generation)	WIN I.	SOL I.	GEO I.	WIN G.	SOL G.	GEO G.	BIO G.
EU Directive 2001/77 *t*-1	-2.357**	1.766*	0.321	-0.940	0.529	0.347***	-2.574***
	[-2.15]	[1.83]	[0.95]	[-1.36]	[1.22]	[3.07]	[-5.91]
Fixed feed in tariff *t*-1	3.360***	0.345	-0.264	1.153***	0.434	-0.038	0.115
	[4.04]	[0.44]	[-0.48]	[3.15]	[1.20]	[-0.25]	[0.27]
Premium feed in tariff *t*-1	3.643**	0.884	0.459	0.691	0.470	0.190	-0.415
	[2.39]	[0.58]	[0.71]	[1.05]	[0.73]	[0.69]	[-0.52]
Cap *t*-1	-0.855	-2.264**	-1.103	-0.362	-0.618	-0.276	0.860
	[-0.75]	[-2.01]	[-1.34]	[-0.80]	[-1.14]	[-0.91]	[0.89]
Quota *t*-1	2.735**	0.936	-0.793	1.034**	0.580	-0.432***	0.028
	[2.23]	[0.86]	[-1.31]	[2.32]	[0.98]	[-3.60]	[0.09]
Tender *t*-1	2.084*	-0.829	-0.019	1.590***	-0.347	0.597	0.438
	[1.71]	[-0.51]	[-0.01]	[3.35]	[-0.52]	[1.29]	[1.23]
Tax incentive/investment grant *t*-1	-1.764	0.802	-0.431	-0.988**	0.273	-0.164	-0.275
	[-1.45]	[0.75]	[-1.27]	[-2.17]	[0.57]	[-1.16]	[-0.40]
Ln GDP *t*-1	-3.162	-5.603**	-3.099**	1.945	-1.656*	-0.495	2.094
	[-0.67]	[-2.04]	[-2.10]	[1.04]	[-1.76]	[-1.19]	[0.96]
Ln oil prices *t*-1	-5.523	0.090	2.083**	-2.037*	-0.884	0.668*	0.614
	[-1.61]	[0.04]	[2.06]	[-1.76]	[-1.15]	[1.96]	[0.36]
Ln coal prices *t*-1	0.304	-1.764	-2.236	0.847	-0.335	-0.688	1.284*
	[0.11]	[-0.66]	[-1.27]	[1.27]	[-0.35]	[-1.03]	[1.95]
Ln natural gas prices *t*-1	4.718*	-1.732	3.824***	2.435***	-1.390	0.439	-1.175*
	[1.81]	[-0.75]	[2.61]	[2.68]	[-1.42]	[0.98]	[-1.77]
Electricity production from oil *t*-1	0.083	0.020	0.084	0.012	-0.018	-0.016	-0.031*
	[1.03]	[0.24]	[1.10]	[0.44]	[-0.66]	[-0.62]	[-1.91]
Electricity production from coal *t*-1	0.055	0.046	-0.009	0.020	-0.042*	-0.010	0.039*
	[0.75]	[0.66]	[-0.25]	[0.86]	[-1.65]	[-0.71]	[1.67]
Electricity production from natural gas *t*-1	0.093	0.117*	-0.010	0.029	-0.027	-0.019	0.014
	[1.32]	[1.72]	[-0.25]	[1.34]	[-1.10]	[-1.27]	[0.78]
Electricity production from nuclear *t*-1	0.038	0.106	-0.023	0.046	-0.009	-0.017	-0.048**
	[0.38]	[1.27]	[-0.57]	[1.29]	[-0.40]	[-1.20]	[-2.29]
Energy consumption pc *t*-1	-0.018	-0.019	0.012	0.009	-0.004	-0.005	0.002
	[-0.50]	[-0.66]	[1.13]	[0.80]	[-0.33]	[-1.47]	[0.13]
Ln patents *t*-1	-0.013	0.030	0.049	0.020	-0.020	0.008	0.038*
	[-0.27]	[0.41]	[1.13]	[1.18]	[-0.79]	[0.78]	[1.85]
Ln corruption perception index *t*-1	-2.890	4.852**	0.302	-1.643**	0.085	-0.102	0.952
	[-1.33]	[2.26]	[0.29]	[-2.02]	[0.11]	[-0.39]	[0.97]

(table continues)

(continued)

Estimation technique	FE	FE	FE	FE	FE	FE	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)/ Ln (added wind, solar, geothermal, biomass electricity generation)	WIN I.	SOL I.	GEO I.	WIN G.	SOL G.	GEO G.	BIO G.
Energy import dependence *t*-1	0.043	0.086**	0.011	0.026**	0.021	0.001	-0.010
	[1.45]	[2.13]	[1.12]	[2.54]	[1.53]	[0.35]	[-0.88]
Ln carbon intensity *t*-1	-1.413	4.195	-1.783	-1.199	3.023**	0.835	-0.568
	[-0.39]	[1.54]	[-1.09]	[-0.82]	[2.09]	[1.53]	[-0.47]
Constant	90.255	151.264**	52.579*	-75.783*	51.757**	3.156	-84.941*
	[0.76]	[2.15]	[1.43]	[-1.57]	[2.13]	[0.29]	[-1.60]
Observations	457	462	460	502	526	527	442
R-squared	0.631	0.552	0.470	0.795	0.647	0.778	0.768

Notes. The dependent variable is added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively. The dependent variable is defined as a rate of change. FE regressions control for time fixed effects. Panel corrected standard errors are in brackets. ***, **, *, denote significance at 1%, 5% and 10% significance levels, respectively. Ln represents logarithm, and *t*-1 indicates the one-year lag.

Table 2.16**:** Robustness check 2: Regressions after excluding Germany, Italy, and Spain

Estimation technique	FE	FE	FE	FE	FE	FE	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)/ Ln (added wind, solar, geothermal, biomass electricity generation)	WIN I.	SOL I.	GEO I.	WIN G.	SOL G.	GEO G.	BIO G.
Fixed feed in tariff *t*-1	2.900***	0.073	-0.163	1.231***	0.753*	0.161	0.055
	[2.87]	[0.08]	[-0.38]	[2.75]	[1.85]	[1.04]	[0.10]
Premium feed in tariff *t*-1	3.743**	0.899	0.613	0.769	0.497	0.255	0.056
	[2.29]	[0.56]	[0.90]	[1.11]	[0.72]	[1.05]	[0.09]
Cap *t*-1	-1.339	-2.346*	-0.959	-0.441	-0.598	-0.238	0.536
	[-1.02]	[-1.83]	[-1.25]	[-0.86]	[-0.99]	[-0.71]	[0.50]
Quota *t*-1	2.183*	1.435	-0.357*	1.103**	1.131*	0.008	-0.174
	[1.65]	[1.03]	[-1.67]	[2.16]	[1.82]	[0.08]	[-0.43]
Tender *t*-1	1.613	-0.317	-0.487	1.572***	-0.119	0.617	0.016
	[1.32]	[-0.18]	[-0.47]	[2.93]	[-0.18]	[1.44]	[0.04]
Tax incentive/investment grant *t*-1	-1.815	0.973	-0.210	-0.748	0.448	-0.001	0.037
	[-1.45]	[0.83]	[-0.69]	[-1.55]	[0.85]	[-0.01]	[0.05]
Ln GDP *t*-1	-3.233	-5.880**	-1.807	1.779	-1.410	-0.144	2.644
	[-0.64]	[-1.99]	[-1.36]	[0.95]	[-1.56]	[-0.37]	[1.27]
Ln oil prices *t*-1	-4.890	-0.668	1.362*	-2.499**	-1.157	0.078	-0.274
	[-1.28]	[-0.32]	[1.72]	[-2.13]	[-1.34]	[0.23]	[-0.15]
Ln coal prices *t*-1	-0.951	-0.595	-1.105	0.527	-0.222	-0.585	0.698
	[-0.31]	[-0.23]	[-0.95]	[0.71]	[-0.22]	[-0.96]	[0.85]
Ln natural gas prices *t*-1	5.248*	-2.042	2.120*	2.688***	-1.667	0.018	-1.278*
	[1.82]	[-0.77]	[1.83]	[2.73]	[-1.60]	[0.04]	[-1.73]
Electricity production from oil *t*-1	0.071	-0.005	0.033	0.019	-0.015	-0.032	-0.065***
	[0.71]	[-0.05]	[0.47]	[0.48]	[-0.43]	[-0.92]	[-3.27]
Electricity production from coal *t*-1	0.060	0.058	0.013	0.028	-0.039	-0.005	0.065***
	[0.78]	[0.81]	[0.46]	[1.02]	[-1.33]	[-0.32]	[2.66]
Electricity production from natural gas *t*-1	0.075	0.137*	0.015	0.030	-0.019	-0.009	0.016
	[1.00]	[1.94]	[0.47]	[1.18]	[-0.71]	[-0.54]	[0.76]
Electricity production from nuclear *t*-1	0.042	0.160*	0.008	0.049	-0.006	-0.011	-0.014
	[0.37]	[1.93]	[0.25]	[1.24]	[-0.26]	[-0.75]	[-0.54]
Energy consumption pc *t*-1	-0.018	-0.018	-0.000	0.013	0.001	-0.004	-0.002
	[-0.47]	[-0.60]	[-0.02]	[1.17]	[0.08]	[-1.22]	[-0.16]

(table continues)

(continued)

Estimation technique	FE	FE	FE	FE	FE	FE	FE
DEPENDENT VARIABLE Ln (added wind, solar, geothermal installed capacity)/ Ln (added wind, solar, geothermal, biomass electricity generation)	WIN I.	SOL I.	GEO I.	WIN G.	SOL G.	GEO G.	BIO G.
Ln patents *t*-1	-0.045	0.053	0.048	0.009	-0.010	0.004	0.036
	[-0.84]	[0.65]	[1.63]	[0.40]	[-0.37]	[0.37]	[1.36]
Ln corruption perception index *t*-1	-1.781	1.979	0.752	-1.459	-0.128	0.182	2.492*
	[-0.68]	[0.85]	[1.29]	[-1.54]	[-0.15]	[0.70]	[1.86]
Energy import dependence *t*-1	0.052	0.070	0.004	0.019*	0.014	-0.003	-0.006
	[1.53]	[1.63]	[0.60]	[1.66]	[1.00]	[-1.58]	[-0.50]
Ln carbon intensity *t*-1	-2.811	4.467	0.002	-2.385	2.678*	1.149*	-2.360*
	[-0.75]	[1.52]	[0.00]	[-1.60]	[1.91]	[1.70]	[-1.88]
Constant	81.211	160.65**	24.504	-62.245	51.188**	-2.935	-76.580
	[0.66]	[2.17]	[0.69]	[-1.33]	[2.12]	[-0.27]	[-1.50]
Observations	403	408	411	443	467	471	386
R-squared	0.571	0.411	0.233	0.767	0.558	0.683	0.734

Notes. The dependent variable is added wind / solar / geothermal installed capacity and added wind / solar / geothermal / biomass electricity generation, respectively. The dependent variable is defined as a rate of change. FE regressions control for time fixed effects. Panel corrected standard errors are in brackets. ***, **, *, denote significance at 1%, 5% and 10% significance levels, respectively. Ln represents logarithm, and *t*-1 indicates the one-year lag.

2.5. Discussion

In this chapter, I have compared the effectiveness of policy elements aiming at supporting renewables as applied within EU countries. By comparing regressions with different dependent variables, I was able to confirm the importance of particular policy elements in the process of SRE diffusion. With a longer data series, this chapter has avoided the small sample sizes and omitted variable biases that constrained previous studies (e.g., Menz & Vachon, 2006). Therefore, its findings can be generalized across the sample of countries considered, excepting those without (or with low) technology-specific SRE potential.

The Renewable Energy Directive 2009/28/EC that amended and repealed the Directive 2001/77/EC, sets individual SRE targets for EU member countries (European Commission, 2009). These national targets are consistent with the EU overall SRE targets (20-20-20, 2030, and 2050). EUFORES (2014) shows that nine EU countries (Austria, Bulgaria, Cyprus, Denmark, Estonia, Italy, Latvia, Romania, Sweden) are progressing well towards the 2020 targets achievements. However, it is questionable whether four EU countries (Finland, Germany, Ireland, Slovakia) will reach their national SRE targets with current support instruments in force. The remaining fourteen EU countries are not progressing well towards 2020 targets, which indicates that their current SRE policies should be reconsidered. If policy measures would be revised on national level, all EU countries would have a potential to achieve or even exceed their national 2020 SRE targets (EUFORES, 2014).

Considering the effectiveness of financial and fiscal instruments in promoting renewables, this chapter's results are consistent with research noting that financial and fiscal support instruments drive diffusion of SRET. This is especially true for fixed and premium FITs, quotas, and tendering schemes in the case of wind technology installations and electricity generation. The impacts of financial and fiscal instruments on solar, geothermal, and biomass installations and electricity generation are also predominantly positive, although not significant. These results are consistent with previous studies (e.g., Groba et al. 2011), which have confirmed that FITs have driven the development of wind energy. Employing an indicator for RPS strength, those authors also identify a positive and significant impact of RPS on added installed capacity for both solar and wind technologies. However, Dong (2012), applying a fixed effects model including time-variant policy variables, shows a positive but insignificant link between FITs and installed wind capacity. On the other hand, Jenner (2012) finds that FITs, measured in nominal units or indicated as a binary variable, only effectively promote solar technologies. The author also demonstrates a negative significant impact of RPS on electricity generation from all SRE sources. However, Jenner's (2012) finding of a positive impact of tax incentives on solar electricity generation supports this chapter's results.

Furthermore, the coefficients on certain support instruments are not statistically significant in certain models. However, when they are positive, having the relevant instrument(s) in force is more effective for a particular country than not implementing the instrument at all. For example, more mature technologies are associated with lower electricity generation costs than are newer clean technology alternatives. Investors could be motivated to install such technologies by receiving a return on their investments or via climate change awareness campaigns, even though their investments would not be (completely) supported by financial instruments. When the coefficients are negative, however, implementing the relevant instrument(s) would be less effective than having no instrument(s) in force. Johnstone et al. (2010) and Aguirre & Ibikunle (2014) further explain that the negative impact of financial and fiscal instruments on SRET diffusion could be a consequence of a lack of investor confidence in the oft-changing level of the instruments' support. When deciding on the policy support instruments, countries that are progressing slower than planned could look into the experience of leading countries in technology specific diffusion. According to the EIA (EIA, 2015) data, among EU countries, Germany generated the highest amount of electricity from biomass sources in 2012 (followed by UK, Italy, Sweden, Finland and Poland). Germany was the leading EU country in solar electricity generation in 2012 (followed by Italy, Spain, France, Czech Republic and Belgium). The highest amount of electricity from wind sources in the EU was also produced by Germany in 2012 (followed by Spain, UK, France, Italy, and Denmark). Italy, one of the few EU countries that generate electricity from geothermal sources, is also the most successful at doing so (followed by Portugal, Germany, France, UK and Austria).

Turning to the socioeconomic elements, the results show that GDP has a negative impact on solar and geothermal installations and electricity production. This negative effect of GDP on these newer and more expensive technologies suggests that these countries might have considerable traditional energy infrastructure. Therefore, they might be more reluctant to assume the high costs of investment in renewables. In line with these findings, Groba et al. (2011) determine that GDP per capita has a significant negative impact on solar installations when a binary variable is used to indicate a FIT. The results for fossil fuel prices show that an increase in oil prices leads to an increase in installation and use of geothermal capacity. An increase in natural gas prices, in contrast, contributes to greater achievements in installing wind and geothermal capacity and using it for electricity generation. These positive impacts arise because increases in the prices of non-renewables raise investors' interest in SRE capacity. Marques & Fuinhas (2011) do not find significant effects of prices on the contribution of renewables to the energy supply, perhaps because their analysis ends in 2006 and does not reflect recent oil price rises, especially those in 2008. It also does not control for continuously rising environmental awareness, the increased stringency of countries' SRE policies (aiming to achieve faster SRE development), or the financial crisis, which also affected the SRE sector. This chapter, in contrast, does control for price effects, including a longer time span and employing the newest IEA data, and finds that electricity production from natural gas has positive impact on solar capacity installations. This is partially consistent with Groba et al.'s (2011) finding that the natural gas share has a positive and significant impact on cumulative installed capacity for all SRE sources. The rationale behind this is that, due to its environmental and logistical benefits, natural gas is a potential complement to SRE electricity generation. Producing electricity from natural gas causes less harmful emissions than when it is produced using other fossil fuels. The results also show that innovation efforts in biomass technologies lead to an increase in the level of electricity later produced from biomass renewables.

Considering the political elements, the results show a significant positive relationship between perceived corruption and both installed solar capacity and electricity generation from biomass. It is surprising that countries with higher levels of perceived corruption tend to be more oriented toward SRE and suggests that there is a greater amount of corruption in the SRE infrastructure construction industry. The results also reveal a significant negative relationship between perceived corruption and electricity production from wind technology. This negative relationship confirms that corrupt energy lobbies prevent the development of wind resources. Bayer et al. (2013) do not find a significant impact of corruption on SRE innovations. However, this chapter is the first to test the impact of corruption on SRE diffusion and related electricity generation within this framework.

As expected, the results also show that higher energy import dependence stimulates the installation of solar and wind capacity and related electricity generation. This indicates that higher reliance on foreign oil motivates domestic technological development. Marques et al. (2010) also identify a positive impact of energy import dependence on the contribution of renewables to the total energy supply. The same effect is identified by Groba et al. (2011) for added wind capacity and by Jenner (2012) for solar and geothermal electricity generation.

As expected, higher carbon intensity supports the installation of solar capacities and related electricity generation. However, it has a negative impact on biomass installations and electricity generation, which is consistent with the results of Marques et al. (2010) and Romano & Scandurra (2011). This suggests that increased pollution is not necessarily a sufficiently strong motivator for investment in SRET. Moreover, these results could reinforce the conclusion that the majority of countries decide to pay penalties for emitting CO_2 instead of investing in SRET. The interests of energy lobbies prevail in these countries, making it challenging to achieve environmental quality improvements.

Considering EU Directive 2001/77, the results confirm that the implementation of the directive significantly contributed to increased solar energy capacity and electricity generation. However, in line with the findings of Marques et al. (2010), the directive has not stimulated wind capacity installations or biomass electricity generation; this suggests that, in the case of larger required capacities, the directive's requirements alone are insufficient to instigate a switch to wind and biomass technologies.

To summarize, this paper's results confirm the equivalent importance of all segments of SRE-supporting policies, be they financial, fiscal, economic, social, environmental, or political.

2.6. Conclusions and Policy Implications

This chapter aimed to show how the effectiveness of different SRE policy elements varies by technology. Its analysis was motivated by several factors: i) energy generation from traditional (non-renewable) sources has negative consequences for the atmosphere and the human population; ii) the policy instruments promoting renewables must be improved if the EU "20-20-20", "2030" and "2050" SRE targets are to be met; and iii) countries have recognized the need to reduce their dependence on foreign fuels. The US Energy Information Administration's data on SRE capacity shows that in the majority of EU countries, with the exception of Austria, Latvia, and Sweden, SRET do not successfully compete with conventional thermal alternatives. In order to increase the share of technology-specific SRE installed capacity in total installed capacity, as well as the share of renewables in electricity generation, countries should examine the set of financial and fiscal instruments they are using to promote particular SRE sources.

The novelty of this chapter lies not only in its focus on the main financial and fiscal policy support tools and their effectiveness in promoting technology-specific SRE sources but also in its examination of the broader palette of additional drivers of SRE diffusion. In the empirical approach, I controlled for a range of socioeconomic, environmental, and political factors. The results should prove instructive for political decision-makers when reconsidering the implementation or removal of policy instruments promoting specific SRE sources.

The main conclusions can be summarized as follows. First, across all models, fixed and premium FITs, quotas, and tendering schemes show the best performance in terms of promoting wind technologies and electricity generation from wind. The impacts of financial and fiscal support instruments on solar, geothermal, and biomass installations and electricity production are predominately positive but insignificant. Second, other explanatory variables have technology- and model-dependent impacts. Design of SRE policies should include reorganization of SRE-promoting policy instruments within certain EU countries, including the possible cancellation of existing instruments and the implementation of new ones. Policymakers should carefully consider the set of financial and fiscal instruments that is in force in a particular country in order to better support the diffusion of solar, geothermal, and biomass technologies.

Building on the work of Jenner (2012), future research should aim to develop more sophisticated indicators that would incorporate all design elements of a particular policy support mechanism. The research could also be extended to cover developing countries. In addition, researchers have typically focused only on the positive characteristics of SRE sources; additional research could further examine the negative aspects. Marques & Fuinhas (2012a) note that the use of natural resources could also be influenced by uncontrollable factors such as weather conditions. As such, non-SRE capacities, such as natural gas power plants, are still needed to guarantee a stable power supply. However, energy storage techniques are continuously evolving, and the question to which extent could SRET replace traditional technologies in the future requires further attention.

3. RENEWABLE ENERGY POLICY INSTRUMENTS AND FIRM PRODUCTIVITY

3.1. Introduction

The official aim of the European Union Emission Trading Scheme (EU ETS) is to '*promote reductions of greenhouse gas emissions (GHG) in a cost-effective and economically efficient manner*' (European Commission, 2003). Although it is known that the EU ETS aims for reduction in emissions, there is no consensus on how this scheme affects firms' productivity / productivity growth, and how it operates in combination with other renewable support instruments. Two major sustainable renewable energy (SRE) support instruments are the feed in tariffs (FITs) and the renewable portfolio standards (RPSs). Both policy instruments, FIT and RPS, aim to support sustainable renewable energy technologies (SRET) and to consequently increase firms' productivity / productivity growth while reducing their CO_2 emissions.

The potential relationship between SRET support instruments and firms' performance is first discussed by Porter (1991). In short, the well-known Porter hypothesis states that firms that invest in SRET could consequently increase their economic and environmental performance. However, these SRET support instruments work in a different way. The FIT guarantees a fixed or premium price per kWh of sustainable renewable electricity produced, usually for a period of 15–20 years. In such way, it reduces the risk of investments in SRET. In contrast, the RPS requires a certain amount of electricity to be produced from SRE sources. The RPS system induces the higher level of risk for SRET investors, as the prices of green certificates in the RPS system are uncertain (see e.g. Mitchell et al., 2006; Agnolucci, 2007), and higher administrative costs (Reddy & Painuly, 2004; Dinica, 2006; Klinge Jacobsen, Pade, Schröder, & Kitzing, 2014; Eleftheriadis & Anagnostopoulou, 2015). Thus, firms operating in countries that implemented RPS (henceforward 'RPS countries') could be less interested in investing in more productive SRET because of the higher SRET investment costs and the uncertain returns on investments (Stern, 2007). However, Menanteau et al. (2003) and Jaraitė & Kažukauskas (2013) also point to potential greater success of RPS than FIT in supporting the firm performance by arguing that RPS is more market oriented and thus should create more competitive markets for SRE electricity.

In line with the rationale behind the Porter hypothesis, firms with higher SRET investments are expected to achieve higher productivity (and productivity growth) and vice versa. The existing research on the effectiveness of FITs and RPSs (see Dong, 2012 for more details), their cost-efficiency, their links with market distortions and transaction costs (see Jaraitė & Kažukauskas (2013) for a review of relevant studies) is divided. Some studies argue that FITs outperform RPSs, while other studies find that RPSs are better than

FITs in achieving SRE policy goals. However, the majority of these analyses were conducted at a macro level, usually comparing the impact of FITs and RPSs on the process of technological change. First, there is no robust evidence identifying factors that contribute to decrease in CO_2 emissions of firms covered by the EU ETS. Second, studies on the productivity premia of firms that use a particular SRE support instrument and on the relationship between firms' productivity growth and ETS and FIT/RPS are highly limited.

In all European Union (EU) countries, SRE support schemes such as FITs or RPSs complement the EU ETS (see Table 3.1). The **EU ETS** was established by Directive 2003/87/EC (European Commission, 2003) and launched in 2005. It is the biggest and most prominent international system for reducing GHG emissions, and it covers around 45% of the EU's GHG emissions.

This chapter studies the effectiveness of the three major EU renewable energy policy instruments at the micro level as measured by the reduction of emissions and increases in productivity. The rationale behind these expected effects is that the EU ETS, in conjunction with FIT or RPS, has a potential to reduce CO_2 emissions and to increase firms' productivity by stimulating SRET diffusion (see Lundgren, Marklund, Samakovlis, & Zhou, 2015). Primary goal of the EU ETS is to reduce CO_2 emissions (European Commission 2011; 2014a) and primary goal of the FIT and RPS is to support technological changes (Haas et al., 2004; Held et al., 2006; EEA, 2011). CO_2 emission reductions could be most effectively and efficiently achieved if firms implement environmentally friendly, more productive technologies (Carley, 2009; Peretto, 2009; Popp, Newell, & Jaffe, 2010; Yin & Powers, 2010; Antoci et al., 2012; Marques & Fuinhas, 2012a; Dong, 2012; Aguirre & Ibikunle, 2014). And if implemented, these technologies could improve firms' performance, i.e. firms' productivity (Porter, 1991; Porter and van der Linde, 1995; Ambec et al., 2013).

This chapter aims to clarify the recent findings in the literature by answering several relevant questions. It **first** aims to identify the factors that could have an impact on verified emissions of firms covered by the EU ETS. **Second**, this chapter aims to estimate the productivity premia of firms that are included in the EU ETS scheme before and after the inclusion in the scheme. **Third**, it aims to estimate whether and in what extent the EU ETS in the FIT-RPS environment contribute to firms' productivity growth.

This analysis evaluates the impact of SRE support instruments on firms' CO_2 emissions and on their productivity (and productivity growth). In doing so, it utilizes the data collected from multiple sources and it uses a number of econometric techniques. The data is gathered from the Amadeus (Bureau van Dijk), the European Union Transaction Log (EUTL), Haas et al. (2011), the Energy Information Administration (EIA), the International Energy Agency (IEA), Res-legal, and REN21. The econometric techniques used to estimate the models include pooled ordinary least squares (OLS), fixed effects (FE), random effects (RE) and system generalised method-of-moments (GMM).

This study covers the period between 1992 and 2012, which means that both phases of the EU ETS (2005–2007 and 2008–2012) are considered. The analysis focuses on EU ETS firms in the electricity and manufacturing sectors.

This chapter improves and builds on the recent literature in several ways. **First**, it focuses on the interactions between EU ETS and FIT/RPS, which have been largely ignored in previous econometric analyses. **Second**, it provides a detailed overview of the main findings of the EU ETS econometric studies relevant to this chapter's research questions, with special focus on their methodology. **Third**, it provides crucial information about the EU ETS for policy makers within the EU as well as outside the EU borders. Since the EU ETS is the largest example of emission trading in operation currently, policy makers worldwide consider the EU ETS experience before implementing new carbon pricing policies in their countries (Ellerman, Convery, & de Perthuis, 2010; Laing et al., 2013).

The main results indicate that the FIT and RPS have positive, although insignificant impact on CO_2 emission reductions of the EU ETS firms. The EU ETS does not have a significant impact on firms' productivity (except in periods around its implementation, i.e. in years t_0 and t_1). Firms that are using the FIT support have been productive before and after the EU ETS implementation. Firms that are operating in countries that have implemented RPS started to increase their productivity after 2005, i.e. when the EU ETS is implemented. The EU ETS and FIT-RPS interactions do not have a systematic impact on the productivity of firms affected.

The rest of this chapter is organised as follows. The research framework is developed in Section 3.2, highlighting the relevant recent empirical findings on the impact of renewable policy instruments on firms' performance. Section 3.3 describes the empirical approach and econometric issues. Section 3.4 presents the data and descriptive statistics. Section 3.5 presents and discusses the results, identifies the limitations, and discusses further research possibilities. Section 3.6 concludes this chapter with recommendations for the SRE policies of a country.

3.2. Review of literature and conceptual framework on the impact of sustainable renewable energy support instruments on firm performance

This section first summarises the main findings of recent theoretical, econometric and case studies that examine the impact of SRET support instruments on firms' performance. In particular, I focus on the methodology and research limitations of the most relevant econometric studies. It then discusses potential impacts of the EU ETS and FIT / RPS on firms' verified CO_2 emissions, EU ETS productivity premia and firms' productivity growth.

3.2.1. Review of literature

There are a number of studies that analyse the impact of the EU ETS (or other support instruments) on firm performance. The EU ETS limits GHG emissions from around 13,500 energy-using installations in the electricity generating and manufacturing sectors and from the airline industries in 31 countries (28 EU countries, Iceland, Liechtenstein, and Norway). The EU ETS follows the 'cap and trade' approach. It sets a 'cap' or limit on the total amount of GHG that can be emitted by a certain firm in the EU ETS system. The limit decreases over time, and the total emissions consequently decrease. According to the European Commission (2014a), the emissions from the sectors covered by the EU ETS will be 21% lower in 2020 and 43% lower in 2030 as compared to the emissions in 2005. Each firm covered by the EU ETS (henceforward 'EU ETS firms') must surrender a certain number of emission allowances that equal its emissions or pay a penalty for non-compliance. The EU ETS firms can trade these emission allowances among themselves. That is, firms can sell allowances if they emit less, or they can buy allowances if their emissions exceed the number of allowances they originally obtained. Further, a firm that reduces its emissions can decide to save the unused allowances to cover its future needs (see Appendix F).

Early studies evaluated and discussed the performance of the EU ETS, exploring different aspects such as emission reductions, productivity, profitability, investments, innovations, competitiveness, employment, and so on. I am particularly interested in determining the impact of the EU ETS and FITs/RPSs on the verified emissions of firms and firms' productivity / productivity growth. Evolutionary economists (see e.g. Dosi, Malerba, Marsili, & Orsenigo, 1997) stress the importance of looking at the firm level in examining the SRE policy's role in the process of technological change.

Several studies provide a survey of the literature on the EU ETS. I first summarise the main findings of relevant review papers addressing the EU ETS, SRE support instruments, emission reductions, and firm performance. Oberndorfer, Rennings, & Sahin (2006) find that the results of the reviewed environmental regulation studies strongly depend on the reference scenario. They identify that the impact of the EU ETS is smaller than that of other regulation instruments (e.g. 'command-and-control' instruments). Laing et al. (2013) focus on the EU ETS impact on emission abatement, investment and innovation, and profits and price. They conclude that non-flexibility in the structure of the EU ETS cap could decrease its efficiency in supporting emission reductions. The over-allocation of emission allowances in the first phase of the EU ETS and the economic recession in the second phase reduced the impact of the EU ETS on emissions. However, rigorous monitoring and carbon pricing led to some emission reductions. Further, the free allocation of allowances together with trading in the first phase of the EU ETS created the potential for the improved performance of firms. However, the market reacted to the price crashes of allowances due to their over-allocation. Policy reacted by auctioning off the allowances in the second phase of the EU ETS. The evidence shows that firms achieved significant profit only for a limited time.

Future research should incorporate another measure of firm performance, i.e. firm productivity, to examine the effectiveness of the scheme further. As previously explained, the EU ETS could potentially influence firms' productivity through firms' investments in SRET. Similar to Laing et al. (2013), Martin et al. (2014a) evaluate the literature on the impacts of the EU ETS on CO_2 emissions, economic performance (in terms of profits, revenue, productivity and employment), competitiveness and innovation. Studies that examined data for France and Germany show that the EU ETS influenced the emission reductions of manufacturing firms during the second phase but not during the first phase of the EU ETS. These results need to be confirmed by including other countries in the sample. Future research needs to clarify whether these emission reductions are a consequence of carbon leakage. Previous studies of the EU ETS firms' economic performance show heterogeneous results for different sectors. However, these studies do not find a significant negative relationship between the EU ETS and the economic performance of regulated firms.

A question that deserves more research attention is whether having both instruments—the EU ETS and FIT, or the EU ETS and RPS—in force, is a waste of money and time. Lehmann & Gawel (2013) summarise different research assessments of the combination of the EU ETS and other SRE support schemes. They report that one group of researchers states that SRE support schemes decrease the effectiveness of the EU ETS and do not contribute to SRET investments and consequent emission reductions. Lehmann & Gawel (2013) warn that these conclusions are not based on realistic market and policy assumptions. They support the group of researchers who believe that SRE support instruments should be combined with the EU ETS. This is needed because SRE support schemes provide additional benefits such as renewables development. Gawel, Strunz, & Lehmann (2014) find that SRE support schemes contribute to a more effectively designed Emission Trading Scheme (ETS) and increase the overall efficiency of the energy policy if the policy makers are not focused on environmental protection alone.

Studies that examine various aspects of the EU ETS predominantly cover the first four years of the EU ETS (Laing et al., 2013). The **pilot phase** covering the years 2005–2007 could be characterised as the 'learning by doing' period. In this period, the EU ETS covered power generators and energy-intensive industries. The first EU ETS phase succeeded in establishing carbon prices, free trade with allowances, and the infrastructure for tracking the emissions of the EU ETS firms. The failure of the first phase of the EU ETS was in the over-allocation of allowances, which caused the price of allowances to fall to zero. The majority of the EU countries allocate emission allowances free of charge to the firms covered by the EU ETS. The free allocations are aimed to prevent the profit losses of firms, which could occur in the absence of free allowance allocation (Sijm, Neuhoff, & Chen, 2006). However, the absence of more stringent environmental regulation could cause that the EU ETS did not sufficiently motivate firms' SRET investments that would subsequently increase their productivity. The penalty for non-compliance in this phase was €40 per tonne of emissions.

The second phase of the EU ETS overlapped with the first commitment period of the Kyoto Protocol (for more details about the Kyoto Protocol targets, see UNFCCC, 1997). The plan for the second phase (2008–2012) was that the EU ETS should function effectively to help the EU countries to achieve their Kyoto Protocol targets. In the second phase, the proportion of free allowances decreased, some EU countries held auctions of emission allowances, and the penalty for non-compliance increased. Based on the verified emissions in the first phase, the European Commission (EC) tightened the cap on emissions by approximately 6.5% compared to the 2005 levels (European Commission, 2014a). However, the economic crisis that began in 2008 impacted at the production volume to decrease and hence reduced the associated carbon dioxide (CO_2) emissions. Subsequently, the crisis affected the demand for emission allowances, leading to a large number of unused allowances, which had a great impact on the carbon price.

Laing et al. (2013) point out that regardless of the drastic changes in business environments, only a few studies empirically evaluated the post-2008 EU ETS. The conclusions of the post-2008 studies are in line with those of the pre-2008 studies, which report only a small impact of the EU ETS on emission reductions and negative or insignificant impact of the EU ETS on firm productivity. However, the post-2008 studies generally end in 2010. Therefore, further research is needed to capture the effects of the EU ETS during the most difficult period of the financial crisis (i.e. 2011 and 2012).

I proceed with the review of econometrics papers addressing the EU ETS, SRE support instruments, emission reductions, and firm performance (the summary is provided in the Appendix E). So far, only a few studies empirically examined the impact of SRE policy instruments on firm productivity / productivity growth. Therefore I additionally describe the studies that examine the impact of SRET support instruments on firm profitability. The methodological framework developed in these studies could be utilized to further study the impact of policy instruments on firm productivity / productivity growth.

Commins, Lyons, & Schiffbauer (2011) use an OLS regression in first differences to examine the impact of the EU ETS and energy taxes on the productivity, profitability, employment, and investments of European firms from 1996 to 2007. Their results indicate that the EU ETS had a negative impact on productivity. Moreover, Commins et al. (2011) identify large variations among the industries observed in their study. As emphasised by the authors, further research should use data from the second phase of the EU ETS to re-examine these questions.

Jaraitė & Kažukauskas (2013) conduct a pioneering ex-post analysis of how SRE support instruments, tradable green certificates (TGCs), and FITs affect the profitability of electricity-generating firms. Additionally, they control for the interactions between support instruments and the EU ETS. Jaraitė & Kažukauskas (2013) use the data from 24 EU countries in the period 2002–2010 using ordinary least squares (OLS) regression, a random effects (RE) model with Mundlak terms, and a dynamic panel data model. Their main finding indicates that the electricity-generating firms operating in countries that implemented TGCs (henceforward 'TGC countries') were more profitable compared to the electricity-generating firms operating in FIT countries (henceforward 'FIT countries'). The EU ETS did not have an effect on the electricity-generating firms in TGC countries.

Yu (2010) examines the impact of implementing the EU ETS on the profitability of a sample of Swedish energy firms in 2005 and 2006. Using the treatment/control and before/after design of the natural experiment approach, Yu (2010) finds no significant impact of the EU ETS on firms' profitability in 2005 and a negative significant impact of the EU ETS on firms' profitability in 2006. As explained by the author, the free allocation benefits and the high price of allowances in 2005 cancelled out the induced investment costs. In 2006, the low price of allowances reduced the free allocation benefits and led to difficulties in covering the induced investment cost. It is also possible that these firms invested more in emissions abatement in 2006. Additionally, Yu (2010) finds that under-cap firms respond to the EU ETS differently than over-cap firms do.

Further studies should use settings similar to those of Jaraitė & Kažukauskas (2013) and Yu (2010) to examine the relationship between SRE support instruments and firms' productivity.

Using propensity score matching, Abrell, Faye, & Zachmann (2011) compare the performance of EU ETS and non-EU ETS firms in different sectors. They find that the EU ETS induced emission reductions in the second phase; there were differences in emission reductions between the phases; the EU ETS had a modest impact on the added value, profits, and employment of regulated firms. However, the 5-year panel prevented Abrell et al. (2011) from including as many controls as needed. Including additional years of the EU ETS implementation would increase the robustness of the results.

In summary, the recent literature on the impact of the EU ETS and other SRE policy instruments on CO_2 emissions, productivity (and productivity growth) of firms provide conflicting evidence. Further research is needed to validate these results and to evaluate the performance of the EU ETS during its second phase.

3.2.2. Conceptual framework on the impact of sustainable renewable energy support instruments on firm performance

One of the crucial criteria for success of SRE policy measures is their ability to create incentives for increasing firms' productivity growth by fostering SRET implementation and use (Lundgren et al., 2015). There are different streams in the literature that attempt to explain how SRE policy regulation and support instruments may influence firms' productivity / productivity growth. Considering the EU ETS, Jaffe, Newell, & Stavins (2005) and Ambec, Cohen, Elgie, & Lanoie (2013) points to adverse effects of the scheme on firms' productivity. One group of recent studies argue that the impact of environmental regulation mechanisms, i.e. the EU ETS, on firm productivity is positive or would be positive after considering both phases of the EU ETS (Smale et al., 2006; Ellerman, Marcantonini, & Zaklan, 2014; European Commission, 2014a; Gawel, Strunz, & Lehmann, 2014). Another group of studies in line with the traditional reasoning argue that firms attempting to reduce CO_2 emissions become less productive (Abrell et al., 2011; Commins et al, 2011). Third group of studies reveal the absence of a significantly robust relationship between the EU ETS and economic activity of companies, i.e. their SRET investments (Anger and Oberndorfer, 2008; Chan, Li, & Zhang, 2013; Jaraite and Di Maria, 2014).

The EU ETS scheme is primarily introduced to promote CO_2 emission reductions (European Commission 2011; 2014a). The basic rationale behind the EU ETS is that firms have to buy emission allowances if they exceed the allowed level of emissions. Decrease in emissions could be achieved through increased use of SRET (i.e. Apergis et al., 2010; Marques et al., 2011; Dong, 2012; Jenner, 2012; Marques & Fuinhas 2012a; European Commission 2014a). Therefore, the additional purpose of the EU ETS is to motivate firms, and especially high CO_2 emitters, to invest in SRET. If firms invest in SRET, and replace their old conventional technologies with new, clean and more productive alternatives, they could consequently increase their productivity (Porter, 1991; Porter and van der Linde, 1995).

Firms might be additionally motivated to invest in SRET by two factors. First, such investments might lead to reduction in firms' verified emission. Second, firms that implement SRET would no longer need to buy emission allowances for meeting their quotas. In line with the above reasoning, the controversial Porter hypothesis (Porter, 1991) states that strict environmental regulations could have a positive impact of firms' productivity growth by stimulating SRET innovations. The critics, however, argue that firms should decide to innovate, implement and use SRET on their own, without being pressured by environmental regulations. Behavioral economists, on the other side, do not support critics and claim that firm managers do not always realize the full potential benefits of SRET investments. Thus, they would not implement as many new technologies as they would if not being forced by environmental regulation (see Ambec et al., 2013 for the recent overview of these theories).

On the other hand, a potential negative effect of the EU ETS could occur if firms decide to change their location to countries with less stringent environmental regulation instead of investing in more productive SRET (also known as the pollution haven hypothesis; for more details see Babiker et al., 2005; Barker et al., 2007; Næss–Schmidt et al., 2010). The impact of the EU ETS on firms' productivity could potentially be negative also due to the over-allocation of the emission allowances in the first phase of the EU ETS and the economic crisis in the second phase (e.g. Abrell et al., 2011; European Commission, 2014a.

Considering the FIT and RPS, they should both have positive impact on firms' productivity / productivity growth, as their primary goal is to encourage firms SRET investments. However, there are arguments in favor of the idea that FIT may outperform the RPS because FIT provides long-term financial support for SRET diffusion, while the prices of TGCs within the RPS are uncertain (Mitchell, Bauknecht, & Connor, 2006; Agnolucci, 2007; Dong, 2012; Mabee et al., 2012; Jaraitė & Kažukauskas, 2013).

Based on the discussion in this section, we can outline the following research hypothesis to be empirically verified:

First, FIT-RPS induce emission reductions of firms covered by the EU ETS. **Second**, the productivity premia of firms in FIT-RPS countries increases after their inclusion in the EU ETS scheme. **Third**, the EU ETS in the FIT-RPS environment significantly contributes to firms' productivity growth.

Section 3.3 details the empirical approach developed in this study to examine the impact of policy support instruments aimed at reducing CO_2 emissions and increasing productivity / productivity growth of firms in 27 EU countries, from 1992 to 2012.

3.3. Empirical approach and econometric issues

The empirical strategy of this study follows that of Jaraitė & Kažukauskas (2013), Abrell et al. (2011), Commins et al. (2011), and Wagner (2007). This study aims to contribute to the on-going debate on SRE support instruments and: emission reductions of the EU ETS regulated firms; the EU ETS productivity premia; productivity growth of firms. The analysis focuses on the EU ETS and non EU ETS firms in the electricity and manufacturing sectors in the period 1992–2012. The electricity sector includes all the producers of electricity, regardless of the electricity-generating technology they utilise. This sector accounts for the highest amount of emissions among the sectors covered by the EU ETS. It was the only sector that had to buy additional allowances during the first and second phase of the EU ETS. The CO_2 emissions from the other sectors were below the specified limits; therefore, these sectors began selling their unused emission allowances (see Abrell et al., 2011). In particular, this analysis consists of three parts.

The first part of the analysis (see model 3.1) evaluates the effectiveness of FIT and RPS in reducing CO_2 emissions of the firms covered by the EU ETS. It extends the regression model developed by Abrell et al. (2011) to determine how the two main SRE support instruments (i.e. FIT and RPS) contribute to the emission reductions of EU ETS regulated firms. Prior researchers mainly examined the effectiveness of the EU ETS solely in the context of reducing emissions (see e.g. Abrell et al., 2011; Commins et al., 2011).

The model developed by Abrell et al. (2011) is extended to additionally control for SRE support instruments (FIT and RPS) and for macro-level controls: SRE electricity capacity installations and electricity prices. Model 3.1 is specified as follows:

$$\Delta y_{ijct} = \alpha_0 + \beta_1 \Delta t_{ijct} + \beta_2 l_{ijct} + \beta_3 FITRPS_{ct} + \beta_4 \Delta C_{ct} + u_{ijc} + \varepsilon_{ijct} \tag{3.1}$$

where y_{ijct} is the annual growth rate of verified emissions, and t_{ijct} is the annual growth rate of turnover, of firm *i* in sector *j* of country *c* in year *t*. The growth rates are calculated as the first differences of the logged variables in two consecutive years. l_{ijct} denotes a logarithm of employment and controls for the size of firm. $FITRPS_{ct}$ represents the country-specific energy policy instruments (feed in tariffs or renewable portfolio standards), and C_{ct} is the vector of country-level characteristics, including the logarithms of absolute increases of renewable electricity capacity installations and electricity price. u_{ijc} is the firm's fixed effect, and ε_{ijct} is the usual standard error.

One of my objectives is to determine how the two main SRE support instruments (i.e. FIT and RPS) contribute to the emission reductions of EU ETS regulated firms. Different from this analysis, Abrell et al. (2011) focus on a shorter period (2005–2008) and examine the effectiveness of the EU ETS in reducing emissions alone. Moreover, following the relevant literature (Commins et al., 2011; Marques & Fuinhas, 2012; Jaraitė & Kažukauskas, 2013), I include additional controls for country-level factors such as logarithms of increases in the levels of renewable electricity capacity installations and electricity price. It is expected that higher prices of electricity would cause a reduction in CO_2 emissions, either by motivating

SRET investments or by influencing electricity production. However, considering the finding by Apergis, Payne, Menyah & Wolde-Rufael (2010), the lack of SRET capacity would cause that firms further rely on emission generating technologies.

The model (3.1) is estimated using pooled OLS and a random effects (RE) model. The analysis focuses on the period after the introduction of the EU ETS, i.e. 2005–2012. In the first model (model 3.1), the variables denoting RPS and FIT are constant since RPSs were introduced prior to 2005 in all the countries in the sample, and FIT in 24 countries in the sample. Thus, following the approach taken by Jaraitė & Kažukauskas (2013), one dummy variable FITRPS is introduced to capture both SRE policy environments (one is assigned for firms operating in FIT countries and zero for all other firms operating in RPS countries). The FE model would not allow the identification of the RPS effect on the amount of verified CO_2 emissions. Therefore, the RE approach is used instead of the FE model. The use of RE is additionally supported by the results of the Hausman test (see Table 3.1). Moreover, the results of the Arellano-Bond tests indicate that serial correlation is not present in the data. Therefore, the system GMM approach is not required to estimate this model.

Table 3.1: The Hausman test results

	Hausman test
χ^2	7.12
Prob > χ^2	0.6245

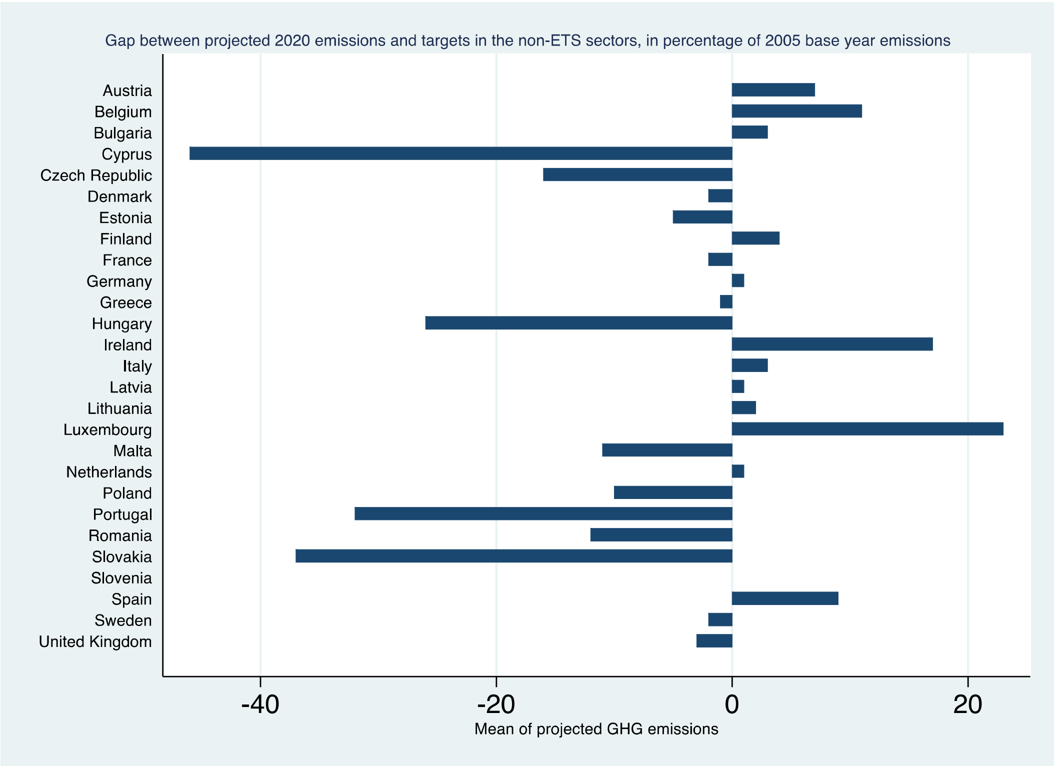
In order to validate the robustness of the results, I perform two robustness checks.

Robustness check 1

Based on the latest EC report (European Commission, 2014c), the sample is divided in two sub-samples (see Figure 3.1). First sub-sample includes 14 countries that are projected to be above their Kyoto Protocol GHG emission targets for 2020 with the existing financial and fiscal instruments in force. These countries are Greece, Malta, Denmark, France, Sweden, the UK, Estonia, Poland, Romania, the Czech Republic, Hungary, Portugal, Slovakia, and Cyprus. The second sub-sample includes 13 countries that will need additional efforts to meet their emission reduction targets. These countries are Luxembourg, Ireland, Belgium, Spain, Austria, Finland, Italy, Bulgaria, Lithuania, Latvia, the Netherlands, Germany, and Slovenia.

This ex-post analysis is expected to reveal a significant negative link among the financial, fiscal, and economic factors and verified emissions in countries that are projected to be above their Kyoto targets in 2020. However, it could be the case that some other factors (e.g. increased environmental awareness) led to the reductions in harmful emission. In countries that are projected to be below their Kyoto targets, the support instruments are also expected to trigger a decrease in emissions, although this link might be less significant. One potential factor that might affect the effectiveness of these instruments in reducing emissions is the existence of traditional energy lobbies in countries with highly developed conventional energy infrastructure.

Figure 3.1: Gap between projected 2020 CO_2 emissions and targets in the non-ETS sector, in percentage of emissions in 2005 (the base year)



Source: European Commission, *Progress towards achieving the Kyoto and EU 2020 objectives*, 2014.

Robustness check 2

Following Anger & Oberndorfer (2008), Yu (2010), and Abrell et al. (2011), the sample is divided in two categories based on the relative allocation of allowances. The first group includes the under-cap firms, whose verified emissions are below the allocated allowances. The second group comprises the over-cap firms, whose verified emissions exceed the allocated allowances. Under-cap firms can sell the surplus allowances, while over-cap firms need to buy additional allowances. Anger & Oberndorfer (2008) develop an allocation factor that measures the allowances allocation of the EU ETS relative to the firm's actual emissions. The authors calculate the allocation factor (AF) as the allocated emission allowances (AEA) divided by the verified emissions (VE). An allocation factor greater than 1 denotes the under-cap firms, and an allocation factor smaller than 1 indicates the over-cap firms.

$$AF = \frac{AEA}{VE}; \frac{if\ AF > 1 \rightarrow under\ cap\ firms}{if\ AF < 1\ \rightarrow over\ cap\ firms}$$

The under cap firms are expected to achieve more emission reductions due to the sale of spare allowances, while the over-cap firms are expected to be higher CO_2 emitters, as they have to buy additional allowances. However, the difference between under-cap and over-cap firms might turn out to be small. Such a result would indicate that the trade of emission allowances is not the main factor that affects the CO_2 emissions. Financial, fiscal, and economic factors are expected to have greater positive influences on the emission reductions of under-cap firms. Over-cap firms potentially rely more heavily on conventional technologies; therefore, they need additional support to reduce emissions.

The second part of the analysis focuses on the second research aim, i.e. on estimating the productivity premia of firms that are included in the EU ETS before and after the inclusion in the scheme. The key differences of this study compared to prior relevant studies could be summarised as follows. First, this analysis focuses on the firms' productivity premia instead of focussing on the more frequently used measures of firm profitability (such as EBIT margin, return on assets (ROA), etc.). Second, it uses a longer time series (from 1992 to 2012), and the analysis is able to control for the effects of the both phases of the EU ETS (2005–2007 and 2008–2012) on firms performance. Third, this research controls for the year of introduction of FIT and RPS in a particular country, which is different from the approach used in other studies that used a similar setting (see e.g. Jaraitė & Kažukauskas, 2013). Prior studies simply indicated whether a country adopted FIT or RPS instruments. Since the variables used in this paper to denote policy support instruments are time-variant, I use the fixed effects (FE) approach instead of a random effects (RE) approach. I use a similar methodology presented by Wagner (2007), Commins et al. (2011) and Jaraite & Kažukauskas (2013) to assess whether firms in the EU ETS scheme experience a significant productivity premia over the non-EU ETS firms, whereby controlling for the country-specific policy instruments (FITs or RPSs). The model is estimated as follows:

$$y_{ijct+s} = \alpha_0 + \beta_1 k_{ijct} + \beta_2 ETS_{ijct} + \beta_3 T_{ct} + \beta_4 ETS_{ijct} * RPS_{ct} + \beta_5 ETS_{ijct} * FIT_{ct} + \beta_6 C_{ct} + \beta_7 X_{ijct-2} + u_{ijc} + \varepsilon_{ijct} \quad (3.2)$$

where y_{ijct+s} is log of labour productivity of firm *i* in sector *j* of country *c* in year *t*, where s = -3, -2, -1, 0, 1, 2, 3. k_{ijct}, is log of firm's *i* capital intensity, measured as capital to labor ratio. Capital is defined as the stock of tangible fixed assets, and labour is calculated as the number of employees. ETS_{ijct} denotes firms covered by the EU ETS, T_{jct} is the vector of a set of country-specific energy policy instruments (FITs and RPSs), and C_{ct} is the vector of country-level characteristics (log of renewable electricity capacity installations and electricity price). X_{ijct-2} denotes a firm's size measured by number of employees. This variable is lagged by two years in order to avoid correlation with the labor productivity and capital intensity. u_{ijc} is the firm's fixed effect, and ε_{ijct} is the usual standard error. C_{jct} and X_{ijct} are chosen in accordance with the relevant literature as they might explain the variation in firm productivity.

The first dummy variable ETS takes the value 1 if a firm is covered by the EU ETS, and 0 otherwise. The EU ETS productivity premia is calculated from the estimated coefficient β as $100*(\exp(\beta)-1)$.

The second set of dummy variables relates to SRE policy support instruments. The FIT dummy variable equals 1 if a firm operates in a country that has implemented FIT, and 0 if the firm operates in a country that has implemented RPS. The RPS dummy variable is constructed in a similar way; it takes the value 1 if the firm operates in an RPS country, and 0 if the firm operates in a FIT country. Table 3.2 presents an overview of the FIT and RPS countries. Additionally, Table 3.2 shows the time of introduction of a particular SRE support instrument in a particular EU country. FIT is first implemented in Germany (before 1992) and RPS is first implemented in Poland in 2000.

Table 3.2: Year of implementation of either FIT or RPS in individual EU countries in the period 1992–2012

YEAR	**FEED IN TARIFF**	**RENEWABLE PORTFOLIO STANDARD**
1992	Germany	
1993	Luxembourg, *Denmark*	
1994	Spain, Greece	
1998	Austria	
2000		Poland
2001	France, Portugal	Italy
2002	Czech Republic, Hungary, Lithuania	Belgium, United Kingdom
2003	Bulgaria, *Estonia*, Netherlands	Sweden
2004	Malta, Slovenia	
2005	*Ireland*, Slovakia	Romania
2006	*Cyprus*	
2010	Latvia	
2011	*Finland*	

Note. Each row represents a policy type. *Italics* denote premium FIT policies. FIT was implemented in Germany in 1990. Years in which instruments were not implemented are removed from the Table.

Source: R. Haas et al., A historical review of promotion strategies for electricity from renewable energy sources in EU countries, 2011; REN21, *Renewable Energy Policy Network for the 21st Century*, 2012; Res-legal, *Legal sources on renewable energy*, 2012; and IEA/IRENA, *Joint Policies and Measures database*, 2014.

Following the basic rationale behind the policy support instruments, FIT and RPS are expected to positively affect the firms' productivity through the diffusion of sustainable renewable energy technologies (SRET). It should be emphasised that during its existence, the EU ETS has undergone some remarkable changes that improved its structure (see e.g. Ellerman, Marcantonini, & Zaklan, 2014). Therefore, on the one hand, we might expect to see positive effects of the EU ETS on the firms' productivity. On the other hand, the over-allocation of emission allowances in the first phase and the global recession in the second phase of the EU ETS might diminish the scheme's effectiveness.

Following Marques & Fuinhas (2012a) and Jaraitė & Kažukauskas (2013), I include SRET capacity to control for potential lobbying effects. If large conventional energy lobbies do not prevent renewables diffusion, firms that implement SRET should achieve higher productivity. The relevant literature (Commins et al., 2011; Jaraitė & Kažukauskas, 2013) suggests the use of electricity prices to proxy for the fuel prices when the data on fuel prices is not available. In particular, for electricity-generating firms, changes in fuel prices would influence the firms' choice of the fuel that would be used for electricity generation, which would further influence the price of generated electricity. Consequently, higher electricity prices could negatively influence the firm's productivity through lower demand for electricity. On the other hand, if the high fuel prices motivate firms to invest in SRET, we can expect a positive link between electricity prices and the firms' productivity. Moreover, manufacturing firms could be motivated by higher electricity prices to invest in SRET, which would consequently increase their productivity. However, if these firms rely heavily on conventional technologies, they might decide not to invest in SRET, which would have a negative effect on their competitiveness and productivity in the long run. Currently, countries are constantly increasing their commitments to implement SRET and to produce clean energy.

The regressions additionally control for firm size (measured by the number of employees). The on-going renewable energy debate suggests that smaller firms are predominantly focused on SRET, while larger firms rely more on conventional technologies. Therefore, smaller firms should be associated with higher productivity in the long run. On the other hand, it could happen that larger firms more easily handle the costs of SRET investments.

The problem in applying the classical OLS to model (3.2) using the panel data, for example, is that the regressors are correlated with the fixed effects in the error term. Consequently, these correlations would bias the coefficient estimates. The OLS estimator is consistent when the independent variables are exogenous and unbiased, and the errors are homoscedastic and not serially correlated. Compared to pooled OLS, the FE model is estimated to additionally control for firms' heterogeneity.

The third part of the analysis utilises the standard growth accounting model (3.3) to test whether the firms that are part of the EU ETS scheme have increased their productivity faster as compared to non-EU ETS firms, whereby controlling for the country-specific policy instruments (FITs or RPSs). The model is specified as follows:

$$\Delta y_{ijct} = \alpha_0 + \beta_1 \Delta k_{ijct} + \beta_2 ETS_{ijct} + \beta_3 T_{ct} + \beta_4 ETS_{ijct} * RPS_{ct} + \beta_5 ETS_{ijct} * FIT_{ct} + \beta_6 \Delta C_{ct} + \beta_7 l_{ijct-2} + u_{ijc} + \varepsilon_{ijct} \tag{3.3}$$

where y_{ijct} and k_{ijct}, are the annual growth rates of labour productivity and capital intensity, respectively, of firm i in sector j of country c in year t. The growth rates are calculated as the differences of the logged variables in two consecutive years. Capital is defined as the stock of tangible fixed assets, and labour is calculated as the number of employees. ETS_{ijct} denotes firms covered by the EU ETS, T_{jct} is the vector of a set of country-specific energy policy instruments (FITs and RPSs), and C_{jct} is the vector of country-level characteristics (logarithm of annual change in absolute values of renewable electricity capacity installations and electricity price). l_{ijct-2} denotes the firm's size measured by number of employees and lagged by 2 years. u_{ijc} is the firm's fixed effect, and ε_{ijct} is the usual standard error. C_{jct} and X_{ijct} are chosen in accordance with the relevant literature as they might explain the variation in firm productivity growth.

When estimating growth models, due to the simultaneity correlation could exist between the dependent variable in the current period and the lagged dependent variable as well as between the lagged dependent variable and the independent variables in the current period. Consequently, these correlations would bias the coefficient estimates. The OLS estimator is consistent when the independent variables are exogenous and unbiased, and the errors are homoscedastic and not serially correlated. An intuitive first attempt to remove the fixed effects out of the error term is to include dummy variables for each individual, i.e. to use a least squares dummy variable (LSDV) estimator. Alternatively, an FE estimator would produce the same results more succinctly. Compared to pooled OLS, the FE model is estimated to additionally control for firms' heterogeneity. However, an even more practical strategy is needed to remove dynamic panel bias, one that involves a different transformation of the data. Three sophisticated methods could be used to solve the endogeneity problem between input levels and the unobserved firm-specific shocks. First, Olley and Pakes (OP, 1996) suggest using investment expenditure as a proxy for unobservable technological shocks. Additionally, OP method controls for the relationship between firm productivity and input demand.

Weakness of the OP method is in the fact that investment proxy takes into account only the unanticipated part of the technology shock, causing some correlation to remain between the unobserved technological shock and capital. To overcome this problem, the total factor productivity (TFP) could be calculated using the standard Levinsohn-Petrin (LP, 2003) approach that uses intermediate inputs (energy consumption or material costs) to control for potential endogeneity problems in TFP due to unobservable productivity shocks (Levinsohn & Petrin, 2003; Petrin, Poi, & Levinsohn, 2004). Material costs include entire productivity shocks and not their unanticipated parts only. However, LP method is difficult to use due to the data limitation problems (i.e. data on aggregate materials use is available while data on the use of particular materials is often not available).

Therefore, two commonly used transformations of the data to control for the endogeneity problems are difference GMM and system GMM. Blundell & Bond (1998) report that weak instruments could cause large finite sample biases when the standard difference GMM estimator is used. Arellano & Bover (1995) suggest using a system GMM estimator to overcome the problem of weak instruments when using the standard first-differenced GMM. In system GMM, the lagged first differences are used as instruments for both the equations in the levels as well as the differenced equation, which increases the efficiency of the estimates. The system GMM estimator developed by Arellano-Bover and Blundell-Bond (Arellano & Bover, 1995; Blundell & Bond 1998) has become increasingly popular. This estimator is particularly useful for the current analysis as it is designed for panels with few time series and many individuals (small T, large N), where the dependent variable depends on its own past realisations, the independent variables are not strictly exogenous, and the errors are serially correlated. Detailed discussion of empirical methods used to estimate production function is provided by Damijan, Rojec, Majcen, & Knell (2013).

3.4. Data and descriptive statistics

This analysis uses a micro panel dataset for 27 EU countries in the period 1992–2012. The newly constructed dataset records the key firm characteristics, the data on the verified emissions of EU ETS firms, and the data on the other main SRE policy support instruments. It includes information on firms in the electricity and manufacturing sectors. These sectors hold the majority of annual emission allowances. The sectors are defined according to their NACE Rev. 2 primary codes (see Table 3.3). Table 3.3 shows the number of EU ETS and non-EU ETS firms in a particular sector.

Table 3.3: NACE Rev. 2 primary codes used in the study

NACE Rev. 2 code	Description of the NACE Rev. 2 code	ETS firms	Non ETS firms
1910	Manufacture of coke oven products	38	1,197
1920	Manufacture of refined petroleum products	107	14,445

(table continues)

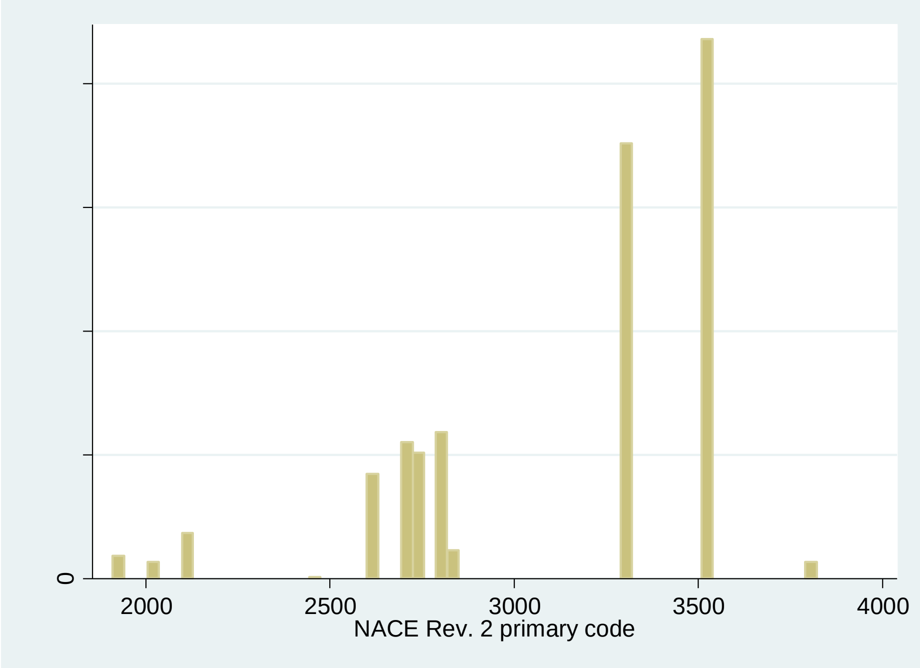
(continued)

NACE Rev. 2 code	Description of the NACE Rev. 2 code	ETS firms	Non ETS firms
2013	Manufacture of other inorganic basic chemicals	40	13,723
2120	Manufacture of pharmaceutical preparations	56	36,816
2446	Processing of nuclear fuel	0	449
2611	Manufacture of electronic components	22	69,682
2612	Manufacture of loaded electronic boards	0	9,935
2711	Manufacture of electric motors, generators and transformers	8	48,522
2712	Manufacture of electricity distribution and control apparatus	16	44,264
2720	Manufacture of batteries and accumulators	0	4,611
2731	Manufacture of fibre optic cables	0	860
2732	Manufacture of other electronic and electric wires and cables	7	14,584
2733	Manufacture of wiring devices	0	12,298
2740	Manufacture of electric lighting equipment	0	52,563
2752	Manufacture of non-electric domestic appliances	0	6,721
2790	Manufacture of other electrical equipment	0	96,412
2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	0	20,184
2821	Manufacture of ovens, furnaces and furnace burners	8	22,854
3312	Repair of machinery	0	261,528
3313	Repair of electronic and optical equipment	8	33,929
3314	Repair of electrical equipment	0	54,490
3511	**Production of electricity**	**1098**	**427,170**
3812	Collection of hazardous waste	7	6,733
3822	Treatment and disposal of hazardous waste	0	6,764

Source: AMADEUS database.

Figure 3.2 presents the frequency of a particular sector in the sample and indicates that the majority of firms included in this study are electricity producers within the electricity sector.

Figure 3.2: Frequency of a particular NACE Rev. 2 code in the dataset



Source: AMADEUS database.

Using the data for a period of over 20 years, I can compare the firms' productivity / productivity growth in two periods: before and after the EU ETS was launched.

Firm-level data is collected from the Amadeus database (Bureau van Dijk). The Amadeus database includes comprehensive and comparable historical financial information for European firms. This analysis uses data on value added per employee, capital, labour, and firm turnover.

Installation data is taken from the European Union Transaction Log (EUTL) and is aggregated to the firm level. Following the revision of the ETS Directive in 2009, the EU registry operated by the EC replaced the national registries of the EU countries. The EU registry accounts for EU ETS allowances. A firm or a person that wants to participate in the EU ETS needs to open an account at the EU registry. The EUTL verifies the transfer of allowances from one account to another in the EU registry to ensure that all the transfers are consistent with the EU ETS rules. The EUTL is the main source of information on the EU ETS scheme at the EU level. It provides information on obligated installations, the account holders of the installations, as well as allowance and compliance transaction data. All this information is published at the account level. Each installation regulated under the EU ETS is linked with only one Person Holding Accounts (PHAs) and Operator Holding

Accounts (OHAs). One account holder can control several PHAs/OHAs. One firm could be responsible for several account holders. In order to merge the EU ETS data with the firm-level Amadeus data, the EU ETS dataset has to be at the firm level instead of at the account level. Jaraitė, Jong, Kažukauskas, Zaklan, & Zeitlberger (2013a) attempted to aggregate the EU ETS accounts to obtain firm-level information related to EU ETS transactions and compliance data. 'The Ownership Links and Enhanced EUTL Dataset' proposed by them includes installation names, details of PHAs and OHAs (such as national ID, name, country code, and firm type), and BVD ID numbers. A technical note (Jaraitė, Jong, Kažukauskas, Zaklan, & Zeitlberger, 2013b) contains the complete description required for matching the current information on the EU ETS PHAs and OHAs with the historical information on the firms that own them. First, I merge 'The Ownership Links and Enhanced EUTL Dataset' with the complete 'EUTL Database' to obtain additional information on emission allowances and verified emissions from 2005 to 2012. Subsequently, I use the BVD ID numbers identified by Jaraitė et al. (2013a) to merge 'The Ownership Links and Enhanced EUTL Dataset' and the 'EUTL Database' with the accounting data from the Amadeus database. The installation data includes information on emission allowances and verified emissions in the period 2005–2012. Thus, it covers the two phases of the EU ETS, 2005–2007 and 2008–2012. This is especially important due to the lack of econometric evaluations of the effectiveness of the second EU ETS phase.

The macro data is gathered from Haas et al. (2011), the Energy Information Administration (EIA), the International Energy Agency (IEA), Res-legal, and REN21. The macro data includes information on the policy support instruments FIT and RPS, i.e. the year of their introduction in each EU country, renewable electricity generation, and electricity prices. The data is merged to form a balanced panel.

Table 3.4 identifies the variables of interest and specifies the measurement units, data sources, and data availability periods.

Table 3.4: Description of variables

Variables of interest (independent)	**Description of the variable**	**Unit of measurement**	**Data source**	**Period**
VAPE	Value added per employee	Nonimal units and growth rate in %	AMADEUS	1992-2012
T	Turnover	Nonimal units and growth rate in %	AMADEUS	1992-2012
CPE	Capital per employee	Nonimal units and growth rate in %	AMADEUS	1992-2012
EMP	Employees	Nonimal units and growth rate in %	AMADEUS	1992-2012
AEA	Allocated emission allowances	Nominal units	EUTL	2005-2012
VE	Verified emissions	Nonimal units and growth rate in %	EUTL	2005-2012
FIT	Feed in Tariff	Binary	Haas et al. (2011), REN21 (2012), Res-legal (2012) and IEA/IRENA	1992-2012
RPS	Renewable Portfolio Standard or Quota	Binary	Haas et al. (2011), REN21 (2012), Res-legal (2012) and IEA/IRENA	1992-2012
ETS	European Union Emission Trading Scheme	Binary	EUTL	2005-2012
SREC	SRE capacity installed	Logarithm of change in absolute values	EIA	1992-2012
SREG	Sustainable renewable electricity generation	Logarithm of change in absolute values	EIA	1992-2012
ELP	Electricity prices	Logarithm of change in absolute values	IEA	1992-2012

Further, the descriptive statistics of the variables of interest are presented in Tables 3.5, 3.6, and 3.7. Table 3.5 first provides the descriptive statistics for all observations included in the sample and than for the FIT and RPS firms separately. Table 3.5 shows that firms operating in FIT environment achieve greater success in reducing CO_2 emissions than firms operating in countries that implemented RPS.

Table 3.5: Descriptive statistics—All firms, FIT firms, RPS firms (Model 3.1)

	All firms			**FIT firms**			**RPS firms**		
Variable	**Obs**	**Mean**	**Std.**	**Obs**	**Mean**	**Std.**	**Obs**	**Mean**	**Std.**
Δ VE	438	-.004	.528	281	-.029	.466	129	.031	.529
Δ T	438	.138	1.26	281	.181	1.54	129	.053	.498
Δ EMP	438	.180	2.10	281	.285	2.60	129	-.005	.365
Δ SREC	438	.225	.257	281	.216	.291	129	.283	.171
Δ ELP	438	.053	.067	281	.056	.064	129	.048	.076
RPS	438	.294	.456	281	0	0	129	1	0
FIT	438	.641	.480	281	1	0	129	0	0

Note: VE – verified emissions, T – turnover, EMP – employees, SREC – SRE capacity installed, ELP – electricity prices, RPS – renewable portfolio standard, FIT – feed in tariff.

Table 3.6 first provides the descriptive statistics for all observations included in the sample. Subsequently, the variables are grouped according to the SRET support provided by the 27 EU countries (either FIT or RPS) in the period 1992–2012. Table 3.6 reveals no significant differences in productivity of FIT and RPS firms.

Table 3.6: Descriptive statistics—All firms, FIT firms, RPS firms (Model 3.2)

	All firms			**FIT firms**			**RPS firms**		
Variable	**Obs**	**M.**	**Std.**	**Obs**	**M.**	**Std.**	**Obs**	**M.**	**Std.**
Ln VAPE	102309	3.77	1.02	51701	3.78	.983	31903	3.81	1.04
Ln CPE	102309	2.60	2.33	51701	2.45	2.56	31903	2.78	2.11
ETS	102309	.003	.058	51701	.004	.064	31903	.003	.058
RPS	102309	.311	.463	51701	0	0	31903	1	0
FIT	102309	.505	.499	51701	1	0	31903	0	0
Ln ELP	102309	4.66	.136	51701	4.67	.106	31903	4.72	.119
Ln SREC	102309	3.61	.972	51701	3.72	.927	31903	3.63	.810
Ln EMP	102309	3.13	1.75	51701	2.90	1.76	31903	3.24	1.66

Note: VAPE – value added per employee, CPE – capital per employee, ETS – emission trading scheme, RPS – renewable portfolio standard, FIT – feed in tariff, ELP – electricity prices, SREC – SRE capacity installed, EMP – employees.

Similar to table 3.6, table 3.7 first provides the descriptive statistics for all observations included in the sample. Subsequently, the variables are grouped according to the SRET support provided by the 27 EU countries (either FIT or RPS) in the period 1992–2012. Table 3.7 reveals higher increases in productivity growth of FIT firms. Additionally, table 3.7 depicts that firms operating in RPS countries installed less SRETs due to higher price increases compared to the FIT environment.

Table 3.7: Descriptive statistics—All firms, FIT firms, RPS firms (Model 3.3)

	All firms			**FIT firms**			**RPS firms**		
Variable	**Obs**	**M.**	**Std.**	**Obs**	**M.**	**Std.**	**Obs**	**M.**	**Std.**
Δ VAPE	102309	.024	.631	51701	.034	.606	31903	.001	.643
Δ CPE	102309	-.005	1.35	51701	.000	1.57	31903	-.022	1.18
ETS	102309	.003	.058	51701	.004	.064	31903	.003	.058
RPS	102309	.311	.463	51701	0	0	31903	1	0
FIT	102309	.505	.499	51701	1	0	31903	0	0
Δ ELP	102309	.024	.067	51701	.027	.071	31903	.035	.063
Δ SREC	102309	.067	.154	51701	.078	.179	31903	.071	.123
Δ EMP	102309	.020	.371	51701	.014	.336	31903	.029	.411

Note: VAPE – value added per employee, CPE – capital per employee, ETS – emission trading scheme, RPS – renewable portfolio standard, FIT – feed in tariff, ELP – electricity prices, SREC – SRE capacity installed, EMP – employees.

Tables 3.8, 3.9 and 3.10 present the correlations among the variables included in Models 3.1, 3.2 and 3.3, respectively.

Table 3.8: Correlation matrix—Model 3.1

	Δ VE	Δ T	Δ EMP	Δ SREC	Δ ELP	RPS/FIT
Δ VE	1.0000					
Δ T	0.1172*	1.0000				
Δ EMP	0.0045	0.4151*	1.0000			
Δ SREC	0.0240	0.0235	0.0025	1.0000		
Δ ELP	-0.1292*	-0.0418	-0.0174	-0.2402*	1.0000	
RPS/FIT	0.0273	-0.0383	-0.0551	0.1309*	-0.0442	1.0000

Note: VE – verified emissions, T – turnover, EMP – employees, SREC – SRE capacity installed, ELP – electricity prices, RPS/FIT – renewable portfolio standard / feed in tariff.

Table 3.9: Correlation matrix—Model 3.2

	Ln VAPE	Ln CPE	ETS	RPS	FIT	Ln ELP	Ln SREC	Ln EMP
Ln VAPE	1.0000							
Ln CPE	0.4307*	1.0000						
ETS	0.0859*	0.0779*	1.0000					
RPS	0.0230*	0.0508*	0.0005	1.0000				
FIT	0.0064*	-0.0660*	0.0138*	-0.6804*	1.0000			
Ln ELP	0.0169*	-0.0117*	0.0417*	0.3058*	0.0841*	1.0000		
Ln SREC	0.2476*	-0.0102*	0.0056	0.0190*	0.1145*	0.1101*	1.0000	
Ln EMP	0.0247*	0.1259*	0.0605*	0.0442*	-0.1304*	-0.0134*	-0.2359*	1.0000

Note: VAPE – value added per employee, CPE – capital per employee, ETS – emission trading scheme, RPS – renewable portfolio standard, FIT – feed in tariff, ELP – electricity prices, SREC – SRE capacity installed, EMP – employees.

Table 3.10: Correlation matrix—Model 3.3

	Δ VAPE	Δ CPE	ETS	RPS	FIT	Δ ELP	Δ SREC	Δ EMP
Δ VAPE	1.0000							
Δ CPE	0.1232*	1.0000						
ETS	0.0034	0.0019	1.0000					
RPS	-0.0245*	-0.0085*	0.0005	1.0000				
FIT	0.0155*	0.0049	0.0138*	-0.6804*	1.0000			
Δ ELP	-0.0317*	-0.0079*	0.0250*	0.1111*	0.0463*	1.0000		
Δ SREC	0.0106*	0.0047	0.0126*	0.0189*	0.0732*	-0.0137*	1.0000	
Ln EMP	-0.3753*	-0.1750*	-0.0063*	0.0150*	-0.0173*	0.0154*	-0.0224*	1.0000

Note: VAPE – value added per employee, CPE – capital per employee, ETS – emission trading scheme, RPS – renewable portfolio standard, FIT – feed in tariff, ELP – electricity prices, SREC – SRE capacity installed, EMP – employees.

The next section (section 3.5) presents and discusses the results, identifies the limitations, and suggests avenues for further research.

3.5. Results, discussion, and further research

The results of this study identify the impact of the policy instruments on CO_2 emissions, on the EU ETS productivity premia, and on the productivity growth of the firms in 27 EU countries from 1992 to 2012. This chapter examines the EU's largest support scheme (the

EU ETS) for reducing CO_2 emissions, operating either in FIT or in RPS environment. In this section, I present and discuss main results of estimating the models 3.1, 3.2 and 3.3. In subsection 3.5.1 I present results on the impact of EU ETS on verified CO_2 emissions (results obtained by estimating the model 3.1). In subsection 3.5.2, results on the productivity premia of EU ETS firms in the FIT or RPS environment are presented (results obtained by estimating the model 3.2). Subsection 3.5.3 presents the results on the effects of EU ETS on the productivity growth by accounting for the FIT and RPS environment (results obtained by estimating the model 3.3).

3.5.1. Impact of EU ETS on verified CO_2 emissions

This subsection presents and discusses the results on the impact of economic, financial/fiscal, and political elements on the verified CO_2 emissions of the EU ETS firms (see Table 3.11). These results are obtained by estimating the model 3.1.

Table 3.11: Results of the empirical model for estimating the impact of factors that could potentially decrease CO_2 emissions of firms covered by the EU ETS (Model 3.1)

Estimation technique	OLS	RE	RE	RE	RE	RE
Dependent variable	Δ Verified emissions					
Sample	All firms	All firms	Under-cap firms	Over-cap firms	Countries below their Kyoto targets	Countries above their Kyoto targets
Δ T	0.057*	0.059*	0.338**	0.180	0.351**	0.047
	[1.65]	[1.67]	[2.10]	[0.91]	[2.03]	[1.62]
Log EMP	-0.013*	-0.013	-0.403**	0.000	-0.314**	-0.008
	[-1.77]	[-1.54]	[-2.00]	[0.09]	[-2.06]	[-1.11]
Δ SREC	0.081	0.083	0.131	-0.057	-0.093	0.037
	[0.77]	[0.78]	[1.14]	[-0.25]	[-0.50]	[0.22]
Δ ELP	-0.825**	-0.752*	-0.883	-0.126	-1.281	-0.265
	[-2.15]	[-1.76]	[-1.57]	[-0.23]	[-1.57]	[-0.45]
RPS/FIT	-0.217	-0.225	-0.078	0.001	0.191	-0.069
	[-1.35]	[-1.57]	[-0.50]	[0.01]	[1.03]	[-1.28]
Constant	-0.141	-0.074	-0.267	1.243***	-0.603***	-0.045
	[-0.72]	[-0.53]	[-1.57]	[2.96]	[-2.68]	[-0.37]
Observations	438	438	254	184	264	174

Notes. VE – verified emissions, T – turnover, EMP – employees, SREC – SRE capacity installed, ELP – electricity prices, RPS/FIT – renewable portfolio standard / feed in tariff. The model is in first differences. Pooled OLS and RE regressions control for time, country, and industry fixed effects. Robust standard errors are in square brackets. ***, **, *, denote significance at 1%, 5%, and 10% significance levels, respectively.

Table 3.11 depicts the robust results of the pooled OLS and RE estimation techniques. To begin with, the results based on the full sample of EU ETS firms show that the changes in turnover have a positive and significant impact on the changes in CO_2 emission. This predictable positive interaction between changes in turnover and changes in emissions (see e.g. Abrell et al., 2011) means that the CO_2 emissions of firms would decrease if their turnover declines. This conclusion holds for firms that do not completely rely on SRET. Further, the results suggest that larger electricity producers (in terms of the number of employees) handle the costs of emissions more easily compared to smaller firms. Moreover, an increase in electricity prices triggers a decline in electricity consumption, which in turn leads to lower electricity production and lower emissions.

The policy support instruments (RPS and FIT) are primarily designed to support SRET implementation and electricity generation from SRET. Therefore, these instruments should lead to reductions in emissions. Although the signs and coefficients of the FIT and RPS instruments are not statistically significant, it would still be better for a country to have these instruments in force. In particular, the negative signs of the support instruments indicate that they lead to emission reductions through the implementation of SRET. Based on the over-cap firms and countries projected to be below their Kyoto targets in 2020, we could observe a positive but insignificant link between the support instruments and emissions. This result implies that FIT and RPS failed to achieve emission reductions. Therefore, a closer examination of country-specific instrument design is recommended in future research. It could be that the FIT does not provide enough support for electricity generation from SRET, thereby causing firms to rely further on conventional technologies. Additionally, the country-specific quotas might not be strict enough to cause faster transition from conventional technologies to SRET. In summary, the results show that the economic activity of companies and country-level factors such as electricity prices have a significant influence on the emissions of firms compared to the impact of financial instruments aimed at supporting the diffusion of SRET. This first part of the analysis aimed to compare the CO_2 emission reductions of the EU ETS firms in two different environments: one regulated by FITs, and the other regulated by RPSs. Future research could re-examine these issues and compare the EU ETS and non EU ETS firms by using matching and difference-in-differences approaches.

3.5.2. Productivity premia of EU ETS firms

This subsection presents and discusses the results on the productivity premia of the EU ETS firms that are operating in either FIT or in RPS countries. These results are obtained by estimating the model 3.2. The results are presented separately for each year in the period from *t*-3 to *t*+3, where *t* denotes the year of the EU ETS implementation, i.e. 2005. This will allow us to infer whether the EU ETS could have impact also on firms' productivity growth. Table 3.12 presents the pooled OLS results related to the impact of the productivity premia of EU ETS firms that operate in FIT countries or in countries that set quotas to facilitate the diffusion of environmentally friendly and more productive technologies.

Table 3.12: **Pooled OLS** results on the productivity premia of firms that are included in the ETS scheme before and after the inclusion in the scheme (Model 3.2)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time period	-3	-2	-1	0	1	2	3
ETS	0.002	-0.052	-0.044	-0.081	-0.023	0.019	0.214
	[0.992]	[0.731]	[0.763]	[0.572]	[0.886]	[0.908]	[0.339]
RPS	-0.053***	-0.054***	-0.047***	-0.016	0.013	0.048***	0.083***
	[0.000]	[0.000]	[0.000]	[0.110]	[0.244]	[0.000]	[0.000]
FIT	0.250***	0.227***	0.252***	0.218***	0.207***	0.181***	0.163***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
ETS*RPS	0.200	0.254	0.280*	0.495***	0.293*	0.240	0.073
	[0.297]	[0.154]	[0.091]	[0.002]	[0.099]	[0.208]	[0.764]
ETS*FIT	0.250	0.278	0.223	0.334**	0.195	0.150	-0.035
	[0.204]	[0.124]	[0.192]	[0.043]	[0.288]	[0.440]	[0.889]
Log CPE	0.061***	0.066***	0.076***	0.095***	0.084***	0.075***	0.070***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Log ELP	0.424***	0.369***	0.276***	0.053**	0.097***	0.063**	0.124***
	[0.000]	[0.000]	[0.000]	[0.013]	[0.000]	[0.028]	[0.000]
Log SREC	0.147***	0.164***	0.183***	0.175***	0.153***	0.139***	0.120***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Log EMP	0.025***	0.024***	0.015***	-0.008***	0.012***	0.012***	0.012***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Constant	-2.258***	-1.990***	-1.594***	-0.437***	-0.633***	-0.370**	-0.578***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.011]	[0.002]
Observations	70,287	89,148	111,381	153,385	111,052	88,042	68,790
R-squared	0.352	0.350	0.351	0.337	0.355	0.354	0.357
beta1	0.173	-5.084	-4.282	-7.791	-2.233	1.900	23.81
beta2	-5.171	-5.258	-4.610	-1.572	1.274	4.917	8.695
beta3	28.39	25.52	28.71	24.38	23.03	19.85	17.74
beta4	22.20	28.89	32.27	64.05	34.02	27.07	7.607
beta5	28.37	32.07	25.01	39.68	21.50	16.18	-3.484

Notes. ETS – EU emission trading scheme; RPS – renewable portfolio standard; FIT – feed in tariff; CPE – capital per employee; ELP – electricity prices; SREC – SRE capacity installed; EMP – employees; beta1 – EU ETS productivity premia; beta2 – RPS productivity premia; beta3 – FIT productivity premia; b4 – EU ETS*RPS productivity premia; b5 – EU ETS*FIT productivity premia. The model is estimated using pooled OLS. Regressions control for time, country, and industry fixed effects. The dependent variable is the log value of labour productivity. Robust standard errors are in square brackets. ***, **, *, denote significance at 1%, 5%, and 10% significance levels, respectively.

The model 3.2 is first estimated by pooled OLS, and these results are presented in table 3.12. The main results on the EU ETS productivity premia indicate that the EU ETS does not have an impact on firms' productivity. These results are in line with previous findings (Anger and Oberndorfer, 2008; Chan, Li, & Zhang, 2013; Jaraite and Di Maria, 2014). When observing two other main SRE policy support instruments, FIT and RPS, the OLS estimates show that RPS started to boost firm's productivity after the implementation of the EU ETS in 2005. Results on the FIT impact on the productivity of firms reveal that the FIT has a significant positive impact on firms' productivity. In particular, the FIT has been an effective support instrument during the whole period observed (1992-2012), before and after the implementation of the EU ETS. This finding is in line with the economic rationale behind the FIT, i.e. that FIT offers a long-term support for SRET investments that further lead to increased firms' productivity (Mitchell, Bauknecht, & Connor, 2006; Agnolucci, 2007; Dong, 2012; Mabee et al., 2012; Jaraitė & Kažukauskas, 2013; Lundgren et al., 2015). The results confirm the significant positive relationship between SRET capacity installation and firms' productivity in all years observed. However, the OLS estimates reveal that the EU ETS and FIT/RPS interactions do not have a systematic impact of firms' productivity except in the period around 2005, the year when the EU ETS was implemented. Table 3.13 presents the FE results on the productivity premia of EU ETS firms in the FIT or RPS environment.

Table 3.13: ***Robustness check.*** **FE** results on the productivity premia of firms that are included in the ETS scheme before and after the inclusion in the scheme (Model 3.2)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Time period	-3	-2	-1	0	1	2	3
ETS	-0.081	-0.250	-0.023	0.207*	0.385*	0.444	0.550
	[0.298]	[0.390]	[0.784]	[0.084]	[0.092]	[0.147]	[0.226]
RPS	0.007	-0.012	-0.027**	0.037***	0.008	0.022*	0.066***
	[0.560]	[0.299]	[0.012]	[0.001]	[0.422]	[0.090]	[0.000]
FIT	0.190***	0.138***	0.168***	0.151***	0.106***	0.080***	0.081***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
ETS*RPS	0.158	0.399	0.175	-0.064	-0.209	-0.300	-0.423
	[0.291]	[0.234]	[0.324]	[0.702]	[0.421]	[0.364]	[0.365]
ETS*FIT	0.130	0.268	0.023	-0.242*	-0.410	-0.310	-0.387
	[0.244]	[0.388]	[0.866]	[0.097]	[0.101]	[0.340]	[0.402]
Log CPE	0.006***	0.011***	0.024***	0.051***	0.021***	0.002	-0.002
	[0.008]	[0.000]	[0.000]	[0.000]	[0.000]	[0.439]	[0.569]
Log ELP	0.299***	0.258***	0.168***	-0.012	-0.053**	-0.079***	-0.038
	[0.000]	[0.000]	[0.000]	[0.559]	[0.041]	[0.007]	[0.248]
Log SREC	0.202***	0.209***	0.216***	0.201***	0.134***	0.087***	0.027
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.184]
Log EMP	0.033***	0.035***	-0.043***	-0.399***	-0.059***	-0.019*	0.001
	[0.004]	[0.002]	[0.000]	[0.000]	[0.000]	[0.075]	[0.946]
Constant	-2.122***	-1.933***	-1.329***	0.515***	-0.005	0.189	0.097
	[0.000]	[0.000]	[0.000]	[0.000]	[0.968]	[0.156]	[0.548]
Observations	70,287	89,148	111,381	153,385	111,052	88,042	68,790
R-squared	0.023	0.019	0.021	0.119	0.010	0.003	0.003
Number of firms	21,822	25,240	28,876	35,484	28,958	25,270	21,632
beta1	-7.757	-22.11	-2.309	22.97	46.91	55.95	73.32
beta2	0.733	-1.154	-2.709	3.718	0.846	2.240	6.802
beta3	20.93	14.85	18.31	16.25	11.22	8.373	8.442
beta4	17.09	48.98	19.07	-6.166	-18.86	-25.90	-34.51
beta5	13.89	30.80	2.344	-21.46	-33.62	-26.68	-32.12

Notes. ETS – EU emission trading scheme; RPS – renewable portfolio standard; FIT – feed in tariff; CPE – capital per employee; ELP – electricity prices; SREC – SRE capacity installed; EMP – employees; beta1 – EU ETS productivity premia; beta2 – RPS productivity premia; beta3 – FIT productivity premia; b4 – EU ETS*RPS productivity premia; b5 – EU ETS*FIT productivity premia. The model is estimated using FE. Regressions control for time, country, and industry fixed effects. The dependent variable is the log value of labour productivity. Robust standard errors are in square brackets. ***, **, *, denote significance at 1%, 5%, and 10% significance levels, respectively.

As a robustness check, the model 3.2 is estimated by FE. The main results on the EU ETS productivity premia are in line with the results obtained by estimating the model by pooled OLS. The results presented in table 3.13 indicate that the EU ETS does not have an impact on firms' productivity, except in the period around the EU ETS implementation phase, i.e. in years t_0 and t_1. Considering the other SRE policy support instruments, FE estimates also support the pooled OLS results that show that RPS started to have a positive impact on firm's productivity after the EU ETS is implemented. The FE estimates support also the OLS results on the FIT effectiveness in increasing the firms' productivity. In particular, the FE results confirm that FIT has a positive impact on firms' productivity during the whole period observed, before and after the implementation of the EU ETS. However, the EU ETS and FIT/RPS interactions do not have a systematic impact of firms' productivity.

3.5.3. Productivity growth of EU ETS and non EU ETS firms

This subsection presents and discusses the results on the impact of the policy support instruments on firms' productivity growth. The main policy support instruments aimed at facilitating the diffusion of SRET and thus consequently increasing the productivity growth of firms are the EU ETS, FIT and RPS. The model (model 3.3) is estimated in first differences (table 3.14).

Table 3.14: Results of the empirical model for estimating the impact of SRE support instruments on firms' productivity growth, first differences, dependent variable: labour productivity (Model 3.3)

VARIABLES	(1) FD	(2) FE	(3) System GMM
ETS	0.042	-0.248	-0.079
	[0.29]	[-0.81]	[-0.79]
RPS	-0.161***	-0.056*	0.075
	[-4.96]	[-1.91]	[1.44]
FIT	0.224***	0.389***	0.285***
	[3.31]	[6.30]	[3.46]
ETS*RPS	0.035	0.530	0.224
	[0.23]	[1.51]	[1.28]
ETS*FIT	-0.094	0.233	0.066
	[-0.60]	[0.74]	[0.45]
Δ CPE	0.052***	0.059***	0.065***
	[8.90]	[7.98]	[3.39]
Δ ELP	0.018***	0.009***	0.013***
	[4.03]	[2.64]	[2.71]
Δ SREC	-0.005	-0.004	0.001
	[-0.81]	[-0.77]	[0.11]
L2.log VAPE	-0.056***	-0.095***	0.531**
	[-7.73]	[-3.12]	[2.44]
L2.log ELP	0.255***	-0.076	0.044
	[4.54]	[-1.08]	[0.47]
L2. SREC	-0.001	-0.009***	-0.005
	[-0.78]	[-3.38]	[-1.41]
L2.log EMP	0.005*	-0.049**	0.023***
	[1.95]	[-2.05]	[2.68]
L.log VAPE			-0.088
			[-0.47]
Constant	-1.693***	4.136***	1.704**
	[-4.98]	[11.71]	[2.02]
Observations	35,269	40,411	35,283
R-squared	0.042	0.066	
Number of id		18,645	
Hansen			30.70
p_Hansen			0.163
AR1			-1.524
p_AR1			0.128
AR2			-1.826
p_AR2			0.0679

Notes. ETS – emission trading scheme, RPS – renewable portfolio standard, FIT – feed in tariff, CPE – capital per employee, ELP – electricity prices, SREC – SRE capacity installed, EMP – employees. The dependent variable is the growth rate of VAPE – labour productivity. Pooled OLS, FE, and system GMM regressions control for time, country, industry, and firm fixed effects. Robust standard errors are in square brackets. ***, **, *, denote significance at 1%, 5%, and 10% significance levels, respectively.

The results obtained using the three different estimation methods (pooled OLS, FE, and system GMM) indicate that there are no major differences in the signs and significance of the estimated coefficients. Hansen's J statistics, which is robust to heteroskedasticity and autocorrelation, confirms the validity of the instruments when using the system GMM. System GMM is used instead of Olley and Pakes (OP) and Levinsohn-Petrin (LP) method (Olley & Pakes, 1996; Levinsohn & Petrin, 2003) as a robustness check to control for the endogeneity in the production function.

From the time it was introduced in 2005, the EU ETS has been the subject of dynamic policy and research debates. Analogous to the results of previous studies examining the impact of the EU ETS on firms' performance (Anger and Oberndorfer, 2008; Chan, Li, & Zhang, 2013; Jaraite and Di Maria, 2014), the results of this study indicate that the EU ETS had no significant impact on firms' productivity growth. This could be a consequence of the grandfathering in the first phase of the EU ETS instead of the auctioning of allowances and of the global economic crisis in the second phase.

Other main results are in line with the results obtained in the second model (model 3.2), when observing the period from t_1 till t_3. RPS had a negative impact on firms' productivity growth till 2005 and therefore its overall coefficient is negative (or insignificant in the model estimated by the system GMM). The impact of FIT on firms' productivity growth is significant and positive in all models. These findings are in line with expectations, since FIT guarantees long-term financial support for SRET investments, thus reducing the investment risk for firms. However, firms operating in RPS countries face higher SRET investment risk because the prices of TGCs in an RPS context are uncertain. The insignificant coefficients for the EU ETS and RPS-FIT interaction terms indicate that there was no statistically significant difference in the productivity of EU ETS and non-EU ETS firms operating in RPS-FIT countries.

It should be noted that previous econometric studies do not explicitly discuss the impact of the EU ETS on the productivity of firms in FIT and RPS environments. The only similar research was conducted by Jaraitė & Kažukauskas (2013) who analyse the impact of these instruments on firm profitability. The results of the current analysis show that the changes in the productivity growth of firms could be better explained by the changes in the economic environment rather than by the influence of the EU ETS.

The third phase of the EU ETS (operating from 2013 to 2020) is significantly different from phases 1 and 2. The main changes in the third phase of the EU ETS include: a single EU-wide emissions 'cap' replaces the previous national caps; auctioning replaces the free allocation of allowances; for those allowances that are still given for free, free allocation is based on ambitious benchmarks for GHG emissions performance; more sectors are covered; the NER 300 programme is implemented, funded from the sale of 300 million allowances from the New Entrants' Reserve (NER) to support SRE and carbon capture and storage technologies (European Commission, 2014a). Some authors (e.g. Abrell et al., 2011) warn that while the full auctioning of allowances could stimulate emission reductions, it could negatively affect the profitability of the EU ETS firms. Additional research on the effectiveness of the third phase of the EU ETS is needed after more data becomes available. Another interesting research topic would be to examine the effectiveness of the NER 300 programme in supporting the use of and innovations in source- and firm-specific renewable technologies.

3.6. Concluding remarks and policy implications

The main aim of this chapter was to identify how the productivity and productivity growth of firms in addition to CO_2 emissions of the EU ETS firms in different sectors change in response to climate policy instruments over 20 years. This relationship was studied on a micro level by assessing the impact of the EU ETS and two major SRE support instruments (FITs and RPSs) on the verified emissions, productivity and productivity growth of firms. This analysis utilised data from two main sources (the Amadeus database and the EUTL) for 27 EU countries in the period 1992–2012.

Considering the first model, the results confirm that country-level factors (such as electricity prices) have a greater influence on CO_2 emissions compared to the financial and fiscal support instruments (FIT and RPS). Although the impact of FIT and RPS is statistically insignificant, it is positive. Therefore, it is recommended that the SRE policies of countries should implement these support instruments.

The results obtained by estimating the second and third model are in line with the findings of prior studies (Demailly & Quirion, 2008; Anger & Oberndorfer, 2008; Abrell et al., 2011; Kažukauskas & Jaraite, 2011; Commins et al., 2011) that the EU ETS had no significant impact on firm performance, or its impact is negative. As previously explained, the insignificant or negative impact of the EU ETS on firms' productivity / productivity growth could be a consequence of the free allocation of allowances in the first phase of the EU ETS and the global economic crisis in the second phase. Due to the free allocation of emission allowances and the economic downturn, the firms did not have sufficient motivation to invest in SRET. If the firms had invested in SRET, the utilisation of new clean technologies would have consequently increased their productivity / productivity growth. However, in this case, the increase in the productivity and productivity growth of firms could be explained by the changes in the firms' economic activity and economic environment rather than by the influence of the EU ETS. Further research is needed before conclusive policy recommendations can be made regarding the EU ETS. In particular, the model developed in this study should be re-examined after countries recover from the economic crisis and after data for the third phase of the ETS becomes available. It is important to include the new EU ETS data since (learning from past experience) in the third EU ETS trading period (2013–2020), the emission allowances will be auctioned, not freely allocated. Thus, future analyses are expected to identify the positive significant impact of the EU ETS on firms' productivity / productivity growth.

Further, the main results reveal that the firms operating in FIT countries are more productive compared to the firms operating in countries that had set quotas for electricity to be produced from SRET. The explanation for this finding is that the FIT system's support better stimulates the firms' SRET investments, which subsequently leads to an increase in their productivity / productivity growth. The FIT system guarantees long-term payments to SRE electricity producers, which decreases their investment risk. In contrast, the RPS system is mainly criticised for the higher level of risk for SRET investors, as the prices of green certificates in the RPS system are uncertain (see e.g. Mitchell et al., 2006). Thus, firms operating in RPS countries are less interested in investing in more productive clean technologies because of the higher SRET investment costs and the uncertain returns on investments. Prior macro-level research findings (Sawin, 2004; Mitchell, Bauknecht, & Connor, 2006; Lipp, 2007; Butler & Neuhoff, 2008; Jenner, 2012; Mabee et al., 2012) predominantly support the finding that the FIT is more effective than the RPS in promoting a particular type of SRET. However, this study is the first firm-level econometric examination of the impact of FIT versus the impact of RPS on the productivity and productivity growth of firms. To the best of my knowledge, the only similar extant study that examines the impact of FIT and RPS on firm profitability is Jaraitė & Kažukauskas (2013). In general, governments should carefully consider the use of the EU ETS in combination with other policy support instruments. Based on the results that emerge from this analysis, governments should implement FITs that have been proved to increase the productivity / productivity growth of firms. Thus, the SRE policies of different countries would have greater success in achieving their specific economic and climate change targets.

The results of this analysis of the effectiveness of the EU ETS and SRE support instruments should prove instructive for policy makers worldwide, since the policies related to carbon pricing emerge outside the EU. Policy makers should study the 10-year European experience with the EU ETS, which is the largest emission trading scheme in operation today. To recap, the primary goal of the EU ETS is to reduce CO_2 emission and fulfil the Kyoto targets at minimal costs. It is not intended to boost the EU economy. However, an effective combination of the EU ETS and SRE policy instruments in force could facilitate emission reductions, money savings, energy savings, and economic growth. In addition, these instruments would encourage the investments of firms in SRET, which would subsequently lead to the increased productivity of firms. This would in turn boost the SRE achievements of these countries.

CONCLUSION

The purpose of the last chapter of this doctoral dissertation is to emphasize and discuss its main findings. Based on these findings, this chapter offers recommendations for energy policy decision-makers and for firm managers. This chapter also highlights the dissertation's main scientific contribution, describes its boundaries, and provides suggestions for further relevant research.

Summary of main findings

The main findings of this doctoral dissertation are organized in three parts. These parts summarize the findings from the three chapters of the thesis, namely, policy instruments for eco-innovations, macroeconomic analysis of the effectiveness of policy instruments in promoting technological changes, and renewable energy policy instruments and firm productivity.

In general, the technological change process decreases the negative political, socio-economic and environmental effects of non-SRE production and use (e.g., Johnstone et al., 2010; OECD, 2010; Dong, 2012; Jaraitė & Kažukauskas, 2013; Aguirre & Ibikunle, 2014; Boehringer, et al., 2014). No single instrument alone can challenge the complete process of technological change. Within this context, the dissertation presents the country-level and firm-level results.

In particular, the literature review analysis informs that the impact of policy support instruments differs with respect to SRET type and stage of development. The problem is that studies predominantly focus on the most popular support instruments and on technologies with a greater number of installations (e.g., Dong, 2012). Moreover, other elements that could impact SRET development are not sufficiently considered. This dissertation's comprehensive econometric analysis that addresses all of the above-mentioned problems reveals that FITs, both premium and fixed, RPS and tenders effectively promote wind technologies. These results are consistent with relevant econometric findings of Falconett and Nagasaka (2010), Groba et al. (2011), and Dong (2012). The success of these instruments is confirmed in the case of wind capacity installations and in the case of electricity generation from wind technologies. Consistent with previous research, other results proved to be technology- and model- dependent. The results of another econometric analysis presented in this thesis reveal that the economic activity of companies and country-level factors such as electricity prices have a greater impact on firms' CO_2 emissions than financial instruments aimed at supporting SRET. Moreover, the EU ETS had no impact or had a modest impact on firms' productivity / productivity growth. Firms operating in RPS countries were less productive than firms in the FIT environment.

Recommendations for the EU Energy Policy

This doctoral thesis provides comprehensive policy suggestions for choosing the most effective support instruments to encourage technological changes. National SRE departments should first prepare the market for SRET development. The preparation process should primarily focus on raising public environmental awareness. Second, it should provide detailed information on SRET support instruments that are available for use to industries and households.

Policy makers in the energy sector should first find a compromise between the often-conflicting countries' political and SRE objectives. For example, if some countries have highly developed non-SRE energy infrastructure, their energy policy could have less interest in promoting SRET. In such situation, it is recommended that SRE advocates face traditional energy lobbyists. When policy makers decide on the desired level of SRET development, they can focus on SRET support instruments. Before deciding on an instrument's (re)design, implementation or removal, policy makers should be familiar with the current level of SRET development in their countries. In particular, they need to know the exact number of wind, solar, biomass and / or geothermal technology innovations and installations. They should also carefully consider the information on technological performance, indicated by the amount of electricity generated from SRE sources. This is an important factor in deciding on the level of financial and fiscal support for technological development. If some technologies are already successfully implemented in a particular country, e.g., wind technologies in Germany, then policy makers should decide to give higher incentives for other technologies and less for wind. This does not imply that support instruments for wind technologies should be completely removed. It is important that SRET technologies are continuously supported to eventually commercially compete with traditional technologies. In this case, only changes in the design of particular support instruments are recommended (e.g., lower amount of support or shorter guaranteed FIT support period). In the next case, changes should consider instrument implementation or removal. New support instruments are required if already implemented instruments are not effective in promoting SRET in a particular country. In line with this reasoning, non-effective instruments should no longer be in force. The recommendations for such changes are based on the comprehensive empirical research presented in this doctoral dissertation. The first set of energy policy recommendations is associated with elements that could impact SRET diffusion. To summarize, wind FITs, potentially in combination with tendering schemes, are a recommended policy option for promoting wind technology diffusion. In particular, these instruments are effective in supporting both implementation and electricity generation from wind technologies. The impact of policy instruments and other political, socio-economic and environmental elements on SRET proved to be technology dependent. As such, these elements should be individually observed. Moreover, the relevant literature and SRE policy legislation further suggest that SRE and emission reduction targets mainly address the technological diffusion phase. Given that innovations are a necessary precondition for successful technological changes, policy makers should require a certain amount of technology specific innovations from each country. The results presented in this thesis suggest that innovations in biomass technologies increase the electricity generation from biomass technologies. Based on these findings, it is recommended that policy makers increase the level of support for innovations for less diffused types of SRET. The second set of energy policy recommendations refers to the impact of SRE policy support instruments on a firm's CO_2 emissions and its related productivity / productivity growth. It is recommended that RPS countries implement FIT as the results identify higher productivity growth and lower CO_2 emissions of the EU ETS firms operating in an FIT environment.

In conclusion, it is very important that financial and fiscal decisions at the policy level are carefully planned in advance. Policy makers should be well aware of the fact that frequent changes in SRE decisions, practices and laws could be very dangerous. Uncertainty caused by frequently changing policy support instruments in force or by frequently changing their level of support is one of the most serious SRET investment barriers.

Recommendations for firms' management

SRE oriented business philosophy is a prerequisite for a firm's success in a competitive environment. The results obtained in the thesis, especially in the third chapter, should attract the attention of business experts. Currently, the majority of top-level managers are expected to have a highly developed environmental awareness. However, in many cases, there is still a discrepancy between achieving the relationship between decreasing a firm's CO_2 emissions and increasing a firm's productivity. In cases when firms still struggle with emissions and have not reached the desired level of productivity, the following recommendations could help: in countries where available, firms should use FIT support. Both the literature and practice reveal that not all managers have sufficient knowledge on the policy support that they can get for SRET. Therefore, managers should get more acquainted with country-specific SRE policy. It is also recommended that firm managers consider the relevant output of firm level research analyses. Because SRE policies change over time, the following updates should be seen as a competitive advantage.

Original scientific contribution, limitations and further challenges

This doctoral dissertation could contribute to energy and environmental economics theory, policy and practice. Compared to previous studies, this research differs as follows: first, it provides the most comprehensive and systematic review analysis to date. This analysis contributes to the literature because it addresses multiple SRET support instruments with respect to technology type and stage. In addition, it offers valuable methodological suggestions for addressing unsolved issues regarding SRET development. To the best of my knowledge, this is the first literature analysis in the energy and environmental economics field that uses such an approach. Second, the empirical part of this doctoral dissertation contributes to the literature, energy policy and industry because it overcomes the shortages of previous studies. The first empirical analysis presented in this thesis provides the innovative methodological framework to evaluate all elements that could potentially impact technological diffusion. In particular, the first analysis focuses on multiple financial and fiscal instruments introduced to support renewables. Additionally, it controls for the impact of political, socio-economic and environmental elements that should have not been neglected in previous research. Among others, it is a pioneer in introducing the variable that serves to capture the perception of corruption into the technological diffusion framework. This is particularly important because it helps to discover potential barriers to SRET implementation, such as perceived corruption in the energy sector. The second empirical analysis presented in the thesis reveals new findings on the relationship between support instruments and firms' economic and environmental performance. It is focused on the EU ETS in combination with other SRET support instruments, not on the EU ETS solely, as in a majority of previous studies. It is important to emphasize that both analyses use a longer time series (1990-2011 and 1992-2012) that allows the identification of recent changes in the environment on SRET implementation, electricity generation from SRET and firm performance. In particular, with a longer series, one can control for the impacts of the recent financial crisis, energy price increases, changes in the EU ETS design, rising public environmental awareness, more stringent climate change targets, etc. The analyses apply different advanced estimation techniques (pooled OLS, PCSE, FE, RE and system GMM) to confirm the robustness of the results. The results of such an analyses aim to clarify the conflicting results on policy instruments, SRET and firms' performance obtained thus far.

This doctoral dissertation has some data limitation problems. As a consequence, more comprehensive indicators that would include all of the design characteristics of SRET support instruments could not be constructed. Instead, this doctoral dissertation follows the approach taken in a majority of relevant studies and uses a binary variable to indicate a particular policy instrument. Second, some countries (e.g., Malta) are excluded from the analysis because of incomplete data. Third, in cases when data are not available (e.g., data for energy prices) for all EU countries (but covers only OECD countries) indexes for OECD Total serve as a proxy.

Researchers may use insights from this doctoral thesis to examine relevant topics and to facilitate this journey towards a cleaner environment. Several topics for further research are suggested. First, building on the work initiated by Jenner (2012), further studies should develop indicators that would capture a SRET support instrument's specific design. Second, to support the econometric assessment of SRET support instruments, additional data should be collected through elite interviews with policy makers and business professionals. They should be asked to rank the policy instruments according to their effectiveness in achieving political, socio-economic and environmental targets. Third, using the methodological framework presented in the third chapter, how SRET specific innovations contribute to firm's CO_2 emission reductions should be investigated. Another interesting task would be to determine the impact of a firm's SRET capacity innovations and installations on a firm's productivity. Fifth, the effectiveness of the 3rd phase of the EU ETS should be analysed as data becomes available. Sixth, further research should examine the role of the other Kyoto instruments, JI and CDM, in the process of climate change. Seventh, it is recommended that further research extends to include developing countries when more data becomes accessible. Finally, researchers should constantly keep up with the turbulent changes in the energy sector. One of the major current issues is the sharp decline in oil prices that creates uncertainty for SRET diffusion and use. Although SRE prices are also falling, they are still not competitive with the prices of energy produced from conventional technologies. In this case, ex-ante analysis should predict the effectiveness of implemented policy instruments in supporting renewables in a changing environment. If implemented instruments are ineffective, one potential solution is to remove the incentives for producing fossil fuels. Instead, these incentives should be used to encourage technological change. Taking into account the market signs that oil prices should remain low for a longer period now is the right time to rethink incentive policies.

In conclusion, the results obtained in the doctoral dissertation are expected to attract the interest of energy policy makers, firm managers, researchers and broader society.

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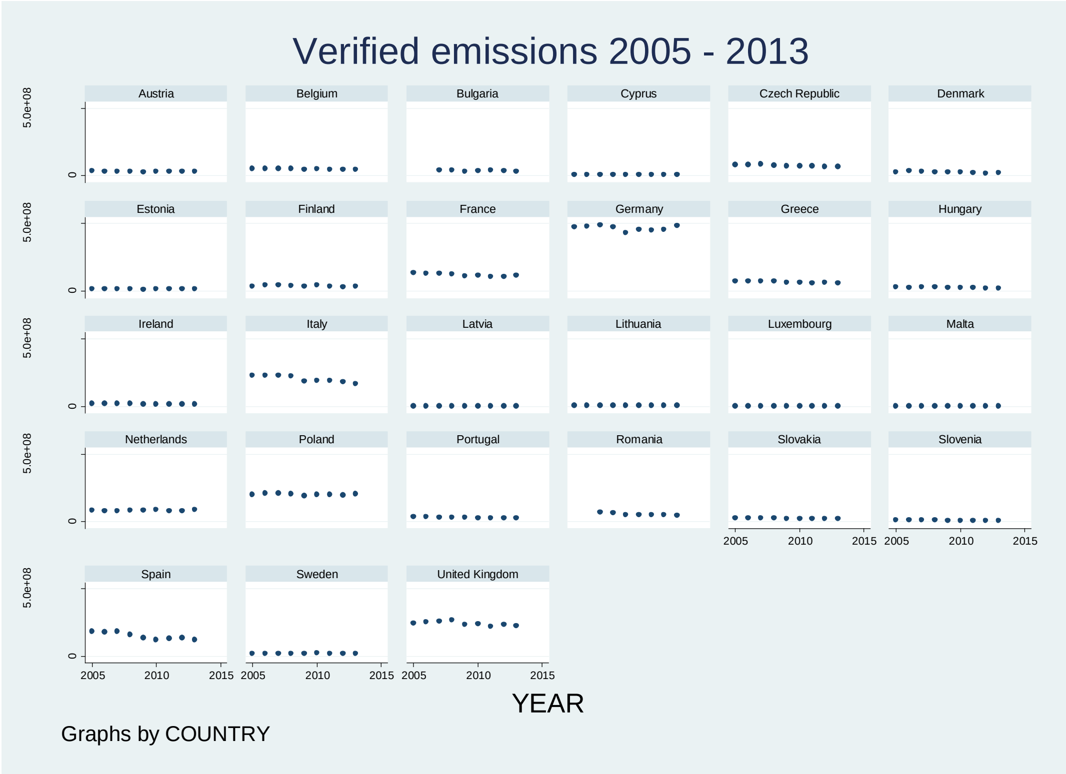
APPENDICES

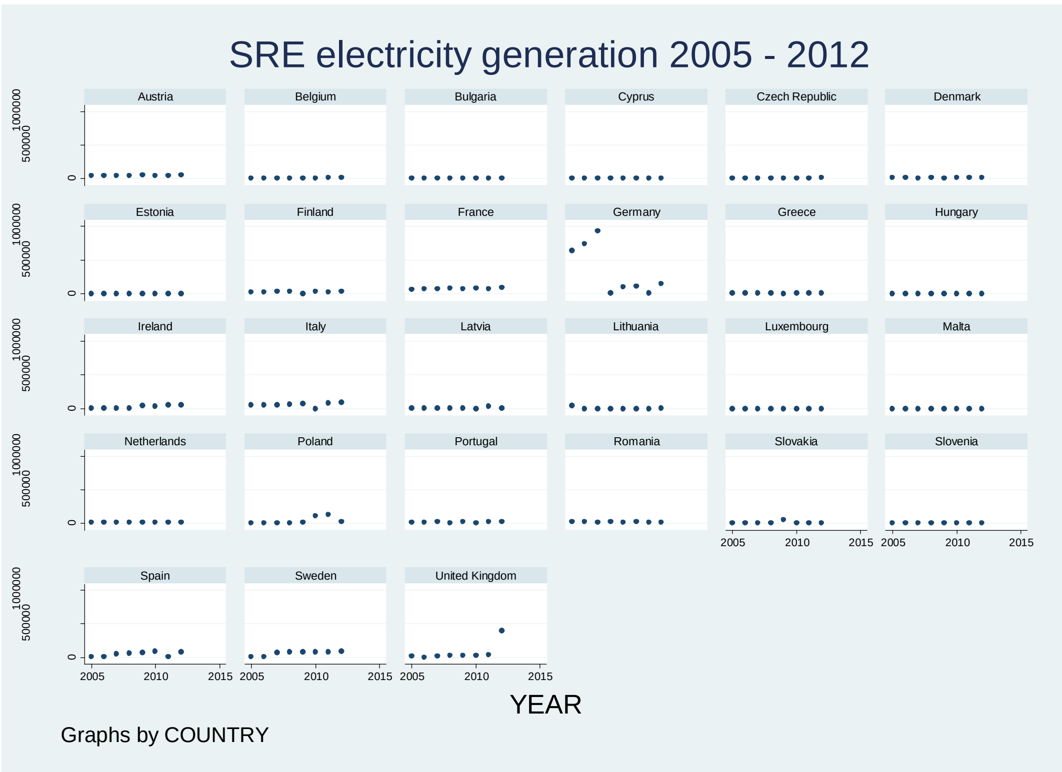
LIST OF APPENDICES

Appendix A: Total verified EU ETS emissions in the period from 2005 to 2013



Source: European Environment Agency, *EU ETS data from the EUTL*, 2014.

Appendix B: Total electricity generation from SRET in the period from 2005 to 2012



Source: IEA, *International Energy Statistics*, 2014.

Appendix C: Energy price movements 1990-2011

YEAR	CODE	CP	EP	OP	NGP	CODE	CP	EP	OP	NGP
1990	**AT**	87.4	101.5	88.3	71.0	**IT**	68.0	75.6	82.4	80.7
1991	**AT**	84.0	102.5	83.0	74.4	**IT**	67.0	81.5	86.6	93.7
1992	**AT**	74.5	102.7	82.7	70.1	**IT**	63.1	83.5	83.9	92.3
1993	**AT**	73.2	104.3	80.1	68.1	**IT**	73.1	82.5	86.6	92.2
1994	**AT**	71.5	101.0	79.2	66.7	**IT**	70.3	86.2	82.7	94.1
1995	**AT**	70.7	100.4	84.4	65.7	**IT**	70.5	82.9	84.7	92.2
1996	**AT**	68.9	105.9	86.5	69.0	**IT**	67.2	82.0	86.2	93.9
1997	**AT**	63.0	110.1	87.7	73.6	**IT**	71.5	81.3	86.0	97.0
1998	**AT**	62.4	109.2	81.3	71.1	**IT**	69.7	82.1	81.2	94.7
1999	**AT**	60.0	88.1	82.6	69.9	**IT**	64.3	77.7	84.9	92.7
2000	**AT**	59.8	79.4	98.8	69.6	**IT**	73.0	85.2	94.6	91.7
2001	**AT**	62.4	81.4	93.3	74.7	**IT**	81.9	100.1	89.7	92.3
2002	**AT**	69.6	84.3	90.0	72.7	**IT**	79.8	98.7	87.5	92.8
2003	**AT**	69.1	85.4	88.1	93.5	**IT**	68.1	102.0	87.2	93.6
2004	**AT**	100.0	101.0	92.7	96.8	**IT**	78.3	96.8	90.3	94.2
2005	**AT**	100.0	100.0	100.0	100.0	**IT**	100.0	100.0	100.0	100.0
2006	**AT**	100.2	100.9	106.6	104.9	**IT**	102.1	113.4	102.3	113.6
2007	**AT**	99.7	110.4	104.9	111.6	**IT**	96.4	114.5	99.8	110.3
2008	**AT**	108.6	117.7	111.6	110.7	**IT**	139.2	124.3	107.4	117.4
2009	**AT**	114.3	121.4	93.6	119.3	**IT**	118.0	127.6	92.4	111.9
2010	**AT**	98.9	123.9	112.8	110.5	**IT**	143.6	121.3	100.5	114.0
2011	**AT**	106.8	122.3	122.1	115.6	**IT**	176.9	118.8	112.6	114.5
1990	**BE**	66.4	114.0	65.4	72.5	**LV**	78.6	107.6	72.3	73.9
1991	**BE**	68.6	110.2	66.3	77.4	**LV**	79.7	108.7	73.3	79.2
1992	**BE**	64.2	108.3	65.5	70.3	**LV**	78.3	109.8	71.6	76.6
1993	**BE**	66.1	110.7	67.6	69.4	**LV**	78.0	109.8	72.3	75.1
1994	**BE**	60.7	107.8	66.7	67.3	**LV**	79.4	107.4	72.2	74.5
1995	**BE**	64.3	107.3	64.1	65.2	**LV**	76.8	103.5	71.0	72.8
1996	**BE**	66.6	105.4	70.3	63.7	**LV**	77.7	101.6	74.7	72.3
1997	**BE**	70.8	103.6	72.2	66.4	**LV**	81.3	98.2	76.3	75.4
1998	**BE**	67.8	104.1	65.6	64.9	**LV**	80.0	96.9	72.5	73.5
1999	**BE**	63.4	99.2	69.4	62.3	**LV**	74.1	93.2	77.8	71.7
2000	**BE**	64.0	94.0	84.0	70.7	**LV**	75.1	87.8	90.7	79.0
2001	**BE**	72.2	95.5	79.5	83.9	**LV**	80.8	92.3	86.8	86.3
2002	**BE**	71.1	96.6	75.3	89.6	**LV**	81.9	93.7	84.7	87.5
2003	**BE**	72.6	93.9	78.3	100.3	**LV**	78.2	97.3	85.9	91.7
2004	**BE**	118.8	102.9	88.0	96.0	**LV**	92.4	96.8	90.0	89.7
2005	**BE**	100.0	100.0	100.0	100.0	**LV**	100.0	100.0	100.0	100.0
2006	**BE**	99.4	100.8	101.3	110.7	**LV**	97.9	106.6	103.3	118.7
2007	**BE**	123.2	103.9	99.9	102.3	**LV**	99.9	110.1	101.9	118.4
2008	**BE**	192.5	112.4	110.0	123.4	**LV**	131.9	118.6	111.7	132.8
2009	**BE**	157.0	112.8	90.0	104.4	**LV**	131.0	127.0	96.1	130.7
2010	**BE**	192.6	107.1	100.7	96.8	**LV**	140.7	127.9	107.2	123.3
2011	**BE**	183.4	108.6	113.1	108.7	**LV**	154.5	128.5	118.0	129.6
1990	**BG**	78.6	107.6	72.3	73.9	**LT**	78.6	107.6	72.3	73.9
1991	**BG**	79.7	108.7	73.3	79.2	**LT**	79.7	108.7	73.3	79.2
1992	**BG**	78.3	109.8	71.6	76.6	**LT**	78.3	109.8	71.6	76.6
1993	**BG**	78.0	109.8	72.3	75.1	**LT**	78.0	109.8	72.3	75.1
1994	**BG**	79.4	107.4	72.2	74.5	**LT**	79.4	107.4	72.2	74.5
1995	**BG**	76.8	103.5	71.0	72.8	**LT**	76.8	103.5	71.0	72.8
1996	**BG**	77.7	101.6	74.7	72.3	**LT**	77.7	101.6	74.7	72.3
1997	**BG**	81.3	98.2	76.3	75.4	**LT**	81.3	98.2	76.3	75.4
1998	**BG**	80.0	96.9	72.5	73.5	**LT**	80.0	96.9	72.5	73.5

1999	**BG**	74.1	93.2	77.8	71.7	**LT**	74.1	93.2	77.8	71.7
2000	**BG**	75.1	87.8	90.7	79.0	**LT**	75.1	87.8	90.7	79.0
2001	**BG**	80.8	92.3	86.8	86.3	**LT**	80.8	92.3	86.8	86.3
2002	**BG**	81.9	93.7	84.7	87.5	**LT**	81.9	93.7	84.7	87.5
2003	**BG**	78.2	97.3	85.9	91.7	**LT**	78.2	97.3	85.9	91.7
2004	**BG**	92.4	96.8	90.0	89.7	**LT**	92.4	96.8	90.0	89.7
2005	**BG**	100.0	100.0	100.0	100.0	**LT**	100.0	100.0	100.0	100.0
2006	**BG**	97.9	106.6	103.3	118.7	**LT**	97.9	106.6	103.3	118.7
2007	**BG**	99.9	110.1	101.9	118.4	**LT**	99.9	110.1	101.9	118.4
2008	**BG**	131.9	118.6	111.7	132.8	**LT**	131.9	118.6	111.7	132.8
2009	**BG**	131.0	127.0	96.1	130.7	**LT**	131.0	127.0	96.1	130.7
2010	**BG**	140.7	127.9	107.2	123.3	**LT**	140.7	127.9	107.2	123.3
2011	**BG**	154.5	128.5	118.0	129.6	**LT**	154.5	128.5	118.0	129.6
1990	**CY**	78.6	107.6	72.3	73.9	**LU**	118.5	82.2	60.4	98.5
1991	**CY**	79.7	108.7	73.3	79.2	**LU**	117.3	81.8	59.4	105.2
1992	**CY**	78.3	109.8	71.6	76.6	**LU**	78.3	79.7	61.2	103.6
1993	**CY**	78.0	109.8	72.3	75.1	**LU**	78.0	80.4	67.5	103.1
1994	**CY**	79.4	107.4	72.2	74.5	**LU**	79.4	81.1	68.6	104.1
1995	**CY**	76.8	103.5	71.0	72.8	**LU**	76.8	83.7	67.8	101.1
1996	**CY**	77.7	101.6	74.7	72.3	**LU**	77.7	88.0	73.0	114.8
1997	**CY**	81.3	98.2	76.3	75.4	**LU**	81.3	87.2	75.0	124.3
1998	**CY**	80.0	96.9	72.5	73.5	**LU**	80.0	86.3	68.2	113.2
1999	**CY**	74.1	93.2	77.8	71.7	**LU**	74.1	89.9	78.9	110.0
2000	**CY**	75.1	87.8	90.7	79.0	**LU**	75.1	83.4	92.9	94.2
2001	**CY**	80.8	92.3	86.8	86.3	**LU**	80.8	83.1	86.9	97.8
2002	**CY**	81.9	93.7	84.7	87.5	**LU**	81.9	90.7	83.8	90.9
2003	**CY**	78.2	97.3	85.9	91.7	**LU**	78.2	95.4	83.8	91.0
2004	**CY**	92.4	96.8	90.0	89.7	**LU**	92.4	82.7	87.5	89.5
2005	**CY**	100.0	100.0	100.0	100.0	**LU**	100.0	100.0	100.0	100.0
2006	**CY**	97.9	106.6	103.3	118.7	**LU**	97.9	92.4	102.9	106.0
2007	**CY**	99.9	110.1	101.9	118.4	**LU**	99.9	101.6	100.6	101.6
2008	**CY**	131.9	118.6	111.7	132.8	**LU**	131.9	79.0	110.6	119.1
2009	**CY**	131.0	127.0	96.1	130.7	**LU**	131.0	103.3	92.7	120.9
2010	**CY**	140.7	127.9	107.2	123.3	**LU**	140.7	89.9	104.2	116.9
2011	**CY**	154.5	128.5	118.0	129.6	**LU**	154.5	81.8	112.1	126.5
1990	**CZ**	79.8	80.8	139.2	75.4	**NL**	78.6	75.4	76.5	61.6
1991	**CZ**	78.8	90.2	119.6	87.5	**NL**	79.7	75.2	79.5	66.2
1992	**CZ**	84.9	103.2	117.1	79.8	**NL**	78.3	70.4	80.2	62.4
1993	**CZ**	84.8	93.0	101.2	70.9	**NL**	78.0	80.1	87.1	61.5
1994	**CZ**	85.1	91.4	96.4	68.1	**NL**	79.4	78.5	84.2	60.7
1995	**CZ**	83.3	84.8	95.5	65.5	**NL**	76.8	78.4	82.1	60.3
1996	**CZ**	75.1	80.1	90.6	63.8	**NL**	77.7	83.1	86.4	60.7
1997	**CZ**	80.4	80.4	90.2	67.6	**NL**	81.3	82.4	84.1	66.6
1998	**CZ**	82.6	87.1	80.9	74.9	**NL**	80.0	83.1	82.0	66.0
1999	**CZ**	85.2	90.3	85.6	76.4	**NL**	74.1	85.9	85.4	62.3
2000	**CZ**	81.9	93.1	104.1	89.2	**NL**	75.1	89.7	94.8	74.9
2001	**CZ**	84.6	92.3	95.5	91.0	**NL**	80.8	96.2	90.2	81.5
2002	**CZ**	87.4	96.0	85.6	89.7	**NL**	81.9	92.5	87.5	81.8
2003	**CZ**	88.3	93.2	86.7	90.6	**NL**	78.2	95.5	87.1	88.9
2004	**CZ**	88.0	94.6	92.5	86.3	**NL**	92.4	94.4	93.7	87.5
2005	**CZ**	100.0	100.0	100.0	100.0	**NL**	100.0	100.0	100.0	100.0
2006	**CZ**	100.7	107.9	102.6	121.7	**NL**	97.9	112.6	102.4	109.0
2007	**CZ**	102.6	113.9	98.6	108.4	**NL**	99.9	109.5	101.7	120.2
2008	**CZ**	111.6	120.4	101.4	131.6	**NL**	131.9	93.3	107.5	129.9
2009	**CZ**	122.5	136.1	89.1	136.4	**NL**	131.0	106.9	92.7	130.3
2010	**CZ**	125.0	130.5	102.4	133.3	**NL**	140.7	91.4	101.2	112.5
2011	**CZ**	126.2	130.2	108.6	139.4	**NL**	154.5	86.8	107.0	114.6

1990	**DK**	124.9	79.5	73.3	75.5	**PL**	55.7	52.4	70.6	37.6
1991	**DK**	117.3	84.5	75.4	75.1	**PL**	70.7	60.5	67.9	51.2
1992	**DK**	114.9	84.1	72.0	70.3	**PL**	67.9	70.2	72.2	66.8
1993	**DK**	88.8	88.0	73.1	71.2	**PL**	76.7	71.6	71.6	70.5
1994	**DK**	85.5	83.0	70.8	68.0	**PL**	82.7	72.9	64.0	68.4
1995	**DK**	84.6	81.8	72.7	63.8	**PL**	78.1	72.1	55.7	71.4
1996	**DK**	79.9	86.0	76.5	69.0	**PL**	80.1	71.9	55.8	75.2
1997	**DK**	84.8	86.4	79.2	70.5	**PL**	81.6	72.7	58.5	77.8
1998	**DK**	96.7	93.8	77.1	66.9	**PL**	80.7	74.8	56.6	80.1
1999	**DK**	99.9	92.9	84.2	69.0	**PL**	74.4	79.0	67.4	82.3
2000	**DK**	97.2	97.6	98.3	87.3	**PL**	72.0	79.9	84.6	86.0
2001	**DK**	101.2	97.7	94.1	84.6	**PL**	77.7	89.2	81.0	98.9
2002	**DK**	105.3	99.1	91.6	79.5	**PL**	78.0	94.4	80.7	103.4
2003	**DK**	106.0	101.6	91.0	80.7	**PL**	75.9	101.1	85.0	98.5
2004	**DK**	104.8	99.8	91.9	85.5	**PL**	96.0	97.5	90.5	93.4
2005	**DK**	100.0	100.0	100.0	100.0	**PL**	100.0	100.0	100.0	100.0
2006	**DK**	100.1	104.9	103.9	103.9	**PL**	91.7	102.1	101.5	121.4
2007	**DK**	99.7	100.1	102.7	96.2	**PL**	94.7	100.9	101.2	133.4
2008	**DK**	95.4	106.8	109.4	103.2	**PL**	130.1	116.8	107.3	157.1
2009	**DK**	100.7	101.0	94.7	87.4	**PL**	123.9	137.6	94.4	165.5
2010	**DK**	102.7	102.0	106.4	97.7	**PL**	140.6	135.6	106.7	157.4
2011	**DK**	106.2	105.7	117.8	102.5	**PL**	157.7	132.9	116.3	158.7
1990	**EE**	78.6	107.6	72.3	73.9	**PT**	154.2	136.4	90.9	73.9
1991	**EE**	79.7	108.7	73.3	79.2	**PT**	150.7	144.8	89.8	79.2
1992	**EE**	78.3	109.8	71.6	76.6	**PT**	125.9	152.3	86.2	76.6
1993	**EE**	78.0	109.8	72.3	75.1	**PT**	122.3	154.1	85.5	75.1
1994	**EE**	79.4	107.4	72.2	74.5	**PT**	119.8	148.6	84.9	74.5
1995	**EE**	76.8	103.5	71.0	72.8	**PT**	120.6	137.7	82.7	72.8
1996	**EE**	77.7	101.6	74.7	72.3	**PT**	120.6	127.9	81.7	72.3
1997	**EE**	81.3	52.0	27.6	85.8	**PT**	127.3	124.5	82.0	96.6
1998	**EE**	80.0	77.5	70.9	96.1	**PT**	112.2	126.1	80.9	101.3
1999	**EE**	74.1	80.8	76.6	98.8	**PT**	98.7	113.2	78.2	96.5
2000	**EE**	75.1	78.8	89.7	99.3	**PT**	106.7	103.3	83.1	98.5
2001	**EE**	80.8	85.2	87.4	99.0	**PT**	133.0	101.0	82.8	109.3
2002	**EE**	81.9	94.7	83.6	100.9	**PT**	109.4	99.6	78.1	97.7
2003	**EE**	78.2	98.0	82.9	99.9	**PT**	107.5	99.6	84.1	97.4
2004	**EE**	92.4	96.4	87.5	99.8	**PT**	98.4	99.0	88.8	90.1
2005	**EE**	100.0	100.0	100.0	100.0	**PT**	100.0	100.0	100.0	100.0
2006	**EE**	97.9	99.0	103.9	103.0	**PT**	98.2	102.2	107.5	107.7
2007	**EE**	99.9	95.8	97.4	105.9	**PT**	96.0	106.1	108.5	102.8
2008	**EE**	131.9	96.4	113.5	146.3	**PT**	93.3	98.2	117.5	108.1
2009	**EE**	131.0	107.6	94.9	147.0	**PT**	98.9	103.6	101.1	103.7
2010	**EE**	140.7	115.8	111.3	155.2	**PT**	99.1	103.9	111.6	102.4
2011	**EE**	154.5	113.4	120.9	158.0	**PT**	93.4	108.6	123.9	112.7
1990	**FI**	46.2	83.1	67.5	58.0	**RO**	78.6	107.6	72.3	73.9
1991	**FI**	47.0	83.6	67.3	60.1	**RO**	79.7	108.7	73.3	79.2
1992	**FI**	48.7	83.4	64.1	58.2	**RO**	78.3	109.8	71.6	76.6
1993	**FI**	51.4	87.5	72.5	61.1	**RO**	78.0	109.8	72.3	75.1
1994	**FI**	51.8	85.5	65.2	64.1	**RO**	79.4	107.4	72.2	74.5
1995	**FI**	51.8	86.1	65.6	71.7	**RO**	76.8	103.5	71.0	72.8
1996	**FI**	53.2	93.1	73.6	77.6	**RO**	77.7	101.6	74.7	72.3
1997	**FI**	63.0	90.5	74.9	84.3	**RO**	81.3	98.2	76.3	75.4
1998	**FI**	66.2	90.7	73.0	85.0	**RO**	80.0	96.9	72.5	73.5
1999	**FI**	69.1	87.2	78.1	82.6	**RO**	74.1	93.2	77.8	71.7
2000	**FI**	70.6	81.6	91.7	92.1	**RO**	75.1	87.8	90.7	79.0
2001	**FI**	78.0	82.9	87.4	94.0	**RO**	80.8	92.3	86.8	86.3
2002	**FI**	78.1	87.7	84.0	91.2	**RO**	81.9	93.7	84.7	87.5

2003	**FI**	75.9	105.3	86.4	96.3	**RO**	78.2	97.3	85.9	91.7
2004	**FI**	86.5	105.2	90.8	93.6	**RO**	92.4	96.8	90.0	89.7
2005	**FI**	100.0	100.0	100.0	100.0	**RO**	100.0	100.0	100.0	100.0
2006	**FI**	96.8	101.7	103.4	121.9	**RO**	97.9	106.6	103.3	118.7
2007	**FI**	94.3	99.4	100.1	115.5	**RO**	99.9	110.1	101.9	118.4
2008	**FI**	136.9	104.4	111.4	139.3	**RO**	131.9	118.6	111.7	132.8
2009	**FI**	117.7	115.5	95.6	141.1	**RO**	131.0	127.0	96.1	130.7
2010	**FI**	116.3	115.9	105.7	146.8	**RO**	140.7	127.9	107.2	123.3
2011	**FI**	172.7	126.7	118.0	195.0	**RO**	154.5	128.5	118.0	129.6
1990	**FR**	88.0	139.1	77.0	83.7	**SK**	78.6	107.6	72.3	73.9
1991	**FR**	89.9	133.6	74.7	84.7	**SK**	79.7	108.7	73.3	79.2
1992	**FR**	88.4	133.4	70.4	83.3	**SK**	78.3	109.8	71.6	76.6
1993	**FR**	85.7	135.2	72.1	81.6	**SK**	78.0	109.8	72.3	75.1
1994	**FR**	86.0	131.8	73.3	79.4	**SK**	79.4	107.4	72.2	74.5
1995	**FR**	78.9	128.8	72.6	75.6	**SK**	76.8	103.5	71.0	72.8
1996	**FR**	80.3	126.5	77.1	74.3	**SK**	77.7	101.6	74.7	72.3
1997	**FR**	82.4	118.5	79.2	78.1	**SK**	81.3	98.2	76.3	75.4
1998	**FR**	81.7	115.0	75.1	77.1	**SK**	80.0	96.9	72.5	73.5
1999	**FR**	78.0	111.8	79.4	73.0	**SK**	74.1	93.2	77.8	71.7
2000	**FR**	79.0	105.7	93.7	83.6	**SK**	75.1	87.8	90.7	79.0
2001	**FR**	83.1	103.8	86.3	96.6	**SK**	80.8	92.3	86.8	86.3
2002	**FR**	85.4	103.2	83.0	92.0	**SK**	81.9	93.7	84.7	87.5
2003	**FR**	78.5	102.7	83.4	94.8	**SK**	78.2	97.3	85.9	91.7
2004	**FR**	81.3	102.1	88.9	89.7	**SK**	92.4	96.8	90.0	89.7
2005	**FR**	100.0	100.0	100.0	100.0	**SK**	100.0	100.0	100.0	100.0
2006	**FR**	109.5	98.5	103.8	117.5	**SK**	97.9	106.6	103.3	118.7
2007	**FR**	98.1	111.8	102.8	113.7	**SK**	99.9	110.1	101.9	118.4
2008	**FR**	128.4	108.3	113.6	129.3	**SK**	131.9	118.6	111.7	132.8
2009	**FR**	133.0	113.1	95.2	119.2	**SK**	131.0	127.0	96.1	130.7
2010	**FR**	137.9	119.0	106.4	127.6	**SK**	140.7	127.9	107.2	123.3
2011	**FR**	156.9	124.3	118.5	139.8	**SK**	154.5	128.5	118.0	129.6
1990	**DE**	78.6	117.1	64.3	65.6	**SI**	78.6	107.6	72.3	73.9
1991	**DE**	79.7	113.3	68.4	70.7	**SI**	79.7	108.7	73.3	79.2
1992	**DE**	78.3	110.2	66.2	67.0	**SI**	78.3	109.8	71.6	76.6
1993	**DE**	78.0	110.4	63.7	64.8	**SI**	78.0	109.8	72.3	75.1
1994	**DE**	79.4	109.7	67.0	63.1	**SI**	79.4	107.4	72.2	74.5
1995	**DE**	76.8	107.4	65.0	60.5	**SI**	76.8	103.5	71.0	72.8
1996	**DE**	77.7	97.7	68.9	59.1	**SI**	77.7	101.6	74.7	72.3
1997	**DE**	81.3	96.1	69.6	63.3	**SI**	81.3	98.2	76.3	75.4
1998	**DE**	80.0	94.4	64.0	61.4	**SI**	80.0	96.9	72.5	73.5
1999	**DE**	74.1	89.3	70.6	59.5	**SI**	74.1	93.2	77.8	71.7
2000	**DE**	75.1	77.4	85.5	69.5	**SI**	75.1	102.1	86.6	98.7
2001	**DE**	80.8	81.8	83.8	77.9	**SI**	80.8	101.1	88.5	100.0
2002	**DE**	81.9	84.6	84.0	86.4	**SI**	81.9	100.5	87.8	98.3
2003	**DE**	78.2	92.0	86.7	92.0	**SI**	78.2	99.9	85.9	98.4
2004	**DE**	92.4	94.1	89.9	90.0	**SI**	92.4	100.4	88.7	98.2
2005	**DE**	100.0	100.0	100.0	100.0	**SI**	100.0	100.0	100.0	100.0
2006	**DE**	97.9	104.4	104.4	119.3	**SI**	97.9	99.7	105.1	101.8
2007	**DE**	99.9	109.8	104.4	119.4	**SI**	99.9	100.2	103.0	101.6
2008	**DE**	131.9	121.1	114.5	126.4	**SI**	131.9	98.6	110.9	116.1
2009	**DE**	131.0	131.4	97.2	121.6	**SI**	131.0	111.3	100.8	110.9
2010	**DE**	140.7	134.6	107.5	113.1	**SI**	140.7	108.7	114.3	117.1
2011	**DE**	154.5	139.8	120.0	117.3	**SI**	154.5	106.4	121.6	122.8
1990	**GR**	78.6	155.8	81.8	73.9	**ES**	78.6	143.9	74.9	80.7
1991	**GR**	79.7	149.6	88.7	79.2	**ES**	79.7	148.4	78.6	80.9
1992	**GR**	78.3	148.4	91.0	76.6	**ES**	78.3	147.3	80.3	80.6
1993	**GR**	78.0	133.7	93.9	75.1	**ES**	78.0	145.9	83.8	81.4

1994	**GR**	79.4	123.2	85.8	74.5	**ES**	79.4	142.1	82.2	84.5
1995	**GR**	76.8	122.7	81.9	72.8	**ES**	76.8	131.9	78.6	84.0
1996	**GR**	77.7	117.7	85.1	72.3	**ES**	77.7	127.6	82.4	87.2
1997	**GR**	81.3	114.0	82.4	78.0	**ES**	81.3	121.9	83.2	90.2
1998	**GR**	80.0	113.2	73.1	60.0	**ES**	80.0	116.1	78.2	84.9
1999	**GR**	74.1	107.8	74.8	68.2	**ES**	74.1	106.6	81.6	82.3
2000	**GR**	75.1	99.3	95.7	99.0	**ES**	75.1	98.4	92.7	107.9
2001	**GR**	80.8	100.6	90.5	93.5	**ES**	80.8	93.5	88.8	110.1
2002	**GR**	81.9	100.4	83.3	85.5	**ES**	81.9	96.0	87.1	98.6
2003	**GR**	78.2	100.5	83.3	85.4	**ES**	78.2	91.1	85.8	98.1
2004	**GR**	92.4	99.3	90.6	78.4	**ES**	92.4	89.0	89.4	92.1
2005	**GR**	100.0	100.0	100.0	100.0	**ES**	100.0	100.0	100.0	100.0
2006	**GR**	97.9	102.1	105.3	110.9	**ES**	97.9	102.9	102.0	118.3
2007	**GR**	99.9	103.9	105.6	125.2	**ES**	99.9	97.7	99.9	116.7
2008	**GR**	131.9	110.4	113.7	147.6	**ES**	131.9	109.8	110.0	128.2
2009	**GR**	131.0	116.2	98.0	122.8	**ES**	131.0	108.2	93.9	123.2
2010	**GR**	140.7	118.8	123.2	134.5	**ES**	140.7	133.2	107.0	115.1
2011	**GR**	154.5	117.9	135.7	146.3	**ES**	154.5	142.7	118.8	122.3
1990	**HU**	135.0	97.9	123.0	67.2	**SE**	78.6	75.1	69.6	73.9
1991	**HU**	120.8	83.6	109.3	77.0	**SE**	79.7	77.4	67.9	79.2
1992	**HU**	68.3	71.7	103.1	73.5	**SE**	78.3	79.3	63.9	76.6
1993	**HU**	63.8	63.3	97.3	67.8	**SE**	78.0	72.5	70.3	75.1
1994	**HU**	63.3	56.3	93.5	60.3	**SE**	79.4	71.8	68.3	74.5
1995	**HU**	53.1	65.3	86.2	66.2	**SE**	76.8	70.3	66.9	72.8
1996	**HU**	80.2	67.0	87.1	65.8	**SE**	77.7	76.4	69.5	72.3
1997	**HU**	99.8	77.9	86.6	87.3	**SE**	81.3	75.2	70.4	75.4
1998	**HU**	95.4	81.8	83.0	101.3	**SE**	80.0	77.0	68.8	73.5
1999	**HU**	95.8	85.5	92.3	99.0	**SE**	74.1	74.4	72.9	71.7
2000	**HU**	98.5	82.4	105.0	88.9	**SE**	75.1	73.8	86.1	79.0
2001	**HU**	101.6	81.2	95.6	83.2	**SE**	80.8	80.9	86.1	86.3
2002	**HU**	101.0	82.8	91.4	86.1	**SE**	81.9	84.1	83.9	87.5
2003	**HU**	99.2	90.5	92.6	107.3	**SE**	78.2	100.6	83.9	91.7
2004	**HU**	101.1	97.8	91.0	92.5	**SE**	92.4	101.3	89.2	89.7
2005	**HU**	100.0	100.0	100.0	100.0	**SE**	100.0	100.0	100.0	100.0
2006	**HU**	104.2	103.4	104.0	126.3	**SE**	97.9	109.6	103.6	118.7
2007	**HU**	108.4	112.5	99.8	182.6	**SE**	99.9	118.6	101.1	118.4
2008	**HU**	113.1	123.3	107.9	203.9	**SE**	131.9	130.7	111.4	132.8
2009	**HU**	129.1	127.5	92.7	211.6	**SE**	131.0	132.5	102.1	130.7
2010	**HU**	131.2	121.9	105.5	174.7	**SE**	140.7	140.9	108.9	123.3
2011	**HU**	133.4	118.2	117.7	187.6	**SE**	154.5	138.5	117.2	129.6
1990	**IE**	78.6	87.7	91.6	96.6	**UK**	94.0	117.1	69.4	102.5
1991	**IE**	79.7	87.8	89.5	96.2	**UK**	89.9	119.6	70.0	103.7
1992	**IE**	78.3	85.8	82.4	94.8	**UK**	91.0	121.7	68.9	100.4
1993	**IE**	78.0	83.8	80.7	91.5	**UK**	86.9	120.7	72.7	95.1
1994	**IE**	79.4	82.0	77.9	90.0	**UK**	88.2	119.1	73.1	97.3
1995	**IE**	76.8	79.8	76.7	88.6	**UK**	84.7	115.5	73.8	94.2
1996	**IE**	77.7	80.4	87.6	88.7	**UK**	84.5	111.2	75.9	89.4
1997	**IE**	81.3	80.9	85.6	87.7	**UK**	82.7	103.5	81.0	85.5
1998	**IE**	80.0	79.0	76.6	66.6	**UK**	82.1	98.5	83.1	81.4
1999	**IE**	74.1	78.0	75.8	71.1	**UK**	82.5	96.9	89.8	79.5
2000	**IE**	75.1	73.4	86.3	59.4	**UK**	81.4	90.8	99.6	76.6
2001	**IE**	80.8	74.7	82.5	65.3	**UK**	85.5	88.5	93.9	82.3
2002	**IE**	81.9	81.4	77.6	70.2	**UK**	87.7	87.2	90.2	85.9
2003	**IE**	78.2	90.4	81.0	81.3	**UK**	86.6	85.3	91.5	85.5
2004	**IE**	92.4	91.3	88.4	85.0	**UK**	90.5	88.7	94.1	90.0
2005	**IE**	100.0	100.0	100.0	100.0	**UK**	100.0	100.0	100.0	100.0
2006	**IE**	97.9	104.6	104.8	129.2	**UK**	100.7	119.3	102.2	124.6

2007	**IE**	99.9	114.6	103.2	138.6	**UK**	103.7	119.4	101.3	116.8
2008	**IE**	131.9	120.9	118.1	125.9	**UK**	119.3	133.8	112.1	137.5
2009	**IE**	131.0	122.8	100.2	125.0	**UK**	134.2	141.2	103.2	151.6
2010	**IE**	140.7	111.0	119.8	113.2	**UK**	136.3	127.4	113.0	139.9
2011	**IE**	154.5	115.5	137.5	118.0	**UK**	141.7	129.3	121.1	153.1

Note. CP, EP, OP and NGP denote coal prices, electricity prices, oil prices and natural gas prices, respectively. AT, Austria; BE, Belgium; BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DK, Denmark; EE, Estonia; FI, Finland; FR, France; DE, Germany; GR, Greece; HU, Hungary; IE, Ireland; IT, Italy; LV, Latvia; LT, Lithuania; LU, Luxembourg; NL, Netherlands; PL, Poland; PT, Portugal; RO, Romania; SK, Slovakia; SI, Slovenia; ES, Spain; SE, Sweden; UK, United Kingdom.

Source: IEA, *Energy Prices and Taxes Database*, 2014.

Appendix D: Overview of the relevant up-to date studies on policy instruments aimed at supporting the SRET diffusion

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
Aguirre & Ibikunle (2014)	1990 - 2010	EU countries, remaining OECD countries, and BRICS	Biomass, solar, wind energy potential; not technology specific	Contribution of RE to energy supply	- CO_2 emissions - net energy imports - energy use - population growth - GDP per capita - year of full deregulation of electricity market (dummy) - continuous commitment to renewables (dummy) - ratification of the Kyoto Protocol (dummy) - electricity production from coal, gas, nuclear, and oil sources - coal, natural gas, crude oil prices and electricity rates for industry - biomass, solar, wind potential - total number of RE policies and measures (direct investment, FIT, fiscal & financial support, grants & subsidies, green certificates, information and education, loans, market based instruments, negotiated agreements, RD&D, regulatory instruments, policy support and planning, voluntary instruments)	FEDV and PCSE
Bayer et al. (2013)	1990-2009	74 countries across the world	Wind, solar, hydro	Renewable patent counts	INDEPENDENT VARIABLES: - oil prices - installed renewable electricity capacity - democratic institutions - corruption CONTROL VARIABLES: lagged by one year - ln GDP - net inflows of FDI as % of GDP - sum of imports and exports as percent of GDP - urban population - OECD membership ROBUSTNESS CHECK: - capital account openness - KOF globalization index	FE negative binomial models

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
					- ln total expenditures on education - the share of the working population with tertiary education - cumulative count of projects registered under the CDM	
Carley (2009)	1998-2006	48 US States	Not technology specific	Ln of RE (excluding hydroelectricity) percentage of electricity generation per year - total amount of RE generation, excluding hydro	- RPS, binary **POLITICAL AND ENVIRONMENTAL INSTITUTION FACTORS** - a state's legislative commitment toward environmental policy - number of state and local natural resource governmental employees per 1000 capita - % of total gross state product (GSP) that is attributable to petroleum and coal manufacturing **STATE SOCIOECONOMIC FACTORS** - annual GSP pc - annual change in state population **STATE ELECTRICITY TRENDS** - the amount of total electricity generated per capita - deregulation - the average annual retail price of electricity across end users **NATURAL RESOURCE ENDOWMENT** - windy land area - estimated cumulative biomass quantities - technical daily max of total solar energy **OTHER STATE ENERGY POLICIES AND POLICY INTERACTIONS** - weighted index of corporate, sales, industrial, and property tax options - weighted index of grants, loans and rebates - percent of regional states that have PRS policy, lagged by one year	- FE - FEVD
Dong (2012)	2005-2009	53 countries (Country	Wind	Total /cumulative wind capacity installed at the end	- FIT and RPS + their interaction term dummies - GDP per capita - electricity net consumption	OLS, FE

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
		names not specified)		of each year, annual wind capacity	- net oil imports - wind resources - CO_2 intensity - information about other promotion policies that each country has	
Gan & Smith (2011)	1994-2003	26 OECD / IEA countries	Renewable energy in general and bioenergy	Per capita supply of renewable energy or bioenergy	- energy price - natural resources endowments, LAND area per capita, and forest land area per capita - GDP pc, - government R&D on RE and bioenergy - CO_2 emissions, t CO_2 per capita - policies: research and innovation policies, market deployment policies, market-based energy policies, number	- one way (country) FE model - Generalized Least Squares
Groba et al. (2011)	1992-2008	26 EU countries (Malta excluded due to incomplete data	Solar PV and onshore wind	- total capacity - annual added capacity	- Indicator ROI, nominal units - Indicator for RPS strength - FIT, binary - Tax or grant, binary - Tender, binary - GDP pc - land area - net import ratio, % – ln of net electricity imported to total electricity produced - energy consumption per capita, - nuclear, oil, natural gas, coal share - EU 2001, binary – indicates the ratification year of the 2001/EC/77 Directive	Pooled OLS, FE
Jenner (2012)	1990-2010	26 EU countries	Biomass, geothermal, solar PV, onshore wind	Biomass, geothermal, solar PV, onshore wind electricity generation	- biomass, geothermal, solar PV, onshore wind FIT: binary, tariff amount-eurocents, SFIT - % - ISI, % - tax break or investment grant, binary - tendering scheme, binary - nuclear, oil, natural gas, coal share - GDP pc	OLS, FE, PCSE

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
					- Net import ratio of electricity - Energy consumption per capita	
Marques & Fuinhas (2011)	Two time spans: 1990-1998, 1999-2006	21 EU country	Not diversified	- contribution of renewables to total energy supply as a percentage of the total primary energy supply	- Total number of energy efficiency policies and measures - CO_2 per capita (kg/cap) - Per capita energy - GDP - Real - Import dependency on energy - Importance of coal, oil, gas, nuclear to electricity generation - Coal price - Natural Gas price - Oil price	Quantile regression technique
Marques & Fuinhas (2012a)	1990-2007	23 EU countries	- not diversified	- Contribution of renewables to energy supply	- CO_2 per capita - Per capita energy - Import dependency of energy - Importance of coal, oil, gas, nuclear to electricity generation - Dummy = 1 if CRES higher or equal 10 - Accumulated number of RE policies and measures	- PCSE - RE, FE
Marques & Fuinhas (2012b)	1990-2007	24 EU countries	- not diversified	Ln of real GDP	- Per capita energy - Ln of the factor of contribution of renewables to total primary energy supply - Import dependency of energy - Contribution of coal, oil, gas, nuclear to electricity generation	Pooled OLS, PCSE
Marques et al. (2010)	1990-2006	European Union countries	Not diversified	- contribution of renewables to total energy supply as a percentage of the total primary energy supply	1. **political factors** - to be member of the EU in 2001 - import dependency on energy 2. **socioeconomic factors** - prices of oil, natural gas and coal - CO_2 per capita emissions - contribution of coal, oil, natural gas and nuclear to electricity generation - energy consumption per capita - income (GDP) – real GDP 3. **country specific factors**	OLS, RE, FE, FEVD

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
					- geographic area - continuous commitment on RE	
Popp et al. (2011)	1991-2004	26 OECD countries	Wind, solar photovoltaic, geothermal, biomass and waste	- RE capacity per capita, - Technology specific investment per capita, - % of RE electricity capacity	- the global knowledge stock for technology j (4 specifications) - GDPpc - % growth of electricity consumption (t-1) - % of electricity production from nuclear (t-1) - % of electricity production from hydro (t-1) - production of coal, natural gas, oil per capita - % of energy imported (t-1) - ratification of the Kyoto Protocol - REC - % of RE power required by any REC program in the country - FIT - continuous - other policies - dummy	Pooled regression with technology specific dummies, year fixed effects, country fixed effects
Romano & Scandurra (2011)	1980-2008	29 countries	Not technology specific	- Ratio: Total Renewable Electricity Net Generation / Total Net Electricity Generation-Net Electricity Imports (shREN)	- $shREN_{-1}$ - ln GDP in $2000 constant prices - ln energy intensity - ln CO_2 emissions - ratio: nuclear electricity net consumption/total net electricity generation-net electricity imports	Dynamic panel analysis
Salim & Rafiq (2012)	1980-2006	Brazil, China, India, Indonesia, Philippines and Turkey	Not technology specific	Renewable energy consumption	- real GDP - Carbon emission - oil prices	- panel methods – FMOLS, DOLS - time series method ARDL - Granger causality test (in ARDL approach)
Shrimali & Kniefel (2011)	1991-2007	50 US States	Wind, biomass, geothermal and solar	- the ratio of total non-hydro RE capacity to the total net generation	**REGULATORY POLICY VARIABLES** - RPS with a capacity requirement, - RPS with a sales requirement, - RPS with a sales goal	- basic pooled OLS model - a state and time fixed effects model

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
			photovoltaic	- the ratios of the wind, biomass, geothermal and solar capacities to total net electricity generation	- State Government Green Power Purchasing, - required green power options, - clean energy fund; all BINARIES **ECONOMIC VARIABLES** - electricity prices - natural gas prices, the data is deflated using the CPI - GDP pc **POLITICAL VARIABLES** - coal capacity - LCV rating	with state-specific time-trends
Yin & Powers (2010)	1993-2006	50 US States	Not technology specific	- % of generating capacity in a state that is non-hydro renewable	- Incremental percentage requirement (RPS) - RPS binary - RPS trend - RPS nominal - mandatory green power option, binary - public benefits fund, binary - net metering, binary - interconnections standards, binary - electricity price - state income - league of conservation voters scores - import ratio (electricity) - REC free trade - neighbor - penalty cap	FE
THIS THESIS (2nd CHAPTER)	1990-2011	26 EU countries	Wind, solar, biomass, geothermal	Added capacity installations, electricity generation	- technology specific fixed and premium FITs - cap and trade schemes - RPS - tender - tax incentive / investment grant - energy import dependence - coal, oil, natural gas prices - carbon intensity	OLS, FE with year dummies included, PCSE

STUDY	TIME PERIOD	SAMPLE	TECHNO-LOGIES	DEPENDENT VARIABLE/S	INDEPENDENT VARIABLES	ECONOMETRIC APPROACH
					- electricity production from coal, natural gas, nuclear and oil - energy consumption per capita - GDP - corruption perception index - solar, wind, geothermal and biomass patents	

Source: Own compilation according to the studies cited.

Appendix E: Overview of the relevant empirical studies that focus on the impact of the EU ETS and other SRE policy instruments on firm's performance

Study	Time period	Sample	Dependent variable	Independent variables	Econometric approach
Abrell et al. (2011)	2005 - 2008	2101 European firm	Log value of verified emissions; Added value, profit margin, employment	Time dummy, controls 1: turnover and labour in logs, controls 2: sectorial and country dummies; Impact of EU ETS, changes in fixed capital / turnover, changes in employment	Propensity score matching
Calel and Dechezleprêtre (2013)	The change in the number of low carbon patents from 2000-2004 to 2005-2009	Over 30 million firms across 23 countries (22 EU countries plus the US), 5.500 firms regulated under the EU ETS	Low-carbon patents	EU ETS firms / non EU ETS firms (sample of non-regulated firms similar to the EU ETS firms based on pre-2005 characteristics); turnover, employment	Matched difference-in-differences study design, a Tobit-modified empirical-likelihood estimator
Chan, Li, & Zhang (2013)	2001 - 2009	5873 firms in 10 EU countries in power, cement, and iron & steel industries	Firm competitiveness measured by: unit material costs, employment and revenue	EU ETS, non EU ETS firms (phase I participation, phase II participation, phase I x log (surrendered), phase II x log (surrendered), phase I x log (allocated), phase II x log (allocated)), firm fixed effects, country-year fixed effects	Difference in differences (DD), two way fixed effects linear regression model
Commins et al. (2011)	1996 - 2007	European firms across various sectors	lnTFP, lnEmployment, Return on Capital Employed, lnInvestment	lnEnergy taxes, lnEnergy taxes with one year lag, Import intensity, Education, Output gap, lnElectricity price, Labour cost, ETS	OLS regression in first differences
Jaraitė & Kazukauskas (2012)	2005 - 2007	Firms in the 22 EU countries (Bulgaria, Cyprus, Malta, Luxembourg	The probability of trading (Hurdle 1), the amount of traded	Firm output, firm capital, firm net allocation position, firm size in terms of allocation, the sectorial and regional	The modified Cragg's log-normal hurdle model

Study	Time period	Sample	Dependent variable	Independent variables	Econometric approach
		and Romania were excluded)	allowances by individual firms (Hurdle 2)	dummies, and some transaction costs variables	
Jaraitė & Kažukauskas (2013)	2002 - 2010	The EU-24 (Cyprus, Luxembourg and Malta were excluded), electricity generation sector (NACE 3511, Rev. 2.0)	Firm level EBIT margin	TGC, EU ETS firms, and 1st phase of the EU ETS dummies and their interactions, industry, time, size, regional dummies, lagged assets (log), firm age, market concentration, electricity market opening, lagged electricity price (log), lagged RE capacity (log)	OLS, RE with the Mundlak terms, dynamic panel data model
Martin, Muûls, de Preux, & Wagner (2014b)	2005 - 2008	Manufacturing firms in six European countries: Belgium, France, Germany, Hungary, Poland and the UK	Firm's vulnerability score	Trade and carbon intensity, interview noise controls and country dummies, for robustness check: employment and capital	OLS, Weighted Least Squares (WLS), and Probit regression, robust standard errors, clustered by 4-digit NACE sector
Yu (2010)	2004 - 2006	Sample of Swedish energy firms associated with electricity production and district heating	Firm profitability	Pre-EU ETS period and EU ETS period dummies, EU ETS firms and other firms in the pre-EU ETS years dummies, under-cap and over-cap dummies	Difference-in-differences, fixed effect
Zaklan (2013)	2005 and 2006	The EU firms	Ln (Inter-firm sales, inter-firm purchases, intra-firm transfers)	Quantitative variables: lnEUA stock, lnTurnover, EUA stock / turnover, ln (Turnover / total assets), return on assets. Categorical variables: government-owned firms, family-owned firms, EUA position (allocation>verified emissions=1, zero otherwise), industry (outside of the combustion=1, 0 otherwise)	Corner solution model, Heckman's two step procedure
THIS THESIS 3rd CHAPTER)	1992 – 2012	The EU firms in the electricity and manufacturing sectors in 27	Annual growth rate of verified emissions;	Annual growh rate of turnover, log of employment, FIT/RPS binary, log of	Pooled OLS, RE, FE, FD, system GMM

Study	Time period	Sample	Dependent variable	Independent variables	Econometric approach
		EU countries	log of labour productivity; annual growth rate of labour productivity	absolute increases of SRE capacity installations and electricity price; log of firm's capital intensity, ETS, RPS, and FIT binaries plus their interaction terms, log of SRE capacity installations and electricity price, firm size; annual growth rate of capital intensity, ETS, RPS, and FIT binaries plus their interaction terms, log of annual change in absolute values of SRE electricity capacity installations and electricity price, firm size	

Source: Own compilation according to the studies cited.

Appendix F: Firm's benefits from the EU ETS

	FIRM A	**FIRM B**
Emissions	100.000 tonne/year	100.000 tonne/year
Emissions allowance	95.000 tonne/year	95.000 tonne/year
Emissions > allowance	5.000 tonne/year	5.000 tonne/year
Emission reductions required	5.000 tonne/year	5.000 tonne/year
(A) To purchase 5.000 allowances	----------- **OPTIONS** -----------	**(B)** To not purchase 5.000 allowances
Market price of the allowance	€20 per tonne of CO_2	€20 per tonne of CO_2
Cost of cutting emissions	€10 per tonne of CO_2	€30 per tonne of CO_2
Cost / Price relation	Cost < Price = €10	Cost > Price = €10
Option	**(B)**	**(A)**
Additional emission reduction	5.000 tonne/year	/
Total cost of cutting emissions	€100.000 (10.000 tonne X €10)	€100.000 (5.000 allowances X €20)
Costs covered by the EU ETS	€100.000 (5.000 allowances X €20)	€100.000 (5.000 allowances X €20)
Cost without the EU ETS (if emissions are reduced for 5.000 tonne/year)	€50.000 (5.000 tonne X €10)	€150.000 (5.000 tonne X €30)
Firm's benefit from the EU ETS	**Firm A** will earn extra €50.000	**Firm B** will not need to pay extra €50.000

Source: According to the European Commission, *EU action against climate change. The EU Emission Trading Scheme*, 2009.

Appendix G: Summary in Slovenian language / Daljši povzetek disertacije v slovenskem jeziku

UČINKOVITOST FINANČNIH IN FISKALNIH INSTRUMENTOV ZA SPODBUJANJE TRAJNOSTNIH TEHNOLOGIJ OBNOVLJIVIH VIROV ENERGIJE

Opis raziskovalnega problemskega področja

Doktorska disertacija glavni navdih črpa iz zaveze EU o doseganju ciljev, povezanih s podnebnimi spremembami. Eno najpomembnejših svetovnih okoljskih vprašanj je, kako zmanjšati odvisnost od netrajnostnih virov energije, kot so nafta, premog, zemeljskih plin in uran. V tem okviru EU opredeljuje več ključnih ciljev, ki jih morajo države članice doseči. Prvič, emisije toplogrednih plinov (GHG) je treba zmanjšati za 20 % do leta 2020, za vsaj 40 % do leta 2030 in za 80–90 % do leta 2050 v primerjavi z vrednostmi iz leta 1990. Drugič, delež porabe električne energije iz obnovljivih virov energije se mora povečati za 20 % do leta 2020 in za vsaj 27 % do leta 2030 v primerjavi z vrednostmi iz leta 1990. Tretjič, energetska učinkovitost se mora povečati za 20 % do leta 2020 in za 30 % do leta 2030, tudi v primerjavi z vrednostmi iz leta 1990 (European Commission [Evropska komisija], 2009; 2011; 2014). Te cilje bi bilo nemogoče doseči brez uspešnejših in učinkovitejših veljavnih politik o obnovljivih virih energije (European Commission [Evropska komisija], 2014b). Razprave o instrumentih za podporo politiki za spodbujanje trajnostnih tehnologij obnovljivih virov energije (SRET) so se v zadnjih letih okrepile. Čeprav rezultati kažejo, da instrumenti za podporo politiki spodbujajo nove tehnologije (OECD, 2010), je treba te rezultate obravnavati previdno. Prejšnje raziskave namreč ne obravnavajo vpliva vseh pomembnih elementov energetske politike na tehnološke spremembe in njihov vpliv na produktivnost podjetij (glej npr. Gagelmann & Frondel, 2005; Butler & Neuhoff, 2008; Coria, 2009; Rogge & Hoffmann, 2010; Antoci et al., 2012). Pri presoji vplivov instrumentov politike raziskovalci tehnoloških inovacij in tehnološkega širjenja pogosto ne obravnavajo posebej. Vendar je zelo pomembno, da razlikujemo med tema dvema fazama, saj instrumenti niso zasnovani tako, da bi lahko enakovredno spodbujali vsako fazo ekoloških inovacij ali vsako vrsto tehnologije. Pogosto se zgodi, da raziskovalci prezrejo razlike med vrstami SRET, kot so vetrna in sončna energija, biomasa in geotermalna energija (glej npr. Marques & Fuinhas, 2011; Bodas–Freitas et al., 2012). V takih primerih merijo vpliv instrumentov politike na skupne obnovljive vire. Druge pomanjkljivosti prejšnjih študij so na primer višje raziskovalno zanimanje za Združene države Amerike ali osredotočenost na države OECD, za katere je na voljo več podatkov (Huang et al., 2007; Carley, 2009; Yin & Powers, 2010; Shrimali & Kniefel, 2011). Poleg tega ustrezne raziskave večinoma temeljijo na krajših časovnih vrstah (glej Marques et al., 2010, in Laing et al., 2013, za podroben pregled). Tako ni mogoče preverjanje pomembnejših nedavnih sprememb v poslovnem okolju. Spremembe vključujejo svetovno finančno krizo, nedavno povečanje cen nafte in ozaveščanje javnosti o okolju. Z upoštevanjem teh sprememb bi lahko znatno vplivali na proces[6]tehnoloških sprememb, produktivnost podjetij in njihovih emisij CO_2. Poleg tega raziskovalci pri iskanju rešitev za izpolnjevanje ciljev, povezanih s podnebnimi spremembami, prihajajo do nasprotujočih si zaključkov o učinkovitosti instrumentov politike (npr. Coria, 2009; Johanstone et al., 2010; Anderson et al., 2011; Czarnitzki et al., 2011; Antoci et al., 2012; Bodas–Freitas et al. 2012; Calel & Dechezlepretre, 2012; Noailly, 2012; Jaraitė & Kažukauskas, 2013; Aguirre & Ibikunle, 2014). Glede na vsa omenjena dejstva oblikovalci politike dobijo nezadostne, a zelo pomembne informacije o tem, kako preoblikovati energetsko politiko posameznih držav.

Namen in cilji raziskave

Cilj doktorske disertacije je prispevati k razpravi o instrumentih za podporo politiki SRE s pojasnitvijo trenutnih, nasprotujočih si rezultatov in s premagovanjem prej omenjenih težav. Na splošno skuša oceniti, kako učinkovitost mešanice instrumentov za podporo politiki posameznih držav vpliva na tehnološko širjenje, na emisije CO_2 podjetij in na produktivnost/rast produktivnosti podjetij. Išče odgovore predvsem na naslednja ključna raziskovalna vprašanja:

- Katere so najpomembnejše novejše metodološke izboljšave pri merjenju vpliva instrumentov za podporo politiki v procesu tehnoloških sprememb?
- Kateri so najučinkovitejši instrumenti politik po posameznih državah in tehnologijah, ki se lahko uporabijo za spodbujanje širjenja določene vrste SRET?
- Kakšen je vpliv sistema EU ETS in drugih glavnih instrumentov za podporo politiki na škodljive emisije CO_2 podjetij in na produktivnost/rast produktivnosti podjetij?

Pričakovano je, da bodo rezultati potrdili glavno raziskovalno hipotezo, ki pravi, da je trenutna mešanice energetskih tehnologij in instrumentov v neskladju s politiko EU glede obnovljivih virov energije. Ta hipoteza je zastavljena kot podlaga za prepoznavanje najučinkovitejše mešanice politik za spodbujanje SRET, za spodbujanje zmanjšanja emisij CO_2 in za večanje produktivnosti/rasti produktivnosti podjetij.

[6] Proces tehnoloških sprememb sestavljajo tri faze: izumi, inovativnost in širjenje tehnologij SRE. Za podporo določene faze se izvajajo različni finančni in fiskalni instrumenti. Termini proces tehnoloških sprememb, ekološke inovacije in prehod na SRE so medsebojno zamenljivi.

Povezava med instrumenti za podporo politiki in tehnološkimi spremembami

Analiza obravnava naslednje ključne tržno zasnovane instrumente: okoljske davke, fiskalne spodbude, trgovanje z emisijami, mehanizem za čisti razvoj, skupno izvajanje, zagotovljeno odkupno ceno, portfeljski standard obnovljivih virov energije, državne subvencije in ogljikove dobropise za zmanjšanje emisij. Pri preučevanju povezave med instrumenti politik in ekološkimi inovacijami ločimo med politikami, ki urejajo ceno električne energije SRE, ali politike, ki urejajo proizvedeno količino (Weitzman, 1974).

Instrumenti politik, ki temeljijo na ceni, kot so npr. fiskalne spodbude (davčne spodbude za raziskave in razvoj/davčni dobropisi), in kjotski instrumenti, ki temeljijo na količini, so lahko neposredna podpora naložbam v SRET. Po drugi strani pa drugi instrumenti politik, ki temeljijo na ceni (FIT), in instrumenti, ki temeljijo na količini (RPS), neposredno podpirajo proizvodnjo električne energije iz SRET. Poleg instrumentov politike, ki neposredno spodbujajo SRET, so še drugi instrumenti, npr. okoljski davek, ki posredno vplivajo na tehnološke spremembe (Haas et al., 2004; Held et al., 2006). Toda vsi instrumenti energetske politike lahko vplivajo na vse stopnje procesa tehnoloških sprememb (podrobna analiza inovacij/širjenja je podana v prvem poglavju). Poleg tržno zasnovanih instrumentov na tehnološke spremembe vplivajo tudi pristopi za obvladovanje in nadzor. Ti pristopi vključujejo standarde emisij, specifikacije glede procesov ali opreme in drugo.

Cilj ekonomske logike, na kateri slonijo instrumenti politik za podporo SRET in zmanjšanje emisij CO_2

Ekonomska logika, na kateri slonijo **okoljski davki**, je, da ti davki višajo ceno okolju neprijaznih dejavnosti. Hkrati zagotavljajo spodbude za ublažitev vplivov onesnaženja. Natančneje povedano, te študije so potrdile, da okoljski davki in subvencije za naložbe večajo inovacije in širjenje SRET (za podroben pregled glej European Environment Agency [Evropska agencija za okolje], 2011). Njihov vpliv se spreminja glede na različne sektorje, tehnologije in vrste inovacij. Študije tudi kažejo, da vpliva teh davkov ne moremo preučevati brez upoštevanja različnih oblikovnih značilnosti politik SRE po posameznih državah.

Štiri različne vrste okoljskih davkov so: energetski davki, prometni davki, davki na onesnaženje in davki na vire. Okoljske davke je treba skrbno preučiti in izvajati. Če so v določeni državi prestrogi, imajo nasprotni učinek od želenega in povzročijo učinek premestitve emisij CO_2 (Babiker, 2005; Barker et al., 2007; Næss–Schmidt et al., 2010). To pomeni, da se podjetja preselijo v države z nižjimi davki. Uporabljajo lahko tudi neobnovljive tehnologije, namesto da bi se odločali za inovacije in čiste alternative.

Po drugi strani se za spodbujanje tehnoloških inovacij in širjenje SRET uporabljajo tudi **fiskalne spodbude** (davčne spodbude za raziskave in razvoj, davčni dobropisi, oprostitve in znižanja davka). V nekaterih državah so to glavni podporni instrumenti, drugje pa jih uporabljajo v kombinaciji z drugimi instrumenti politike SRE. Fiskalne spodbude lahko zadostujejo za spodbujanje SRET v državah z višjo stopnjo davka na energijo, sicer je potrebna kombinacija različnih instrumentov (Commission of the European Communities [Komisija Evropskih skupnosti], 2008).

Kjotski protokol je v pomoč državam pri uresničevanju zahtev glede emisij v skladu s Protokolom vzpostavil tri tržno zasnovane instrumente: **trgovanje z emisijami** (ET), **mehanizem za čisti razvoj** (CDM) in **skupno izvajanje** (JI). Trgovanje z emisijami – kot je to določeno v 17. členu Kjotskega protokola – državam, ki presegajo obveznosti glede zmanjšanja emisij v skladu s Protokolom, omogoča nakup enot emisij drugih držav, ki izpolnjujejo kjotske cilje. Mehanizem za čisti razvoj – kot ga določa 12. člen Protokola – državam z zmanjšanimi emisijami ali cilji za omejitev v skladu s Kjotskim protokolom dovoljuje izvajanje projekta za zmanjšanje emisij v državah v razvoju. S takimi projekti države pridobijo dobropise za potrjeno zmanjšanje emisij (CER), pri čemer je vsak dobropis enakovreden eni toni CO_2. CER-i se trgujejo ali prodajajo in industrializiranim državam omogočajo fleksibilnost pri doseganju kjotskih ciljev. Skupno izvajanje – kot ga določa 6. člen Kjotskega protokola – državam z zmanjšanimi emisijami ali zavezo k omejitvi v skladu s Kjotskim protokolom omogoča pridobitev enot zmanjšanja emisij (ERU) v projektu za zmanjšanje emisij ali projektu za odstranjevanje emisij v kateri koli drugi državi, katere cilji so v skladu s Protokolom. ERU-ji so enakovredni eni toni CO_2.

Splošna ekonomska logika, na kateri temeljijo kjotski instrumenti, je, da se zmanjšanje emisij in posledično naprave, ki uporabljajo nizkoogljične tehnologije, dosegajo na gospodaren način.

Zagotovljena odkupna cena (FIT) je instrument politike, ki zmanjšuje tveganje dolgoročnih naložb v SRET. V skladu s FIT proizvajalci električne energije SRE dobijo fiksen znesek ali premijo za vsako proizvedeno kilovatno uro, medtem ko so cene zajamčene za določeno časovno obdobje. **Kvotne obveznosti** ali **portfeljski standardi obnovljivih virov energije (RPS)** dobavitelje obvezujejo k določenemu deležu SRE v njihovi proizvodnji električne energije. Certificirani proizvajalci energije iz obnovljivih virov prejmejo certifikate za enote proizvedene električne energije (**certifikati električne energije iz obnovljivih virov – REC**). Proizvajalci energije iz obnovljivih virov lahko prodajo tiste REC, kjer lahko dokažejo, da je bil vir električne energije SRE.

Osnovna ekonomska logika, na kateri slonijo FIT-i in RPS-i, je zmanjšanje stroškov proizvodnje električne energije iz SRE.

Raziskovalne metode in podatki

Doktorska disertacija podaja celovitejši analitični okvir in strožjo ekonometrično analizo kot druge novejše študije. Pri tem ponuja nove empirične rezultate, ki prispevajo k politiki in odločanju na ravni podjetja. V tej doktorski disertaciji so ocenjeni štirje glavni modeli. Prvi model je razširitev standardnih ekonometričnih modelov (ki jih uporabljajo npr. Groba, Indvik, & Jenner, 2011; Marques, Fuinhas & Manso, 2011; Dong, 2012) za testiranje učinkovitosti elementov politik pri spodbujanju določene vrste SRET. Drugi model (na podlagi modela, ki so ga razvili Abrell in dr. (2011)) se uporabi za opredelitev dejavnikov, ki prispevajo k manjšanju emisij CO_2 podjetij v sistemu EU ETS. Tretji model, ki temelji na modelih, ki so jih razvili Wagner (2007), Commins in dr. (2011) in Jaraite & Kažukauskas (2013), se uporablja za oceno, ali so podjetja, vključena v sistem EU ETS, deležna znatnih produktivnostnih premij v primerjavi s podjetji, ki niso vključena v sistem EU ETS, ob hkratnem preverjanju instrumentov politike posameznih držav (FIT ali RPS). Četrti model je standardni model računovodstva rasti, ki preučuje vpliv instrumentov politike na rast produktivnosti podjetja. Prvi model se oceni z uporabo metod pooled OLS, FE in PCSE; drugi model z uporabo pooled OLS in RE; tretji model z uporabo pooled OLS in FE; četrti model pa se analizira z uporabo pooled OLS, FE in sistemske GMM. V analizi so uporabljene različne ekonometrične tehnike za doseganje večje zanesljivosti rezultatov. Metode ocenjevanja so izbrane glede na vrsto podatkov in temeljijo na rezultatih ustreznih ekonometričnih testov (npr. Hausmanov test, modificiran Waldov test za heteroskedastičnost, Pesaranov test s presečno odvisnostjo, Wooldridgeov test za avtokorelacijo v panelnih podatkih, Arellano-Bond test za avtokorelacijo, itn.).

Doktorska disertacija analizira panelne podatke za države EU za leta med 1990 in 2011 (prvi model) ter med 1992 in 2012 (drugi model). **Podatki na makro ravni** so bili pridobljeni iz naslednjih virov statističnih podatkov: Energy Information Administration (EIA), International Energy Agency (IEA), EUROSTAT, Haas et al. (2011), Res-legal, REN21, Program Združenih narodov za okolje (UNEP), Kazalci svetovnega razvoja Svetovne banke, Transparency International in PATSTAT. **Podatki na mikro ravni** so bili pridobljeni iz ustreznih statističnih virov: AMADEUS (Bureau van Dijk). **Podatki na ravni naprav** so bili pridobljeni iz evidence transakcij Evropske unije (EUTL) in združeni na ravni podjetij.

Okvirni opis disertacije

Doktorska disertacija se začne z uvodom o področju raziskave, temu pa sledijo štiri poglavja: 1. Instrumenti politike za ekološke inovacije; 2. Makroekonomska analiza učinkovitosti instrumentov politike pri spodbujanju tehnološkega širjenja; 3. Instrumenti energetske politike in produktivnost podjetij; in Zaključek.

Uvod opisuje širše raziskovalno področje, poda raziskovalne teme, namen in cilje. Na splošno podaja jasen odgovor na naslednje vprašanje: Zakaj je ta raziskava potrebna? Nadalje predstavlja pregled raziskovalnih metod, uporabljenih v doktoratu, in ocenjuje, kakšen je izvirni doprinos k znanosti.

Prvo poglavje ima šest pododdelkov. Uvod podaja okvirni pregled raziskovalnega področja. Drugi pododdelek obravnava najpomembnejše konvencije in zakonodajo o podnebnih spremembah, ki spodbujajo razvoj SRET. Tretji pododdelek obravnava razmerje med finančnimi in fiskalnimi instrumenti ter inovacije in širjenje SRET glede na vir. Četrti pododdelek ocenjuje uspešnost in učinkovitost instrumentov politike pri podpori tehnoloških sprememb. Peti pododdelek predlaga nadaljnje raziskovalne usmeritve in predstavlja morebitne posledice za politiko. Zadnji pododdelek zaključi prvo poglavje doktorske disertacije.

Drugo poglavje ima šest pododdelkov. Prvi pododdelek predstavlja splošni uvod v ta del raziskave. Drugi pododdelek podaja pregled literature o učinkovitosti instrumentov za podporo politiki pri podpori širjenja SRET. Poudarja, kako pomembno je širjenje SRET za doseganje ciljev EU, povezanih z obnovljivimi viri energije – »20-20-20«, »2030« in »2050«. Poleg tega podrobneje opredeljuje empirični pristop in razvito ekonometrično strategijo. Tretji pododdelek predstavlja podatke in opisno statistiko. Rezultati so podani v četrtem pododdelku, razprava o podatkih je podana v petem pododdelku. Šesti pododdelek zaključi to poglavje in predstavi možnosti za nadaljnje raziskave.

Tretje poglavje ima šest pododdelkov. Prvi pododdelek obravnava problemsko področje raziskave. V drugem pododdelku je razvit raziskovalni okvir. Predstavlja kritični pregled pomembne empirične literature o vplivu instrumentov politike SRE na uspešnost podjetij. Tretji pododdelek opredeljuje empirični pristop in ekonometrična vprašanja. V četrtem pododdelku so predstavljeni podatki, uporabljeni v analizi, in opisna statistika. V petem pododdelku so predstavljeni pridobljeni rezultati. Šesti pododdelek zaključi to poglavje, poudari omejitve ter predlaga nove pomembne teme prihodnjih raziskav.

Četrto poglavje zaključuje disertacijo s povzetkom glavnih ugotovitev raziskave in poudari, kakšen je njen prispevek k znanosti. Na podlagi teh ugotovitev podaja priporočila za energetsko politiko EU in upravljanje podjetij. Poleg tega zadnje poglavje predstavi raziskovalne omejitve disertacije in razvije nekatere ideje za nadaljnje raziskave na tem področju.

Povzetek glavnih ugotovitev

Glavne ugotovitve doktorske disertacije so razporejene v tri dele. Ti deli povzemajo ugotovitve treh poglavij disertacije. To so: Instrumenti politike za ekološke inovacije, Makroekonomska analiza učinkovitosti instrumentov politike in spodbujanje tehnoloških sprememb in Instrumenti politike o obnovljivih virih energije in produktivnost podjetij. **Na splošno** proces tehnoloških sprememb zmanjšuje negativne politične, družbenoekonomske in okoljske učinke proizvodnje in uporabe netrajnostnih in neobnovljivih virov energije (npr. Johnstone et al., 2010; OECD, 2010; Dong, 2012; Jaraitė & Kažukauskas, 2013; Aguirre & Ibikunle, 2014; Boehringer, et al., 2014). Celotnega procesa tehnoloških sprememb ne more podpirati zgolj en sam instrument. V tem okviru disertacija predstavi rezultate na ravni držav in podjetij. **Poudariti je treba**, da analiza kritičnega pregleda literature kaže, da se vpliv instrumentov za podporo politiki razlikuje glede na vrsto SRET in stopnjo razvoja. Težava je tem, da so raziskave večinoma osredotočene na najbolj priljubljene podporne instrumente in tehnologije z večjim številom naprav (npr. Dong, 2012). Po drugi strani pa drugi elementi, ki bi lahko vplivali na razvoj SRET, niso dovolj upoštevani. Celovita ekonometrična analiza, izvedena v okviru te disertacije, ki obravnava vse zgoraj omenjene težave, kaže, da tako premije kot fiksni FIT-i, RPS-ji in razpisi učinkovito spodbujajo razvoj vetrnih tehnologij. Rezultati so v skladu s pomembnimi ekonometričnimi ugotovitvami Falconett & Nagasaka (2010), Groba et al. (2011) in Dong (2012). Uspešnost teh instrumentov potrjujejo naprave, ki uporabljajo energijo vetra, in proizvodnja električne energije z vetrnimi tehnologijami. Kot v prejšnjih raziskavah se je tudi tu pokazalo, da so rezultati odvisni od tehnologij in modelov. Rezultati druge ekonometrične analize, ki je predstavljena v tej disertaciji, so pokazali, da imajo gospodarska dejavnost podjetij in dejavniki na ravni posameznih držav večji vpliv na emisije CO_2 podjetij kot finančni instrumenti, namenjeni podpori SRET. Poleg tega EU ETS ni imel vpliva oziroma je imel le majhen vpliv na produktivnost/rast produktivnosti podjetij. Podjetja, ki delujejo v državah RPS, so bila manj produktivna kot podjetja na območju FIT.

Priporočila za energetsko politiko EU

Doktorska disertacija podaja predloge celostne politike za izbor najučinkovitejših podpornih instrumentov za spodbujanje tehnoloških sprememb. Nacionalni oddelki za SRE morajo trg najprej pripraviti za razvoj SRET. Postopek priprave se mora osredotočiti predvsem na večanje ozaveščenosti javnosti o okolju. Podati mora tudi natančne informacije o podpornih instrumentih za SRET, ki so na voljo za uporabo v industriji in gospodinjstvih.

Oblikovalci politike in energetski sektor morajo najprej najti kompromis med pogosto nasprotujočimi si političnimi cilji in cilji glede SRE v posameznih državah. Če imajo nekatere države zelo razvito energetsko infrastrukturo za netrajnostne in neobnovljive vire energije, je interes za spodbujanje SRET v energetski politiki teh držav manjši. V takih primerih je priporočeno, da se zagovorniki SRE soočijo s tradicionalnimi energetskimi lobisti. Potem ko se oblikovalci politike odločijo glede želene stopnje razvoja SRET, se lahko osredotočijo na podporne instrumente. Oblikovalci politike morajo pred odločanjem glede (ponovnega) oblikovanja instrumentov, izvajanja ali odstranitve dobro poznati trenutno razvojno raven SRET v svoji državi. Predvsem morajo poznati točno število tehnoloških inovacij in naprav, ki uporabljajo energijo vetra, sonca, biomaso in/ali geotermalno energijo. Podrobno morajo preučiti informacije o tehnološki učinkovitosti, ki jo ponazarja količina električne energije iz virov SRE. To je pomemben dejavnik pri odločanju o ravni finančne in fiskalne podpore tehnološkemu razvoju. Če se nekatere tehnologije v določeni državi že uspešno izvajajo, npr. vetrne tehnologije v Nemčiji, potem naj oblikovalci politike bolj spodbujajo druge tehnologije, manj pa vetrno. To pa še ne pomeni, da je treba podporne instrumente za vetrne tehnologije popolnoma ukiniti. Tehnologije SRET je treba nenehno podpirati, da nazadnje tradicionalnim tehnologijam konkurirajo tudi na trgu. V takem primeru so priporočene le spremembe v zasnovi določenih podpornih instrumentov (npr. manjša podpora ali manjše zajamčeno podporno obdobje s FIT). V naslednjem primeru pa naj spremembe vključujejo uvedbo ali odstranitev instrumentov. Novi podporni instrumenti so potrebni, če obstoječi instrumenti niso učinkoviti pri spodbujanje SRET v določeni državi. Priporočila za take spremembe temeljijo na celostni empirični raziskavi, predstavljeni v tej doktorski disertaciji. Prvi sklop priporočil za energetsko politiko se nanaša na elemente, ki bi lahko vplivali na širjenje SRET. Če povzamemo, vetrni FIT-i, lahko tudi v kombinaciji z razpisnimi shemami, so priporočljiva politična možnost za spodbujanje širjenja vetrnih tehnologij. Ti instrumenti so zlasti učinkoviti pri podpiranju izvajanja in proizvodnje energije iz vetrnih tehnologij. Vpliv instrumentov politike in drugih političnih, družbenoekonomskih in okoljskih elementov na SRET je odvisen od tehnologije. Zato jih je treba obravnavati posamično. Poleg tega ustrezna literatura in zakonodaja kažeta, da se SRE in cilji za zmanjšanje emisij nanašajo predvsem na fazo tehnološkega širjenja. Glede na dejstvo, da so inovacije nujni predpogoj za uspešne tehnološke spremembe, morajo oblikovalci politike v posameznih državah zahtevati določeno mero inovacij, specifičnih za te tehnologije. Predstavljeni rezultati kažejo, da tehnološke inovacije, ki vključujejo biomaso, povečujejo proizvodnjo električne energije iz biomase. Na podlagi teh ugotovitev je priporočeno, da oblikovalci politike povečajo raven podpore predvsem za inovacije za manj razširjene vrste SRET. Drugi sklop priporočil za energetsko politiko se nanaša na vplive podpornih instrumentov za izvajanje politike SRE na emisije CO_2 podjetij in s tem povezano produktivnost/rast produktivnosti podjetij. Priporočljivo je, da države RPS izvajajo FIT, saj rezultati kažejo, da je rast produktivnosti večja, emisije CO_2 pa manjše pri podjetjih v sistemu EU ETS, ki delujejo na območju FIT.

Sklenemo lahko, da morajo biti finančne in fiskalne odločitve na ravni politike dobro in vnaprej premišljene. Oblikovalci politike se morajo zavedati dejstva, da je pogosto spreminjanje odločitev, prakse in zakonodaje o SRET lahko zelo nevarno. Negotovost, ki jo povzroča pogosto spreminjanje instrumentov za podporo politiki ali pogosto spreminjanje ravni podpore, je ena najresnejših ovir za naložbe v SRET.

Priporočila za upravljanje podjetij

Poslovna filozofija, usmerjena v SRE, je predpogoj za uspešnost podjetja v konkurenčnem okolju. Rezultati disertacije, predvsem v tretjem poglavju, bi morali vzbuditi pozornost strokovnjakov s poslovnega področja. Danes je večina višjih vodstvenih delavcev visoko ozaveščena o okolju. Ne glede na to pogosto še vedno prihaja do odstopanj pri doseganju naslednjega razmerja: zmanjšanje emisij CO_2 podjetja – povečanje produktivnosti podjetja. Če imajo podjetja še vedno težave z emisijami in še niso dosegla želene stopnje produktivnosti, bi lahko pomagalo naslednje priporočilo: v državah, kjer je podpora FIT na voljo, naj podjetja to podporo koristijo. Literatura in praksa kažeta, da nimajo vsi vodstveni delavci zadostnega znanja o podpori, ki so je lahko deležni pri izvajanju SRET. Zato bi se moralo vodilno osebje bolj spoznati z SRE politiko posameznih držav. Poleg tega je priporočljivo, da vodstveni delavci podjetij upoštevajo ustrezne rezultate raziskovalnih analiz na ravni podjetja. Ker se politike SRE spreminjajo s časom, je na spremljanje novosti treba gledati kot na konkurenčno prednost podjetja.

Izvirni prispevek k znanosti, omejitve in nadaljnji izzivi

Doktorska disertacija pomembno prispeva k teoriji o energetski in okoljski ekonomiki, politiki in praksi. Ta raziskava se od prejšnjih študij razlikuje v naslednjem: prispeva najcelovitejšo in sistematično pregledno analizo do zdaj. Pričujoča analiza pomeni tudi prispevek k strokovni literaturi, saj obravnava različne podporne instrumente SRET glede na vrsto in stopnjo tehnologije. Poleg tega daje pomembna metodološka priporočila za ukvarjanje z nerešenimi vprašanji o razvoju SRET. Po meni znanih podatkih je na področju energetske in okoljske ekonomike to prva analiza literature, ki uporablja tak pristop. Drugič, empirični del doktorske disertacije prispeva k strokovni literaturi, energetski politiki in industriji, saj presega pomanjkljivosti prejšnjih študij. Prva empirična analiza, predstavljena v disertaciji, predstavlja inovativni metodološki okvir za oceno vseh elementov, ki bi lahko vplivali na širjenje tehnologije. Prva analiza se osredotoča predvsem na različne finančne in fiskalne instrumente, ki podpirajo uporabo obnovljivih virov energije. Poleg tega nadzira vpliv političnih, družbenoekonomskih in okoljskih elementov, ki jih prejšnje raziskave ne bi smele spregledati. Med drugim je v okvir tehnološkega širjenja prvič uvedena spremenljivka, ki odraža zaznavo korupcije. To je še zlasti pomembno pri odkrivanju morebitnih ovir pri izvajanju SRET, kot je na primer zaznava korupcija v energetskem sektorju. Druga empirična analiza, ki jo predstavljamo v disertaciji, prikazuje nove ugotovitve o razmerju med podpornimi instrumenti ter ekonomsko in okoljsko učinkovitostjo podjetij. Osredotoča se na sistem EU ETS v kombinaciji z drugimi podpornimi instrumenti SRET, torej ne samo na sistem EU ETS, kot sicer velja za večino prejšnjih študij. Treba je poudariti, da obe analizi uporabljata daljše časovne vrste (1990–2011 in 1992–2012). To omogoča opredelitev nedavnih sprememb v okolju na izvajanje SRET, proizvodnjo električne energije iz SRE in na uspešnost podjetja. Z daljšimi časovnimi vrstami lahko nadzorujemo vplive nedavne finančne krize, večanja cen energije, sprememb v oblikovanju sistema EU ETS, večanja splošne ozaveščenosti o okolju, strožjih ciljev v povezavi s podnebnimi spremembami itn. V analizah so za potrditev zanesljivosti rezultatov uporabljene različne napredne ocenjevalne tehnike (metoda OLS, PCSE, FE, RE in sistem GMM). Rezultati teh analiz skušajo razjasniti nasprotujoče si rezultate o instrumentih politike, SRET in uspešnosti podjetij, pridobljene v dosedanjih raziskavah.

Omejitve doktorske disertacije so predvsem posledica pomanjkljivih podatkov. Prvič, zaradi pomanjkljivih podatkov ni bilo možno oblikovati celovitejših kazalnikov, ki bi vključevali vse oblikovne značilnosti instrumentov v podporo SRET. Kot rešitev za omenjeni problem ta doktorska disertacija za prikaz določenih instrumentov politike uporablja binarno spremenljivko. Ta pristop uporablja tudi večina zadevnih študij iz področja. Drugič, nekatere države (npr. Malta) so bile iz analize izvzete. Tretjič, če podatki niso bili na voljo za vse države EU (npr. podatki o cenah električne energije), so bili kot približek vzeti podatki OECD.

Raziskovalci bi spoznanja doktorske disertacija lahko uporabili pri preučevanju ustreznih tem in tako pomagali utirati poti k čistejšemu okolju. Za nadaljnje raziskave predlagamo več tem. Prvič, na podlagi dela, ki ga je začel Jenner (2012), bi bilo treba v nadaljnjih raziskavah razviti kazalnike, ki bi zajemali specifično zasnovo podpornih instrumentov SRET. Drugič, v podporo ekonometrični oceni podpornih instrumentov SRET bi morali zbrati dodatne podatke prek elitnih intervjujev z oblikovalci politike in strokovnjaki. Instrumente politike bi morali razvrstiti glede na njihovo učinkovitost pri doseganju političnih, družbenoekonomskih in okoljskih ciljev. Tretjič, ob uporabi metodološkega okvira, predstavljenega v tretjem poglavju, bi morali preučiti, kako inovacije, specifične za SRET, prispevajo k zmanjšanju emisij CO_2 podjetij. Poleg tega bi bilo zanimivo določiti vpliv inovacij in naprav, ki uporabljajo SRE, na produktivnost podjetij. Petič, učinkovitost tretje faze EU ETS bi bilo treba analizirati, ko bodo na voljo podatki. Šestič, v nadaljnjih raziskavah bi bilo treba preučiti vlogo drugih kjotskih instrumentov – JI in CDM – glede podnebnih sprememb. Končno, priporočeno je, da nadaljnje raziskave vključijo tudi države v razvoju, ko bo za to na voljo več podatkov. In kot zadnje, raziskovalci morajo slediti burnim spremembam v sektorju električne energije. Trenutno je eno pomembnejših vprašanj izraziti padec cen nafte, kar ustvarja določeno negotovost pri širjenju in uporabi SRET. Čeprav cene SRE padajo, še vedno ne konkurirajo cenam energije iz konvencionalnih tehnologij. V tem primeru bi morala predhodna analiza predvideti učinkovitost izvajanja instrumentov politike pri podpori obnovljivih virov v spreminjajočem se okolju. Če se izkaže, da so izvedeni instrumenti neučinkoviti, je možna rešitev tudi odstranitev spodbud za proizvodnjo fosilnih goriv. Namesto tega je treba spodbude uporabiti za spodbujanje tehnoloških sprememb. Ob upoštevanju tržnih signalov, namreč da naj bi cena nafte ostala nizka daljše obdobje, je to pravi čas, da ponovno razmislimo o politikah glede spodbud.

Pričakovano je, da bodo rezultati, pridobljeni v doktorski disertaciji, pritegnili interes oblikovalcev politike, vodstvenih delavcev, raziskovalcev in širše javnosti.