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

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**ABSTRACT:** *The new EU target of achieving 80-95% emission reductions by 2050 calls for novel energy policy solutions. Previous research has failed to evaluate the influence of all relevant elements of energy policy on technology-specific sustainable renewable energy diffusion. This paper adds to existing research by studying the effectiveness of financial and fiscal instruments on diffusion, additionally controlling for potential political, economic, social, and environmental drivers. These drivers are analysed for 26 EU countries over the period 1990-2011. The main results show that feed-in tariffs, quotas, and tenders effectively promote wind technologies. Other explanatory variables have technology- and model-dependent impacts.*

**Keywords:** *urenewable energy technology, sustainability, financial instrument, fiscal instrument, effectiveness*

**JEL Classification:** Q01; Q43

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## 1. INTRODUCTION

Sustainable renewable energy (SRE) technologies play a critical role in powering national economies, satisfying increasing energy needs, and reducing harmful emissions. Identifying potential strategies for accelerating the process of SRE technology 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 SRE sources should increase by at least 27%, and energy efficiency should increase by 30% until 2030, compared to 1990 levels. The "2050" target requires reducing GHG emissions by 80-90% of 1990 levels by 2050 (European Commission, 2009; 2011; 2014). 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 SRE technologies.

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As such, the aim of this paper 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 SRE technology diffusion. Determining the effectiveness of these elements will provide additional support for countries in their design of renewable energy policies. In this paper, 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, Haščič & Popp, 2010) that focuses on patenting activity (the innovation phase) to study development of renewables[2] finds that the effect of SRE policies depends highly on the type of renewable energy source. To validate this finding, this paper'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 SRE technology 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 paper 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 paper is organized as follows. Section 2 provides a current overview of the literature on effectiveness of renewable policy instruments in terms of reaching the EU's "20-20-20"

2 According to the European Environment Agency (EEA, 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.

and "2050" renewable energy targets. Section 3 describes the paper's empirical approach and econometric strategy. Section 4 describes the data and offers descriptive statistics. Section 5 presents results on the impact of policy elements on technology diffusion. Section 6 discusses results and concludes, considering further research avenues.

## 2. LITERATURE REVIEW

This section includes a survey of the relevant literature (summarised in Appendix 1). 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 et al. (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 SRE technologies. However, econometric examinations of the impact of public policy instruments on the implementation of SRE technologies are rare, although they have increased in the last two years.

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 SRE technology or support instrument (e.g., Marques, Fuinhas & Manso, 2010; Marques & Fuinhas, 2011, 2012; Marques, Fuinhas & Manso, 2011; Salim & Rafiq, 2012). 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 SRE technologies (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, Fuinhas & Manso (2010) conduct the first econometric analysis of SRE technologies 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. Aguirre & Ibikunle (2014) apply FEVD and panel corrected standard errors (PCSE) estimators to panel data from the EU, OECD, and BRICS countries. They observe period from 1990 until 2010 to examine elements that could influence macro level SRE growth. Aguirre & Ibikunle (2014) find, amongst other, that some SRE policies (i.e. financial and fiscal; voluntary agreements) slow down SRE investments, what implies 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, Haščič & Medhi (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, Dolan & Urpelainen (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 SRE technologies (Yin & Powers, 2010; Groba, Indvik & Jenner, 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, Indvik & Jenner (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 SRE technologies. To analyse this relationship between policy support instruments and SRE technologies, the author applies the PCSE approach. 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. 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. 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.

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. In particular, this paper aims to analyze the impact of financial and fiscal, political, economic, social and environmental elements on technology specific diffusion. The next section details the empirical approach used to do so.

## 3. EMPIRICAL APPROACH AND ECONOMETRIC ISSUES

The analysis examines the effectiveness of 26 EU countries' energy policy instruments. Different modelling 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.

(1)

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

where $i$ denotes a country, $j$ denotes a particular SRE source, and $t$ is time in years. $\Delta X_{ijt}$, defined as $\Delta X_{ijt} = X_{ijt} - X_{ijt-1}$, 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. $\delta T$ denotes time dummies, $u_{it}$ is a fixed effects term, and $\varepsilon_{it}$ 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).

Primarily, I test the adequacy of the use of the panel data structure by employing the Breusch and Pagan Lagrangian multiplier test.

I then perform estimations using the most common panel data techniques: ordinary least squares (OLS), random effects, and fixed effects. Next, I run the Hausman test (1978) to examine if, given the nature of the data, the fixed effects model is superior to the random effects one. 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 employ the modified Wald test for groupwise heteroscedasticity, the Pesaran cross-sectional dependence test, and the Wooldridge test for autocorrelation in panel data.

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 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 SRE technologies. 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 an Feasible Generalized Least Squares (FGLS) estimator. However, FGLS tends to provide inaccurate standard errors estimates. Moreover, FGLS can be used when T is greater than N (Beck & Katz, 1995). Beck & Katz (1995) develop the PCSE, an estimator that is alternative to FGLS. Compared to FGLS, it provides more accurate standard error estimates with no or little efficiency loss. Therefore, following Shrimali & Kniefel (2011), Jenner (2012), and Marques & Fuinhas (2012), I use the panel-corrected standard errors estimator to correct for heteroscedasticity and serial and contemporaneous correlation.

In order to further verify the robustness of the results, I follow Marques, Fuinhas & Manso (2010) and include a control variable for EU Directive 2001/77 (European Commission, 2001), 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 that, according to their high environmental achievements, might be driving the results. These countries are Italy, Germany, and Spain. The third robustness check includes annual growth rate of GDP and yearly dummies for the economic crisis.

## 4. 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, Haščič & Popp (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, 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 3 provides summary statistics.

Table 3: *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 |
| Annual growth rate of GDP | 571 | .0041247 | .3904943 | -4.112694 | 2.707832 |
| 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 |

The two types of dependent variables used indicate promotion of SRE technologies, 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 SRE technology 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 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 1.

Table 1: *Variables description*

| Variables of interest | 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<br>- prefix 'f' indicates fixed, and 'p' premium tariff<br>- 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 |

| Variables of interest | Description of the variable | Unit of measurement | Data source | Period |
|---|---|---|---|---|
| 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 |
| 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 SRE technologies: geothermal, wind, solar, and biomass.

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).

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, Fuinhas & Manso, 2010; Groba, Indvik & Jenner, 2011), we might expect different instruments to have different impacts on different SRE technologies. 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, Indvik & Jenner, 2011), countries with higher **GDPs** should be more easily able to afford the costs of the SRE technological 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, Fuinhas & Manso, 2010; Marques & Fuinhas, 2011), I include **prices of coal, natural gas, and oil**[3] 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 feasible and competitive. Insignificant results could also be seen, potentially because small price increases are insufficient to encourage a shift towards re-

3 For non-OECD countries, indexes for OECD Total serve as a proxy.

newables. Energy price movements (1990-2011) reveal price increases for the majority of countries in the sample during the last decade.

Following Huang et al. (2007), Marques, Fuinhas & Manso (2010), and Groba, Indvik & Jenner (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, Fuinhas & Manso (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 el al., 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)[4]. The patent search is conducted using the appropriate International Patent Classification (IPC) codes, as determined by Popp, Haščič & Medhi (2011). These codes relate directly to SRE in the areas of wind, solar PV, geothermal, and biomass and waste.

Ideally, increased patenting activity should have a positive and significant impact on SRE technology development. However, as noted by Popp, Haščič & Medhi (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 SRE technologies. 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, Dolan & Urpelainen (2013), corruption could negatively impact the process of transitioning to renewables if SRE technology 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, Fuinhas & Manso (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.

The Variance Inflation Factor (VIF) test indicates that multicollinearity is not a concern, as the highest mean VIF among all models is 3.

4 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.

## 5. 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).

The analysis starts with the Breusch and Pagan Lagrangian multiplier test that rejects the null hypothesis, confirming that there is a significant difference across entities, i.e. panel effect. Then, 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, the modified Wald test for groupwise heteroscedasticity confirms the presence of heteroscedasticity. The Pesaran cross-sectional dependence test confirms that the residuals are correlated among entities. The Wooldridge test for autocorrelation in panel data confirms that the data is characterized by first-order autocorrelation[5]. Therefore, in line with Shrimali & Kniefel (2011), Jenner (2012), and Marques & Fuinhas (2012), PCSE estimator is employed to correct for heteroscedasticity, serial and contemporaneous correlation.

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 5 presents the results of models in which the dependent variables are added wind, solar, and geothermal installed capacity. Table 6 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 pooled OLS with country and year dummies) and PCSE included for each dependent variable. To additionally demonstrate the robustness of findings, the results with the control variable for EU Directive 2001/77 are presented in Appendix 2. Moreover, the results obtained after excluding Italy, Germany, and Spain are presented in the Appendix 3. The results obtained after including the annual growth rate of GDP and yearly dummies for the economic crisis are presented in the Appendix 4.

Table 5: *Impact of policy elements on added renewable installed capacity (1991-2009) 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]** |

5 Results for all tests are available from the author on request.

| | | | | | | |
|---|---|---|---|---|---|---|
| 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 |

*Notes*: 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 6: *Impact of policy elements on added renewable electricity generation (1990-2011) in 26 EU countries*

| **Estimation echnique** | **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 5), 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 6, 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 5 and 6, 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 5 and 6 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 5 and 6 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 results of models that include the additional control variable (EU 2001/77 Directive), presented in Appendix 2, 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, significance, as well as the signs of variables, predominantly remain the same after excluding Italy, Germany, and Spain form the sample, which is an additional confirmation of the robustness of the results (Appendix 3). The results of models that include the annual growth rate of GDP and yearly dummies for the economic crisis, presented in Appendix 4, remain predominantly the same as the main results. Results show that annual change in GDP does not have a significant impact on SRET diffusion. Moreover, results reveal a predominantly positive impact of the crisis on SRET diffusion.

## 6. DISCUSSION, CONCLUSIONS AND POLICY IMPLICATIONS

In this paper, 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 paper 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's (2014) study 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 paper's results are consistent with research noting that financial and fiscal support instruments drive diffusion of SRE technologies. 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. The absence of a significant positive relationship between e.g. FIT and geothermal resources could be caused by two potential reasons: first, only a few EU countries use geothermal resources and second, the FIT design in terms of the tariff amount and contract duration is not (sufficiently) efficient. Therefore, if a particular EU country has better preconditions for the diffusion of other types of SRET, these technologies should receive a higher support. Consequently, conventional technologies could be replaced to a greater extent. These results are consistent with previous studies (e.g., Groba, Indvik & Jenner, 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 paper's results.

Furthermore, the coefficients on certain support instruments are positive but not statistically significant in certain models. 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. However, in this case, it is not possible to conclude that SRET would diffuse completely without being supported by policy 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 lack of investors' confidence in often changing level of 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, Indvik & Jenner (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 paper, 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, Indvik & Jenner (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, Dolan & Urpelainen (2013) do not find a significant impact of corruption on SRE innovations. However, this paper is the first to test the impact of corruption on SRE diffusion and related electricity generation within this framework. Corruption coefficients are relatively high and significant, but, with exception of the wind, are not very robust. Therefore, the results for other SRE sources should be taken with caution. The model should be re-estimated with longer time series and with newly collected data on corruption (perception) within the SRET specific sector.

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, Fuinhas & Manso (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, Indvik & Jenner (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, Fuinhas & Manso (2010) and Romano & Scandurra (2011). This suggests that increased pollution is not necessarily a sufficiently strong motivator for investment in SRE technologies. Moreover, these results could reinforce the conclusion that the majority of countries decide to pay penalties for emitting $CO_2$ instead of investing in SRE technologies. 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, Fuinhas & Manso (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. Moreover, results show a predominantly positive impact of the economic crisis on SRET diffusion. This is in line with Geels' (2013) findings regarding the positive influence of the crisis on sustainability transition in its early period (2008-2010). The crisis started to impede SRET diffusion after 2010-2011 (Geels, 2013). Therefore, its impact on SRET diffusion in the later period should be further verified when more data becomes available.

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. The results should prove instructive for political decision-makers when reconsidering the implementation or removal of policy instruments for promoting specific SRE sources. However, implemented instrument's design or re-design (in terms of e.g. tariff amount or support duration) should always be country specific, technology specific, and considered within the existing country's policy design.

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.

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## APPENDICES

Appendix 1: *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 | ECONOME-TRIC APPROACH |
|---|---|---|---|---|---|---|
| Aguirre & Ibikunle (2014) | 1990 - 2010 | EU countries, remaining OECD countries, and BRICS | Biomass, solar, wind energy potential; not technology specific | Contribution of renewable energy (RE) to energy supply | - $CO_2$ emissions; net energy imports; energy use; population growth; GDP per capita (pc); year of full deregulation of electricity (el.) market (dummy); continuous commitment to RE (dummy); ratification of the Kyoto (dummy); el. production from coal, gas, nuclear, and oil; coal, natural gas, crude oil prices and el. rates for industry; biomass, solar, wind potential; total number of 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, 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 RE el. capacity; democratic institutions; corruption; CONTROLS (lagged by one year): ln GDP; net inflows of FDI as % of GDP; sum of imports and exports as % of GDP; urban population; OECD membership; ROBUSTNESS: capital account openness; KOF globalization index; ln total expenditures on education; the share of the employees with tertiary education; total count of CDM projects | FE negative binomial models |

| STUDY | TIME PERIOD | SAMPLE | TECHNO-LOGIES | DEPENDENT VARIABLE/S | INDEPENDENT VARIABLES | ECONOME-TRIC APPROACH |
|---|---|---|---|---|---|---|
| Carley (2009) | 1998-2006 | 48 US States | Not technology specific | - RE share<br>- RE total | - RPS, binary; a state's legislative commitment toward environmental policy; pc natural resource employees; petrol / coal manufacturing gross state product (GSP); annual GSP pc; growth rate of population; the amount of total el. generated pc; deregulation; el. price; wind, biomass and solar potential; tax index; subsidy index; % of regional states that have PRS policy, lagged by one year | - FE<br>- FEVD |
| Dong (2012) | 2005-2009 | 53 countries | Wind | Cumulative and annual wind capacity installed | - FIT and RPS + their interaction terms; GDP pc; el. net consumption; net oil imports; wind resources; $CO_2$ intensity; other promotion policies in each country | OLS, FE |
| Gan & Smith (2011) | 1994-2003 | 26 OECD / IEA countries | Renewable energy in general and bioenergy | Supply of renewable energy or bioenergy pc | - Energy price; natural resources endowments, land area pc, and forest land area pc; GDP pc; government R&D on RE and bioenergy; $CO_2$ emissions, t $CO_2$ pc; policies: research and innovation policies, market deployment policies, market-based energy policies, number | - One way (country) FE model<br>- GLS |
| Groba et al. (2011) | 1992-2008 | 26 EU countries | Solar PV and onshore wind | - Total capacity<br>- 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 el. imported to total el. produced; energy consumption pc; nuclear, oil, natural gas, coal share; EU 2001/EC/77 Directive, binary | Pooled OLS, FE |

| STUDY | TIME PERIOD | SAMPLE | TECHNO-LOGIES | DEPENDENT VARIABLE/S | INDEPENDENT VARIABLES | ECONOME-TRIC APPROACH |
|---|---|---|---|---|---|---|
| Jenner (2012) | 1990-2010 | 26 EU countries | Biomass, geothermal, solar PV, wind | Biomass, geothermal, solar PV, onshore wind el. 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; net import ratio of el.; energy consumption pc | OLS, FE, PCSE |
| Marques & Fuinhas (2011) | 1990-1998; 1999-2006 | 21 EU country | Not diversified | - Contribution of RE to total energy supply | - Total number of energy efficiency policies and measures; $CO_2$ pc (kg/cap); pc energy; GDP – Real; import dependency on energy; importance of coal, oil, gas, nuclear to el. generation; coal price; natural gas price; oil price | Quantile regression technique |
| Marques & Fuinhas (2012) | 1990-2007 | 23 EU countries | - Not diversified | - Contribution of RE to energy supply | - $CO_2$ pc; pc 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<br>- Random effects, FE |
| Marques et al. (2010) | 1990-2006 | European Union countries | Not diversified | - Contribution of RE to total energy supply | - Member of the EU in 2001; import dependency on energy; prices of oil, natural gas and coal; $CO_2$ pc emissions; contribution of coal, oil, natural gas and nuclear to el. generation; energy consumption pc; income; geographic area; continuous commitment on RE | OLS, random effects, FE, FEVD |
| Popp et al. (2011) | 1991-2004 | 26 OECD countries | Wind, solar photovoltaic, geothermal, biomass and waste | - RE capacity pc,<br>- Technology specific investment pc,<br>- % of RE el. capacity | - The global knowledge stock for technology; GDP pc; % growth of el. consumption (t-1); % of el. production from nuclear and from hydro (t-1); production of coal, natural gas, oil per capita; % of energy imported (t-1); ratification of the Kyoto; REC - % of RE power required by any REC program in the country; FIT – continuous; other policies - dummy | Regression with technology specific dummies, year and country FE |

| STUDY | TIME PERIOD | SAMPLE | TECHNO-LOGIES | DEPENDENT VARIABLE/S | INDEPENDENT VARIABLES | ECONOME-TRIC APPROACH |
|---|---|---|---|---|---|---|
| Romano & Scandurra (2011) | 1980-2008 | 29 countries | Not technology specific | - Ratio: total RE el. net generation / total net el. generation-net el. imports (shREN) | - $shREN_{-1}$; ln GDP; ln energy intensity; ln $CO_2$ emissions; ratio: nuclear el. net consumption/total net electricity generation-net el. imports | Dynamic panel analysis |
| Salim & Rafiq (2012) | 1980-2006 | Brazil, China, India, Indonesia, Philippines and Turkey | Not technology specific | RE consumption | - real GDP; Carbon emission; oil prices | - FMOLS, DOLS<br>- ARDL - Granger causality test |
| Shrimali & Kniefel (2011) | 1991-2007 | 50 US States | Wind, biomass, geothermal and solar photovoltaic | - ratio: total non-hydro and technology specific RE capacity / total net el. generation | RPS with a capacity requirement; RPS with a sales requirement; RPS with a sales goal; State Government Green Power Purchasing; required green power options; clean energy fund; all BINARIES; el. prices; natural gas prices, the data is deflated using the CPI; GDP pc; coal capacity; LCV rating | - pooled OLS<br>- a state and time FE 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 RE | - Incremental % 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 (el.); REC free trade; neighbour; penalty cap | FE |

Source: Own compilation according to the studies cited.

Appendix 2: *Robustness check 1. Impact of policy elements on added renewable installed capacity / electricity generation (1990-2011) in 26 EU countries*

| **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] |
| 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.

Appendix 3: *Robustness check 2. Impact of policy elements on added renewable installed capacity / electricity generation (1990-2011) in 23 EU countries*

| 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] |
| 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.

Appendix 4: *Robustness check 3. Impact of economic crisis on added renewable installed capacity / electricity generation (1990-2011) in 26 EU countries*

| **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. |
| **Economic crisis dummy** | 0.488 | 21.800 | 0.228** | 0.537 | 17.951** | -8.030** | 0.548 |
| | [1.28] | [1.27] | [2.13] | [1.21] | [2.53] | [-2.56] | [0.99] |
| Fixed feed in tariff *t*-1 | 3.517*** | 0.171 | -0.208 | 1.171*** | 0.394 | -0.040 | 0.356 |
| | [4.19] | [0.22] | [-0.39] | [2.99] | [1.08] | [-0.26] | [0.72] |
| Premium feed in tariff *t*-1 | 3.527** | -0.003 | -0.019 | 0.966 | 0.105 | 0.046 | 0.671 |
| | [2.30] | [-0.00] | [-0.03] | [1.60] | [0.16] | [0.17] | [1.01] |
| Cap *t*-1 | -1.022 | -2.248** | -1.062 | -0.401 | -0.618 | -0.270 | 0.489 |
| | [-0.93] | [-1.99] | [-1.29] | [-0.86] | [-1.13] | [-0.87] | [0.45] |
| Quota *t*-1 | 2.461** | 1.302 | -0.644 | 0.805* | 0.654 | -0.357*** | -0.458* |
| | [2.03] | [1.12] | [-1.18] | [1.78] | [1.12] | [-3.22] | [-1.74] |
| Tender *t*-1 | 1.485 | -0.790 | -0.168 | 1.495*** | -0.301 | 0.619 | 0.113 |
| | [1.22] | [-0.47] | [-0.14] | [3.35] | [-0.45] | [1.35] | [0.27] |
| Tax incentive/investment grant *t*-1 | -1.737 | 0.561 | -0.654* | -0.803* | 0.186 | -0.224* | -0.002 |
| | [-1.49] | [0.48] | [-1.92] | [-1.72] | [0.39] | [-1.70] | [-0.00] |
| Annual growth rate of GDP | 0.064 | 1.240 | 0.663 | -2.278 | -2.000 | 0.115 | 4.061 |
| | [0.01] | [0.38] | [0.51] | [-0.79] | [-0.98] | [0.18] | [1.12] |
| Ln oil prices *t*-1 | -5.201 | 0.083 | 2.344** | -2.124* | -0.955 | 0.679* | 0.693 |
| | [-1.48] | [0.04] | [2.24] | [-1.74] | [-1.25] | [1.93] | [0.38] |
| Ln coal prices *t*-1 | -0.223 | -1.326 | -2.050 | 0.654 | -0.217 | -0.601 | 0.495 |
| | [-0.08] | [-0.48] | [-1.19] | [0.96] | [-0.23] | [-0.90] | [0.63] |
| Ln natural gas prices *t*-1 | 4.805* | -1.708 | 3.728** | 2.491*** | -1.425 | 0.384 | -0.844 |
| | [1.81] | [-0.70] | [2.58] | [2.63] | [-1.46] | [0.84] | [-1.16] |
| Electricity production from oil *t*-1 | 0.073 | 0.008 | 0.078 | 0.018 | -0.023 | -0.017 | -0.025 |
| | [0.90] | [0.10] | [1.05] | [0.67] | [-0.86] | [-0.65] | [-1.46] |
| Electricity production from coal *t*-1 | 0.067 | 0.031 | -0.014 | 0.030 | -0.047* | -0.013 | 0.062*** |
| | [0.92] | [0.45] | [-0.37] | [1.32] | [-1.84] | [-0.90] | [2.64] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Electricity production from natural gas *t*-1 | 0.081 | 0.111 | -0.017 | 0.033 | -0.032 | -0.020 | 0.020 |
| | [1.16] | [1.62] | [-0.41] | [1.58] | [-1.28] | [-1.30] | [1.01] |
| Electricity production from nuclear *t*-1 | 0.069 | 0.114 | -0.016 | 0.048 | -0.011 | -0.017 | -0.034 |
| | [0.70] | [1.39] | [-0.41] | [1.34] | [-0.54] | [-1.23] | [-1.34] |
| Energy consumption pc *t*-1 | -0.027 | -0.042* | -0.000 | 0.017 | -0.014 | -0.007** | 0.018* |
| | [-0.88] | [-1.83] | [-0.04] | [1.59] | [-1.20] | [-2.15] | [1.80] |
| Ln patents *t*-1 | -0.040 | 0.039 | 0.053 | 0.011 | -0.019 | 0.009 | 0.048** |
| | [-0.85] | [0.55] | [1.22] | [0.65] | [-0.78] | [0.84] | [2.20] |
| Ln corruption perception index *t*-1 | -2.180 | 3.955* | 0.043 | -1.203 | 0.029 | -0.238 | 1.707 |
| | [-1.02] | [1.78] | [0.04] | [-1.56] | [0.04] | [-0.96] | [1.48] |
| Energy import dependence *t*-1 | 0.040 | 0.065 | 0.005 | 0.032*** | 0.014 | -0.001 | 0.004 |
| | [1.42] | [1.56] | [0.54] | [3.03] | [1.08] | [-0.44] | [0.41] |
| Ln carbon intensity *t*-1 | -1.720 | 9.410*** | 0.286 | -3.045*** | 4.431*** | 1.424*** | -4.514*** |
| | [-0.67] | [5.55] | [0.28] | [-2.58] | [3.51] | [2.95] | [-6.96] |
| Constant | 5.348 | 12.227 | -28.704*** | -16.437** | 9.741 | -9.065 | -18.124** |
| | [0.22] | [0.77] | [-3.36] | [-2.12] | [1.57] | [-3.21] | [-1.99] |
| Observations | 457 | 462 | 460 | 502 | 526 | 527 | 442 |
| R-squared | 0.620 | 0.513 | 0.476 | 0.786 | 0.641 | 0.776 | 0.749 |

***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.