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Determinants of Renewable Energy Growth: A Global Sample Analysis

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Abstract. We investigate factors influencing country-level renewable energy growth by applying FEVD and PCSE estimation methods in a unique sample analysis. With a longer time series (1990- 2010) and a broader sample size of countries (including Brazil, Russia, India, China and South Africa) than previous studies, our results reveal new insights. The results suggest that certain government-backed energy policies impede renewable energy investments, thus implying significant failures in policy design. These policies may be failing mainly because of uncertainty and the likelihood of discontinuity. Weak voluntary approaches are introduced in order to satisfy public demand for more sustainable investments and programmes; we find that these may have negative influences on the growth of renewables as well. The insight gained is consistent over the estimation methods employed.

Keywords: Renewable energy; Energy policy; Panel corrected standard errors

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1. Introduction

Renewables deployment has been a component of national planning agenda for many developed countries over the past few decades. Agenda in the 1980s focused largely on the then brewing "energy crises", thus reflecting the volatile nature of oil prices at the time. Renewables therefore emerged as possible alternatives to traditional fuels. Subsequently, in the 1990s, renewable energy sources became linked with sustainable development, forming part of international action aimed at addressing climate change (see Gan et al., 2007). Many countries and international organisations now view renewables as important elements of energy security, dynamic economic development, environmental protection and greenhouse gas (GHG) emissions reduction efforts (Carley, 2009; Gan et al., 2007; Johnstone et al., 2010; Marques and Fuinhas, 2012). Bolstered by this increasing importance, deployment of renewable energy sources has experienced a remarkable global growth profile in recent times. According to the IEA (2010), renewables deployment attained a 165.4% increase in power generation over the decade ending in 2009. However, evenly spread global participation is still limited. Coal still remains the main fuel source of power generation, accounting for 40.9% of total power output globally. The current trend shows a level of deployment asymmetry between developed and developing economies; however, countries from the same economic block and continent also show quite significant differences in deployment levels. Several studies have attributed these variations in renewables deployment to different factors. For example, Marques et al. (2010) identify some political, socioeconomic and country-specific factors as important determinants of renewables deployment. The first category includes policies (political factors), such as quotas, feed-in tariffs or investment in research, development and demonstration (RD&D), among others. The second category includes income and energy consumption, as examples of socioeconomic factors. A third category, which includes renewable energy potential, is identified as consisting of country-specific drivers. The first category, political drivers, is perhaps the most critical; this is mainly because renewables are currently more expensive options than fossil fuels. Of course, this is to be expected, since the environmental benefits of renewables and externalities of fossil fuels have not been internalised by firms. This market failure needs to be corrected by governments through policies that can discourage disproportionate dependence on fossil fuels, either by making them more expensive due to emissions or by subsidising clean sources of energy (see also Popp et al., 2011). This will ultimately help renewable energy become cost competitive with traditional energy sources (Carley, 2009). Further, Ibikunle and Okereke

(2013) argue that when the cost of employing fossil fuel-based power generators is made prohibitively high enough through the creation of an emissions-constrained environment, renewables will become competitive without the need for any other policy support mechanism.

Most of the available literature discussing policies and other factors affecting renewable energy deployment is qualitative and theoretical (see as examples Bird et al., 2005; Gan et al., 2007; Harmelink et al., 2006; Wang, 2006). Although most of the qualitative and theoretical studies argue in favour of a positive relationship between policy variables and renewables deployment, the scarce body of empirical work available (see as examples Carley, 2009; Johnstone et al., 2010; Marques and Fuinhas, 2012; Marques et al., 2010; Menz and Vachon, 2006) is less clear and conclusive, particularly in terms of the role of policies. Testing the relevance of the different factors and quantifying the relationship between them and renewable energy is critical for policy formulation. In light of several cases of sovereign debt crisis in some developed countries and the struggle for financial independence in many developing countries, this is particularly crucial for governments when valuable (and finite) resources are being exhausted through energy policies. Our study thus, in the first instance, contributes to the limited body of evidence in this area.

Regarding studies directly related to our research questions, Menz and Vachon (2006) were the first to test the effectiveness of policies designed to promote wind power generation in the United States. Using OLS, their study examines 39 states between 1998 and 2003, and considers five different policy instruments, including renewable portfolio standard (RPS), fuel generation disclosure requirement (FGS), mandatory green power option (MGPO), public benefit fund (PBF) and retail choice (RET). Key limitations of this study include the small sample size and the possibility of an omitted variables bias. Carley (2009) controls for these issues, using data covering all 50 states of the United States between 1998 and 2006. Using a Fixed Effects Vector Decomposition (FEVD) model, Marques et al. (2010) conduct an analysis of 24 European countries using panel data covering 1990 to 2006.

Marques et al. (2010) do not include policy variables and (insufficient) renewable energy potential in their analysis. The omission of policy variables has subsequently been addressed by Marques and Fuinhas (2012) in their investigation of renewable energy adoption as a dynamic process. Using data available from the IEA, nine policy-related variables are formulated: education and outreach, financial, incentives/subsidies, policy processes, public investment, R&D, regulatory instruments, tradable permits and voluntary agreements.

Both Marques et al. (2010) and Marques and Fuinhas (2012) work with several countries, but since they are in a similar political framework and geopolitical structure, their results may still not be applicable to countries from other regions. Only two works have been found to employ a more heterogeneous sample of countries, Johnstone et al. (2010) and Popp et al. (2011); however, their key focuses are not renewable energy deployment or contribution to the energy supply. Johnstone et al. (2010) examine the effect of policies on technological innovation in renewables, using number of patents as a proxy. Their sample is of 25 OECD countries over the 1978-2003 period and in addition to the policy variables they include two further control variables: electricity consumption and price of electricity. Popp et al. (2011) also examine technology, but unlike Johnstone et al. (2010), they test the hypothesis that as technology improves, the cost gap between renewables and traditional fossil fuel-based energy is reduced, thus making the former a more attractive option. Their evidence therefore suggests that countries should adopt more (stringent) policies promoting investment in renewable energy technologies (see Popp et al., 2011).

Our study takes a different approach and improves on the existing literature in several ways. The first improvement comes in terms of the sample of countries (*N=38*) and the period selected. Instead of focusing on the United States, the OECD or the European Union, we include all EU countries with available data, the remaining OECD countries (those outside the EU), and the BRICS (Brazil, Russia, India, China and South Africa), representing the emerging economies component. This is intended to assess the heterogeneity of countries, particularly through the inclusion of the BRICS. Thus, the variation in renewables adoption between developed and developing countries can be examined empirically. Further, our sample period coverage is longer than both Marques et al. (2010) and Marques and Fuinhas (2012); the time series is also more recent. As Marques and Fuinhas (2012) point out, this is significant because certain issues arose after 2006, such as the oil price boom, increasing social and political pressure for the development of cleaner energy, and the financial crisis. Secondly, we introduce more disaggregated and definitive variables. For example, for renewables potential we use scalar values of country-level potential for several renewable energy types, whereas in Marques et al. (2010) – as an example – ‘Surface Area’ is adopted for the same variable. Thirdly, in our econometric analysis, for robustness, we employ two different procedures considered by existing literature to be most suited to these studies, but which have not been previously conducted and compared within the same study. Thus, in order to test the robustness of our findings, we adopt both FEVD and panel corrected standard errors (PCSE) estimation methods. We also compare these to a further estimation technique. Consistent with previous studies, we report mixed results. The remaining sections of this paper are structured as follows: Section 2 explains the determinants of renewable energy growth included in our study. Section 3 discusses our data and methodology; Section 4 presents and discusses our empirical results, while Section 5 concludes.

2. Determinants of Renewable Energy Growth

Similar to the classification presented by Marques et al. (2010), we present the determinants of renewable energy growth that we use in three categories as political, socioeconomic and country-specific factors.

2.1. Political Factors

2.1.1. Public Policies

In the 1970s, renewables policy framework was dominated by Research and Development (R&D) programmes, while Obligations and Tradable Certificates became the most employed policy in the 2000s. As important as the type and number of policies implemented by nations, is the need to evaluate how effective and significant they are in promoting renewables. We present seven policy-type variables, which correspond to year-on-year changes to the accumulated number of policies and measures by year (less the discontinued policies) for the 38 countries. The data employed in our analysis is more disaggregated than previous studies, with the purpose of including as many details and characteristics as practicable within the constraints of our analytical framework. This is in line with Johnstone et al. (2010); thus, we acknowledge that within a broad category there are several policy variants, all of which are likely to have different effects on renewables adoption. Ideally, the variables should have been continuous in order to capture dissimilarities in their design among countries and across time. However, most of the policies vary significantly across several dimensions, for example the rates and the eligible technologies and capacities (Popp et al., 2011), thus complicating the homogenization of the variable. Given that they are aimed at fuelling renewables growth, we expect a positive relationship between the seven policy variables and renewables growth.

2.1.2. Institutional variable—Ratification of the Kyoto Protocol

We reckon that the commitment to reduce GHG emissions is a significant factor in global renewables deployment. One of the first key international steps in this direction was the adoption of the Kyoto Protocol in 1997. Countries that have ratified this agreement are expected to have a greater commitment to renewables deployment, as shown by Popp et al. (2011). In this paper, a dummy variable for the ratification of the Kyoto Protocol is used: the Kyoto dummy is 1 for a year, *t* for countries that have ratified the protocol before August of that year and zero otherwise. We anticipate a positive relationship with renewables deployment.

2.1.3. Energy Security

Energy security dependency is a critical policy issue for both developed and emerging economies. Literature supports the hypothesis that energy security advances renewables deployment (see for example Chien and Hu, 2008; Gan et al., 2007). We therefore include energy security as a potential determinant of renewables growth by following Marques et al. (2010) in employing energy import dependency as a proxy for energy security. Theoretically, we contend that the higher the reliance of a country on energy imports, the higher the level of renewables deployment required in order to improve that country's energy security. Thus, we expect that energy imports will be positively related to renewables growth.

2.2. Socioeconomic factors

2.2.1. Carbon Dioxide emissions

Following Marques et al. (2010), we proxy environmental concerns by including CO_2 emission levels in our analysis. Given its significance, we expect CO_2 to have a positive influence on renewables deployment. The expectation that environmental concerns drive renewables investment is well held in literature (see for example Sadorsky, 2009).

2.2.2. Prices (Oil, Natural gas, Coal and Electricity)

van Ruijven and van Vuuren (2009) examine the interaction of renewables and hydrocarbon prices in high and low GHG emission mitigation scenarios. When strong policies to reduce

GHG emissions are in place, an increase in hydrocarbon prices generate a shift from natural gas with carbon capture and storage (CCS), to coal with CCS, nuclear and wind power. Based on van Ruijven and van Vuuren (2009), we also include coal, natural gas and oil prices in our model. Marques et al. (2010) record erratic results for these variables; however, several studies (see as examples Awerbuch and Sauter, 2006; Chang et al., 2009) report their relatedness to renewables, since renewables deployment could shield countries' oil and gas price volatility. Chang et al. (2009) find a significant and positive relationship between energy prices and the contribution of renewables to energy supply in regions with high economic growth, although there is no significance in lower economic growth nations. Another strand of literature shows that renewables deployment reduces electricity prices (see Gelabert et al., 2011; Sensfuß et al., 2008; Würzburg et al., 2013). It seems that renewables, at least in the short term, generate a decrease in electricity prices, due to their lower marginal costs in relation to fossil fuels (Jensen and Skytte, 2002); however, different policy incentives are required. In recognition of the two-way relationship document in literature, we include industry electricity prices to capture the impact of electricity market prices on renewables deployment. Given the relationship captured in literature, we expect that electricity prices will negatively affect renewables deployment.

2.2.3. Welfare

Chang et al. (2009) documenting differences in the relationship between energy prices and renewables composition of the energy mix for low and high economic growth countries suggests that the economic standing of a country will impact renewables deployment. We therefore follow Marques et al. (2010), Carley (2009), Sadorsky (2009) and Chien and Hu (2008) in including GDP per capita in our analysis. The hypothesis is that higher income countries are more likely to deploy renewables, since they can easier afford the costs of developing such technologies and encourage their deployment through economic incentives. The heterogeneity of our sample of countries will be very important for this variable, considering the large gap between lower per capita income countries like China and India, compared to higher per capita ones such as Norway or Iceland.

2.2.4. Contribution of traditional energy sources to electricity generation

Contribution of traditional energy sources to the electricity mix is a measure employed by Marques et al. (2010) and Marques and Fuinhas (2012) as an approximation to the competition between these energy technologies and renewables, as well as the influence traditional energy sources have on policies and the economy, also known as lobby. Similarly, Carley (2009) also employ the percentage of total gross state product that is attributable to petroleum and coal manufacturing. Based on insights gained from all three papers, we anticipate that a higher share of fossil fuel in electricity generation will lead to countries being less likely to pursue important environmental policies and therefore participating less in renewables deployment (see Huang et al., 2007). Same situation applies to nuclear power, because although this and renewables can be considered environmentally friendly, they are mostly treated as substitutes.

2.2.5. Energy Needs

Two variables representing the energy needs of a country are also employed: energy use and population growth. The effects of both variables are uncertain since large energy use and/or growing energy needs due to population expansion could be supplied either by traditional energy sources or by renewable energy (see Carley, 2009; Marques et al. 2010).

2.3. Country specific factors

2.3.1. Renewables potential

As previously stated, previous literature only employ an approximation for renewable energy potential in their analysis, i.e. ‘Surface Area’. In this study, we obtain estimations of the potential for wind, solar and biomass energy by country, although no data about the evolution of this potential through the years could be acquired, therefore the variable is time invariant. In any case, such potentials are rarely changing given their nature. We expect that these variables will have a positive influence on renewables growth.

2.3.2. Deregulation of the electricity market

There is little consensus in the literature about how a more competitive market could affect renewable energy deployment, since a more competitive market could boost renewables in an emissions-constrained economy, or keep promoting traditional sources of energy due to economies of scale and lower costs. We include a dummy to capture the impact of full deregulation of the electricity market. It is important to note that we consider the year of full deregulation rather than the start date of the deregulation, since the difference between the two can be significant. This can be due to setbacks faced after initial pledges to deregulate by a certain date.

2.3.3. Continuous commitment

A further dummy variable is to proxy the continuous commitment of a country to renewable energy. This takes a value of 1 when the proportion of renewables used by a country is higher than 20% and 0 otherwise. This is expected to reflect any economies of scale generated as a result of previous investment in technologies and infrastructure, which should benefit renewables participation in the future.

3. Data and Methodology

3.1. Data

The number of countries used in this study, as dictated by availability of data, is 38. The economic and regional distribution includes countries from the EU, the OECD and the five BRICS. Specifically, we include Australia, Austria, Belgium, Brazil, Canada, China, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Russia, the Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States of America. The annual time series spans 1990 to 2010; thus, the dataset reflects the evolving trend in global action on climate change. These milestones include the adoption of the United Nations Framework on Climate Change Convention in Rio in 1992, the Kyoto Protocol in 1997 and the commencement of trading in the EU-ETS in 2005.

The dependent variable corresponds to the contribution of renewables to energy supply, measured as the percentage of renewables to total energy generated for a country in a period, available through the OECD Factbooks 2010 and 2012. There are two important reasons for choosing percentage instead of total deployment. The first relates to the fact that different policies are intended to achieve a certain target rate of participation. The second reflects climate change concerns, where the main goal is for renewables to increase, at the same time that fossil fuels decrease; thus, renewables need to displace more polluting options. In Table 2, we present a summary of the variables used in our models, along with their descriptive statistics and data sources.

INSERT TABLE 2 ABOUT HERE

Following Marques and Fuinhas (2012), we source policy-related variables from the IEA's Global Renewable Energy Policies and Measures. Other important sources are the World Data Bank, Eurostat, BP Statistical Review Worlds Energy, UN Data and Solar and Wind Energy Resource Assessment. The amount of countries and time series generated 738 observations. Additionally, we also include country and regional dummies (in several instances) in order to control for potential unobserved heterogeneity among nations.

3.2. *Methodology*

We commence our analysis by conducting preliminary examination of the data using several diagnostic tests. First, we test for unit roots in the dependent variable (renewable growth) using the Augmented Dickey Fuller (ADF) test. Next we expand our test for unit roots to the panel dataset by using the Levin-Lin-Chu and the Im-Pesaran-Shin tests for panel unit root tests. Theoretically, the panel unit root tests are multiple-series unit root tests that are applied to panel data structures such that the presence of cross-sections generates "multiple series" out of a single series. We also test for groupwise heteroscedasticity, serial correlation and cross sectional dependence. The results, which influence our decision on estimation techniques, are all presented in Table 1. A correlation matrix suggesting that Multicollinearity is not an issue with our panel data is also presented in the Appendix. Although the panel unit root tests show that the variables are panel stationary, the ADF results suggest that our dependent variable is of a non-stationary character; therefore the original data is transformed as specified in Equation 1. The same procedure is applied to the price variables employed in the study.

$$\mathrm{Re}\,newablesGrowth = \frac{\mathrm{Re}\,newables_t - \mathrm{Re}\,newables_{t-1}}{\mathrm{Re}\,newables_{t-1}} \qquad (1)$$

All the other diagnostic tests results are in line with expectations except one. The only result contrary to expectations is the lack of contemporaneous correlation in the panel. This situation might be due to the fact that the sample of countries is more heterogeneous than that used in previous studies, and therefore there is a lower probability of any one nation being in a similar political and economic context to another.

INSERT TABLE 1 ABOUT HERE

Employing fixed effects (FE) in order to control for unobserved country heterogeneity, which will help time-variant variables coefficient bias, do not permit the estimation of time-invariant variables' coefficients. Given the need to include both rarely changing/time invariant and time variant variables in our model, we employ the FEVD, which gives more efficient coefficient estimates than the standard FE (see Plumper and Troeger, 2007). The FEVD is estimated in three stages. Following Plumper and Troeger (2007), we obtain the unit effects from the unit effects in a first stage country fixed effects regression employing only the time-variant variables. Then we break up the obtained estimated fixed effects into the explained part and the residuals. The residuals are the error terms from the regression from the estimated unitary effects on the time-invariant variables, which are uncorrelated with the time-variant variables. In the final step we estimate a pooled OLS model incorporating the time-invariant and time-variant variables as well as the unexplained time-invariant residuals (see also Carley, 2009; Marques and Fuhinhas, 2010). Our econometric panel specification is as stated in Equation (2):

$$Y_{ct} = \alpha + \sum_{k=1}^{k} \beta_k X_{kct} + \sum_{j=1}^{j} \delta_j Z_{jc} + \varepsilon_{ct}, \qquad (2)$$

where for each country, c and year, t $\varepsilon_{ct} = \mu_c + \eta_{ct}$, $\boldsymbol{X}$ is a vector of k time-variant variables, $\boldsymbol{Z}$ corresponds to j time-invariant variables and Y represents renewables growth. μ_c is the N-1 country specific effects and η_{ct} correspond to the iid error terms.

Based on the specification tests, our data presents several challenges, among them the presence of spatial correlation. Various authors have studied the presence of spatial and cross-sectional correlation in panel data (see for example Beck and Katz, 1995; Freedman and Peters, 1984; Parks, 1967). Parks (1967) propose an FGLS estimator to deal with this problem. One of the complications of the method is that it can only be utilised when T is greater than or equal to the number of N (see Beck and Katz, 1995; Reed and Ye, 2009). Secondly, although FGLS is known to work well in large samples, little is known about its behavior in finite samples. Thirdly, the method underestimates the standard errors, which leads to overconfidence in the results (see Beck and Katz, 1995; Freedman and Peters, 1984; Jönsson, 2005). Due to these drawbacks and for robustness, we also employ Beck and Katz (1995) PCSE. This method involves using OLS to determine parameter estimates, but replacing the OLS standard errors with PCSE. This allows for the violation of the assumption that ε_{ct} is iid (in Equation 2); thus, ε_{ct} can be contemporaneously correlated and heteroscedatic across the instruments, and (in addition) time series autocorrelation within the regressors is also permitted.

4. Results and Discussion

Table 3 presents the results obtained with FEVD and PCSE estimation methods. The statistically significant variables in both models are CO_2 emissions, energy use (variation), ratification of the Kyoto Protocol, and the participation of coal, oil, natural gas and nuclear power in electricity generation. Also significant are the three variables of renewable energy potential, industry electricity rates and the continuous commitment to renewables. Out of these variables, CO_2 emissions, Kyoto, biomass and solar potential are positively related to renewables participation in the energy matrix, while the remaining variables negatively affect the dependent variable. Other relevant coefficients are the industry electricity tariff variation and the continuous commitment to renewables growth. According to the estimates, the continuous commitment dummy coefficient suggests that on-going commitment to renewables increases renewables participation levels. Similarly, there is the suggestion that a country's endorsement of the Kyoto Protocol translates into improvement in renewables growth. For policy variables, only Fiscal & Financial and Voluntary instruments are slightly significant using both estimation methods; both variables are negatively related to renewables participation growth. In the case of PCSE, Negotiated Agreements is also significant at conventional levels and positively linked to renewables participation.

INSERT TABLE 3 ABOUT HERE

4.1. Socioeconomic and Country-specific variables

The results suggest that environmental concern is an important factor in explaining renewables participation in different countries. This is reflected by the high level of statistical significance and positive relationship between CO_2 emissions and the dependent variable for both estimation methods. This is in line with the existing literature on how countries are committing to the goal of reducing GHG emissions and how renewables are a significant "green" option to achieving this goal, particularly when compared to fossil fuels. This commitment is also reflected in the proxy variable for ratification of the Kyoto Protocol which is also positive and significant in explaining renewables participation (see also Popp et al., 2011). Along with the nominally accepted renewable technologies, nuclear power can also be considered a “green” technology. However, the lack of cohesion around this idea, given the safety concerns surrounding nuclear power technology, is contradictory to this view. This ambiguity is reflected in our results, since our variable of nuclear participation in electricity generation has a negative (and highly significant) relationship with renewables. The latent concerns about the safety of nuclear power came to the fore in the wake of the Fukushima nuclear disaster in 2011. Although our data terminates in 2010, the results underscore these concerns. European countries in particular (perhaps with the exception of France) have accelerated the push for policies aimed at replacing energy produced by old nuclear power facilities with other sources. A good example is Germany, who in our sample changed from a nuclear-sourced energy composition of over 31% in 1997 to less than 23% in 2010. According to our analysis, nuclear power may be seen as a traditional energy source with a stronger negative relationship with renewables participation than oil, natural gas or coal.

Like nuclear participation, natural gas, crude oil and coal as components of the total energy production show individual significant and negative relationships with renewables participation. Theoretically, this is an accurate representation of the relationship anticipated; however, there is also a suggestion of the resilience of these energy sources in the different countries. Traditional energy sources are not only preferred for economic reasons in a non emissions-constrained economic environment; the traditional energy lobby in many countries is also very influential. Thus, the stronger the lobby for these traditional industries, the lower the likelihood of GHG reduction and renewables promotion policies being enacted (see also OECD, 2003). Of the two variables employed to represent the impact of increasing energy demands on a country’s disposition to renewables growth/participation (population growth and energy use), only the latter variable is highly significant. The results thus suggest that countries with increasing energy requirements are inclined to pursue more fossil fuel solutions and other cheap alternatives instead of renewables. Although not a surprising result, it is contrary to Marques et al.’s (2010) findings, where the relationship is positive. This disparity in results may have been influenced strongly by the presence of the largest developing countries in our sample, where, for example, India and China’s energy needs are two of the highest (and still have an upward trend) in the world. Although these two countries have been investing in renewable energy technologies, their use of fossil fuels is significantly greater than renewables. Thus, one might suggest that for countries with large population and whose growth is energy intensive, there is a greater emphasis on the use of fossil fuels and less inclination to increase renewables relative to energy requirements. Another argument may be that in our sample, there are several countries that have not undertaken to reduce their GHG emissions under any international treaty, i.e. the BRICS. Thus, there are varying degrees of commitment to renewables even though virtually all the countries in our sample ratified the Kyoto Protocol by 2009.

Renewable technologies are still expensive and thus cannot compete with fossil fuel technologies in the absence of supporting policies or costing for externalities. The continuous commitment dummy seems to reflect how countries that have considerable investments in renewables are more likely to keep increasing their use in the future. The case appears to be the opposite for countries with comparatively lower levels of renewables investment portfolios. This is in line with Marques et al.'s (2010) results for the analysis of EU member countries. The levelised cost of renewables varies for different locations depending on the resources available; this is why renewable potential is proxied via variables in the model. As expected, solar, biomass and wind potential are statistically significant in explaining renewables participation/growth. While solar and biomass potential variables show positive relationships, wind potential has a negative relationship with renewables participation. This is not surprising since existing literature shows similar results (see as examples Carley, 2009; Marques et al., 2010). The asymmetry of the related variables could also be the result of some countries altering the relationship with renewables growth in the model. For instance, the United States and Russia have among the highest wind potential, but their renewables participation is limited compared to countries with low wind resources, like Hungary. Hungary has a very low wind potential, but the country had a renewables participation rate of about 83% in 2010. This is a limitation of the available data, where ideally renewables participation rate should be disaggregated by technology, in order to compare the deployment with the potential of each. According to Popp et al. (2011), to pool all the technologies constrains the effect of the independent variable to be the same across all technologies.

Contrary to the work of Chang et al. (2009), our results suggest that fossil fuel prices are not relevant factors in explaining renewables deployment; however, this insight is consistent with Marques et al. (2010). The result may be explained by the inability of our data to reflect any shift from fossil fuels to renewables, since this change is slow and occurs on a long-term basis (although our data has a longer time series than most previous studies). On the other hand, Awerbuch and Sauter (2006) explain how losses and gains from replacing fossil fuels with RE due to rising energy prices are somewhat abstract and speculative; therefore, the benefits do not carry the same political weight as the large upfront investments in renewables. Van Ruijven and van Vuuren (2009) also note that when the climate policy is not prioritised, appreciation in oil and gas prices could lead to more consumption of carbon rather than renewables. Consequently, the relationship between fossil fuel prices and renewables investment might not be too obvious, and clearly depends on other factors. Industrial electricity prices are seen to be significant and negatively related to renewables deployment, as expected (see Gelabert et al., 2011; Würzburg et al., 2013), suggesting that when electricity prices are high, deployment of renewables could lead to a reduction in electricity prices. Awerbuch and Sauter (2006) also make this suggestion in their analysis of abstract and speculative long-term profits.

Energy imports, GDP per capita and Deregulation are not significant variables in the model. These results suggest that energy security is not a main driver behind renewables participation. Popp et al. (2011) present the same results after controlling for both the energy imported and the natural resource base of a country. Considered alongside estimates for variables representing CO_2 emissions and the ratification of the Kyoto Protocol, one can argue that over the past couple of decades, environmental concerns have been more critical drivers of countries' decisions to increase renewables investments than energy security. This could be related to more open and competitive markets since the '90s, with the enlargement of the EU, the ascension of the emerging economies and other global developments, leading to wealthier countries in the medium term. Thus, countries can *afford* to be concerned with climate change-related issues and the environment. Further, new technologies have continued to open up new frontiers for accessing fossil fuel deposits that were previously thought to be inaccessible; hence, energy security is becoming less of a concern to policy makers and their citizens. The relationship between the deregulation proxy and renewables participation rate is positive, although not statistically significant. This suggests that a more competitive market does not necessarily translate into more renewables investment and deployment. A closer look at the data reveals that most of the countries show a rising trend in renewables participation rate over time, i.e. before and after the year of their electricity markets are fully deregulated. This also helps in explaining why the deregulation proxy is not significant.

According to Palmer and Burtraw (2006) in their analysis based on United States data, the increase in market demand for “green” power after the restructuring has yet to materialise. In fact, most of the green power sales have occurred due to regulations, rather than retail market forces that emerge as a consequence of deregulation. The situation has not been altered since 2005, given the increase in shale gas exploration in the United States. Thus, neither the absolute size of an economy nor the living standards of the population are critical indicators of renewables participation.

4.2. Policy variables

There are very few instances of statistical significance for our tested range of policy variables. Although an improvement over previous works (Marques and Fuinhas, 2012), our policy variables only reflect the existence of different policy types, which makes them unable to summarise the peculiarities of policies, as well as the differences between them and among countries, in terms of design, years of implementation, eligible technologies, etc. (see Carley, 2009; Popp et al., 2011). Nevertheless, there are cases in the previous literature where even more details about the policies do not generate the expected results. For example, Popp et al. (2011) use the price level guaranteed for each technology as the feed-in tariff variable, while they also employ the percentage of electricity that must be generated in order to comply with the policy for renewable energy certificates. Both variables are not statistically significant in their analysis. Carley (2009) relates this to inadequate policy enforcement, policy duration uncertainty, overly aggressive RPS benchmarks or excess flexibility offered to utilities providers. Menz and Vachon (2006) only find significance for RPS, while green power options and public benefit funds are not significant.

In our models, Negotiated Agreements is positively linked with renewables growth. Although Negotiated Agreements may be voluntary, they also involve a multilateral partnership, not only inside a country, but also between nations, an example is the Global Methane Initiative (GMI). Global agreements, such as the Kyoto Protocol, could be more valuable for promoting renewables deployment than policies at the national level because of technology transfer and the pressure among peers to achieve the expected results. Voluntary Agreements show a negative relationship with renewables participation. The validity of this kind of policy has been generally discussed in the renewables and GHG emissions literature. There are several cases where the approaches only confirm the business-as-usual situation for companies, which suggests that several factors (market prices, consumer preferences, technological knowledge, etc.) other than the given voluntary approaches seem to explain the major part of any environmental improvement. According to a study carried out by the OECD, policy makers could sometimes collude with industries to use voluntary approaches, in order to appear to diligently undertake actions to solve environmental problems in response to public demand, as well as to save its budget resources (see OECD, 2003). Our results may have reflected this, where voluntary approaches is seen to be conversely related to renewables growth instead of reinforcing it, since they are displacing mandatory measures that generate more significant results compared to voluntary or less stringent processes.

Fiscal and Financial Instruments is negatively linked with renewables participation. This is a surprising result since the primary objective of such instruments is to financially enhance renewables. Johnstone et al. (2010) relate this situation to the fact that investors may have little or no confidence in policies that depend on public finance, since they are not likely to remain in place over the long term, and they are more likely to be withdrawn abruptly with a change in administration. A good example of this is the Production Tax Credit (PTC) for wind power in the United States. This fiscal incentive has had a pattern of repeated expiration and short-term renewal (usually no more than a couple of years), creating a boom-bust cycle in investments in this technology over the years, which is also believed to be damaging the industry's prospects due to the uncertainty it creates (see Barradale, 2010). In addition, although the industry agrees on the necessity of a five to ten-year incentive, legislators do not want to be associated with big spending programs, which is why the PTC is likely to remain as a two-year deal with option of renewal indefinitely. Another source of uncertainty for fiscal and financial instruments is economic downturn, especially during a financial crisis, when there are limited resources to support these measures. It would seem that the issue with the lack of positive reinforcement of renewables by fiscal incentives is a result of the uncertainty of the policies. Wang (2006) contrasts how the stability of policies in Germany has created a larger effect on renewables than in Sweden, which has suffered from a lack of consistency in its policies. Gan et al. (2007) also criticises how these measures do not necessarily guarantee the achievement of their expected targets.

4.3. *Assessment of Robustness*

Our first robustness testing measure is the use of two relevant estimation methods appropriate to our data characteristics. It is interesting to note that in terms of the explanatory effects (positive or negative) of the regressors on renewables growth, both methods generate very similar results, including the R^2 values (see Table 3). The only slight difference comes from the level of significance of the variables. For example, renewable energy potential (biomass, solar and wind) is significant at 1% in the case of FEVD, but only at 5% with PCSE. That the two sets of results lead to identical conclusions regardless of the model used (FEVD or PCSE) is a strong indication of the robustness of our analysis. Further, Parks' (1969) GLS also generates more or less the same positive or negative relationship between the variables, but with different degrees of significance (see Table 4). In fact, 20 variables are significant with GLS, compared to 15 with PCSE. This situation is mainly due to the lower standard deviation generated with GLS, as shown in Table 5. On average, the standard deviations from GLS are 43.5% lower than from PCSE. This can be viewed as a validation of Beck and Katz's (1995) observation that Parks' (1969) GLS method has a tendency to underestimate standard deviations. We also estimate the models without the respective insignificant variables in an attempt at parsimony. However, the results we obtain are qualitatively similar to the ones we present. Further, we vary the inclusion of certain variables such as including the policy variables in an aggregated form; we find that the results obtained may be driven by the Fiscal and Financial Instruments and Voluntary variables. Thus this additional level of analysis adds no further insight. Finally, we also exclude the insignificant variables from the respective models and observe the behaviour of the models. We find that the coefficients obtained from the alternate estimations are qualitatively similar to the reported coefficients and that there are also very slight variations in the levels of statistical significance observed.

INSERT TABLES 4 AND 5 ABOUT HERE

5. Conclusion

In this paper, we conduct a large sample analysis of the determinants of country-level renewables participation. In order to enhance the robustness of our results, we conduct our analysis using FEVD and PCSE estimation methods and a third (GLS) for further comparison; all the results, especially the FEVD and PCSE are identical. Our results indicate that CO_2 emission levels are significant indicators of renewables participation, while energy import level is not. This suggests that environmental concerns are more relevant than energy security for countries in our sample. Energy use is negatively linked to renewable energy participation, implying that under high pressure to ensure the energy supply, countries have a tendency to employ less renewable energy, and probably more fossil fuels due to their cost advantage. High electricity rates for the industry sector (signifying scarcity) also lead to lower renewable energy investments, suggesting that renewables could in fact help to reduce electricity prices. The trade-off between renewable energy and fossil fuels, as well as nuclear power, is reflected in the negative relationship between renewables participation and the composition of coal, oil, natural gas and nuclear power in the energy mix. The results underscore the policy lobbying strength of the traditional energy mix industries.

Countries that have greater renewable energy potential are expected to deploy more of these technologies. Our results imply that this is consistent for biomass and solar power, but there is a negative relationship in the case of wind power. This suggests that countries with lower resources work harder to develop this technology in order to compensate for the reduced environmental conditions. On the other hand, this problem could be related to our data, where renewable energy participation is not disaggregated by technology, thereby assuming that the different technology potentials have the same influence over the dependent variable. Three of our policy proxies are significant explanatory variables for renewable energy participation. Two of them (Voluntary Approaches and Fiscal and Financial Instruments) have negative relationships with the dependent variable. There is a critical insight to be gained here for policy makers, because the two policy types are the most commonly deployed instruments in our sample of 38 countries. A negative influence suggests important failures in the design, particularly in terms of uncertainty and discontinuity, two of the main sources of concern for potential renewables investors. On the other hand, results suggest that Voluntary Approaches are not generating the expected results, and, even more problematic, they might only be implemented by governments pretending to engage in environmental action. If voluntary measures do not produce positive results, they should only be employed as transitional measures towards mandatory policies, thus helping companies and customers become familiar with the rules and procedures, as well as the additional costs they might bear and the adjustments to be made prior to a mandatory regime.

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Table 1

Specification Tests

	Pooled	Fixed Effects
Levin-Liu-Chu test t*	-18.07***	
Im-Pesaran-Shin W-stat	-16.46***	
Bartlett's Equality of Variances (residuals)	536.14***	
Levene's Equality of Variances (residuals)	4.17***	
Wooldridge test F(N(0,1))	10.19***	
Pesaran's test	-0.40	0.52

*Notes: Levin-Liu-Chu and Im-Pesaran-Shin tests test the null hypothesis of a unit root; Levin-Liu-Chu assumes common unit root process, while Im-Pesaran-Shin assumes individual unit root process. For Bartlett and Levene's tests we use residuals of a pooled OLS regression and unstack them by country. Wooldridge test is N(0,1) and tests the null of no serial correlation. Pesaran's test tests the null hypothesis of cross-section independence; the test is parametric procedure and follows a standard normal distribution. *** denote statistical significance at 1% level.*

Table 2
Variables Definition and Descriptive Statistics

	Definition	Source	Observations	Mean	Maximum	Minimum	Std. Dev.
Dependent variable							
Renew	Contribution of renewable energy to energy supply (%)	OECD Factbook 2010 and 2012	738	13.67	81.80	0.40	15.46
Independent Variables							
CO2	CO_2 emissions (metric tons per capita)	World Data Bank	738	8.92	27.52	0.79	4.53
Eneimpo	Net Energy Imports (%)	World Data Bank	738	13.57	99.16	-842.44	127.54
Eneuse	Energy Use (Kg of oil equivalent per capita)	World Data Bank	738	$39.7x10^2$	$16.9x10^3$	$3.63x10^3$	$22.41x10^2$
Population growth	Population growth (%)	World Data Bank	738	0.74	6.02	-1.03	0.70
GDP/capita	Gross domestic product per capita (constant 2010 US$)	World Data Bank	738	$17.5x10^3$	$56.3x10^3$	$3.13x10^2$	$11.94x10^3$
Deregulation	Year of full deregulation of electricity market (DUMMY)	Various sources	738	0.26	1.00	0.00	0.44
Cont_commitment	Continuous commitment to renewables (DUMMY)	Own elaboration	738	0.20	1.00	0.00	0.40
Kyoto	Ratification of the Kyoto Protocol (DUMMY)	UNFCCC	738	0.37	1.00	0.00	0.48
Other fuels participation							
Coalpart	Electricity production from coal sources (%)	World Data Bank	738	34.72	97.49	0.00	28.80
Gaspart	Electricity production from natural gas sources (%)	World Data Bank	738	15.41	93.90	0.00	17.61
Nuclearpart	Electricity production from nuclear sources (%)	World Data Bank	738	16.37	79.08	0.00	20.32
Oilpart	Electricity production from oil sources (%)	World Data Bank	738	6.85	53.58	0.00	10.57

Prices							
Coalprice	Coal prices (US$ per tonne)	BP Statistical Review of World Energy	738	52.10	147.67	28.79	27.32
Gasprice	Natural Gas prices (US$ per million Btu)	BP Statistical Review of World Energy	738	3.99	8.85	1.49	2.35
Oilprice	Crude Oil prices (US$ per barrel)	BP Statistical Review of World Energy	738	42.24	101.61	17.55	21.98
Industry	Electricity rates for industry	International Energy Agency/ Eurostat	738	72.71	289.80	5.23	35.02
Renewable Energy Potential							
Biomass	Estimated biomass quantities (thousand MT)	UN Data	738	48.04x10^{3}	63.22x10^{4}	1.43	11.23x10^{4}
Solar	Solar potential (MWh per year)	Solar and Wind Energy Resource Assessment	738	49.70x10^{8}	30.60x10^{9}	44.84x10^{5}	92.50x10^{8}
Wind	Wind potential (wind areas (km2) class 3-7 at 50m)	Solar and Wind Energy Resource Assessment	738	30.03x10^{4}	32.25x10^{5}	0.00	76.07x10^{4}
Public Policies	*Accumulated number of RE Policies and Measures (ANPM)*						
Direct_invest	ANPM- Direct investment	IEA Global RE Policies and Measures	738	0.49	15.00	0.00	1.19
Feed_in_tariff	ANPM- Feed-in tariff	IEA Global RE Policies and Measures	738	0.58	8.00	0.00	1.11
Fiscal_financial	ANPM- Fiscal and financial support	IEA Global RE Policies and Measures	738	3.22	27.00	0.00	4.37
Grants_subsidies	ANPM- Grants and Subsidies	IEA Global RE Policies and Measures	738	1.47	18.00	0.00	2.39
Green_certificates	ANPM- Green certificates	IEA Global RE Policies and Measures	738	0.20	5.00	0.00	0.59
Info_education	ANPM- Information and Education	IEA Global RE Policies and Measures	738	0.65	24.00	0.00	2.17

Loans	ANPM- Loans	IEA Global RE Policies and Measures	738	0.29	4.00	0.00	0.68
Market_based	ANPM- Market based instruments	IEA Global RE Policies and Measures	738	0.29	7.00	0.00	0.78
Neg_agreements	ANPM- Negotiated agreements	IEA Global RE Policies and Measures	738	0.24	6.00	0.00	0.71
RD_D	ANPM- Research, Development and Deployment	IEA Global RE Policies and Measures	738	1.07	21.00	0.00	2.07
Regulatory	ANPM- Regulatory instruments	IEA Global RE Policies and Measures	738	1.61	21.00	0.00	2.23
Support_planning	ANPM- Policy Support and Planning	IEA Global RE Policies and Measures	738	1.58	15.00	0.00	2.11
Voluntary	ANPM- Voluntary instruments	IEA Global RE Policies and Measures	738	0.38	8.00	0.00	0.97

Table 3
Results from panel analysis estimated with FEVD and PCSE

Dependent variable: Renew_var				
	FEVD		PCSE	
Variable	Coefficient	S.E.	Coefficient	S.E.
Cons	-0.12	0.13	0.02	0.08
CO$_2$	0.03***	6.82 x 10^{-3}	0.02***	6.39 x 10^{-3}
Eneimp	2.77 x 10^{-6}	2.50 x 10^{-4}	-4.16 x 10^{-5}	2.47 x 10^{-4}
Eneuse_var	-0.96***	0.12	-0.92***	0.13
GDP_percapita	-2.08 x 10^{-6}	2.79 x 10^{-6}	-3.22·10^{-6}	2.78 x 10^{-6}
Kyoto	0.04***	0.01	0.04***	0.01
Coalpart	-4.90 x 10^{-3}***	1.40 x 10^{-3}	-5.03 x 10^{-3}***	1.36 x 10^{-3}
Gaspart	-4.10 x 10^{-3}***	1.17 x 10^{-3}	-4.40 x 10^{-3}***	1.24 x 10^{-3}
Nuclearpart	-6.19 x 10^{-3}***	1.91 x 10^{-3}	-6.23·10^{-3}**	2.76 x 10^{-3}
Oilpart	-4.59 x 10^{-3}***	1.48 x 10^{-3}	-4.96 x 10^{-3}***	1.59 x 10^{-3}
Biomass	2.75 x 10^{-5}***	8.03 x 10^{-6}	2.32 x 10^{-5}**	9.29 x 10^{-6}
Solar	9.37 x 10^{-11}***	2.85 x 10^{-11}	7.82 x 10^{-11}**	3.19 x 10^{-11}
Wind	-2.96 x 10^{-6}***	8.65 x 10^{-7}	-2.51E x 10^{-6}**	1.01 x 10^{-6}
Coalprice_var	-0.02	0.02	-0.02	0.02
Gasprice_var	5.77 x 10^{-3}	1.98 x 10^{-2}	4.71 x 10^{-3}	1.98 x 10^{-2}
Oilprice_var	0.04	0.03	0.04	0.03
Industry_var	-0.06**	0.03	-0.06**	0.02
Population_growth	0.01	0.01	0.01	0.01
Cont_commitment	0.12*	0.07	0.06**	0.02
Deregulation	0.01	0.02	0.02	0.02
Policies				
Direct_invest	-3.90 x 10^{-3}	7.47 x 10^{-3}	-3.06 x 10^{-3}	6.46 x 10^{-3}
Feed_in_tariff	4.62 x 10^{-3}	8.35 x 10^{-3}	2.20 x 10^{-3}	9.64 x 10^{-3}
Fiscal_financial	-8.67 x 10^{-3}*	4.94 x 10^{-3}	-8.17 x 10^{-3}*	4.77 x 10^{-3}
Grants_subsidies	9.70 x 10^{-3}	6.88 x 10^{-3}	9.49 x 10^{-3}	6.15 x 10^{-3}
Green_certificates	-0.01	0.02	-0.01	0.02
Info_Education	7.75 x 10^{-3}	6.14 x 10^{-3}	6.87 x 10^{-3}	5.16 x 10^{-3}
Loans	0.01	0.01	0.01	0.01
Market_based	0.01	0.02	0.01	0.02
Neg_agreements	0.03	0.02	0.03*	0.01
RD_D	-1.03 x 10^{-3}	5.76 x 10^{-3}	3.67 x 10^{-5}	4.98 x 10^{-3}
Regulatory	1.76 x 10^{-3}	5.30 x 10^{-3}	1.39 x 10^{-3}	6.49 x 10^{-3}
Voluntary	-0.03*	0.02	-0.03*	0.01
Unexplained	-2.12	1.63	-1.30	0.19
R^2	0.27		0.26	
Adjusted R^2	0.19		0.19	
S.E. of regression	0.10		0.10	

*Notes: The table reports coefficients and standard errors for determinants of renewables growth using fixed effects with vector decomposition (FEVD) and panel corrected standard errors (PCSE) estimation methods. *, ** and *** represent significance at 10%, 5% and 1%, respectively. All variables are as defined in Table 2.*

Table 4
Summary of results by estimation methods

Dependent variable: RENEW_VAR			
	Methods		
Dependent Variables	FEVD	PCSE	GLS
Cons	+ *(NS)*	+ *(NS)*	- *(NS)*
CO_2	+ (***)	+ (***)	+ (***)
Eneimp	- (NS)	- (NS)	+ (NS)
Eneuse_var	- (***)	- (***)	- (***)
GDP_percapita	- (NS)	- (NS)	- (NS)
Kyoto	+ (***)	+ (***)	+ (***)
Coalpart	- (***)	- (***)	- (***)
Gaspart	- (***)	- (***)	- (***)
Nuclearpart	- (***)	- (**)	- (***)
Oilpart	- (***)	- (***)	- (***)
Biomass	+ (***)	+ (**)	+ (**)
Solar	+ (***)	+ (**)	+ (***)
Wind	- (***)	- (**)	- (**)
Coalprice_var	- (NS)	- (NS)	- (NS)
Gasprice_var	+ (NS)	+ (NS)	- (NS)
Oilprice_var	+ (NS)	+ (NS)	+ (***)
Industry_var	- (**)	- (**)	- (***)
Population_growth	+ (NS)	+ (NS)	+ (**)
Cont_commitment	+ (*)	+ (**)	+ (***)
Deregulation	+ (NS)	+ (NS)	+ (*)
Policies			
Direct_invest	- (NS)	- (NS)	- (NS)
Feed_in_tariff	+ (NS)	+ (NS)	+ (*)
Fiscal_financial	- (*)	- (*)	- (***)
Grants_subsidies	+ (NS)	+ (NS)	+ (*)
Green_certificates	- (NS)	- (NS)	- (NS)
Info_Education	+ (NS)	+ (NS)	+ (NS)
Loans	+ (NS)	+ (NS)	+ (NS)
Market_based	+ (NS)	+ (NS)	+ (NS)
Neg_agreements	+ (NS)	+ (*)	+ (NS)

RD_D	+ (NS)	+ (NS)	+ (*)
Regulatory	+ (NS)	+ (NS)	+ (NS)
Voluntary	- (*)	- (**)	- (***)
R^2	0.27	0.26	0.52

*Notes: The table reports a summary of the relationship between determinants of renewables growth and renewables growth, estimated using fixed effects (FE), fixed effects with vector decomposition (FEVD), panel corrected standard errors (PCSE) and Parks' (1967) generalised least squares (GLS) estimation methods. *, ** and *** represent significance at 10%, 5% and 1%, respectively. NS refers to 'not statistically significant'.*

Table 5
Standard deviation with PCSE and GLS

	Standard Deviations		GLS difference to PCSE
Variable	PCSE	GLS	
Cons	0.08	0.06	-27.70%
CO_2	6.39 x 10^{-3}	3.32 x 10^{-3}	-48.00%
Eneimp	2.47 x 10^{-4}	2.01 x 10^{-4}	-18.60%
Eneuse_var	0.13	0.06	-55.20%
GDP_percapita	2.78 x 10^{-6}	1.73 x 10^{-6}	-37.80%
Kyoto	0.01	0.01	-48.30%
Coalpart	1.36 x 10^{-3}	7.67 x 10^{-4}	-43.60%
Gaspart	1.24 x 10^{-3}	6.68 x 10^{-4}	-46.10%
Nuclearpart	2.76 x 10^{-3}	1.39 x 10^{-3}	-49.70%
Oilpart	1.59 x 10^{-3}	8.50 x 10^{-4}	-46.50%
Biomass	9.29 x 10^{-6}	5.57 x 10^{-6}	-40.00%
Solar	3.19 x 10^{-11}	1.84 x 10^{-11}	-42.30%
Wind	1.01 x 10^{-6}	6.00 x 10^{-7}	-40.60%
Coalprice_var	0.02	8.11 x 10^{-3}	-57.80%
Gasprice_var	0.02	8.60 x 10^{-3}	-56.60%
Oilprice_var	0.03	0.01	-57.70%
Industry_var	0.02	0.01	-47.60%
Population_growth	0.01	6.95 x 10^{-3}	-41.00%
Cont_commitment	0.02	0.01	-54.60%
Deregulation	0.02	9.52 x 10^{-3}	-36.60%
Policies			
Direct_invest	6.46 x 10^{-3}	2.98 x 10^{-3}	-53.90%
Feed_in_tariff	9.64 x 10^{-3}	4.40 x 10^{-3}	-54.40%
Fiscal_financial	4.77 x 10^{-3}	2.97 x 10^{-3}	-37.70%
Grants_subsidies	6.15·10^{-3}	3.79 x 10^{-3}	-38.40%
Green_certificates	0.02	0.01	-30.70%
Info_Education	5.16 x 10^{-3}	3.09 x 10^{-3}	-40.10%
Loans	9.42 x 10^{-3}	5.13 x 10^{-3}	-45.60%
Market_based	0.02	0.01	-35.50%
Neg_agreements	0.01	9.24 x 10^{-3}	-32.00%
RD_D	4.98 x 10^{-3}	3.15 x 10^{-3}	-36.60%
Regulatory	6.49 x 10^{-3}	2.72 x 10^{-3}	-58.20%
Voluntary	0.01	8.08 x 10^{-3}	-33.50%
		Average	-43.50%

Notes: The table reports standard deviation estimates for both panel corrected standard errors (PCSE) and Parks' (1969) generalised least squares (GLS) estimation methods. The final column reports, for each variable, the differences between the estimated standard deviations by the two estimation methods, expressed as percentages of the PCSE values. All variables are as defined in Table 2.

Table A1

Correlation matrix

	Renew_var	CO_2	Cont_comm	Deregulation	Eneimp	Eneuse_var	GDP_capita	Kyoto	Population	Coalpart	Gaspart	Nuclearpart	Oilpart	Coalprice	Gasprice	Oilprice
Renew_var	1.00															
CO_2	0.09	1.00														
Cont_comm	0.00	-0.26	1.00													
Deregulation	0.16	0.14	0.04	1.00												
Eneimp	0.06	-0.04	0.09	-0.28	1.00											
Eneuse_var	-0.36	-0.09	0.06	-0.19	0.01	1.00										
GDP_capita	0.08	0.52	-0.11	0.33	-0.16	-0.09	1.00									
Kyoto	0.17	-0.05	-0.01	0.38	0.02	-0.10	0.10	1.00								
Population	-0.07	-0.02	0.04	-0.06	-0.02	0.05	0.04	-0.05	1.00							
Coalpart	0.02	0.17	-0.26	-0.20	0.09	0.04	-0.39	-0.07	0.08	1.00						
Gaspart	0.09	0.25	0.07	0.09	0.16	-0.12	0.22	0.21	0.00	-0.27	1.00					
Nuclearpart	0.03	-0.06	-0.16	-0.01	0.21	-0.08	0.08	0.02	-0.37	-0.30	-0.20	1.00				
Oilpart	-0.09	-0.21	-0.13	-0.26	0.17	0.10	-0.18	-0.16	0.20	-0.05	0.08	-0.21	1.00			
Coalprice_var	-0.10	0.03	-0.01	-0.03	0.00	0.31	0.01	0.01	0.00	0.01	0.00	0.00	0.01	1.00		
Gasprice_var	-0.10	0.02	0.00	-0.16	0.00	0.30	-0.03	-0.19	0.00	0.02	-0.06	0.01	0.06	0.72	1.00	
Oilprice_var	-0.01	0.02	-0.01	0.06	-0.01	0.22	0.04	0.19	-0.02	-0.01	0.07	0.00	-0.05	0.65	0.71	1.00
Industry_var	-0.02	0.06	-0.04	0.11	0.04	0.01	0.00	0.26	-0.01	0.01	0.10	0.00	0.01	0.19	0.08	0.13
Biomass	-0.09	-0.32	0.03	-0.14	0.00	0.10	-0.30	-0.01	0.28	0.22	-0.16	-0.14	-0.10	0.00	0.00	0.00
Solar	-0.11	0.16	0.04	-0.09	-0.16	0.03	-0.23	-0.10	0.15	0.15	-0.06	-0.20	-0.12	0.00	0.00	0.00
Wind	-0.06	0.18	0.13	0.00	-0.12	-0.01	-0.04	-0.07	0.14	-0.12	-0.11	-0.11	-0.14	0.00	0.00	0.00
Policies																
Direct_invest	0.02	0.34	-0.02	0.26	0.04	-0.08	0.20	0.11	0.05	0.04	0.09	0.02	-0.13	-0.03	-0.09	0.03
Feed_in_tariff	0.09	0.09	-0.15	0.18	0.15	-0.12	0.24	0.35	-0.08	-0.07	0.13	0.25	-0.16	-0.08	-0.16	0.01
Fiscal_financial	0.12	0.34	-0.23	0.51	-0.06	-0.19	0.42	0.37	-0.03	-0.07	0.11	0.25	-0.25	-0.06	-0.17	0.07
Grants_sub	0.09	0.37	-0.17	0.46	-0.06	-0.17	0.38	0.27	0.05	-0.04	0.10	0.16	-0.24	-0.07	-0.17	0.04
Green_cert	0.12	0.06	0.05	0.20	0.04	-0.09	0.14	0.30	-0.05	-0.05	0.32	-0.04	-0.04	0.01	-0.07	0.07
Info_educ	0.02	0.36	-0.10	0.23	-0.05	-0.10	0.29	0.01	0.06	0.01	0.04	0.09	-0.11	-0.02	-0.07	0.03
Market_based	0.13	0.04	0.01	0.32	-0.25	-0.12	0.22	0.32	-0.05	-0.11	0.28	-0.08	-0.06	-0.02	-0.11	0.05
Neg_agree	-0.01	0.33	-0.15	0.18	-0.03	-0.09	0.28	0.06	0.05	0.08	0.01	0.02	-0.11	0.00	-0.07	0.05
RD_D	0.04	0.36	-0.19	0.35	-0.03	-0.12	0.36	0.12	0.01	0.02	0.03	0.12	-0.15	-0.03	-0.11	0.04

Regulatory	0.12	0.28	-0.20	0.42	-0.04	-0.20	0.34	0.34	-0.05	-0.01	0.18	0.11	-0.14	-0.07	-0.20	0.05
Support_plann	0.11	0.16	-0.06	0.46	-0.04	-0.17	0.29	0.40	0.04	-0.01	0.19	-0.07	-0.09	-0.07	-0.21	0.06
Voluntary	-0.03	0.34	-0.13	0.30	-0.27	-0.08	0.33	0.07	0.07	0.01	-0.03	-0.01	-0.14	0.01	-0.06	0.08

	Industry_var	Biomass	Solar	Wind	Direct_invest	Feed_in_tariff	Fiscal_fin	Grants_sub	Green_cert	Info_educ	Market_based	Neg_agree	RD_D	Regulatory	Support_plann	Voluntary
Industry_var	1.00															
Biomass	-0.06	1.00														
Solar	-0.01	0.41	1.00													
Wind	-0.01	0.30	0.77	1.00												
Policies																
Direct_invest	0.03	0.15	0.30	0.38	1.00											
Feed_in_tariff	0.07	-0.04	-0.18	-0.14	0.08	1.00										
Fiscal_financial	0.09	0.03	0.15	0.24	0.59	0.47	1.00									
Grants_sub	0.06	0.01	0.24	0.29	0.61	0.23	0.90	1.00								
Green_cert	0.10	-0.07	-0.04	-0.03	0.06	0.11	0.30	0.29	1.00							
Info_educ	0.02	0.12	0.33	0.41	0.78	0.04	0.68	0.68	0.11	1.00						
Market_based	0.10	-0.08	-0.06	-0.02	0.13	0.06	0.36	0.32	0.87	0.20	1.00					
Neg_agree	0.02	0.07	0.33	0.28	0.64	0.15	0.54	0.54	0.15	0.67	0.19	1.00				
RD_D	0.05	0.06	0.28	0.32	0.77	0.15	0.75	0.75	0.12	0.84	0.21	0.71	1.00			
Regulatory	0.09	0.05	0.12	0.17	0.64	0.34	0.79	0.68	0.36	0.75	0.45	0.63	0.76	1.00		
Support_plann	0.10	0.05	0.12	0.12	0.56	0.20	0.63	0.59	0.41	0.55	0.53	0.56	0.65	0.71	1.00	
Voluntary	0.01	0.06	0.33	0.31	0.66	0.14	0.61	0.60	0.14	0.73	0.27	0.91	0.75	0.66	0.64	1.00

Notes: The table shows the correlation coefficients for all variables examined in this paper. The variables are as defined in Table 2.