Environ Resource Econ (2011) 49:351–366
DOI 10.1007/s10640-010-9436-8

A Quantile Approach to Identify Factors Promoting Renewable Energy in European Countries

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Accepted: 11 November 2010 / Published online: 30 November 2010

Abstract This paper analyses the impact of several factors on the use of renewable energy sources in a set of European Union countries, by applying a quantile regression approach. We find that different factors are effective for different levels of renewable energy commitment and the magnitudes of some effects evolve in accordance with the level of renewable energy sources used. Consequently, some policies that do not take into account the different stages could carry different effects. The results suggest that the lobbying effect of the established industries hampers the development of renewable sources, and that this effect is greater for lower initial level of renewable energy use. The results reveal that environmental concerns have not yet achieved enough pressure to stimulate major developments on renewables. We include two new drivers, geographic area and European Union Directive 2001/77/EC. That Directive was effective in signaling the commitment to renewables, namely for countries with lower renewables use.

Keywords Renewable energy · Quantile regression · EU Directive 2001/77/EC · European countries

JEL Classification N74 · Q42 · Q58

Research supported by: NECE, I&D unity funded by the FCT - Portuguese Foundation for the Development of Science and Technology, Ministry of Science, Technology and Higher Education.

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1 Introduction

Literature on general issues in renewable energy sources is vast. However, literature on drivers towards renewables is mainly focused on a normative perspective about what factors should influence the RE commitment (e.g. Wang 2006). In fact, the empirical evidence about drivers promoting its use is still scarce, and mainly applied to USA (e.g. Menz and Vachon 2006; Carley 2009). Menz and Vachon (2006) used Ordinary Least Squares to study wind power development for 30 American States, using 1 year data. For 48 American States, Carley (2009) estimated a model of fixed effects, and a model of fixed effects with vector decomposition, using data over a span of time of 9 years (1998–2006).

The Framework Convention on Climate Change created by United Nations General Assembly in year 1990, and the Kyoto Protocol in the year 1997, together constitutes milestones in fight path against global warming. As well known, renewables are a weapon in battling global warming. For the European Union Members countries those environmental concerns brought about by carbon dioxide emissions, mainly from fossil fuels, are in the genesis of the White Paper on Renewable Energy Sources and the EU Directive 2001/77/EC, (updated by the Directive 2009/28/EC (EU 2001; EU 2009), which constitute the framework of the guidelines towards renewables use.

European Union (EU) and their members were firmly committed to the Kyoto Protocol, as noted by Vachon and Menz (2006). Compared with Europeans, Americans have shown less willingness to pay higher prices or higher taxes to mitigate the climate changes. In Europe, Van Rooijen and Van Wees (2006), Wang (2006), Wüstenhagen and Bilharz (2006) study the Netherlands, Sweden and Germany respectively. They use a short span of time to study the impact of policy measures on renewable electricity, in each of those countries. Better accuracy of results could be achieved extended the span of time.

This paper presents a quantile regression approach to assess the main factors driving RE use by a set of European countries since the beginning of the 1990s. The use of RE sources, in general, remains limited and heterogeneous among countries; some countries, such as the Czech Republic and Ireland, have rates lower than 5% of the total energy generated by these sources, while in others, such as Iceland, that percentage is larger than 75%. Therefore it is expected that factors promoting RE have different consequences according to the stage of the RE development. An increase in oil prices ought to lead to diverse engagements for countries with different renewables weight on total energy. Likewise it is expected that seeking energy security, which is suggested by literature (e.g. Gan et al. 2007) as a key driving force behind renewable sources use, can call for different policies, depending on whether the country is almost totally dependent on energy imports and does not produce internally from renewable sources, or whether it is a country that uses these sources on a large scale. We also think that this factor suggested by the literature can not be verified for countries where those renewable sources are already relatively significant in the energy supply.

Our main motivation is to better understand the drivers towards renewables in Europe, in order to provide additional support for design of political guidance, in the field of the strategic sector of energy. We contribute by: (i) showing that quantile regression is appropriate to explain the factors encouraging the use of renewable sources, which clearly evolve with the level of RE deployment; (ii) focusing on one of the economic leader block that is in the vanguard of the fight against climate changes; (iii) adding empirical evidence about drivers promoting renewables, for a long span of time - we particularly control, both for the effect of EU Directive 2001/77/EC and the geographical area.

Results support that factors influencing RE commitment depend on the actual level of development of renewables. The results verify in Europe the effect of lobbying associated with traditional sources of energy. Carbon dioxide emissions are significant in explaining RE use. The EU Directive 2001/77/EC had a positive impact in the promotion of RE use, making the targets defined effective.

The second section defines the variables used in this analysis. The third section presents the data, the model and describes the estimation procedure. The fourth section shows the results and finally, the last one, the fifth, discusses the results found and presents some concluding remarks.

2 Determinants of RE Commitment

The use of renewable sources in a given country can be measured in several ways. We are interested in explaining how renewable sources represent as a share of total primary energy supply. In accordance, we focus on relative values. One way the literature measures the development of the RE sources is the natural logarithm of the RE share on total electricity generation (e.g. Carley 2009). Using a similar approach we use as dependent variable, the natural logarithm of the RE share on a country's total primary energy supply (*LCRES*). The explanatory variables are chosen in accordance with the literature. They cover several dimensions of interests, such as social features, economics features and environmental concerns. Following, we list the variables and, in a summary way, we discuss the rational of their inclusion in our model.

- *The carbon dioxide emissions per capita (CO2PC).* Climate change is associated with the emission of large quantities of greenhouse gases, such as Carbon Dioxide (CO_2), Chlorofluorocarbons, Methane, Nitric Acid and Ozone. The most common factor to be held responsible for degrading environment and contribute to climate change is the CO_2, as suggested by the majority of the literature. Nowadays, CO_2 is a benchmark in any international treaties to handle with climate change. Moreover, CO_2 has been object of the carbon market. Europe has the largest multi-national experiment with an emissions trading system for carbon dioxide, which is known as the European Union Emissions Trading Scheme. The variable CO_2 is used in the literature (e.g. Sadorsky 2009a; Van Ruijven and Van Vuuren 2009; Menyah and Wolde-Rufael 2010). We control for *CO2PC*. The signal will be the result of the supremacy of one of two effects. On one hand, larger levels of CO_2 emissions could strengthen social conscience and environmental concerns, provoking pressure to increase the use of renewables sources. On the other hand, a negative signal could result from the fact that larger levels of CO_2 emissions would be a signal of social alienation about environmental concerns. This scenario creates political conditions to maintain the commitment with fossil fuels.
- *Energy consumption per capita (ENERGPC).* Traditionally, energy consumption is used as a development indicator. We control for the consumption of energy per capita, expecting either a positive or a negative effect on the RE. Energy consumption could be supplied by traditional pollutant energy sources, through clean sources, and by using a mixture of both, traditional and clean sources. Actually, larger consumptions could be an incentive to commit to renewable sources or a force leading to higher levels of fossil fuels use.
- *Contribution of coal, oil, natural gas and nuclear for electricity generation (SCOALEG, SOILEG, SGASEG, SNUCLEG).* The strength of the traditional energy sources is pointed out by some literature (e.g. Sovacool 2009), as one of the main hinders of RE deployment. That pressure could be done either in politics, in economics or labour

markets. Following Huang et al. (2007), we assess for the hypothesis of lobbying controlling for the contribution of the traditional sources of energy on electricity generation. We expect negative effects.

- *Energy security (IMPTDP).* Literature suggests looking for the degree of self-sufficiency as an incentive to locally generate energy from renewable sources (e.g. Gan et al. 2007), allowing a positive effect on the current transaction balance. We test the hypothesis of energy security promoting RE. To that propose, we use the energy import dependency. It is expected that larger energy-dependency, originates higher investment in its own renewable sources.
- *Income (GDP).* Income effect is one of most studied in literature of RE (e.g. Chang et al. 2009; Sadorsky 2009b). The measurement of income is usually made in two ways: (i) by Gross Domestic Product (hereafter *GDP*); or (ii) alternatively by GDP per capita. Such as Huang et al. (2007), we use, as explanatory variable, the absolute economic size measure (GDP). We will discuss our option later. The sign depends on the dominance of one of two main opposite effects. The positive one is due to the hypothesis of higher income which could means more available resources to promote environmentally sustainable energy alternatives. Moreover, higher income could allow supporting regulatory costs to promote renewables (such as higher prices and taxes). The negative one results from the hypothesis of higher income could imply additional energy consumption, namely from the fossil sources nowadays available in the market, to maintain the citizens' perception quality of life and to support higher production levels.
- *Prices of Oil, Natural Gas and Coal (OILP, GASP, COALP).* Conventional energy sources, such as oil, natural gas and coal, have relatively low prices compared to clean energy, namely those obtained from renewable sources. As pointed out by Menz and Vachon (2006), these price biases, due to the prices of conventional sources, therefore do not include environmental costs they are responsible for. Because they do not reflect the real costs of their use, literature pointed out that RE prices are not yet full market competitive. Heal (2010) helps with a deep revision about costs and the competitiveness of renewables sources. Following most of the literature (e.g. Bird et al. 2005; Van Ruijven and Van Vuuren 2009) our model includes the prices of natural gas, oil, coal and nuclear. We expect to verify the substitution effect, i.e., higher prices of traditional energy sources are promoting the switching to renewables sources.
- *Geographic area (AREA).* The potential of renewables production is referred by literature (e.g. Vachon and Menz 2006) as an important factor to promote RE deployment. This effect is intuitive. However, when we consider data over a large span of time, the potential for production evolves in a different manner according to the nature of the technology of production of each source used. This fact could be seen in "Europe's onshore and offshore wind energy potential" (European Environment Agency—EEA—Technical Report no 6/2009). Therefore, due to the lack of data about that evolution over the span of time considered, we use geographic area as a proxy. That proxy has the desirable features of being constant throughout the span of time and not being dubious. Given that RE is generally associated with natural resources endowment, it is expected that a larger country's area makes that country more capable to cope with renewables deployment. As far as our knowledge, testing the effect of geographical area as a driver allowing renewables deployment is new in literature.
- *EU Directive 2001/77/EC (D0206).* In Europe, the EU Directive 2001/77/EC of (2001) imposed mandatory targets for member countries. Such as Harmelink et al. (2006), we consider 2001 as a mark of EU policies in the promotion of clean energy. EU Directive 2001/77/EC, of (2001), imposed mandatory targets for member countries, meanwhile it

signalizes for the EU adherent countries to compulsory commitment they have to face, after their adhesion processes. To that propose, a shift dummy assuming the value 1, was introduced in the years after the Directive was adopted (2001). We expect to observe the positive signaling effect in promoting RE use. As far as our knowledge, testing the effect of this institutional variable to the RE deployment is new in literature.

More recently, with the aim of promoting the use of renewable energy, a set of public policies have been implemented, such as R&D incentive programs, investment incentives (grants or low-interest loans), incentive taxes, incentive tariffs, mainly feed-in-tariffs, voluntary programs, compulsory renewable targets (production quotas and tradable certificates). The objectives, advantages and disadvantages of each one of these policies are summarized by Gan et al. (2007). Contrary to Johnstone et al. (2010), in our study we do not include these variables due to three types of reasons: (i) there is no available data about those policies for all the countries considered throughout the entire span of time (1990–2006); (ii) most of these policies have been adopted in the late 1990s and particularly in the early 2000s, as is the case of compulsory renewable targets; (iii) Johnstone et al. (2010) conclude that the effect of public policies largely depends on the type of renewable source. Considering them together, they find that only the obligations (for instance, production quotas) are significant at the 1% level of significance, the rest are not statistically significant at any level of significance. The authors also conclude that feed-in-tariffs levels are not statistically significant in the patenting activity when considering all renewable sources.

In this paper, the renewable sources are taken together. The inclusion of EU Directive 2001/77/EC partially allows us to handle with the lack of data over the span of time considered. In this way, our model controls for the effect of recent policies designed to stimulate the RE deployment. It is worth noting that for most of countries, many of the compulsory renewables targets were precisely defined in this EU Directive.

The source and summary of these explanatory variables, the model and the estimation procedures are presented, in detail, in the following section.

3 Model, Data and Estimation Procedure

This paper uses data collected from several sources. Table 1 summarizes this data, namely the definition of the variables and the data sources. The descriptive statistics of variables are shown in the Table 5 (see appendix). We use a time spam of 17 years, beginning in 1990 and ending in 2006. The countries considered in the analysis are the EU Members on the 1st of January 2007, with the exceptions of Cyprus, Bulgaria, Latvia, Lithuania, Malta and Romania, countries for which there is no data (available only after the 1990s). Also considered in the analyses were three other non-member countries that are usually referred to in the EU technical reports because they were candidates applying for EU membership (see, for instance, the EEA, Technical Report no 6/2009): Iceland, Switzerland and Turkey. The number of total countries included is the database is twenty-four.

The OLS estimation reports parameter estimates at the average contribution of renewables to energy supply. This procedure requires the normality of the error term and of the one of the dependent variable. As Koenker and Bassett (1978) pointed out, a conventional least squares estimator may be seriously deficient in linear models with non-Gaussian errors. Figure 1 displays the kernel density estimates for renewables use. The conditional distribution does not follow Gaussian distribution. We compute the Shapiro–Wilk test and the Skewness-Kurtosis test, rejecting the null hypothesis of normality in both cases. Large sample

Table 1 Data: definition and sources

Variable	Definition	Source
CRES	Contribution of renewables to energy supply (% of total primary energy supply)	OECD Facebook, 2009
CO2PC	CO2 *per capita* (kg/cap)	Eurostat, December 2008, EC, DG TREN
ENERGPC	*Per capita* energy (kgoe/cap)	Eurostat December 2008, EC, DG TREN
SCOALEG	Importance of coal to electricity generation	Ratio between electricity generation coal (TWh) and total elect. generation (TWh). Eurostat December 2008, EC, DG TREN
SOILEG	Importance of oil to electricity generation	Ratio electricity generation oil / total elect. Generation. Eurostat December 2008, EC, DG TREN
SGASEG	Importance of gas to electricity generation	Ratio electricity generation gas / total elect. Generation. Eurostat December 2008, EC, DG TREN
SNUCLEG	Importance of nuclear to electricity generation	Ratio electricity generation nuclear / total elect. generation. Eurostat December 2008, EC, DG TREN
IMPTDP	Import dependency of energy (%)	Eurostat December 2008, EC, DG TREN
GDP	Real gross domestic product (billions dollars, 2005)	World Bank World Development Indicators, and International Financial Statistics of the IMF
COALP	Coal price (US$ per tone, 1995)	BP Statistical Review o World Energy 2009
GASP	Natural Gas price (US$ per million Btu, 1995)	BP Statistical Review of World Energy 2009
OILP	Oil price (US$ per barrel, 2008)	BP Statistical Review of World Energy 2009
AREA	Surface area (km^2)	United Nations Statistics Division, Demographic Yearbook
D0206	Dummy,= 1 if year 2002–2006	

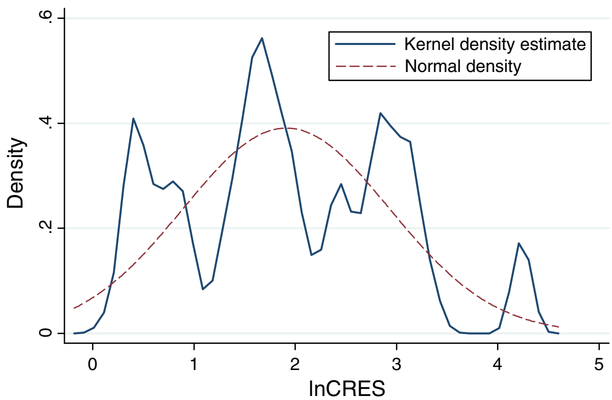

Fig. 1 Estimated density of log renewables use. *Notes* Parzen kernel density estimated is presented. The kernel density bandwidth is set to 0.2781

sizes could alleviate that concern, which is not the case of our sample. Quantile regression results are robust to outliers and heavy-tailed distributions. Moreover, while conventional regressions as OLS focus on the mean, another advantage of quantile regression is the ability to describe the entire conditional distribution of the dependent variable.

The quantile regression technique has been increasingly applied, including the willingness to pay for air and noise pollution reductions made by O'Garra and Mourato (2007). It is done not only due to its robust property in the absence of normality but also due to its power to estimate effects at different points of the conditional outcome distribution. Due to the reasons expressed above, the resulting estimates of various effects on the conditional mean of renewables use could not be indicative of both size and nature on the tails' distribution. For that reason, conventional least squares regression methods could be replaced by estimating a family of conditional quantile functions, which give us a complete picture of covariate effects Koenker and Hallock (2001). Indeed, by applying quantile regression techniques it is possible to estimate effects of the conditional CRES distribution. Using this technique, we are able to examine the determinants of the renewables deployment throughout the conditional distribution, particularly focusing on the determinants of the take-off of renewables and on the high levels of contribution of renewables to energy supply.

First introduced by Koenker and Bassett (1978), the quantile regression model, particularly the τth regression quantile, $0 < \tau < 1$ solves the problem:

$$\min_{\omega_\tau} \left\{ \sum_{i,t:y_{it} \geq x'_{it}\omega}^{N} \tau \left| y_{it} - x'_{it}\omega \right| + \sum_{i,t:y_{it} < x'_{it}\omega}^{N} (1-\tau) \left| y_{it} - x'_{it}\omega \right| \right\} \tag{1}$$

The optimization process of Eq. (1) uses linear programming methods. With Q_τ denoting quantile τ, we estimate the model for τ = 5th, 10th, 25th, 50th, 75th, 90th, 95th. The option for these quantiles is a consequence of the nature of data, namely of the distribution of Contribution of Renewables to Energy Supply (CRES). On the one hand, it appears that in the period under analysis in some countries, such as the Czech Republic and Ireland, renewable sources contribute with less than 5% of total energy. On the other hand, the national indicative target defined in the White Paper on Renewable Energy Sources and presented in the EU Directive 2001/77/EC was 12% of gross national energy consumption by 2010. Meanwhile indicative share of electricity produced from renewable energy sources in total EU electricity consumption was 22.1%. We intend to understand the factors that influence the commitment to renewable energy sources not only in the middle of the distribution but also in the tails, particularly in the take-off phase, i.e., in the initial commitment with renewable energy.

Different choices of τ correspond to different values of ω. The quantile regression estimates the marginal impact of vector X_{it} denoting the independent variables on the log of CRES (*LCRES*) at the conditional quantiles of the CRES distribution. The conditional quantile function becomes:

$$\begin{aligned} &Q_\tau\left(LCRES_{it} \mid X_{it}\right) \\ &\quad = \kappa_\tau + \lambda_\tau CO2PC_{it} + \theta_\tau ENERGPC_{it} + \beta_{1\tau} SCOALEG_{it} \\ &\qquad + \beta_{2\tau} SOILEG_{it} + \beta_{3\tau} SGASEG_{it} + + \beta_{4\tau} SNUCLEG_{it} + \phi_\tau IMPTDP_{it} \\ &\qquad + \gamma_\tau GDP_{it} + \delta_{1\tau} OILP_{it} + \delta_{2\tau} GASP_{it} + \delta_{3\tau} COALP_{it} + \xi_\tau AREA_i + \eta\tau D0206_t \end{aligned} \tag{2}$$

To obtain heteroskedasticity-robust estimates, we report robust standard errors for OLS estimates. In quantile regression, whereas the sufficient number of bootstrap repetitions is inversely related to sample size, we do not report Koenker and Basset standard errors but instead we provide bootstrapped standard errors, using 10,000 bootstrapping repetitions.

4 Results

Taking into account the large number of variables deserving our interest in the analysis, we began by examining the correlation matrix (see Table 6 in the appendix). The correlation matrix suggests that problem of collinearity is absence for all variables, except between prices of natural gas and oil. To dissipate any doubt about collinearity, the Variance Inflation Factor (VIF) test for multicollinearity was carried out. The mean VIF of 3.80 is far from 10, suggesting that collinearity is not a concern.

We estimate the model considering all the variables. The results obtained both from OLS and from quantile regression shown that the prices of oil, coal and natural gas are not statistically significant in explaining the use of renewable energy, for the span of time and the countries under analysis. These results are available from the authors upon request. In order to confirm if these variables should continue in the estimations, we use a joint significance test of the subset of coefficients, under the null hypothesis of $H_O = \delta_{1\tau} = \delta_{2\tau} = \delta_{3\tau} = 0$ for all the quantiles. The results of these exclusion tests are shown in Table 2.

We do not reject the null hypothesis of all these coefficients being zero, with the exception of quantiles $\tau = 90$th and 95th For these two quantiles in the top of distribution we do not reject this hypothesis at 1% significance level but we reject it at 5%. Also, for these two quantiles we do not reject the hypothesis of the individual price coefficients being zero. When comparing the estimated coefficients for these two quantiles, with and without prices, we observe that the results appear robust. The magnitude of these effects is similar in the two estimates and there is no change in the effects for the statistically significant variables.

In fact, throughout this span of time, energy prices were not a significant factor in the promotion of RE. It is worth noting that recent price increases, those which took the price of oil to 150 US dollars a barrel in July, 2008, are not included in this data. A similar effect is obtained by Sadorsky (2009a) in a study developed for the G7 countries, where he concluded that the real price of oil does not seem to have a strong effect on the consumption of renewables, since throughout the entire estimation period, oil prices are low at several times. Therefore, the variables of prices were excluded. Once again we test multicollinearity. The mean VIF 2.75, strongly suggests absence of collinearity.

Table 3 reveals both OLS and quantile regression estimates. Lower values of the dependent variable means lower levels of the use of renewable sources in the total energy supply.

In order to test whether all coefficients are zero at different conditional quantiles we provide a global F test. We reject the null hypothesis of jointly coefficient equality at different conditional quantiles at a significance level of 1%.

The results of the estimation of the quantile regression reveal that the effect of *per capita* CO_2 emissions is consistently negative and statistically significant throughout the conditional distribution of renewable sources use in the total energy supply. It is therefore correlated with

Table 2 Exclusion test of Prices

	OLS	Quantiles						
		5%	10%	25%	50%	75%	90%	95%
Wald Test	0.89	0.57	0.36	0.91	0.37	2	2.92**	3.43**

** denote significance at 5% significance level

Table 3 Determinants of renewables use: Benchmark OLS vs Quantile Regressions

Independent variables	Dependent variable—logged share of contribution of renewables to energy supply							
	OLS	Quantiles						
		5%	10%	25%	50%	75%	90%	95%
CO2pc	−0.0001***	−0.0003***	−0.0002***	−0.0001***	−0.0001***	−0.0001**	−0.0002***	−0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0000)
ENERGPC	0.0002***	0.0002***	0.0002***	0.0001***	0.0001*	0.0003*	0.0004***	0.0004***
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
SCOALEG	−1.4736***	−2.1442***	−1.7915***	−2.2581***	−1.8486***	−0.9375**	−0.6649**	−0.5175**
	(0.2077)	(0.4016)	(0.3955)	(0.3369)	(0.4153)	(0.4754)	(0.2654)	(0.2016)
SOILEG	−1.5637***	−3.6407***	−2.9474***	−2.5819***	−2.0591***	−0.9299*	−0.7205***	−0.8908***
	(0.4194)	(0.905)	(0.8229)	(0.4139)	(0.3482)	(0.4981)	(0.2261)	(0.2172)
SGASEG	−2.7858***	−3.3767***	−4.0217***	−4.1051***	−3.1098***	−2.3832***	−1.7218***	−1.7631***
	(0.2622)	(0.4852)	(0.4674)	(0.3665)	(0.4802)	(0.6202)	(0.4073)	(0.3091)
SNUCLEG	−2.2710***	−3.2731***	−3.296***	−3.1895***	−2.4581***	−1.9064***	−2.1895***	−2.229***
	(0.1862)	(0.2794)	(0.2277)	(0.2304)	(0.3098)	(0.2741)	(0.1275)	(0.1289)
IMPTDP	0.0018	0.0175***	0.0091***	0.0054***	0.0037	0.0000	−0.0021**	−0.0014**
	(0.0014)	(0.0045)	(0.0033)	(0.0019)	(0.0036)	(0.0045)	(0.001)	(0.0007)
GDP	−0.0003***	0.0003**	0.0001	−0.0001***	−0.0002***	−0.0003***	−0.0003***	−0.0003***
	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
AREA	0.0008***	−0.0001	0.0004	0.0007**	0.0004**	0.0004	0.0005*	0.0005*
	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0004)	(0.0003)	(0.0003)
D0206	0.3810***	0.2261	0.4506***	0.3966***	0.2604***	0.3148***	0.1196**	0.1407**
	(0.0688)	(0.1382)	(0.1306)	(0.0714)	(0.0726)	(0.1146)	(0.06)	(0.0591)
CONS	3.7134***	3.9045***	3.9648***	4.0514***	3.9523***	3.7152***	3.6318***	3.5652***
	(0.1998)	(0.3589)	(0.2384)	(0.2611)	(0.3325)	(0.3379)	(0.1063)	(0.0913)
R^2/PseudoR^2	0.73	0.49	0.47	0.52	0.53	0.55	0.61	0.68
F test	106.99	141.35	168.87	182.45	103.98	47.63	163.53	189.31
(*p* value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Bootstrapped standard errors are reported in brackets; OLS-Ordinary Least Squares; Quantile regresssion results are based upon 10,000 bootstrapping repetitions
***,**,* denote significance at 1, 5, and 10% significance levels, respectively

Table 4 Tests of equality of the coefficients at different conditional quantiles

	CO2PC	ENERGPC	SCOALEG	SOILEG	SGASEG	SNUCLEG	IMPTDP
AME	−0.0013	0.0016	−20.0110	−22.2894	−33.6636	−26.6083	0.0405
F test	2.53**	2.05*	5.35***	3.77***	5***	4.56***	4.13***
	GDP	AREA	D0206	All			
AME	−0.0026	0.0048	2.8190	–			
F test	3.77***	0.95	2.45**	9.35***			

AME Average marginal effect
***, **, *, denote significance at 1, 5 and 10% significance levels, respectively

lower RE use. The *per capita* energy consumption favours alternative sources, namely renewable sources. This effect is consistent in all quantiles and it is stronger for high levels of RE use. Both traditional energy sources (coal, oil and gas) and also nuclear energy are consistently significant and contribute to lower RE deployment. Self-sufficiency energy objective also favours the RE use, but only within the bottom-half of the conditional distribution. The effect of income is positive and statistically significant in the quantile $\tau = 5$th and this is the expected effect. It is negative and statistically significant within the top-half distribution. This result is only partially expected and confirms the lack of consensus in the literature about the needs of income to promote renewables. Below, in the conclusion section, we discuss the option for the absolute income size. Results suggest that recent years promote RE use suggesting that the Directive 2001/77/EC to promote the electricity generation from renewable sources could have been effective. As expected, the *AREA* effect is positive and statistically significant, but only within the middle and the top of the conditional distribution, with the exception of quantile $\tau = 75$th.

Taking into account the results of the median regression output gives us the marginal effects for *LCRES*. Instead of it, we can compute the marginal effect on CRES. The average marginal effect is given by $\left\{N^{-1}\sum_{i=1}^{N}\exp\left(x_i'\beta_\tau\right)\right\}\beta_{\tau j}$. From the output of the 50th quantile ($\tau = 50$th), the multiplier of quantile regression in the coefficients of the logarithms of the variables to get average marginal effects is 10.825. As an example, the implied average marginal effect of *IMPTDP* on the levels variable is 0.04045 (10.824837*0.0037365), i.e., its marginal effect on the contribution of renewables to energy supply is near 0.04 (see Table 4). As expected this effect is larger in the lowest quantile.

In order to test the stability of the coefficients throughout the conditional distribution, we provide an individual test of coefficient equality for each variable. We reject the null hypothesis of the coefficients' equality at different conditional quantiles, with exception of the *AREA* variable, supporting the use of the quantile regression technique. The results are also presented in Table 4.

Figure 2 shows a summary of quantile regression coefficients results. Here we display the coefficients of nine variables, those for which stability test reveals different coefficients between quantiles, and their respective confidence intervals. For instance, for the energy self-sufficiency variable, the figure shows that the coefficient is positive over most of the range of τ, and it has a larger effect at lower quantiles. Note that the smaller effect at higher quantiles is the expected result, given that being large, the contribution of renewables to energy supply and knowing that renewable energy in general has a domestic source, then the energy dependency of a country does not have a decisive role in promoting domestic renewable energy sources given that foreign energy bill is tiny. We also observe that the effect on the use of

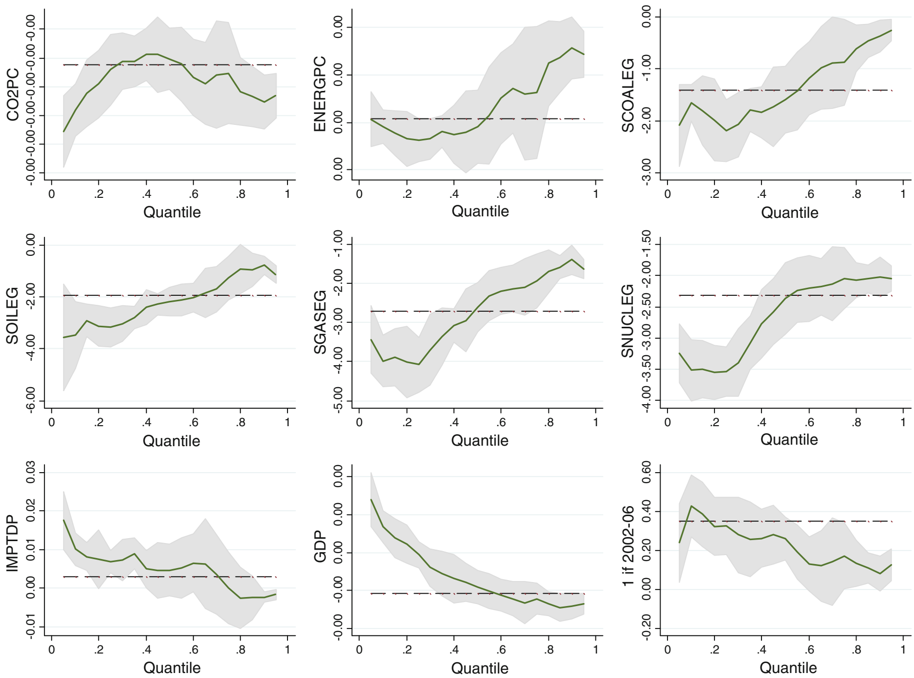

Fig. 2 OLS and quantile regression coefficients for each regressor, as τ varies from 0 to 1. *Notes* The *dashed line* represents the OLS parameter estimate. The *dark shaded* area represents the 95% confidence interval for the quantile regression parameter estimates

renewables for coal, oil, natural gas and nuclear share in electricity generation is strongest for smaller contributions of RE. In turn, the shift dummy D0206 shows that the more recent years have contributed towards RE deployment and that its effect is stronger for least "ecological" countries, those using less RE.

5 Discussion

Carbon dioxide emissions effect is negative and significant in explaining renewables use. The parameter is consistent throughout the conditional distribution and has similar magnitude across all the quantiles. This result is in line with the second effect discussed earlier, i.e., the dominant effect is the alienation of environmental concerns. The maintenance of the commitment with fossil fuels is possibly tolerated due to the fact that social consciousness has not yet achieved enough pressure.

The effect of *per capita* energy consumption is always consistently positive throughout the conditional distribution. Higher levels of consumption mean higher energy demand, which are in part supplied by additional use of renewables sources. The magnitude of this effect, in general, is small and is larger for countries revealing higher levels of renewable use. It suggests that additional energy needs could also improve the production from renewable sources and not just from the traditional ones, sending a positive signal about the pressure to turn to clean energy.

Fossil fuels play an active role in the renewables' development path. The larger the proportion of electricity generated from fossil fuels, the smaller the investments in RE. The effect of traditional energy sources such as coal, oil and natural gas on RE is always negative, strong and consistent across quantiles. This result reinforces the idea of a potential conflict between economic interest groups and environmental policies, delaying RE commitment (e.g. Sovacool 2009). The industry lobbying effect is deeper for low levels of RE use than for high RE commitments, suggesting the existence of an initial barrier to the RE adoption. Once broken, the deterrence effect by renewables is smaller. This conclusion has particular interest for public policy design. To encourage the adoption of RE, policy measures should allow breaking the initial barrier, promoting the take-off of RE market share in order to diminish the lobbies' weight.

We also tested for another factor suggested by the literature, which is the goal of reduces energy dependency. We conclude that the effect of energy self-sufficiency is stronger for countries with lower levels of renewables use. It promotes RE use within the first-half of the conditional distribution, but this effect is bimodal, since it is negative in the countries with more RE commitment. This result is consistent with the evidence that a country seeks to reduce the energy dependency by deploying RE when there is high energy-import dependency, but this incentive is less significant when it produces a lot of energy from renewable sources domestically. It seems that there is a maximum threshold beyond which the cost of substituting imports and producing domestically cannot be profitable.

In sum, we contribute by showing that energy dependency could be an effective driver promoting RE, but only for low levels of renewables use. This is in line with the perspective that energy dependency can be an objective by itself, if and only if, there is relevant dependency. Countries yet using renewables in large scale could have lack of incentive to looking for that objective. On the contrary, for former countries, it works as a disincentive to renewables. Therefore, we show, updating literature, that the effect of energy dependency it is not homogeneous.

Considering the GDP effect, it is worth noting here that we tested several designs of the variable for the inclusion of the income effect. We tested, for example, the *per capita* income (as Carley 2009), the natural logarithm or both the contemporary and lagged growth rates. None of these was statistically significant, unlike the GDP. The explanation for this may be that, during this period and for these countries, the major effect on the commitment to renewables is the absolute economic size of a country and not the standard of living of its population. It should also be noted that the magnitude of this effect is small, being less small in the tails.

Our results show that the GDP effect is not homogeneous throughout the level of RE use and this is new to the literature. There is a positive relationship for smaller share of RE. On the top-half of the conditional distribution, this effect is negative. This result suggests two comments: first, for smaller RE share, the first effect is stronger, i.e., higher income could mean more available resources to promote clean energy alternatives. Larger income encourages the take-off of renewables, allowing countries to support the high costs of investing in renewables. This is the effect mostly reported in the literature (e.g. Vachon and Menz 2006). Similarly, Chang et al. (2009) pointed out that countries with high increases or high growth levels deal better with high energy prices related to the use of RE. Secondly, the negative effect is also verified, i.e., higher income could imply additional energy consumption, namely from the fossil sources presently available in the market. Therefore, countries with higher income do not promote the RE deployment. Both positive and negative significant effects are in the tails, yet with small magnitude.

The results about the negative effect of GDP cope with the supposition that to achieve the large levels of income, this had implied the alienation of use more expensive energy sources, such as the renewables sources. The fossil fuels are cheaper, immediately available and allow transferring to the future a large amount of costs incurred with their consumption. In fact, there is a preference for the present. Under this preference, economic agents do no fully internalize today the real costs of the use of energy.

The geographical area has the strongest effect at the median/mean of the conditional distribution, other things being equal. The results show that geographical area is not significant for the take-off of the use of renewable sources. However, the geographical area helps to encourage the use of renewables in the middle and in the top of the conditional distribution. This suggests that for low levels of renewable sources use, geographic area is not significant in statistical terms, since the small contribution of renewables can be obtained from small hydro sources, for instance. In the middle, countries committed to a further development of RE through solar and wind power, for example, then the greater the geographic dimension greater the commitment, allowing the development of scale economies. The results achieved with the inclusion of this variable geographical area are promissory and it deserves to be object of further analysis.

The dummy $D0206$ capture the specificities of the period time which elapses after the EU Directive 2001/77/EC of (2001). That Directive has had a positive and consistent contribution to RE deployment, even so, for the smallest levels of renewables use, the impact of this policy measure was not statistically significant. As expected, taking into account the targets defined by EU Directive 2001/77/EC, of 12% of gross national energy consumption and 22.1% for the share of electricity produced from renewable energy sources in total community electricity consumption, the magnitude of this effect is larger for quantiles $\tau = 10$th and $\tau = 25$th. This shows that this political factor brought incentives promoting the strong commitment to those sources, namely in the first half of the conditional distribution. Although in this paper we do not include variables of public support, such as the feed-in tariffs for the reasons stated earlier, in fact, in our opinion we do not lose information. On the contrary, our decision to include that variable appeared to be appropriate. We conclude that public intervention is crucial for investment in renewable energies. It was with the EU Directive, in 2001, that countries have established specific mechanisms to promote renewables. Therefore the driver promoting RE do not need to be a specific measure (such as feed-in-tariffs), but instead, that driver should provide global policy guidance.

6 Conclusions

The literature assessing the causes underlying the adoption of RE sources is still scarce and usually focuses on the United States. By studying a set of European Countries, we shed some light on the literature regarding the impact of several drivers towards the deployment of the RE share on total primary energy supply. The quantile regression approach shows itself to be a suitable tool to examine the sensitivity of the determinants of RE use, with respect to its level of deployment. That method seems to be appropriate in enabling us to answer the question: Do the countries with lower and higher contribution of renewables respond similarly to the drivers that affect the option for renewable sources? From the answer one can promote policies measures to encourage the RE adoption, while fighting climate change.

Our findings suggest that if the goal is the deployment of RE, policies encouraging its use should be weighted by the level of RE use, i.e., they must be framed in the specific reality of each country at each time. Policies should pay particular attention to the initial phase of use of those sources, fighting the pressure from the lobbies of the traditional fossil fuels industries. Moreover, income reveals to be a significant driver to boost the use of renewable resources in the early stage of commitment with renewables. In accordance, this justifies international financing of RE investments to ensure that initial stimulus is given to those countries. The actual social consciousness about consequences of dioxide emissions is short to promote strong development of renewables. This reveals some distancing of environmental concerns. Finally, the option to control for two new drivers discloses a valuable decision and a promissory path to motivate further research. It is worth to proceed by understanding either the role of recent policy incentives to promote RE, or of renewables' technology potential.

Acknowledgments We gratefully acknowledge the generous financial support from the NECE—Research Unit in Business Science and Economics, sponsored by the Portuguese Foundation for the Development of Science and Technology. We thank the editor and two anonymous reviewers for useful comments.

7 Appendix: Descriptive Statistics and Correlation Matrix

See Tables 5 and 6.

Table 5 Descriptive statistics

	Min	25th	75th	Max	Mean	SD	*N*
CRES	0.2	2.5	15.7	75.3	11.1503	14.201	408
CO2PC	2488.11	7115	12042.75	33363.39	10244.1	4699.82	408
ENERGPC	930	2824.9	4686.09	14290.2	4168.58	2081.57	408
SCOALEG	0	0.095	0.5	.97	.331	.277	408
SOILEG	0	0.01	0.08	.51	.066	.096	408
SGASEG	0	.02	.22	.76	.157	.170	408
SNUCLEG	0	0	0.38	.78	.203	.227	408
IMPTDP	-50.83	34.96	71.12	99.8	51.91	28.28	408
GDP	6.75	89.96	405.73	2883.12	510.35	707.56	408
COALP	28.59	35.87	49.82	67.29	42.367	10.364	408
GASP	1.787	2.415	3.793	7.578	3.412	1.367	408
OILP	17.322	25.451	36.245	69.581	33.688	13.049	408
AREA	2.586	44.161	325.55	783.562	201.612	209.769	408
D0206	0	0	1	1	.294	.456	408

Table 6 Correlation matrix

	LCRES	CO2PC	ENERGPC	SCOALEG	SOILEG	SGASEG	SNUCLEG
LCRES	1						
CO2PC	−0.419	1					
ENERGPC	0.157	0.652	1				
SCOALEG	−0.318	0.031	−0.406	1			
SOILEG	−0.073	−0.219	−0.384	0.013	1		
SGASEG	−0.401	0.373	0.079	−0.211	0.114	1	
SNUCLEG	−0.033	−0.225	0.017	−0.362	−0.342	−0.314	1
IMPTDP	0.016	0.106	−0.004	−0.415	0.348	0.164	0.036
GDP	−0.248	−0.120	−0.115	−0.079	0.099	0.084	0.261
COALP	0.012	0.046	0.041	−0.008	−0.078	0.076	0.003
GASP	0.076	0.034	0.077	−0.055	−0.135	0.191	−0.001
OILP	0.074	0.032	0.073	−0.055	−0.135	0.187	−0.001
AREA	0.197	−0.45	−0.255	−0.092	0.014	−0.102	0.214
D0206	0.108	0.021	0.086	−0.075	−0.153	0.252	−0.002

	IMPTDP	GDP	COALP	GASP	OILP	AREA	D0206
IMPTDP	1						
GDP	−0.068	1					
COALP	0.019	0.016	1				
GASP	0.026	0.052	0.639	1			
OILP	0.026	0.052	0.690	0.939	1		
AREA	−0.007	0.463	0.000	0.000	0.000	1	
D0206	0.019	0.063	0.451	0.717	0.681	−0.000	1

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