The path to renewable energy consumption in the European Union through drivers and barriers: A panel vector autoregressive approach

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Abstract

Renewable energy consumption brings sustainable economic growth and pollution reduction. Despite the worldwide increase in renewable energy consumption, global energy-related carbon dioxide emissions are rising and there are still considerable differences in the share of renewable energy consumption in national energy portfolios. These concerns require further effort at the policy level, especially by countries that make extensive use of energy imports. These countries could improve their lack of energy independence by using renewable energy sources and leveraging a few factors to facilitate their transition. This study aims to investigate renewable energy consumption drivers, focusing on the role of socio-technical (rather than economic) aspects such as policy stringency, lobbying, public awareness, and education. We employ a panel vector autoregressive model in first differences to test the complex dynamic relationships among renewable energy consumption, policy stringency, lobbying, public awareness, and education, controlling for variables such as per capita income and import levels, for 12 European Union net energy importing countries. Results show that the positive income effect prevails in the influence of the level of carbon dioxide emissions (negative) on renewable energy consumption, despite the latter being more significant in countries with higher levels of education. Increasing energy needs push traditional sources towards complementarity with renewable energy consumption, implying a positive lobbying effect. Public awareness is not enough to facilitate the transition to renewable energy consumption. By contrast, policy stringency has positive direct and indirect effects on renewable energy consumption, suggesting that the approach adopted by the European Commission in the recent Green Deal is a step in the right direction. Moreover, as shown, policymakers are able, through renewable energy consumption, to generate a decrease in carbon dioxide emissions and electricity production from oil, gas, coal, and nuclear sources in the first instance, but also in net energy imports, even if at a later stage.

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1. Introduction

It is well known that fossil fuels are not renewable resources and will be exhausted in the future. Moreover, the use of conventional resources is detrimental for the environment. By contrast, renewable resources such as wind, solar and biomass, continuously ‘renew’ themselves and produce a much smaller negative impact on the environment. On the supply side, renewable sources are emerging as an important factor to meet global energy needs. According to the International Energy Agency (IEA, 2019), renewable power capacity will grow by 50% in the next five years. Solar photovoltaic energy represents almost 60% of the estimated increase, followed by onshore wind accounting for 20%. On the demand side, renewable energy consumption (REC, that is the ratio between the gross consumption of energy from renewable sources and the total primary gross energy consumption) offers a strong signal of improvement towards diminishing pernicious environmental consequences.

China leads global progress in renewable energy usage thanks to policies directed to decarbonize all industries and reduce pollution; it will become the major user of renewable energy, exceeding the European Union (EU) by 2023. Even with renewable technologies becoming progressively more competitive, appropriate policies are critical to steer consumption. Heat produced from renewable energy will increase by 20% in the next five years. Buildings account for over half of the expected growth. China, the EU, India, and the United States are accountable for more than 60% of the estimated rise in renewable heat consumption (IEA, 2019).

Despite the worldwide increase in REC, global carbon dioxide emissions are rising and there are still considerable differences in the share of REC in national energy portfolios. These concerns require further policy-level efforts. In the EU, the Renewable energy directive (2009/28/EC) has been revised and the new directive (2018/2001), effective from December 2018, determines a new compulsory goal for the EU of more than 30% by 2030, with a possible upwards adjustment in a few years. With renewable sources accounting for more than half of its gross final energy consumption, Sweden has the highest share among the EU member states, leading Finland (41%), Latvia (39%), Denmark (36%) and Austria (33%). By contrast, the lowest proportions of renewables were recorded by Luxembourg (6%), the Netherlands and Malta (7%), Belgium (9%), and Cyprus and the United Kingdom (10%) (EC, 2019a).

The energy available in the EU comes from both energy generated in loco as well as imported energy. In 2017, the EU produced nearly 45% of its own energy, while 55% was imported (EC, 2019a). By using more renewables to meet its energy needs, the EU might lower its dependence on energy imports and become more sustainable. However, as unequivocally stated in the recent European Green Deal by the EC (2019b), this challenge requires a solid policy answer and not all EU member states commence the transition from the same position or have the same facility to respond. More action is needed, especially in those countries that make extensive use of energy imports. High-energy importing countries should have lower capacity constraints in initiating a more vigorous transition to renewables, and should be more motivated due to their exposure to the mounting volatility of energy prices (Kahia et al., 2017). Importing countries should leverage a few factors to reduce their dependence on foreign sources.

As well summarized by Can Şener et al. (2018) and Bourcet (2020), who provide huge and systematic reviews, the literature on the factors which could assist in realizing the differing paths of renewable energy at national level is rising but presents uneven conclusions.

Economic, environmental, regulatory, political, and social aspects have been discussed in the literature. With good approximation the results on which scholars converge are few and concern the lobby effect from traditional energy sources and the population size. More specifically, some consensus emerges on the overall positive role played by supporting environmental policies and population size, and on the overall negative effect produced by lobbying from traditional energy sources. All other results on the drivers of REC in the literature are mixed, counter-intuitive or require a more in-depth discussion. So, for example, at least for EU countries, it emerges the negative effect generated by energy security, income effect and carbon dioxide emissions. In all evidence, the relationship between REC and its determinants is complicated by the underlying socio-technical background at the country level. As argued by Sovacool (2009), the impediments to renewables go well beyond the economic sphere, to include regulatory, social, political, and cultural aspects.

This study aims to investigate REC drivers, focusing on the role of socio-technical (rather than economic) aspects such as policy stringency, lobbying, public awareness, and education. We employ a panel vector autoregressive (PVAR) model in first differences to test complex dynamic relationships between REC, policy stringency, lobbying, public awareness, education, and controlling variables such as per capita income and imports for 12 EU net energy importing countries. These are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, and Sweden. Among the historic members of the EU, these countries have always imported energy over the last 25 years. Results show that the positive income effect prevails on the level of carbon dioxide emissions (negative) effect on REC, despite the latter being more significant in countries with higher levels of education. Education is an important support, generating positive cross-cutting effects on a high number of drivers. More specifically, education is able to produce a much greater impact on public awareness, thus compensating the public pressure towards economic growth, which is always at the centre of the political debate. Increasing energy needs push traditional sources towards complementarity with REC, implying a positive lobbying effect. Public awareness is not enough to facilitate the transition to REC. By contrast, policy stringency has positive direct and indirect effects on REC, suggesting that the approach adopted by the European Commission with the recent Green Deal is moving in the right direction. Moreover, as shown, policymakers are able, through REC, to generate a decrease in carbon dioxide emissions and oil, gas, coal, and nuclear sources in the first instance, but also in net energy imports, even if at a later stage.

The remainder of the paper is organized as follows. Section 2 illustrates the literature on the determinants of REC. Section 3 provides the empirical analysis, introducing the model specification and methodology (Section 3.1), presenting the testing framework (Section 3.2) and showing the results (Section 3.3). Section 4 discusses policy implications.

2. Literature

The causal relationship between economic growth, non-renewable sources, carbon dioxide emissions, REC, and other variables has been investigated in several studies.

Some studies are consolidated references to approach the discussion. Sadorsky (2009a) provides a panel cointegration model of REC for the G7 countries and explains that in the long period, expansions in income and carbon dioxide emissions per capita are major drivers behind REC. Oil price has a smaller even if negative impact on REC. Using the same model, Sadorsky (2009b) confirms that raising income per capita has a positive and statistically robust consequence on REC.

Following such seminal papers, an appreciable number of studies have emerged to discuss the drivers behind RE deployment at country level. Apergis and Payne (2010, 2011) examine the link between REC and economic growth for a panel of twenty OECD countries between 1985 and 2005, and for six Central American countries over the period from 1980 to 2006. Interestingly, the Granger-causality results suggest bidirectionality in both the short- and long-term. Apergis et al. (2010) examine the causal relationship between carbon dioxide emissions, nuclear energy consumption, REC, and economic growth for 19 countries over the period from 1984 to 2007 using a panel error correction model. The long-run estimates suggest that there is a positive connection between emissions and REC, suggesting the existence of some public awareness that will be discussed in more detail below. Menegaki (2011) investigates the causal link between economic growth and renewables for 27 European countries in a multivariate framework over the period from 1997 to 2007, using a random effect model. The results do not corroborate causality between REC and income, while panel causality tests disclose short-run interactions between renewables, greenhouse gas emissions and employment. Apergis and Payne (2012) examine the association between REC and non-REC and economic growth for 80 countries within a multivariate panel framework over the period from 1990 to 2007. The results show bidirectionality between REC and non-REC and economic growth. It should be noted that bidirectional short-run causality emerges between REC and non-REC, which seems to be symptomatic of substitutability between the two sources.

Menyah and Wolde-Rufael (2010) explore the causal association between carbon dioxide emissions, renewable (and nuclear) energy consumption, and real income for the United States for the period from 1960 to 2007. They find no causality running from renewable energy to carbon dioxide emissions. Such a finding, in light of the prevailing literature and the expected results, allows to appreciate the complexity of the relationship between the observed variables. Omri (2013) investigates the interconnection between carbon dioxide emissions, energy consumption, and economic growth in 14 countries for the period between 1990 to 2011 and finds a bidirectional causality between energy consumption and economic growth. Alper and Oguz (2016) study the connection between economic growth, REC, capital, and labour for new EU member countries in a time interval of twenty years, and find a causal relationship from economic growth to REC only in Bulgaria; whereas, REC has positive consequences on economic growth for all investigated countries. Interestingly, Belloumi and Alshehry (2014) scrutinize the interrelation between fossil fuels consumption, carbon dioxide emissions and economic growth in Saudi Arabia and find a unidirectional causality between economic growth and energy consumption in the long-run. In such a case, the findings would suggest the implementation of energy conservation policies with no fear of adversely affecting economic growth.

In line with literature supporting the relationship between income and energy consumption (including REC), Salim and Rafiq (2012) explore the drivers of REC in six major emerging economies that are hastening the deployment of renewables. They show that in the long-run, REC is significantly affected by income and pollution in Brazil, China, India, and Indonesia, whereas it is mostly impacted by income in the Philippines and Turkey. Accordingly, Omri and Nguyen (2014) focus on the drivers of REC for 64 countries from 1990 to 2011 by using a dynamic system-generalised method of moments (GMM). They show that carbon dioxide emissions and openness to trade are the main determinants. Kahia et al. (2019) show that economic growth drives to environmental degradation in a panel of 12 Middle East and North Africa countries over the period 1980–2012, while renewable energy together with international trade and foreign direct investments brings to a decrease in carbon dioxide emissions.

Sung and Park (2018) use unbalanced panel data from 25 OECD countries, for the period from 1990 to 2014. They use a PVAR model and demonstrate that government and markets directly stimulate the transition to renewable energy, while the conventional energy sources directly hamper such a process. Conversely, the public does not directly encourage the transition to a green economy. They also show that the government and public have positive indirect consequences, by interacting with the market. Cadoret and Padovano (2016) consider how political factors facilitate the use of renewables. They find that lobbying negatively influences renewable energy, while public policy generates a positive impact. Sovacool (2009) demonstrates that the obstacles to renewable power are ‘socio-technical, a term that encompasses the technological, social, political, regulatory, and cultural aspects of electricity supply and use’ (Sovacool, 2009: 4501). Utility operators reject renewables because accustomed to address the energy challenge only in terms of large, conventional power plants, while consumers disregard renewables because they do not correctly perceive price signals: market alterations prevent them from becoming totally invested in their electricity choices.

The mixed evidence on the drivers and barriers of the path to REC can be explained by the variety of frameworks, samples, and specifications adopted by scholars (Bourcet, 2020). Such diverging results suggest to carefully account for the homogeneity of the set of observed countries, characterized by a similar socio-technical background at the country level.

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3. Empirical analysis

a. Methodology and model specification

According to the literature review above, we specify a model based on the following variables: renewable energy consumption (REC), environmental policy stringency (EPS), gross domestic product per capita at purchasing power parity (current international 1000$, GDPc), carbon dioxide emissions (metric tons per capita, CO_2), lobbying measured as electricity production from oil, gas, coal, and nuclear sources (% of total, OGCN), net energy imports (% of energy use, IMP) and education attainment level of population (in %, EDU). Relative values or percentages are used in order to avoid possible distortions due to different country sizes.

As said before, REC is the share of renewable energy in total energy consumption. EPS is a country-specific and internationally comparable index of the stringency of environmental policy, that is the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour. The measure is based on the degree of stringency of 14 environmental policy tools, mainly related to air pollution and climate (Botta and Koźluk, 2014; de Serres et al., 2010); it varies from 0 (not stringent) to 6 (highest degree of stringency). CO_2 quantifies carbon dioxide emissions generated during consumption of solid, liquid, and gas fuels and gas flaring. CO_2 is positively related with REC (Menegaki, 2011; Sadorsky, 2009a; Salim and Rafiq, 2012). A potential explanation is that a high level of CO_2 emissions generates an increase in the demand for environment safeguard and stimulates the development and use of alternative renewable energies that are carbon emission free. Conversely, a lower level of CO_2 emissions would cause a decrease in REC. GDPc is gross domestic product converted to international dollars using purchasing power parity rates. The GDPc effect is recurrently tested in literature (Alper and Oguz, 2016; Menegaki, 2011; Sadorsky, 2009a, 2009b). It is expected that a higher income level is associated with greater REC: first, a higher income level implies more resources available to support the development of REC; second, greater GDPc means greater potential to bear higher regulatory costs (that is, higher taxes and prices). OGCN is electricity production from oil, gas, coal and nuclear sources: greater consumption needs can be supplied by a combination of non-renewable and renewable energy sources. We controlled for the consumption of energy, expecting either a positive or negative effect on REC. Moreover, OGCN might refer to lobbying (Marques and Fuinhas, 2011, 2012; Marques et al., 2010). Interest groups, such as the the traditional and nuclear energy industries and trade associations can exercise power, increasing the percentage of fossil- and nuclear-based energy, which can inhibit the development and growth of renewable energy. The effect of lobbying, exercised by the purveyors of traditional energy resources, is considered one of the most important determinant in the development of renewables (Sovacool, 2009). The ease of storage of these resources, the already installed capacity, the costs and the political interests involved might explain the effect of hampering the deployment of renewables. IMP measures the share of net energy imports, estimated as energy use less production, both measured in oil equivalents. A positive value indicates that the country is a net importer. It is expected that this study will confirm that the more dependent on energy imports a country is, the higher the investment in its own renewable sources (Gan et al., 2007; Marques and Fuinhas, 2011). EDU measures the share of population from 15 to 64 years by educational attainment level. It is thought that there is a negative relationship between environmental pollution and education levels: higher education facilitates the formation of social awareness and the solution of common problems (Bimonte, 2002; Dasgupta et al., 2016). Nonetheless, higher education might facilitate more effective lobbying (Gan et al., 2007).

According to some scholars, a role in the development of REC might be played by the prices of conventional energies, such as natural gas, oil, coal, and also nuclear power (van Ruijven and van Vuuren, 2009). Considering the degree of substitution of the different energy sources, it might be expected that higher prices of traditional sources generate greater renewable energy consumption (Henriques and Sadorsky, 2008; Sadorsky, 2009a; Salim and Rafiq, 2012; Silk and Joutz, 1997). However, we exclude non-renewable energy prices from the analysis. First, the prices of conventional energies are not country-specific and, then, we should have had recourse to unique variables common for all countries in the panel. Second, high and middle-income countries show an adequate ability to diversify away the energy price risk through derivatives markets and suitable energy conservation policies. Third, prices of traditional energy resources might fail to reflect the real costs of their use, giving rise to distortions when compared with the cost of renewable energy (Menz and Vachon, 2006). Fourth, we prefer to refer to the direct economic incentives to REC, which are included in EPS by assigning prices to environmental externalities, such as taxes, trading schemes, and feed-in tariffs. Finally, the literature shows that such prices are found to exert no significant effect on REC (Sadorsky, 2009a; Omri and Nguyen, 2014).

We aim to investigate REC drivers, focusing on the role of socio-technical aspects, in a panel of 12 EU Member States that are net energy importers: namely, Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, and Sweden. Because the process of transition to REC is not simple, we use the longest time span possible from 1990 to 2015. Our empirical strategy leverages the PVAR approach, already used in similar contexts (Charfeddine and Kahia, 2019; Lin and Zhu, 2017; Tiwari, 2011). This combines the traditional VAR, which treats all the variables in the system as endogenous, with the panel data approach, which borrows strength from the cross-sectional dimension and focuses on bidirectional effects. Table 1 presents the names of the variables, their definitions, and sources.

Table 1. Variables description

Following Love and Zicchino (2006), who suggested an estimator that permits the presence of stationary endogenous variables and unobserved individual heterogeneity, we used the specified PVAR model:

$$X_{it} = f_i + \Gamma(L)X_{it} + \varepsilon_t \,, \tag{1}$$

where X_{it} represents the vector of stationary variables in our analysis, f_i denotes the vector of deterministic fixed effects, $\Gamma(L)X_{it}$ is a square matrix of polynomials in the lag operator, and ε_t is the random error term. Following Crociata et al. (2019), closer links among member states have been induced by the european integration process, so that variations in the energy sector of one country influence those of others. The descriptive statistics for the variables are shown in Table 2 (*d* denotes the first difference operator).

Table 2. Descriptive statistics

b. Empirical testing

Variables at the macroeconomic level are usually characterised by non-stationarity, which is known to affect the econometric analysis of time series and panels as non-stationary variables generate spurious results. A solution to this problem involves using first-difference transformation. The first step of the empirical analysis is to check the stationarity of the various series using different unit root tests. Two classes of tests investigate the presence of a unit root. The first generation unit root tests are based on the hypothesis of cross-sectional independence between panel units; these include the Levin, Lin and Chu (LLC) tests (Levin et al., 2002), Im, Pesaran and Shin (IPS) tests (Im and Pesaran 2011; Im et al., 2003), and Fisher's type tests (Choi, 2001; Maddala and Wu, 1999). The most important limit of these tests is that they all assume that the individual time series in the panel are cross-sectionally and independently distributed, whereas, a multiple research studies provide evidence for co-movement between economic variables and, as argued by Banerjee et al. (2005), panel unit root tests may be biased if the panel units are cross-cointegrated. Thus, a second generation of unit root tests has been proposed to overcome this problem. These tests relax the assumption of cross-sectional independence, and allow for a variety of dependencies across the different units. These include Pesaran tests, which are based on the cross-sectional augmented Dickey-Fuller test (Pesaran, 2007).

To analyse the order of integration of our variables, the IPS tests, two Fisher type tests (based on augmented Dickey-Fuller and Phillips-Perron tests, respectively), and the Pesaran tests are used. All tests are characterised by a null hypothesis that assumes a unit root. The results of these panel unit root tests are shown in Table 3 (variables in level) and Table 4 (variables in first differences).

Table 3. Unit root tests: variables in level

The results show that all variables are non-stationary in levels, as the null hypothesis is usually not rejected at conventional levels of significance. However, all the chosen variables are stationary after the first difference: all the series are integrated of order one (I(1)).

Table 4. Unit root tests: variables in first differences

Table 5 shows the results of the cointegration tests introduced by Westerlund (2007). These tests assume the null hypothesis of no cointegration. The G_α and G_τ statistics check whether cointegration is present in at least one panel unit. The P_α and P_τ statistics check whether cointegration is present in the entire panel. To take account of cross-section interdependence the robust p-value is calculates through bootstrapping with 100 replications. These values show that all four tests cannot reject the null hypothesis of absence of cointegration. Therefore, the empirical characteristics of the variables inspected require estimation in first differences, as the variables at level are not cointegrated (as well as not stationary).

Table 5. Cointegration tests

Note: p-value are robust critical values obtained through bootstrapping with 100 replications

To assess whether collinearity and multicollinearity were a concern for our analysis, we examined the correlation matrix and the variance inflation factor (VIF). The statistics are presented in Table 6 (dREC is used as the dependent variable). Given the low correlation values and the low VIF and mean VIF values, we can conclude that collinearity and multicollinearity were not a problem.

Table 6. Correlation matrix and variance inflation factor statistics

Prior to the PVAR estimation, the final preliminary step is lag order selection. Choosing the suitable number of lags is crucial for PVAR: too many lags generate a loss of degrees of freedom, with consequent over-parameterisation; too few lags miss to capture the dynamics of the system, leading to exclude variable bias. The results are presented in Table 7. Hansen's J statistics tests the null hypothesis that the model specification is overidentified; that the included instrumental variables are valid instruments and uncorrelated with the error term, while those instruments not included are properly excluded (Hansen, 1982). After passing the Hansen’s J test, following the econometric literature, the optimal lag length should minimize the moment model selection criteria developed by Andrews and Lu (2001): the moment Bayesian information criterion (MBIC), moment Akaike’s information criterion (MAIC), and moment Hannan and Quinn information criterion (MQIC). These criteria are extremely similar to the maximum likelihood-based information criteria, AIC, BIC, and HQIC. Based on the three model selection criteria by Andrews and Lu (2001), a first order PVAR is the preferred model.

Table 7. Lag order selection criteria

We removed the deterministic fixed effects f_i in Eq. (1) by using the first difference transformation. As well known, this method may generate the so-called Nickell bias (Nickell, 1981) due to the correlation between the first-differenced lag and the first-differenced error term, which both depend on ε_{it-1}. In this framework, estimating the dynamic panel equation using OLS will produce biased and inconsistent estimates (Baltagi, 2008). We use forward mean-differencing, also referred to as the Helmert transformation (Love and Zicchino, 2006; Arellano and Bover, 1995) to overcome this problem. This transformation removes the forward mean from each observation, which is the mean of all the future observations available for each unit-period. In so doing, the orthogonality between transformed variables and lagged regressors is preserved. The system may thus be estimated using the Generalized Method of Moments (GMM) and the lagged values of regressors can be used as instruments.

c. Results and discussion

The PVAR model was estimated using one lag and with the GMM-style option (Holtz-Eakin et al., 1988), which replaces the missing values with zeros and can produce more efficient estimates.

Table 8. PVAR results

Note: *p < 0.1; **p < 0.05; ***p < 0.01

The first order PVAR results are shown in Table 8. The Test of overidentifying restriction (Hansen's J chi^2) is equal to 102.31 (p = 0.363): this confirms the goodness of the model, since the null hypothesis that the over-identifying restrictions are valid is verified. The stability of the PVAR was examined and verified as the eigenvalues are strictly less than 1 (see Table 9).

Table 9. Eigenvalue stability condition

Figure 1 shows that none of the roots lies outside of the unit circle; this indicate that the PVAR model is stable and also that the stationarity of the variables is confirmed (Lutkepohl, 2005).

Figure 1. Roots of the companion matrix

Following the first-order PVAR estimation and its corresponding stability check, the Granger causality test was performed. The test assumes the null hypothesis of absence of Granger causality. The results of the Granger causality test are shown in Table 10. A block exogeneity analysis (ALL) confirm the presence of endogeneity.

Table 10. Granger causality test

The income level is positively correlated to its previous levels: countries with higher income levels pollute more, import more energy, and invest more in education (CO_2, IMP, and EDU are positively associated with GDPc). Interestingly, countries with higher education levels need more energy, despite it bringing more carbon-dioxide emissions, and continue to import more energy, indicating that more education and, therefore, more public awareness cannot compensate for the greater demand for energy coming from economic growth and higher income levels. In other words, it seems as if the income (positive) effect prevails in the level of CO_2 (negative) effect on REC, despite the fact that the latter should be more appreciable in countries with higher levels of education (Gürlük, 2009).

Usually, in literature each paper considered at least one economic variable as a control variable (with some exceptions; see for instance Marques and Fuinhas, 2012). Generally, these authors expect that an increase in income (usually taken as GDP per capita) might lead to a higher energy consumption, including REC (see for instance Salim and Rafiq, 2012; Omri and Nguyen, 2014). However, a negative influence is often found for European countries (as in our case). A possible explanation given by Cadoret and Padovano (2016) is that a high economic activity generates a high energy demand, but renewable energy sources might not be able to immediately meet this augmented demand (and their relative weight decreases).

From an economic point of view, an increase in GDPc also generates an increase in CO_2 due to the greater demand for energy. Moreover, GDPc does not show a statistically significant link with OGCN: in energy importing countries, an increase in energy demand can be faced with renewable sources and imports. The results also show that an increase in EPS does not negatively affect GDPc, that is a more stringent environmental policy does not imply a slowdown in the economy.

In line with the relevant literature (Menegaki, 2011; Sadorsky, 2009a; Salim and Rafiq, 2012), an increase in CO_2 emissions leads to a higher use of low-carbon renewable energy sources, due to an increase in the demand for environment safeguard. Moreover, we found that higher levels of REC may generate lower levels of CO_2. To this end, policy-makers should promote public awareness of the importance of the role of REC in achieving sustainable growth.

In line with the relevant literature, results show that OGCN has positive and statistically significant effects on REC. This emphasizes that OGCN complements, but does not substitute for REC. In effect, growing economies and rising GDPc require an increasing amount of total energy, which cannot be exclusively satisfied by energy from renewable sources (Apergis and Payne, 2011).

A decrease in energy imports is usually expected to have a positive influence on the development of renewable energy sources (Marques et al., 2010). However, there is no consensus for samples at a global scale, while at European level, a negative influence of energy security appears (Bourcet, 2020): our results are in line with the relevant literature. Moreover, we found that an increase in REC can stimulate a decrease in IMP.

There is wide consensus in literature concerning the need for public support policies to promote renewable energy use (Marques and Fuinhas, 2012). Focusing on our analysis, in line with the relevant literature, EPS is found to have a positive influence on REC.

The variance decomposition and the impulse response functions resulting from the PVAR model are shown in Table 11 and Figure 2. Specifically, Table 11 reports the variance decomposition, which assesses the relative weight of shocks in one variable to variation in other variables over time. The forecast error variance decomposition follows the Cholesky decomposition and was performed using 1000 Monte Carlo simulations for 10 periods. The Cholesky decomposition assumes that series which are listed earlier in the VAR order affect the following variables contemporaneously, as well as with a lag, whereas the series which come successively in the ordering influence those listed first only through their lags. Hence, the variables that appear earlier in the system are more exogenous. Several estimates have been implemented, ordering the variables in different ways, and very similar results have been achieved (available upon request). The table shows that each variable is mainly influenced by its lag. Particularly, OGCN is mainly determined by REC (49.88%) and EPS (13.43%) on average during a 10 year period. Analogously, REC and EPS have a remarkable effect on CO_2 during the same period. This demonstrates that REC and EPS will gradually influence the production of energy from traditional sources and CO_2 emissions in the future.

Table 11. Variance decomposition analysis

Note: Variation in Response Variable explained by the Impulse Variables in the columns (10 periods ahead)

The impulse response functions illustrate the reaction of one variable to the shocks in another variable in the system, while maintaining all other shocks equal to zero (a Gaussian approximation based on 200 Monte Carlo simulations was used to estimate the impulse response functions, which also in this case followed the Cholesky decomposition). When one positive unit shock is exerted on one variable in the current period, the response variable usually shows a remarkable response in the early phases, following with slight fluctuation thereafter (Figure 2).

Figure 2. Impulse Response Analysis

More specifically, when a positive shock is applied to GDPc in the present period, EDU, IMP, and CO_2 show remarkable positive responses during the early phases, whereas REC shows an initial negative response that becomes a lasting positive response. REC suffers a similar influence from shocks in EDU, whereas positive shocks exerted on EPS, CO_2, and OGCN generate a significant positive response in REC during the early periods.

4. Conclusion and policy implications

Despite the worldwide increase in REC, global energy-related carbon dioxide emissions are rising and there are still considerable differences in the share of REC in national energy portfolios.

These concerns require further efforts at the policy level. By using more renewables to meet its energy needs, the EU might lower its dependence on imported energy and become more sustainable. More action is needed, especially in those countries that make extensive use of energy imports. Importing countries could leverage several factors to increase REC and reduce their dependence on foreign sources. This study aimed to investigate REC drivers, focusing on the role of policy stringency, lobbying, public awareness, and education.

Results show that the positive income effect prevails in the level of carbon dioxide emissions (negative) effect on REC, despite the latter being more significant in countries with higher levels of education.

Public awareness is not enough to facilitate the transition to REC. National governments are called to affect the education variable by working on schools, training institutions, and universities. In this sense, it is reasonable that policymakers begin to implement actions to develop and assess knowledge of, skills for, and attitudes to climate change and sustainable development, providing support materials and facilitating the exchange of good practices in EU teacher-training program networks. A mix between education and public awareness about environmental issues could provide a prompt and robust response to renewable energy deployment. The effect of the combination between education and public awareness has been largely studied in the medical field to anticipate requests for diagnosis and, then, improve health care outcomes, but also to increase the citizens' sensitivity to certain animal species and, finally, to help the perception of the critical level of environmental pollution.

Increasing energy needs push traditional sources towards complementarity with REC, implying a positive lobbying effect. By contrast, policy stringency has positive direct and indirect effects on REC, suggesting that the approach adopted by the European Commission with the recent Green Deal is moving in the right direction. It is easy to understand the positive relationship between EPS and REC which, conversely, accompanies a reduction of OGCN. Moreover, the positive relationship between EPS and GDPc is less intuitive and suggests that more stringent environmental policy intervention does not imply a slowdown in the economy or even a reduction in CO_2. If even this last evidence could at first glance be considered contradictory, it is worth bearing in mind the difficulty and relative slowness of the process of transition to renewable energy. However, more EPS means more imports, and this relationship calls for more in-depth analysis because it gives energy exporting countries the opportunity to influence and, actually, decide on the global environmental challenge.

Last, with regard to the role of REC as an independent variable, rather than as a dependent variable, it should be noted that REC, following the EPS effect, might itself lead to not only a decrease in CO_2 and OGCN in the first instance, but also in IMP, even if only at a later stage following an initial increase.

The next steps of research see two possible developments. First, the adoption of the current model to a homogeneous group of developing countries, target partially neglected by previous studies, in which the purpose is to investigate the role played by the drivers discussed above on renewable energy deployment. Secondly, following the growing literature on green technologies, the introduction in the model of technological aspects, including the count of patent applications in renewable technologies and the level of research and development expenditures in the above set of EU countries.

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Table 1. Variables description

Variable	Definition	Source
REC	Renewable energy consumption (% of total final energy consumption)	World Bank
EPS	Environmental Policy Stringency Index	OECD
CO_2	CO_2 emissions (metric tons per capita)	World Bank
GDPc	GDP per capita, PPP (current international 1000$)	World Bank
OGCN	Electricity production from oil, gas, coal and nuclear sources (% of total)	World Bank
IMP	Energy imports, net (% of energy use)	World Bank
EDU	Population 15-64 years by educational attainment level (%) (isced 3-8)	Eurostat

Table 2. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
REC	252	14.71	12.53	0.94	53.25
EPS	252	1.93	0.84	0.48	4.13
CO_2	252	8.16	2.17	4.24	13.26
GDPc	252	29.27	9.83	11.76	69.06
OGCN	252	73.94	20.03	17.72	98.58
IMP	252	60.83	20.14	0.57	90.68
EDU	232	59.61	15.84	19.30	82.30
dREC	240	0.37	1.25	-3.41	5.22
dEPS	240	0.08	0.26	-0.63	1.00
dCO_2	240	-0.06	0.46	-2.42	2.15
dGDPc	240	1.06	1.36	-2.66	17.99
dOGCN	240	-0.66	4.31	-17.56	16.09
dIMP	240	0.14	2.59	-9.92	15.25
dEDU	217	0.89	1.07	-5.60	3.10

Table 3. Unit root tests: variables in level

Variable	IPS W-t-bar	Fisher ADF-Pm	Fisher PP-Pm	Pesaran Z-t-bar
REC	4.39	-2.93	-2.57	4.86
EPS	-1.17	0.51	1.46*	-0.10
CO_2	3.52	-2.01	0.28	-0.84
GDPc	-0.72	1.094	-0.96	3.95
OGCN	3.08	-1.63	0.30	1.70
IMP	0.33	-1.02	1.68**	1.78
EDU	-0.04	0.98	-0.31	1.38

Table 4. Unit root tests: variables in first differences

Variable	IPS W-t-bar	Fisher ADF-Pm	Fisher PP-Pm	Pesaran Z-t-bar
dREC	-13.56***	12.97***	37.70***	-5.39***
dEPS	-12.20***	10.98***	32.20***	-5.16***
dCO$_2$	-13.10***	12.10***	38.44***	-6.27***
dGDPc	-6.70***	9.57***	13.51***	-1.82**
dOGCN	-14.44***	29.44***	42.19***	-7.08***
dIMP	-9.07***	15.11***	34.18***	-6.79***
dEDU	-8.46***	9.99***	18.94***	-3.23***

Table 5. Cointegration tests

Statistic	Value	p-value
G_τ	-1.696	0.730
G_α	-4.611	0.790
P_τ	-5.476	0.600
P_α	-3.424	0.830

Note: p-value are robust critical values obtained through bootstrapping with 100 replications

Table 6. Correlation matrices and variance inflation factor statistics

	dREC	dEPS	dCO$_2$	dGDPc	dOGCN	dIMP	dEDU
dREC	1.000						
dEPS	0.006	1.000					
dCO$_2$	-0.460	0.052	1.000				
dGDPc	0.003	-0.123	0.138	1.000			
dOGCN	-0.803	-0.004	0.410	0.019	1.000		
dIMP	-0.355	0.054	0.368	0.124	0.313	1.000	
dEDU	-0.089	-0.027	0.032	-0.092	0.024	-0.062	1.000
VIF		1.33	1.25	1.22	1.06	1.03	1.02
Mean VIF	1.15						

Table 7. Lag order selection criteria

Lag	J	J pvalue	MBIC	MAIC	MQIC
1	106.870	0.254	-394.105	-89.130	-212.922
2	47.333	0.541	-203.154	-50.667	-112.563

Table 8. PVAR results

	Dependent Variables						
Indipendent variables	dREC	dEPS	dCO$_2$	dGDPc	dOGCN	dIMP	dEDU
dREC	0.596 (0.000)***	-0.061 (0.02)**	-0.317 (0.000)***	0.009 (0.876)	-2.208 (0.000)***	-0.968 (0.000)***	-0.193 (0.014)**
dEPS	0.689 (0.007)***	0.328 (0.001)***	0.809 (0.000)***	0.409 (0.061)*	-7.881 (0.000)***	2.595 (0.000)***	0.99 (0.000)***
dCO$_2$	1.098 (0.000)***	-0.212 (0.000)***	-0.526 (0.000)***	0.533 (0.000)***	-4.176 (0.000)***	-1.486 (0.000)***	0.088 (0.215)*
dGDPc	-0.201 (0.004)***	0.028 (0.199)	0.142 (0.000)***	0.335 (0.000)***	-0.132 (0.618)	0.816 (0.000)***	0.205 (0.000)***
dOGCN	0.157 (0.000)***	0.003 (0.550)	-0.044 (0.000)***	-0.002 (0.905)	-0.71 (0.000)***	-0.128 (0.003)***	-0.049 (0.011)**
dIMP	-0.122 (0.000)***	-0.001 (0.860)	0.009 (0.517)	0.036 (0.071)*	0.298 (0.010)***	-0.122 (0.082)*	0.031 (0.101)
dEDU	-0.263 (0.015)**	0.013 (0.477)	0.125 (0.001)***	0.033 (0.435)	0.192 (0.625)	0.449 (0.002)***	0.078 (0.107)

Note: *p < 0.1; **p < 0.05; ***p < 0.01

Table 9. Eigenvalue stability condition

Eigenvalue		
Real	**Imaginary**	**Modulus**
0.650	0.000	0.650
-0.331	0.000	0.331
-0.091	0.294	0.308
-0.091	-0.294	0.308
-0.254	0.000	0.254
0.048	-0.149	0.156
0.048	0.149	0.156

Table 10. Granger causality test

Equation Variable	Excluded Variables	Chi2	pvalue
dREC	dEPS	7.245	0.007
	dCO$_2$	24.887	0.000
	dGDPc	8.289	0.004
	dOGCN	30.898	0.000
	dIMP	16.019	0.000
	dEDU	5.909	0.015
	ALL	71.074	0.000
dEPS	dREC	5.384	0.020
	dCO$_2$	27.264	0.000
	dGDPc	1.651	0.199
	dOGCN	0.358	0.550
	dIMP	0.031	0.860
	dEDU	0.506	0.477
	ALL	36.7	0.000
dCO$_2$	dREC	48.775	0.000
	dEPS	32.751	0.000

	dGDPc	19.219	0.000
	dOGCN	17.365	0.000
	dIMP	0.42	0.517
	dEDU	11.05	0.001
	ALL	91.334	0.000
dGDPc	dREC	0.024	0.876
	dEPS	3.498	0.061
	dCO_2	40.778	0.000
	dOGCN	0.014	0.905
	dIMP	3.248	0.071
	dEDU	0.608	0.435
	ALL	80.212	0.000
dOGCN	dREC	30.218	0.000
	dEPS	36.091	0.000
	dCO_2	25.572	0.000
	dGDPc	0.249	0.618
	dIMP	6.577	0.010
	dEDU	0.239	0.625
	ALL	90.676	0.000
dIMP	dREC	52.013	0.000
	dEPS	41.937	0.000
	dCO_2	22.643	0.000
	dGDPc	38.757	0.000
	dOGCN	8.997	0.003
	dEDU	9.563	0.002
	ALL	140.898	0.000
dEDU	dREC	6.101	0.014
	dEPS	23.398	0.000
	dCO_2	1.541	0.215
	dGDPc	20.071	0.000
	dOGCN	6.434	0.011
	dIMP	2.692	0.101
	ALL	68.374	0.000

Table 11. Variance decomposition analysis

	Impulse Variable						
Response Variable	dREC	dEPS	dCO_2	dGDPc	dOGCN	dIMP	dEDU
dREC	76.76%	3.10%	5.52%	2.62%	7.35%	1.57%	3.08%
dEPS	1.43%	91.22%	6.36%	0.55%	0.06%	0.21%	0.17%
dCO_2	21.61%	12.59%	52.30%	5.37%	3.70%	0.47%	3.95%
dGDPc	3.68%	6.34%	17.19%	71.10%	0.43%	0.37%	0.88%
dOGCN	46.88%	13.43%	9.91%	0.19%	28.62%	0.85%	0.11%
dIMP	15.27%	7.05%	11.44%	7.81%	2.48%	53.12%	2.81%
dEDU	2.40%	9.85%	2.81%	4.79%	2.96%	1.58%	75.60%

Note: Variation in Response Variable explained by the Impulse Variables in the columns (10 periods ahead)

Figure 1. Roots of the companion matrix

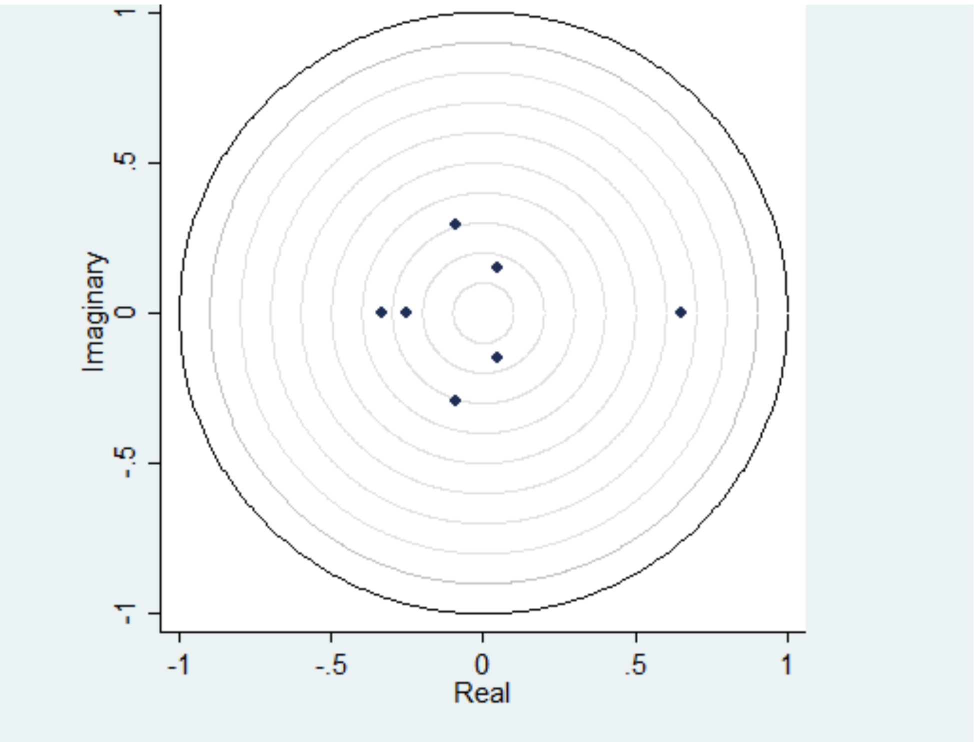

Figure 2. Impulse Response Analysis