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Strategies to make renewable energy sources compatible with economic growth

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ABSTRACT

This paper focuses on the relationship between economic activity, and renewable and non-renewable energy consumption for the set of countries with the largest usage of each energy source. The dominance of one type of energy source could raise an unintentional barrier to a strategy of energy mix diversification. A panel of 28 countries was studied, using annual data for the time span 1995–2013. The ARDL approach was used to capture the short- and long-run effects. The Driscoll-Kraay estimator was used to attain robust results given the presence of the phenomena of heteroscedasticity, contemporaneous correlation, first order autocorrelation and cross-sectional dependence. Results suggest that renewable energy has not contributed to economic growth, while non-renewable energy has contributed. This finding should be incorporated in the definition of energy strategies, specifically by making renewable energy compatible with economic growth.

1. Introduction

Fossil fuels remain the main sources in the global energy mix and are associated with the increase of carbon dioxide (CO_2) emissions. The deployment of renewable energy sources (RES) can play a crucial role to reduce both (CO_2) emissions and fossil fuel dependency [1]. Thus, there is a worldwide trend to promote the use of renewable energy sources. Even so, these sources face severe entry barriers, mostly associated with market failures.

The entry barriers are widely analysed in the literature of industrial economics [2,3]. In fact, there are several kinds of entry barriers, namely: (i) initial investment; (ii) inelastic demand; (iii) restrictive practices; and (iv) research and development. The barriers to the diversification of energy sources, particularly RES, are also common and are analysed, for example, by Luttenberger [4]. According to general studies regarding entry barriers, both intentional and "innocent" entry barriers to RES can also be observed. This paper uses one of these entry barriers, which is the great dependence on, or even a dominant use of, a single source, to define the countries under analysis. This barrier could come from a substantial domestic availability of the resources (innocent barrier), or it could come from an intentional strategy to intensively use a specific source, namely fossil fuel, often due to lobbying by stakeholders in that source.

As such, a country's presence in the top ten of world electricity production by source, was the criterion used to select the countries under analysis, using the year 2012 as a reference. This criterion was based on the data available as of July 2015. When a country is on the list of more than one energy source, then it is considered only once. Annual data for the period 1995 to 2013 was used. Following the literature, energy variables (non-renewable and renewable energy consumption), economic variables (gross fixed capital formation, export of goods and services, and employment) and an environmental variable (carbon dioxide emissions) were used to explain economic growth. The ARDL approach in panel data proved to be suitable to detect the dynamics of the adjustments between the short- and long-run.

This paper contributes to the literature by revealing the relationships between energy sources and economic growth for this set of countries. Moreover, the paper provides support to the process of defining energy strategies, particularly those aiming to combine RES and economic growth. In the short-run, non-renewable energy has a positive impact on economic activity, while in the long-run, RES has a negative impact on economic activity. Energy strategies should enhance the economic rationality for the use of renewables, specifically by adopting demand-side measures to address their characteristics of intermittency.

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2. Literature review

The analysis of the causal relationship between energy consumption and economic activity has received much attention in the literature. Within this energy-growth nexus, four traditional hypotheses have been exhaustively tested [5,6], namely: (i) the *growth hypothesis*, which predicts a unidirectional causality, running from energy consumption to economic growth; (ii) the *feedback hypothesis*, which predicts a bidirectional causality between economic growth and energy consumption; (iii) the *neutrality hypothesis*, when there is no causality relationship between economic growth and energy consumption; and (iv) the *conservation hypothesis*, which consists of a relationship running from economic growth to energy consumption.

Although literature focusing on the nexus is abundant, there is no consensus on the outcomes. Indeed, dissimilar samples and econometric techniques can explain this lack of consensus [6]. The study of the nexus has evolved, from an aggregate perspective using primary energy consumption towards electricity consumption only. Moreover, the energy-growth nexus has also evolved from considering the energy sources as a whole, towards the analysis of each source individually, giving rise to several different nexuses. A summary of the results of the energy-growth nexus can be seen in Ozturk [6] and Menegaki [7]. This paper accompanies this trend, and focuses on energy consumption, by dividing energy into renewable and non-renewable according to its origin.

Diverse relationships between renewable energy consumption and economic growth can be found in the literature. A positive relationship [8], the lack of any link [9], as well as, a bidirectional relationship between renewable energy consumption, non-renewable energy consumption and economic growth [10], are examples of these relationships. We will return to the nature of these relationships, in the discussion section.

3. Data and variables

As stated before, the countries under analysis were chosen according to a single criterion: that the share of the country's electricity production by a specific source is present in the top ten of the countries for that source. According to the data available, the 28 countries selected, for the period 1995–2016, are the following: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. The countries Estonia, Iceland, Israel, Luxembourg, Slovenia and Turkey were excluded due to the lack of data for the entire period under analysis. The data analysis was performed using the software STATA 13.1.

The source of the variables was the World Bank, for: gross domestic product (constant 2005 US$); exports of goods and services (constant 2005 US$); population (number of people); unemployment (% of total labour force); labour force (total); and gross fixed capital formation (constant 2005 US$). The BP Statistical Review of World Energy was the data source for (CO_2) emissions and for each energy source, namely: oil consumption (in tonnes); gas consumption; coal consumption; nuclear energy consumption; hydroelectricity consumption; solar energy consumption; wind energy consumption; geothermal, biomass; and other renewables sources. All variables obtained by BP Statistical Review of World Energy, June 2015 are in million tonnes oil equivalent, except oil consumption and (CO_2) emissions. The variables gross fixed capital formation, exports of goods and services, CO_2 and employment, are used as control variables [11–13].

The variables used in the estimated models are as follows: (i) *YPC* (Gross Domestic Product per capita) – The ratio between Gross Domestic Product and total population; (ii) *NRESPC* (non-renewable energy consumption per capita*)* – This variable is calculated in two steps. The first step consists of the sum of oil consumption, gas consumption, coal consumption and nuclear energy consumption. The second step consists in dividing the above sum by the total population; (iii) *RESPC* (renewable energy consumption per capita) – This variable is also calculated in two steps. The first step consists of the sum of hydroelectricity consumption, solar energy consumption, wind energy consumption and geothermal, biomass and other renewable sources consumption. The second step consists in dividing the above sum by the total population; (iv) *XPC* (exports of goods and services per capita) – The ratio of exports of goods and services, and total population; *(v) GFCFPC* (gross fixed capital formation per capita) – Obtained by dividing the gross fixed capital formation by the total population. *(vi) CO2PC* (carbon dioxide emissions per capita) - Carbon dioxide emissions divided by the total population; and (vii) *EMP* (employment) – This variable is obtained in three steps. The first step consists of dividing unemployment by 100. In the second step, the first result is multiplied by the labour force, in order to obtain an absolute value for unemployment. In the third step, unemployment was subtracted from labour, in order to obtain the employment value.

4. Method

To study the relationship between economic growth, renewable and non-renewable energy consumption in countries with a dominant energy source, it is useful to analyse the dynamic effects in the short- and long-run. The Autoregressive Distributed Lag (ARDL) [14] model allows these effects to be analysed separately. It also allows for a different integration order of variables, i.e. I(0) and I(1) but not I(2), and different lag-lengths for the variables within the model. The dependent variable is *DLYPC*. The general specification of the ARDL model is the following:

$$LYPC = f\,(LNRESPC;\ LRESPC;\ LGFCFPC;\ LCO2PC;\ LXPC;\ DLEMP) \quad (1)$$

In equation (2), the short- and long-run dynamics can be observed, where the prefixes "L" and "D" denote natural logarithm and first difference of the variables, respectively. The subscripts t, I and j denotes the time period, country and lag length, respectively. α denotes the intercept, β_{ij} and λ_i the estimated parameters, and ε_{it} the error term.

$$\begin{aligned} DLYPC_{it} &= \alpha_i + \sum_{j=1}^{k}\beta_{1ij}DLYPC_{it-j} + \sum_{j=0}^{k}\beta_{2ij}DLNRESPC_{it-j} + \sum_{j=0}^{k}\beta_{3ij}DLRESPC_{it-j} \\ &+ \sum_{j=0}^{k}\beta_{4ij}DLGFCFPC_{it-j} + \sum_{j=0}^{k}\beta_{5ij}DLCO2PC_{it-j} + \sum_{j=0}^{k}\beta_{6ij}DLXPC + \sum_{j=0}^{k}\beta_{7ij}DLEMP_{it-j} \\ &+ \lambda_{1i}LYPC_{it-1} + \lambda_{2i}LNRESPC_{it-1} + \lambda_{3i}DLRESPC_{it-1} + \lambda_{4i}DLGFCFPC_{it-1} + \lambda_{5i}DLCO2PC_{it-1} + \lambda_{6i}DLXPC_{it-1} + \lambda_{7i}DLEMP_{it-1} + \varepsilon_{it}. \end{aligned} \quad (2)$$

In studies on panel data, it is necessary to analyse the characteristics of the series and the cross-sections. As such, a battery of tests was carried out to check the order of integration of the series and the eventual presence of cross-sectional dependence and collinearity. Table 1 shows the descriptive statistics and CD-test to test for cross-sectional dependence. Cross-sectional dependence was detected, which could be related mainly to geographical proximity or to the dependency of countries sharing common shocks [15]. Overall, the characteristics of the data determined the battery of econometric techniques used.

Taking into account the presence of cross-sectional dependence, in order to check the integration order of the variables, second generation unit root tests CIPS [16] were carried out (Table 1). This unit root test is robust to heterogeneity. Accordingly, all variables are I(1). As such, considering that the variables are not I(2), the use of the ARDL is shown to be appropriate.

Continuing with the assessment of data characteristics, by checking the eventual collinearity between variables, the Variance Inflation Factor (VIF) was calculated. The absence of collinearity is verified by low VIF statistic values. The mean VIF is 2.56 and 1.51, to variables in levels and first differences, respectively.

Pursuing the objective of detecting the most efficient estimator to deal with the characteristics of the panel data, the presence of individual effects was tested. Fixed effects (FE) against random effects (RE) were tested by the Hausman test, where the null hypothesis is that the random effect model is the appropriate one. The null is rejected ($\chi^2 = 95.64$) at a significance level of 1%, supporting the use of a fixed effect estimator.

Considering the order of integration of the series, the heterogeneous panel data, the presence of dynamic effects, and the cross-sectional dependence, the second generation co-integration test developed by Westerlund [17] was performed, using bootstrapping to obtain robust critical values. The results of the Westerlund co-integration test, for all variables, can be seen in Table 2.

The results show that the null is not rejected and as such they support no co-integration in both statistics.

5. Results

Considering the sample under analysis and taking into account the dominance of a single type of energy source, the possibility of being faced with a heterogeneous panel should be considered. In this case, the Mean Group (MG) and the Pooled Mean Group (PMG) estimators ought to be used and tested. The MG estimator is more flexible than the PMG [18]. This MG estimator is efficient when the long-run coefficients are heterogeneous, whereas the PMG estimator allows for heterogeneous short-run coefficients and homogeneous long-run coefficients. In order to test the adequacy of PMG and MG estimators against FE estimators, the Hausman test was performed once again. The PMG, MG and FE estimators, as well as the results of the Hausman test can be observed in Table 3.

The results confirm that the FE model is the most suitable model, and as such it is appropriate to consider the cross sections as a group sharing common coefficients. Taking into account the presence of fixed effects, in order to select the robust estimator, additional specification tests were made, specifically for the presence of heteroscedasticity, autocorrelation and contemporaneous correlation among cross sections. To check heteroscedasticity, the modified Wald test was performed. Following this, the Wooldridge test to verify the existence of serial correlation was used. The Pesaran test was performed to appraise contemporaneous correlation among cross sections. The specification test results are presented in Table 4.

The specification test results show the rejection of the null hypothesis for the modified Wald test. The data has first order autocorrelation according to Wooldridge test. The existence of contemporaneous correlation was confirmed by the Pesaran test.

Following the results of the specification tests, the Driscoll and Kraay [19] estimator was used, given that standard errors of this estimator are robust in the presence of cross-sectional dependence. The error structure is assumed to be heteroskedastic and auto correlated. The FE model, and FE model with robust standard errors, were also estimated to control the heteroscedasticity. The results are compared and displayed in Table 5.

The results reveal great consistency. There is no change in signals and the level of significance remains unchanged, except the

Table 2
Westerlund co-integration test.

Statistic	Value	Z-value	Robust P-value
Gt	−2.610	1.245	0.400
Ga	−2.523	8.653	0.178
Pt	−7.860	5.364	0.446
Pa	−2.474	6.374	0.121

Notes: The null hypothesis of the Westerlund co-integration test is no co-integration; the bootstrapping regression with 800 reps was performed; Gt and Ga test the cointegration for each country individually, and Pt and Pa test the cointegration of the panel as whole; and the Stata command *xtwest* (with the constant option) was used.

Table 1
Descriptive statistics and cross-sectional dependence.

Variables	Descriptive statistics					Cross-sectional dependence (CD)			2nd generation panel unit root test CIPS	
	Obs	Mean	S.D.	Min	Max	CD-test	corr	abs(corr)	No trend	Trend
LYPPC	532	10.1555	0.6230	8.5632	11.1432	75.73***	0.894	0.894	0.928	1.537
LNRESPC	532	−12.5661	0.4732	−13.8810	−11.1235	29.57***	0.349	0.566	2.176	2.128
LRESPC	532	−15.2415	1.4954	−19.4802	−11.8437	32.46***	0.383	0.451	1.831	1.909
LGFCFPC	532	8.6554	0.6281	6.6992	9.70179	45.64***	0.540	0.640	0.394	−0.031
LCO2PC	530	−11.8161	1.4055	−22.7427	−10.6975	26.65***	0.313	0.565	9.155	7.015
LXPC	532	9.0810	0.8261	7.0242	10.7430	74.16***	0.878	0.881	0.458	1.348
LEMP	532	15.9674	1.1581	14.0704	18.8171	47.70***	0.565	0.678	2.039	2.619
DLYPC	504	0.0172	0.0265	−0.0911	0.10119	49.01***	0.594	0.595	−4.675***	−2.926***
DLNRESPC	504	−0.00131	0.0424	−0.1472	0.17212	25.18***	0.305	0.346	−13.693***	−11.426***
DLRESPC	504	0.05238	0.1684	−0.5248	1.10107	3.31***	0.040	0.236	−15.408***	−12.603***
DLGFCFPC	504	0.01779	0.0710	−0.3350	0.24032	34.99***	0.426	0.449	−7.275***	−5.551***
DLCO2PC	502	0.00764	0.1766	−1.5992	2.52067	21.43***	0.260	0.321	−10.839***	−10.069***
DLXPC	504	0.04519	0.0700	−0.2769	0.25992	52.00***	0.633	0.636	−7.919***	−5.784***
DLEMP	504	0.00895	0.0192	−0.0892	0.07699	21.20***	0.258	0.304	−4.453***	−3.560***

Notes: CD-test has N(0,1) distribution, under H0: cross-sectional independence. All variables are in natural logarithms. *** and ** represent significance levels of 1% and 5%, respectively. CIPS test assumes cross-sectional dependence in the form of a single unobserved common factor, and the null hypothesis in the series is I(1).

Table 3
Heterogeneous estimators and Hausman test.

Models	PMG vs FE	MG vs PMG	MG vs FE
Hausman tests	Chi2(7) = 0.00	Chi2(7) = 0.61***	Chi2(7) = 0.00

Notes: *** represents a significance level of 1%. ECT denotes error correction term; the Hausman test includes constant and H0: differences in non-systematic coefficients. The values of the long-run coefficients are the elasticities.

Table 4
Specification tests.

	Statistics for III, V and VII	Statistics for IV, VI and VIII
Modified Wald test	491.23***	486.57***
Wooldridge test	75.911***	75.911***
Pesaran test	5.417***	5.417***

Notes: *** denotes significance at 1%; the results of the Modified Wald test, Wooldridge test and Pesaran test, are based on Chi-squared distribution, F distribution and standard normal distribution, respectively. The null hypothesis of the modified Wald test, Wooldridge test and Pesaran test is homoscedasticity, no first-order autocorrelation and cross-sectional independence, respectively.

Table 6
Semi-elasticities, elasticities and adjustment speed.

Models	coefficients	FE(VI)	FE Robust (VII)	FE D.K. (VIII)
Semi-elasticities		Significance level		
Constant	0.8232	***	***	***
DLNRESPC	0.0427	***	***	***
DLXPC	0.1558	***	***	***
DLGFCFPC	0.1850	***	***	***
DLEMP	0.1732	***	***	***
Elasticities				
LRESPC(-1)	−0.0366	***	***	***
LXPC(-1)	0.2788	***	***	***
LGFCFPC(-1)	0.2683	***	***	***
LCO2PC(-1)	0.0313	***	***	**
ECT	−0.1599	***	***	***

Notes: *** and ** represent a significance level of 1% and 5%, respectively; ECT means Error Correction Term.

variable *LCO2PC* lagged once in the model VI. Following the parsimonious principle, the reduced forms of the models I, III and V were estimated. The models in reduced form can be seen in Table 6, as well as the specification tests. In order to assess the magnitude of the effects, both semi-elasticities and elasticities were performed.

Regarding Table 6, one result deserves particular attention. The positive effect from *NRESPC* to economic growth in the short-run contrasts with that observed for RES in the long-run. In fact, in the long run, an increase of 1% in *RESPC*, decreases economic growth by 0.03%. This outcome justifies further discussion in the next section.

The results also reveal that *GFCFPC*, as well as *XPC*, have a positive effect in both the short- and long-run. Regarding the environmental variable, CO_2 emissions, it has a positive effect on economic activity in the long-run. In fact, this is not a surprising outcome, and it is consistent with a productive structure that remains very dependent on fossil fuels.

6. Discussion

The main findings of this paper are summarized in Fig. 1. Some of these deserve to be discussed in greater depth, namely the dissimilar effects of RES and NRES on economic growth, highlighting potential strategies capable of overcoming the undesirable observed effects. First of all, one of the central features of the analysis used in this paper is its impartiality regarding the nature or source of the energy a country should use when its objective is to guarantee economic growth. Indeed, results suggest that renewable energy has hampered economic growth, but conversely, non-renewable energy has fostered it. While it may be unexpected, this negative effect of RES on economic growth has already been detected by various authors but remains scarce in the literature (e.g. Refs. [20–22]), which is focused on the analysis of the traditional energy-growth nexus, regardless of the source.

Some literature, such as Marques and Fuinhas [23], advances that the promotion of RES could be placing a heavy burden on the economy. Indeed, the strategy to increase the penetration of RES has been pursued through public policies that have an implicit cost, which is transferred to the economy and society as a whole. Moreover, considering the intermittent nature of these sources, some of the installed capacity could be idle, either due to the absence of instantaneous renewable resources or even the lack of demand when the availability of the resource is higher. As such,

Table 5
Estimation results.

Dependent variable *LYPC*	FE (I)	FE (II)	FE Robust (III)	FE Robust (IV)	FE D.K. (V)	FE D.K. (VI)
Constant	0.9460***	0.8232***	0.9460***	0.8232***	0.9460***	0.8232***
DLNRESPC	0.0469***	0.0427***	0.0469***	0.0427***	0.0469***	0.0427***
DLRESPC	0.0002		0.0002		0.0002	
DLXPC	0.1555***	0.1558***	0.1555***	0.1558***	0.1555***	0.1558***
DLGFCFPC	0.1818***	0.1850***	0.1818***	0.1850***	0.1818***	0.1850***
DLCO2PC	0.0012		0.0012		0.0012	
DLEMP	0.1773***	0.1732***	0.1773**	0.1732***	0.1773***	0.1732***
LYPC(-1)	−0.1603***	−0.1599***	−0.1603***	−0.1599***	−0.1603***	−0.1599***
LNRESPC(-1)	0.0101		0.0101		0.0101	
LRESPC(-1)	−0.0052***	−0.0059***	−0.0052***	−0.0059***	−0.0052**	−0.0059***
LXPC(-1)	0.0444***	0.0446***	0.0444***	0.0446***	0.0444***	0.0446***
LGFCFPC(-1)	0.0397***	0.0429***	0.0397***	0.0429***	0.0397***	0.0429***
LCO2PC(-1)	0.0052***	0.0050***	0.0052***	0.0050***	0.0052***	0.0050*
LEMP(-1)	0.0030		0.0030		0.0030	
Diagnostic statistics						
N	502	502	502	502	502	502
R^2	0.8632	0.8625	0.8632	0.8625	0.8632	0.8632
R^2 adjusted	0.8513	0.8518	0.8595	0.8599		
F	F(13.461) = 223.74***	F(9.465) = 323.99***	F(13.27) = 272.86***	F(9.27) = 168.31***	F(13.17) = 17792.94***	F(9.177) = 2072.46***

Notes: ***, ** and * represent a significance level of 1%, 5% and 10%, respectively.

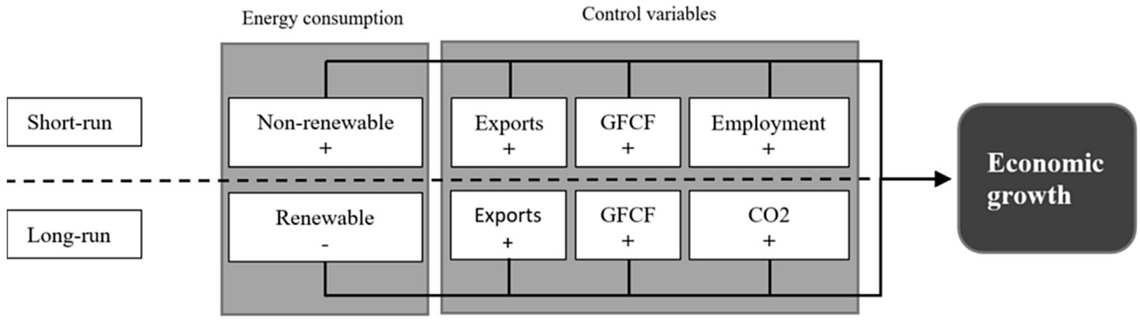

Fig. 1. . Main results. Authors' elaboration.

several strategies could be defined and implemented. The first step should be the deployment of demand-side management programmes. It is time to address the energy mix of consumers. Their pattern of consumption is shown to be essential to accommodate renewables, specifically by increasing consumption when larger renewable resources are available, and decreasing consumption when the source of generation is conventional fossil sources. This strategy could imply a penalty for consumption during the peak periods, thus preventing the overload of the energy system. Alternatively, a benefit in the form of a discount could be attributed to consumption in off-peak periods, in periods with plentiful availability of solar or wind energy, for instance.

The most successful strategies will be those that can handle the intermittent nature of renewable generation. Indeed, in the near future, those strategies will be essential to change the observed negative effect of RES on economic activity. Accordingly, the electrification of economic activities ought to be quickly augmented and those activities that are more intensive in capital and less in labour should be increasingly adapted to function during traditionally off-peak periods or, whenever larger renewable resources are available. E-mobility also needs to be reinforced, by incentivising self-consumption of energy, i.e. household generated, which can then serve as storage reservoir in vehicles, contributing to the electricity grid (V2G strategy) when there is a lack in generation from RES.

One of the most used tools worldwide for the promotion of renewables is a minimum quota of renewables. An alternative strategy could be the definition of maximum quotas for conventional sources, namely fossil sources. Initially, it could be viewed as the same strategy as renewable quotas, but it is definitely not. Renewable quotas have been achieved with massive resources of backup capacity from controllable fossil generation. This fact could be the origin of the negative effect of renewables on economic growth observed in the literature. The alternative strategy that we are proposing here, prevents the installed capacity of fossil sources from only registering a few hours of use, and as such, leaving a large capacity idle. This fact has induced severe economic inefficiencies that hamper economic growth in national economies. Another strategy, closely linked with the former, is the measurement of diversification of the energy mix. The use of a diversity index could be a useful aid for policy design as it promotes the effective diversification of the energy mix. The Shannon-Weaner index is a good example that could provide additional information, because it takes into account the dominance of one energy source. Regarding the diversification of the energy mix, it is worthwhile to note that diversification by itself does not have to be the main strategic energy policy of a country. However, looking not only at the countries under analysis, but also at the current worldwide pressure to join the fight against climate change, it is an increasingly hard task for a country to avoid a strategy of energy mix diversification.

This worldwide trend of integration of policies is clearly proven in the analysis. One can argue that the unit of analysis should be a single country rather than a group of countries. However, the presence of phenomena of cross-sectional dependence and contemporaneous correlation could be related to the greater dependency of countries, sharing common shocks. In other words, countries are increasingly integrated in their policies and strategies. Countries under the same policy guidance execute identical (imposed) strategies and there is a worldwide effect of contagion, such as cases in which feed-in-tariffs were abandoned in favour of market-oriented policies. Overall, the battery of tests support that these countries may be studied together, as long as the cross-sectional dependence effect is taken in consideration.

Another relevant factor is to ensure the stability of the strategies being pursued. In other words, the strategy of promoting *RES* has to be made and focused on the long term, and should not be easily reversed by taking one step forward and then one or even two backward. This sector requires large investment, which is usually more efficient when advantage is taken of scale economies. As such the stakeholders in the generation markets need to know about policies that take into account the payback of investment in generation infrastructure. This practice reduces risk and consequently leaves room for lower prices, given that lower uncertainty provokes lower premium risk.

7. Conclusion

This paper is centred on the analysis of the relationships between renewable and non-renewable electricity sources and their relationship with economic activity. The focus is centred on a set of countries, whose electricity generation by source is in the top ten of countries using that source. The panel data was subjected to an exhaustive battery of tests with the objective both to analyse the properties of the data series, as well as to guarantee the use of appropriate estimators. Once the presence of cross-sectional dependence was detected, the Driscoll-Kraay with fixed effects estimator was used, and the ARDL approach allowed the short- and long-run effects to be determined.

This research uses GDP per capita to measure economic growth, following the vast majority of literature focused on the energy-growth nexus. However, for future research, it could be of special relevance to assess whether the conclusions remain consistent when the focus is placed on sustainable development and not just on economic growth.

Overall, the results reveal great consistency both with the literature and with the economic theory. The results corroborate the well-known positive effect of non-renewable energy on economic growth, unlike renewable energy, which constrain economic growth in the long-run. This finding is extensively discussed and several strategies are proposed in order to make the accommodation of renewables within the energy system not only easier, but also to help reverse this negative effect. A critical success factor for the integration of renewables in the energy system, without compromising the objective of economic growth, should involve enhancing the economic rationale of using renewables. Policymakers should promote measures on the demand side, particularly by giving consumers a more hands-on role, in order to adapt their consumption to the availability of renewable sources.

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Glossary

ARDL	autoregressive distributed lag
PMG	pooled mean group
CO2PC	carbon dioxide emissions per capita
RE	random effects
EMP	employment
RESPC	renewable energy consumption per capita
FE	fixed effects
RES	renewable energy sources
GFCF	gross fixed capital formation per capita
VIF	variance inflation factor
MG	mean group
XPC	exports of goods and services per capita
NRESPC	non-renewable energy consumption per capita
YPC	gross domestic product per capita

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