

Article

Analyzing the Impact of the Renewable Energy Sources on Economic Growth at the EU Level Using an ARDL Model

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Abstract: Energy is one of the most important drivers of economic growth, but as the population is increasing, in normal circumstances, in all countries of the world, there is a demand for energy produced from conventional resources. Increasing prices of conventional energy and the negative impact on the environment are two of the main reasons for switching to renewable energy sources (RESs). The aim of the paper is to quantify the impact of the RESs, by type, on the sustainable economic growth at the European Union (EU) level. The research was performed for all 28 EU member states, for a time frame from 2004 to 2017, through a panel autoregressive distributed lag (ARDL) approach and causality analysis. Furthermore, Hausman test was performed on the regression model. By estimating the panel data regression model with random effects, we reveal through our results that RESs, namely wind, solar, biomass, geothermal, and hydropower energy, have a positive influence on economic growth at EU level. Moreover, biomass has the highest impact on economic growth among all RES. In fact, a 1% increase in biomass primary production would impact the economic growth by 0.15%. Based on econometric analysis, our findings suggest that public policies at the EU level should be focused on investment in RESs.

Keywords: renewable energy; economic growth; energy systems; panel data; econometric model

1. Introduction

Energy is one of the most important drivers of sustainable economic growth [1], but the population growth all over the world is leading to increasing consumption of conventional energy, such as coal, natural gas, and oil. As a direct result, the energy prices get higher and the environment becomes more polluted, while the greenhouse gas emissions lead to climate change [2,3]. Therefore, the dependence on conventional energy will end up, eventually, with environmental degradation [4].

It is estimated [5] that there will be a 48% increase of energy consumption all over the world by 2040. Renewable energy sources (RESs) are the substitutes for conventional energy, as their use is producing less harm to the environment. Developing renewable energy sources (RESs) at the EU level could also decrease the reliance on imports of energy in the member states [6] and increase employment [7], with no safety concern and no security [8]. All governments should use the energy, as long as the sources are limited. A performant economy is based on the smart use of resources [9], and it is based on three pillars: social, economic, and environmental dimensions [10]. Hence, when considering sustainable development, social welfare must also be discussed. The key for solving weather modifications and ecological disasters, as well as economic and social crises, which affect all countries, is sustainable economic growth [11].

The European Commission’s Directive 2009/28/EC on the promotion and use of renewable resources [12] is enforcing compulsory targets by 2020, namely to use 10% of energy from RESs in transport and 20% from total energy use from RESs. The European Council agreed to continue with this strategy through to 2030, by setting a RES target of 27%. Moreover, the European Green Deal is a roadmap for the EU to achieve a sustainable economy. The EU will succeed in turning this into challenging the links of climate change and the environment, with opportunities in all policy areas, and ensuring that the transition is fair and inclusive for European countries.

The EU agenda underlines the importance of sustainable development of the countries as a result of improving the competitiveness of the undertakings in all member states [13]. In this view, governmental policies should implement sustainable strategies of waste-management and transportation [14,15], developing tourism [16] and low-carbon societies [17].

The indicators used in the study are the energy mix produced in the EU, shares of renewable energy in the EU countries, shares of renewable energy in transport, renewable energy shares of electricity in EU member states, and renewable energy primary production. They are described in the next section and presented in Figures 1–5.

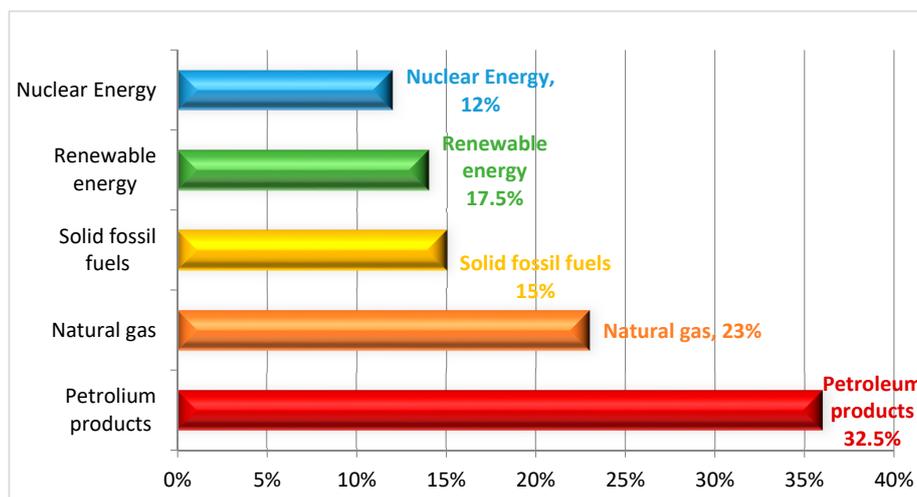


Figure 1. Energy mix produced in the EU in 2017. Source: own computations performed on data retrieved from Eurostat [18].

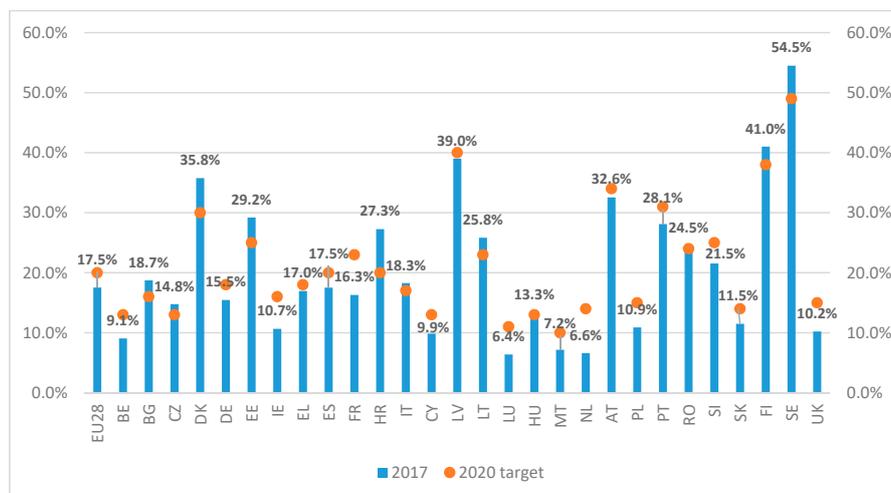


Figure 2. Share of renewable energy in the EU in 2017 and 2020 target. Source: own computations performed on data retrieved from Eurostat [18].

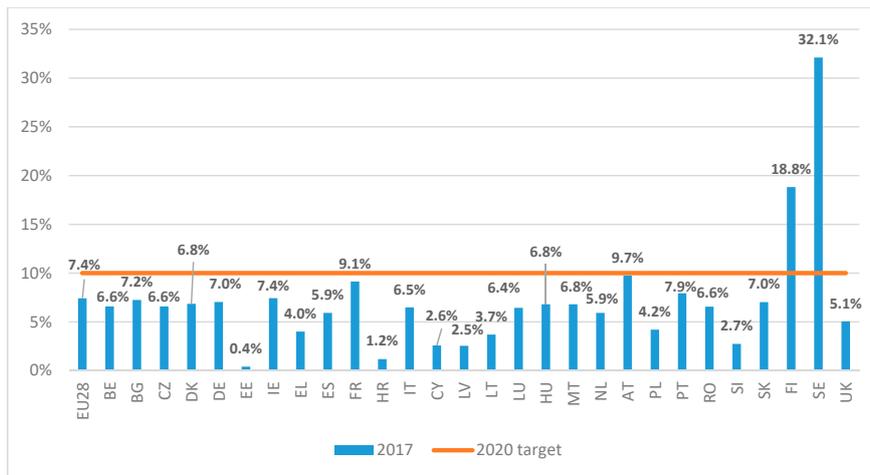


Figure 3. Share of renewable energy in transport, at the EU level, in 2017 and 2020 target. Source: own computations performed on data retrieved from Eurostat [18].

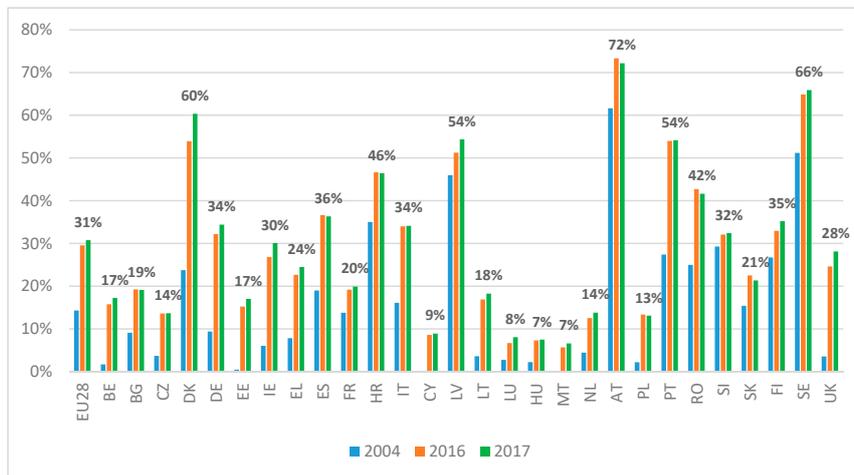


Figure 4. Renewable energy source (RES) shares of electricity in EU member states. Source: own computations performed on data retrieved from Eurostat [18].

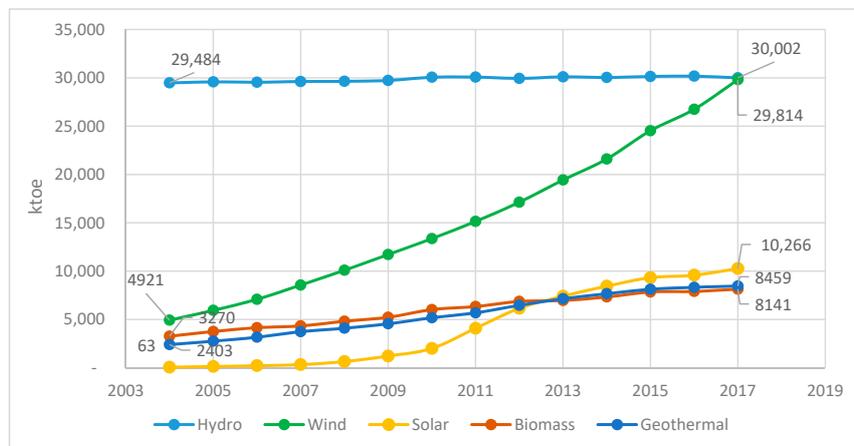


Figure 5. RES primary production in kilo tons of oil equivalent (KTOE), in EU member states, from 2004 to 2017.

The energy consumed in the EU countries comes from both the energy produced within the EU and the imports from other countries. According to Eurostat [18], in 2017, the energy produced in the EU represented a percentage of 45%, while 55% came from imports. The energy mix comes from five sources: nuclear energy, energy from petroleum products, energy from fossil fuels, energy from burning gas, and renewable energy. Figure 1 reveals the energy produced in the EU, by types of energy.

According to Figure 1, at EU the level, the energy consumption produced from renewable sources was 17.5% in 2017, higher than the value from 2016 (16.5%), and it is almost double compared to 2004. These percentages were below the ceiling provided for the Directive 2009/28/EC, which stipulates that the target for 2020 regarding the consumption of energy from RESs is 20%, and 32% for 2030.

Figure 2 shows the percentage of renewable energy consumed in each EU member state and the target set for 2020.

From this chart, it can be seen that only 11 countries in the EU have reached the target set for 2020. With more than half (54.5%) of the energy produced from renewable sources, Sweden is in first place among the energy-producing countries. This is followed in the ranking by Finland (41%), Latvia (39%), and Denmark (35.8%). At the opposite side are the countries with the least renewable energy production, namely Luxembourg (6.4%), the Netherlands (6.6%), and Malta (7.2%).

The 11 countries that have reached the 2020 target for renewable energy are Czech Republic, Bulgaria, Denmark, Croatia, Estonia, Italy, Romania, Lithuania, Finland, Hungary, and Sweden. At the same time, 17 countries did not reach the target set for 2020. Out of these, the Netherlands is at the greatest distance from the proposed target (7.4 pp), followed by France (6.7 pp), Ireland (5.3 pp), and UK (4.8 pp).

With regard to the renewable energy consumption in transport, according to the Directive 2009/28/EC, the target for 2020 is 10% for all the member states. According to Eurostat data [17], in 2017, the average consumption of RESs in transport was 7.4%, up from 7.1% in 2016, and more than five times than in 2004 (1.4%).

Figure 3 shows the consumption of RESs at the EU level, in 2017, and the target set at the European level.

As can be seen from Figure 2, in 2017, only two countries exceeded the target set for 2020, namely Finland (18.8%) and Sweden (32.1%). Of the countries that did not reach their target, the most distant are Latvia (2.5%), Croatia (1.2%), and Estonia (0.4%).

Another important indicator is the use of RESs for electricity production. Figure 4 shows the evolution of renewable energy sources at the EU level, in 2004, 2016, and 2017.

Thus, it can be observed that, at the EU level, the renewable energy used for electricity was 31%, increasing by 1 pp, as compared to 2016, and 17 pp, as compared to 2004. Moreover, except for Slovakia, Poland, and Austria, in all EU member states, the use of RESs has been increasing.

Renewable energy is divided into hydro, wind, solar, biomass, and geothermal. At the EU level, the RES production is measured in kilo ton of oil equivalent (KTOE). KTOE is a unit of energy which is defined as the amount of energy produced from burning one ton of crude oil. In Figure 5, we can see the distribution of RES by energy types, in the EU member states, between 2004 and 2018.

Figure 5 shows the evolution of the main renewable energy systems from 2004 to 2017. Thus, the energy produced from hydro sources had a relatively constant evolution during the analyzed period, having an increase of only 1.7% from 29,484 KTOE in 2014 to 30,002 KTOE in 2017. Wind power had a spectacular growth during this period, from 4921 KTOE in 2004 to 29,814 in 2017, which represents an increase of approximately 506%. At the same time, the energy produced from biomass increased from 3270 KTOE to 8114 KTOE in 2017, representing an increase of 149%. Moreover, solar energy had a spectacular evolution, from 63 KTOE in 2004 to 10,266 KTOE in 2017, which represents an increase of more than 16 times during the analyzed period. Last but not least, geothermal energy grew steadily between 2014 and 2017, from 2403 to 8459 KTOE, which represents an increase of 252%.

The goal of this study is to analyze the impact of RESs, namely hydro, wind, solar, and biomass, on economic growth for a panel of 28 EU member states, from 2004 to 2017. The analysis was performed by an econometric model, and the data were analyzed with the support of EViews 11.0 software.

This paper is structured as follows. First, we make a description of the indicators used in the analysis. Then, a panel autoregressive distributed lag (ARDL) model and causality analysis are performed. Finally, the statistical hypotheses are validated. Discussions, limitations of the analysis, and further research are presented in the conclusions section.

2. Literature Review and Hypotheses Development

As we have noted, in the economic literature, the assessment of the impact of the RESs on economic growth is presented in varied interesting research papers.

As such, Bhattacharya et al. [19], following an analysis conducted between 1991 and 2012 in 38 of the USA states, shows that RESs have a significant and positive impact on economic growth. Inglesi-Lotz [20] finds that, in 34 of the Organization for Economic Co-operation and Development (OECD) members states, RES consumption has been on a positive trend in the past 20 years.

Other studies also analyzed the levels of RES consumption at the EU level. Thus, Huang et al. [21] carried out an analysis on 82 countries divided into three levels, namely high income, middle income, and low income, and proved that there are important differences regarding the impact of the use of RESs on the economic growth.

According to the research conducted by Shahbaz et al. [22] on the types of RESs and their impact on economic growth, the hypotheses are confirmed, finding that the renewable energy produced from biomass is positively correlated with the economic growth based on the research study conducted during the period 1991–2015, in Brazil, Russia, India, China, and South Africa (BRICS countries). Another research paper from 1980 to 2009 [23] indicates that 3% of the economic growth is explained by the use of wind energy in the G7 countries, while only 0.8% of the economic growth of 51 countries in Sub-Saharan Africa is explained by using this energy source. Another study [24] conducted between 1970 and 2012, on data from seven Latin American countries, concludes that there is a close correlation between hydro energy consumption and economic growth in Venezuela and Argentina, in contrast with other countries, having a weakened dependency, such as Brazil, Peru, Chile, Ecuador, and Colombia.

In an analysis from 1985 to 2005, based on 20 OECD member countries, using an estimation methodology on a panel vector error correction model (PVECM) [25], the authors demonstrate that there is a close link between RESs and economic growth. Similar results are found from the analysis of the six Central American countries, from 1980 to 2006 [26], and from 80 other countries around the world [27]. Moreover, in an analysis of the degree of correlation between RESs and economic growth in BRICS countries between 1971 and 2010, the authors of Reference [28] show that, with the exception of China, the degree of correlation is very high.

Several studies complement the correlation analysis with causality tests. Thus, Koçak and Sarkgünesi [29] demonstrate that there is a bi-directional causality between the consumption of energy from renewable sources and the economic growth, making an assessment report on nine countries in the Balkan and Black Sea region, between 1990 and 2012. Similarly, Amri [30] proves the dual causality between economic growth and RESs in a comparative analysis performed on a sample of 23 developed countries and 49 developing countries.

Using the Toda-Yamatoto causality test, Ocal and Aslan [31] indicate the existence of a link between consumption of RESs and economic growth. Similarly, Tiwari [32] evaluates the indicators of 18 emerging countries in the period 1994–2003 and observes that the real growth of GDP per capita has a significant and positive effect on the growth of the renewable energy consumption.

Other authors [33,34] make a radiography of the development of the RESs in the EU member states and highlight the disparities between the Nordic and the southern countries, regarding the degree of the renewable energy use. A benchmarking analysis of the disparities between the EU and

non-EU countries regarding renewable energy [35] shows statistically significant differences between the two categories.

The impact of solar energy on economic growth is addressed in two recent studies [36,37], in which the authors proved that there was a positive and long-term impact of the solar energy on the economic growth. Geothermal energy was analyzed in a recent study [38], in which the authors confirm that investments in geothermal energy production can have a long-term impact on economic growth.

In addition, many researchers [39–42] consider that, in analyzing the impact of the renewable energy systems on economic growth, the indicators of RESs should be taken together with other control factors in determining the econometric models, when using panel time data. These control factors are, when the analysis is done at the state level, macroeconomic indicators. The most used macroeconomic indicators in these studies are labor force, research and development (R&D), resource productivity, greenhouse gas emission, or carbon emissions from transport. Other authors [43,44] consider that one of the solutions for sustainability and resilience transformation in the urban century is to favor the development of green energy.

All of these studies confirm that RESs have a significant impact on economic growth. We will define the statistical research hypotheses, starting with the review of the profile economic literature of this section.

Given the empirical results mentioned in the introductory part, we are addressing the following research question: “What is the impact of the renewable energy on the economic growth at the European level?” To formulate an answer for this question, the author estimates which of the five factors that generate energy from renewable sources, namely, hydro, solar, wind, geothermal, and biomass energy, has a greater impact on the model endogenous variable. In addition to these five independent variables, the model also contains three control variables, which are country-specific, namely resource productivity, labor force in RES, and R&D. According to the aforementioned studies, these independent variables are drivers of economic growth.

To commensurate the impact of the exogenous factors on the dependent variable, five statistical hypotheses were formulated. In Table 1 we can see the research hypotheses of the study.

Table 1. Research hypotheses.

Hypotheses	
H ₁	Hydro energy is a significant factor of the economic growth in EU countries.
H ₂	Wind energy is a significant factor of the economic growth in EU countries.
H ₃	Solar energy is a significant factor of the economic growth in EU countries.
H ₄	Bioenergy is strongly correlated to the levels of economic growth in the EU countries.
H ₅	Geothermal energy is a significant factor of the economic growth in EU countries.

The hypotheses were tested and then validated through an econometric model, which is described in the next section.

3. Research Methodology

3.1. Description of the Sample

Currently, the EU has 28 members, which joined at different times. In the last two decades, there have been three new waves of accession: in 2004, when 10 countries joined the EU; in 2007 when the two new countries joined the EU; and in 2013, when another country, Croatia, adhered to the EU. Thus, our evaluation covers the time period from 2004 to 2017.

In the econometric analysis, 9 indicators were used: one endogenous variable (economic growth) and 8 exogenous variables (5 variables related to RES, by type, and 3 country-level control variables). The data were collected from the Eurostat website, between 2004 and 2017. For the dependent variable, it was used as a GDP/capita as a proxy.

3.2. Model Variables

A description of the endogenous variable (Y) and the 8 independent variables in the model, the 5 variables describing the RESs (X_1 – X_5), by type, and the 3 country-level control variables (X_6 – X_8) can be seen in Table 2.

Table 2. Description of the model variables.

Variable	Name	Definition	Unit
(Y)	Growth of the GDP per capita	The increase of the gross domestic product in EU countries	Percentages (%)
(X_1)	Hydropower	Primary production of hydropower, logarithmic values	KTOE
(X_2)	Wind power	Primary production of wind power, logarithmic values	KTOE
(X_3)	Solar	Primary production of wind solar energy, logarithmic values	KTOE
(X_4)	Biomass	Primary production of wind biomass energy, logarithmic values	KTOE
(X_5)	Geothermal	Primary production of wind solar energy, logarithmic values	KTOE
(X_6)	Resource	The ratio between GDP and domestic material consumption	Percentages (%)
(X_7)	Labor	Labor force in renewable energy sectors, logarithmic values	Millions
(X_8)	R&D	Research and development expenditures as a % of GDP	Percentages (%)

3.3. Research Methodology

This research applies ARDL analysis to the cointegration method. The panel ARDL method was used to test the short-term and long-term cointegration correlations between the independent factors and identify the short-term dynamic by extracting the panel characteristics with the error correction model (ECM). Also, cointegration tests were performed to obtain similar results [45,46]. Eventually, the panel ARDL method was used because it provides more benefits than cointegration.

$$Y_{it} = \alpha_{it} + \beta_{it}X_{it} + u_{it} \tag{1}$$

where Y_{it} is the endogenous variable; X_{it} is the exogenous variables; α_i and β_{it} are the parametric coefficients; u_{it} is the residual term; $i = \overline{1, N}$ is the cross-section dimension, $N = 28$; and t is the time-series dimension, $t = \overline{2004, 2017}$,

$$Y_{it} = \alpha_{it} + \sum_{i=1}^k \gamma_{it} \cdot Y_{i,t-i} + \sum_{i=1}^q \beta_{it} X_{i,t-i} + u_{it} \tag{2}$$

While cointegration test is based on the long-term correlation within the system of equations, the ARDL model is using a concise form [47]. Also, the panel approach in Equation [1] could be applied with the analyzed factors I(0) or I(1) [48]. The panel ARDL model used in Equation (2) could include various lags. This approach cannot be used with standard cointegration tests. Moreover, both short-term and long-term coefficients are provided together when ARDL method is used [49–51].

Equation (2) provides some additional assumptions regarding the exogeneity of the regressors, the parameters and the errors. Furthermore, k is the ideal lag length, and q is the number of independent variables.

To investigate the long-term cointegration correlation between the determinants, the below assumptions are formed:

- H₀: There is no cointegration;
- H₁: There is cointegration.

The no-cointegration assumption can be investigated and compared with the assumption of cointegration by using the F test. Reference [52] is establishing the rules for running the test for small sample volumes. Moreover, if a proof of a long-term correlation between the factors results, the below short-term and long-term in Equations (3) and (4), the models will be estimated simultaneously:

$$(GDPC)_{it} = \beta_2 + \sum_{i=1}^k \alpha_{i2}(GDPC)_{i,t-1} + \sum_{i=0}^k \beta_{i2}(Hydro)_{i,t-1} + \sum_{i=0}^k \gamma_{i2}(Wind)_{i,t-1} + \sum_{i=0}^k \delta_{i2}(Solar)_{i,t-1} + \sum_{i=0}^k \vartheta_{i2}(Biomass)_{i,t-1} + \sum_{i=0}^k \theta_{i2}(Geothermal)_{i,t-1} + \sum_{i=0}^k \varphi_{i2}(Resource)_{i,t-1} + \sum_{i=0}^k \xi_{i2}(Labour)_{i,t-1} + \sum_{i=0}^k \xi_{i2}(R\&D)_{i,t-1} + U_{it} \tag{3}$$

$$\Delta(GDPC)_{it} = \beta_3 + \sum_{i=1}^k \alpha_{i2}\Delta(GDPC)_{i,t-1} + \sum_{i=0}^k \beta_{i2}\Delta(Hydro)_{i,t-1} + \sum_{i=0}^k \gamma_{i2}\Delta(Wind)_{i,t-1} + \sum_{i=0}^k \delta_{i2}\Delta(Solar)_{i,t-1} + \sum_{i=0}^k \vartheta_{i2}\Delta(Biomass)_{i,t-1} + \sum_{i=0}^k \theta_{i2}\Delta(Geothermal)_{i,t-1} + \sum_{i=0}^k \varphi_{i2}\Delta(Resource)_{i,t-1} + \sum_{i=0}^k \xi_{i2}\Delta(Labour)_{i,t-1} + \sum_{i=0}^k \xi_{i2}\Delta(R\&D)_{i,t-1} + \sum_{i=0}^k \psi ECT_{i,t-1} + U_{it} \tag{4}$$

The error correction term (ECT) term is estimated as above, in Equation (4). The parameter Ψ is the coefficient of the ECT in Equation (4) and it validates the fastness of changes of the factors for equation to equilibrium. Also, the parameter gives input for the long-term correlation between the factors in Equation (5). Eventually, validation tests are performed to estimate the sufficiency and accuracy of the equations.

$$ECT_{it} = (GDPC)_{it} - \beta_2 - \sum_{i=1}^k \alpha_{i2}(GDPC)_{i,t-1} - \sum_{i=0}^k \beta_{i2}(Hydro)_{i,t-1} - \sum_{i=0}^k \gamma_{i2}(Wind)_{i,t-1} - \sum_{i=0}^k \delta_{i2}(Solar)_{i,t-1} - \sum_{i=0}^k \vartheta_{i2}(Biomass)_{i,t-1} - \sum_{i=0}^k \theta_{i2}(Geothermal)_{i,t-1} - \sum_{i=0}^k \varphi_{i2}(Resource)_{i,t-1} - \sum_{i=0}^k \xi_{i2}(Labour)_{i,t-1} - \sum_{i=0}^k \xi_{i2}(R\&D)_{i,t-1} \tag{5}$$

To confirm the goodness of fit of the ARDL model, a test of stability was conducted. Parameter stability is important since unstable parameters can result in model misspecification [53]. The Pesaran test [54] involves estimating the vector error correction model (VECM) from Equation (4) and applying the cumulative sum of the residuals (CUSUM) and the cumulative sum of the squares of residuals (CUSUMQ) test to assess the parameter stability.

4. Results

A statistical description of the econometric model variables can be seen in Table 3: median, mean, and standard deviation. These measurements of the central tendency of the indicators show how close the variables of a normal distribution are. In the case of normal distributions, the differences between the average and the median should not be greater than 10% [55]. In the table below, we can see that these values are close, meaning that the variables in the econometric model are following the normal distribution.

Table 3. Description of the model’s variables.

Variable	Mean	Median	Standard Deviation	N
GDPC * (Y)	32,234.88	33,485.23	20,424.61	28
Hydro (X ₁)	1022.04	1053.42	482.56	28
Wind (X ₂)	420.62	440.65	24.89	28
Solar (X ₃)	88.97	102.63	5.89	28
Biomass (X ₄)	2123.67	2240.55	8976.34	28
Geothermal (X ₅)	199.94	185.62	105.82	28
Resource (X ₆)	1.78	1.76	0.51	28
Labor (X ₇)	8.78	8.75	1.59	28
R&D (X ₈)	0.02	0.02	0.02	28

Note: * GDPC = Gross Domestic Product per Capita.

In Table 4, the correlation matrix was calculated for the dependent and independent factors in the model. The correlation matrix was computed to check the existence of multicollinearity between the exogenous factors of the model. According to Dabholkar et al. [56], a multilinear regression model does not have multicollinearity problems when the coefficients of correlation between the exogenous variables have absolute values lower than 0.30.

Table 4. The matrix of correlation.

Variable	Y	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈
Y	1								
X ₁	0.689	1							
X ₂	0.625	0.102	1						
X ₃	0.613	0.164	0.088	1					
X ₄	0.587	0.204	0.203	0.089	1				
X ₅	0.683	0.284	0.089	0.095	0.106	1			
X ₆	0.592	0.153	0.107	0.068	0.107	0.189	1		
X ₇	0.702	0.089	0.112	0.075	0.179	0.197	0.175	1	
X ₈	0.635	0.123	0.093	0.102	0.153	0.202	0.189	0.134	1

Source: Output of EViews 11.0.

As can be seen in Table 4, the coefficients of correlation between the exogenous variables in the model have absolute values lower than 0.30, meaning that there are no problems with multiple collinearity in the econometric model.

For the quantitative analysis, GDP per capita was the endogenous variable (Y), explained by eight independent variables (regressors), namely hydro energy (X₁), wind energy (X₂), solar energy (X₃), bioenergy production (X₄), geothermal energy (X₅), resource productivity (X₆), labor force in RESs (X₇), and R&D development (X₈). In the analysis of the linear regression model, the following stages were followed: model development, estimation of model parameters, and verification of the results obtained.

In Table 5 we could see the results of the panel unit root test for the EU countries between 2004 and 2017. The outcome reveals the stationarity of the sample and the significance of the difference and first difference levels at 1% confidence level. Also, in Table 6 we could observe the Panel Co-Integration Test results for the EU member states in 2004–2017. The results reveal that four of the seven tests are statistically significant at 1% level of confidence, which means that the long-term cointegration correlation between RES and economic growth is plausible. Moreover, Model 1 from Table 7 demonstrates the influence of various factors on the economic growth of EU members from 2004 to 2017.

Table 5. Panel unit root test results for the EU countries, in 2004-2017.

Variable	Difference		First Difference	
	LLC	IPS	LLC	IPS
GDPC (Y)	-6.768 (0.000)	-9.324 *** (0.000)	-4.123 *** (0.000)	-7.546 *** (0.000)
Hydro (X ₁)	-8.213 (0.000)	-8.732 (0.000)	-5.324 (0.000)	-9.145 (0.000)
Wind (X ₂)	-7.497 (0.000)	-7.349 (0.000)	-6.478 (0.000)	-8.546 (0.000)
Solar (X ₃)	-7.415 (0.000)	-5.267 (0.000)	-9.267 (0.000)	-6.842 (0.000)
Biomass (X ₄)	-6.427 (0.000)	-6.348 (0.000)	-10.123 (0.000)	-10.136 (0.000)
Geothermal (X ₅)	-5.195 (0.000)	-7.123 (0.000)	-8.234 (0.000)	-9.652 *** (0.000)
Resource (X ₆)	-4.789 (0.000)	-11.125 *** (0.000)	-6.346 (0.000)	-8.429 (0.000)
Labor (X ₇)	-5.274 *** (0.000)	-9.652 (0.000)	-6.845 *** (0.000)	-6.298 (0.000)
R&D (X ₈)	-8.256 *** (0.000)	-12.145 (0.000)	-11.234 *** (0.000)	-7.863 (0.000)

Notes: *** indicates importance at the 1%, scale. Levin, Lin, and Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS). Values in parentheses are p-values.

Table 6. Panel Co-Integration Test results for the EU member states in 2004–2017.

Dependent Variable: GDPC		
Variables	Without Trend	With Trend
Cross-Section Random		
Pedroni Residual Co-Integration Test		
Alternative hypothesis: common AR coefficients. (within dimension)		
Panel v-Statistic	−0.529 (0.699)	−0.048 (0.521)
Panel rho-Statistic	2.149 (0.884)	2.804 (0.987)
Panel PP-Statistic	−3.849 *** (0.000)	−3.019 *** (0.002)
Panel ADF-Statistic	−6.238 *** (0.000)	−6.698 *** (0.000)
Alternative hypothesis: common AR coefficients. (between dimension)		
Group rho-Statistic	4.402	1.000
Group PP-Statistic	−3.698 ***	(0.000)
Group ADF-Statistic	−5.201 ***	(0.000)

Note: *** refer importance at the 1% scale. Values in parentheses are *p*-values.

Table 7. Summary of the panel regression model 1 for the EU countries during 2004–2017.

Model 1. Panel Data Analysis Estimation for EU States, 2004–2017						
Variable *	Panel PMG		Panel MG		Panel DFE	
	Coefficients	Probability	Coefficients	Probability	Coefficients	Probability
Hydro (X_1)	0.029 ***	(0.000)	0.134	(0.987)	1.109 ***	(0.001)
Wind (X_2)	0.128 ***	(0.000)	0.543	(0.785)	−1.205	(0.041)
Solar (X_3)	0.089 ***	(0.000)	1.098	(0.387)	1.324	(0.325)
Biomass (X_4)	0.078 ***	(0.000)	2.054	(0.143)	1.235	(0.205)
Geothermal (X_5)	0.093 ***	(0.000)	0.789	(0.567)	0.151	(0.678)
Resource (X_6)	0.235 ***	(0.000)	0.481	(0.753)	0.754	(0.267)
Labor (X_7)	0.098 ***	(0.000)	0.127	(0.798)	0.254	(0.674)
R&D (X_8)	0.125 ***	(0.000)	0.874	(0.127)	0.256	(0.769)
Hausman MG test	5.97 (0.179)	(0.000)				

Remark: *** refer importance at the 1% scale. Values in parentheses are *p*-values. PMG = pooled mean group. MG = mean group. DFE = dynamic or difference fixed effect.

The results of the tests from Table 7 reveal the significance of the difference fixed effect (DFE), mean group (MG) and pooled mean group (PMG) tests. The conclusion is that the long-run PMG estimator is more appropriate since the *p*-value of the panel test is statistically insignificant (*p*-value = 0.179). Also, based on the results of the PMG test, we could state that the coefficients of the exogenous variables are positively correlated and are statistically significant with economic growth at 1% level of confidence.

The results of Table 8 indicate the heterogeneous causal direction from the independent variables through dependent variable in EU countries, from 2004 to 2017. The heterogeneous causality tests were firstly indicated in Reference [57]. We could observe that there is a two-way causal direction correlation in the EU members between Gross Domestic Product per Capita (GDPC) and resource; GDPC and labor; and GDPC and R&D. In the same time, there are one-way causality relationships in the EU member states from Hydro to GDPC, from Wind to GDPC, from Solar to GDPC, from Biomass to GDPC, and from Geothermal to GDPC.

Table 8. Panel causality analysis summary for the EU region, from 2004 to 2017.

Heterogeneous Panel Causality Analysis for EU from 2004 to 2017		
Variable *	EU Countries	
	Wald Stat	Probability
Hydro → GDPC	4.271 ***	(0.000)
GDPC → Hydro	1.087	(0.236)
Wind → GDPC	5.256 ***	(0.000)
GDPC → Wind	0.987	0.645)
Solar → GDPC	3.987 ***	(0.000)
GDPC → Solar	0.754	(0.543)
Biomass → GDPC	4.176 ***	(0.000)
GDPC → Biomass	0.964	0.542)
Geothermal → GDPC	2.104 **	(0.032)
GDPC → Geothermal	0.768	(0.256)
Resource → GDPC	5.124 ***	(0.000)
GDPC → Resource	2.389 ***	(0.004)
Labor → GDPC	6.128 ***	(0.000)
GDPC → Labor	0.476	(0.054)
R&D → GDPC	1.267 **	(0.043)
GDPC → R&D	2.897 ***	(0.006)

Notes: ***, **, and * refer importance at the 1%, 5%, and 10% scales, respectively. Values in parentheses are *p*-values.

Next, we examine the long-run and short-run stability of the coefficients. We performed the stability tests for the ECT model, which were described in the previous section. The tests were applied to the residuals of the ECT model (Equation (5)). It can be seen from Figure 6 that the plot of CUSUM stays within the critical 5% bound, and the CUSUMQ is mostly within the 5% significance lines, which suggests the stability of the residual variance. Thus, the results indicate the absence of any instability of ARDL error correction model coefficients.

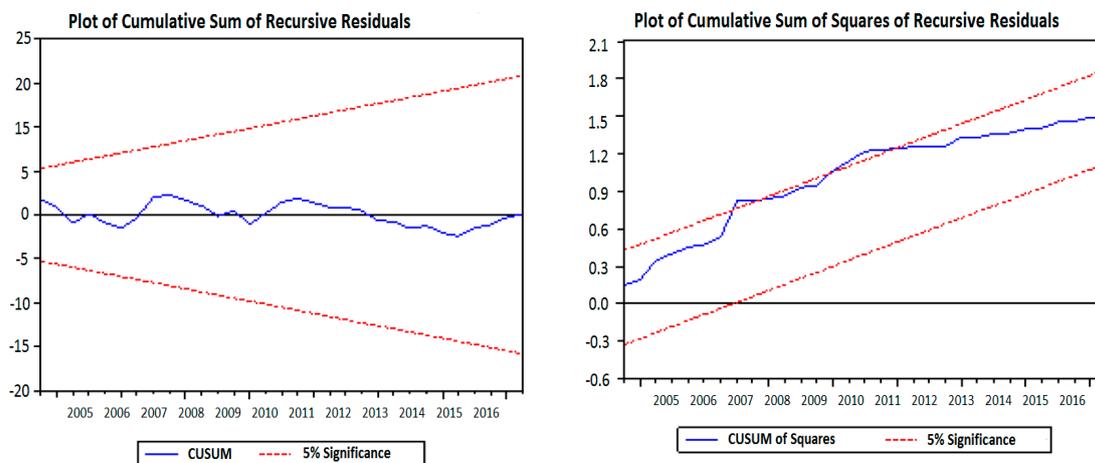


Figure 6. Stability of the coefficients of the autoregressive distributed lag (ARDL) model. Note: The straight lines represent critical bounds at 5% level of confidence. Source: data analysis was performed by the author, using EViews 11.0.

The Hausman test applied to the regression model analyzing the economic growth at EU level during the period 2004-2017, through the independent variables, led to the results that can be observed in Table 9.

Table 9. Impact of hydro energy, wind energy, solar energy, bioenergy production, geothermal energy, resource productivity, labor force, and R&D development in economic growth, at the EU level.

Correlated Random Effects-Hausman Test				
Test Summary		Chi-Square Statistic	Chi-Square d.f. *	Probability
Cross-section random		10.765397	8	0.0856
Dependent variable	Independent variable	Coefficient	Prob.	R-squared
GDPC	Hydro (X ₁)	0.023	0.045	0.245673
	Wind (X ₂)	0.012	0.008	
	Solar (X ₃)	0.007	0.007	
	Biofuels (X ₄)	0.153	0.035	
	Geothermal (X ₅)	0.009	0.003	
	Resource (X ₆)	0.125	0.028	
	Labor (X ₇)	0.237	0.037	
	R&D (X ₈)	0.205	0.005	

Note: * d.f. = degrees of freedom. Source: data analysis was performed by the author, using EViews 11.0.

The results of the panel regression analysis indicate a valid model, while all exogenous variables are statistically significant. In addition, 24.56% of the variability of the dependent variable is explained by the variation of the independent variables. The principal result of these quantitative analyses shows that the determinants of renewable energy (hydro, wind, solar, biofuels, and geothermal) are significantly relevant for the economic growth, while resource productivity, labor force, and R&D development have a positive influence on economic growth, at the European level.

The analysis of the regression coefficients in Table 5 indicates that all renewable energy factors have a positive and significant impact on economic growth. Thus, a 1 percentage point (pp) increase in primary hydro energy production leads to an increase of 0.023 pp of GDP per capita. At the same time, a 1 pp increase in primary production of the wind energy leads to a growth of 0.012 pp of GDP per capita, a 1 pp increase in primary solar energy production leads to an increase of 0.007 pp of GDP per capita, a 1 pp increase in primary biofuels production leads to a 0.153 pp increase in GDP per capita, and a 1 pp increase in primary geothermal energy production leads to a growth of 0.009 pp of GDP per capita. Regarding the control factors, we observe that a 1 pp increase in resource productivity leads to a 0.125 pp increase in GDP per capita, while a 1 pp increase in the labor force leads to an increase of 0.237 pp. GDP per capita and a 1 pp increase in R&D results in a 0.205 pp increase in GDP per capita. Moreover, RESs and the country-control variables, resource productivity, labor force, and R&D explain 24.56% of the economic growth variability.

We next used the Variance Inflation Factor (VIF) test, to test collinearity. The results are shown in Table 10.

Table 10. The Variance Inflation Factor (VIF) test for collinearity.

Variance Inflation Factors			
Date: 10 October 2019 Time: 11:32			
Sample: 2004 2017			
Included Observations: 392			
Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C		5.846	NA
Hydro	1.475	2.107	1.457
Wind	1.598	2.236	1.683
Solar	1.162	2.102	1.108
Bioenergy	1.386	2.607	1.783
Geothermal	1.902	2.107	1.302
Resource	1.476	2.412	1.403
Labor	1.589	2.067	1.355
R&D	1.478	1.987	1.201

C = constant. Source: EViews 11.0 output.

In Table 10, we see that the VIF values for all exogenous variables are from 1 to 5. Hence, we could state that collinearity issues are not presented in our model.

Thus, we see that all five statistical hypotheses developed at the end of the first section are valid.

5. Discussion and Conclusions

Energy is essential for life, but conventional energy is still the principal source of energy. The main problem is that conventional energy causes substantial water and land pollution, and it is also responsible for global warming. As an alternative, renewable energy is limitless, causes less harm for the environment, and creates new jobs. The present paper uses a panel data random-effects regression model, at the EU level, for the timeframe 2004–2017, and demonstrates that the primary production of RESs has a statistically significant and positive impact on economic growth. Moreover, it shows that the county-level control variables are also significant drivers for economic growth.

The cointegration and ECT models developed with the ARDL model, is applied to the data, in order to determine whether a short-run or a long-run equilibrium relationship exists among economic growth and its RES factors. The result indicates that the long-run relationship between the economic growth and its factors is stable. In addition, CUSUM and CUSUMSQ tests confirm the stability of the economic growth model.

The paper was based on the analysis of a panel data regression model, with economic growth, as an endogenous variable and eight exogenous variables: hydro, wind, solar, biofuels geothermal (renewable factors), resource, labor, and R&D (control variables). The results reveal that the strongest impact on economic growth was that of labor force (coefficient = 0.237), followed by R&D (coefficient = 0.205), biomass (coefficient = 0.153), and productivity of the resources (coefficient = 0.125).

From the econometric analysis, having the economic growth as dependent variable and RES as independent factors, we get the following regression equation: $Y = 0.023X_1 + 0.012X_2 + 0.007X_3 + 0.153X_4 + 0.009X_5 + 0.125X_6 + 0.237X_7 + 0.205X_8$.

Given that the value of R-squared is 0.2456, we conclude that 24.56% of the variation of the dependent variable is explained by the independent variables of the model and observe that 75.46% of the variance of the endogenous variable is still determined by other factors which are not included in the study. Moreover, the VIF test reveals that the model does not have collinearity issues.

According to the EU Directive 2009/28/EC, the majority of the EU member states has not yet attained the targets set for the consumption of renewable energy for 2020. According to our analysis, only eleven member states, namely Czech Republic, Bulgaria, Denmark, Croatia, Estonia, Italy, Romania, Lithuania,

Finland, Hungary, and Sweden, achieved their targets, while only two countries, namely Sweden and Finland, met the 10% target of using renewable energy for the transport sector.

The results of our study validate the conclusions of Reference [58], who made a quantitative analysis to determine the factors of economic growth related to energy and demonstrated that the economic growth was partly explained by the levels of R&D, productivity of the resources, and renewable energy. The results are also linked to other research papers [59,60] which state the importance of renewables on economic growth. The authors argue that productivity of the resources and the labor force are two control variables which should be used in the regression model.

In conclusion, we could affirm that the panel data regression model of the economic growth was significant and accurately specified and that the structural factors of RESs, i.e., hydro, wind, solar, biomass, and geothermal primary production, as well as the control variables, such as productivity of the resources, labor force in RESs, and R&D, were significant factors of the economic growth at the EU level. This research paper builds on the recent economic literature dealing with the causality between the renewables and the economic growth, at the EU level [61–68].

Limitations of the study are represented by the timeframe and the number of regressors used in the econometric model. Future research should analyze the impact of RESs on economic growth by using non-linear models. Moreover, the purchasing power parity will not be overlooked as an alternative indicator of the real GDP.

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Abbreviations

EU	European Union
EC	European Commission
GDP	gross domestic product
GDPC	gross domestic product per capita
R&D	research and development
RES	renewable energy systems
EUROSTAT	European Union Statistical Office
OECD	Organization for Economic Co-Operation and Development
ARDL	autoregressive distribution lag
VIF	Variance Inflation Factor
ECT	error correction term
KTOE	Kilo ton of oil equivalent
CUSUM	cumulative sum of the residuals
CUSUMQ	cumulative sum of squares of the residuals

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