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The Nexus Between Convergence of Conventional and Renewable Energy Consumption in the Present European Union States. Explorative Study on Parametric and Semi-Parametric Methods

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Abstract: Economic and social progress is directly and closely related to energy consumption. In the latest decades, there is a higher need to reduce energy consumption from conventional sources, replacing it with energy obtained from unconventional sources. The environmental concern is one of the objectives of the European economic policy, with a particular focus on renewable energy consumption and energy efficiency in order to lower the environmental impact. In this context, we analyzed energy consumption per capita and renewable energy consumption per capita in the EU with the help of parametric methods, using the β -convergence model, and semiparametric methods, using the σ -convergence model. In this research we proposed to study six analysis models of the period 1960–2015, based on the availability of data. We concluded that the EU states went through a convergence process in a slow pace of energy consumption per capita and renewable energy per capita, showing a convergence pattern. The results of the study show that there is a relationship between the convergence of conventional energy consumption and the convergence of renewable (unconventional) energy consumption. The study covers a long period of time in which EU member states had different economic and social systems, implicitly different degrees and rates of development. In addition, the interest in renewable energy is relatively recent in the whole world. There is a possibility that future research will provide more optimistic results, in terms of accelerating the convergence rate, as appropriate measures and technologies are applied to renewable energy production in all EU member states.

Keywords: energy consumption; renewable energy consumption; β -convergence; σ -convergence; EU member states

1. Introduction

The concerns for ensuring a sustainable economic growth, the global concerns regarding the fragile balance between the consumption increase and the resource constraints, the threat of pollution and global warming, and energy security are the starting points for several energy consumption analyses. Beyond the cost-benefit analyses and those aiming to measure the environmental impact of energy consumption, with both positive and normative values, the research on the convergence of

energy consumption are of major importance from the perspective of regulations and policies which can strengthen efforts in this direction. Considering that renewable energy is a key factor the energy efficiency of EU countries [1], the analysis of the convergence of energy consumption must take into account both its conventional form (oil, natural gas, and coal) and unconventional form (wind, solar, wave, biomass, geothermal, etc.).

The interest about mitigating the negative consequences of environmental degradation, price volatility of conventional energy sources, and government policies favorable to the use of renewable energy have led to the increase in the importance of unconventional energy sources in total global energy consumption [2]. Renewable energy is the fastest growing form of energy in the world, expected to become the leading source of primary energy consumption in 2050 [3]. However, increasing energy consumption from renewable sources should meet some requirements in terms of reliability, affordability, and environmental responsibility [4]. For example, Piłatowsha et al. [5] reached the conclusion that increasing renewable energy consumption does not lower the amount of emissions, the impact being negative or insignificant.

The use of renewable energy contributes to the increase of employment and reduces the dependence on external energy sources [1]. However, the reduction of external energy dependence involves exceeding a threshold before which the cost of export substitution by energy production from domestic sources does not make it profitable [6]. Underlying the sustainable growth of energy production capacity is the reduction of the cost of renewable energy and the improvement of the stability of energy systems, through technological evolution [2]. The adoption of policies promoting the energy consumption from renewable sources is conditional, at national level, by a few social aspects. Among them, Vachon & Menz [7] identified the population's level of income, education, and participation rate in environmental pressure groups.

In the EU, the share of energy from renewable sources in gross final energy consumption reached 18.0% in 2018, being duplicated in 2004 (8.5%) [8]. If the goal of the EU is to reach 20% of its renewable energy needs by 2020, and to reach 32% by 2030, at national level the results obtained by the member states are, from one case to another, closer or farther from the proposed targets.

Convergence is correlated with economic growth, but its study is broken down into areas of economic and social interest. Energy has been an area of great interest for convergence analyses, with concerns on the study of the convergence of energy consumption, intensity and use of energy, among countries or regions, energy consumption being an important indicator for the European economy [9]. The purpose of an analysis of the convergence of energy consumption among countries is to improve energy and environmental policies [10,11].

Although the literature abounds with studies on convergence among states regarding energy-related variables, there is little work addressing the concept in EU, and no study examining the convergence of energy consumption per capita among EU28 countries. The analyses generally confirmed the convergence of energy intensity between transition countries and EU member states [12], among EU member states and among European member or non-member states. However, the convergence hypothesis was refuted in a study on the convergence of energy intensity, consumption, and emissions in Europe [13].

Our paper complements the literature debates, exploring with the help of parametric and semi-parametric methods the convergence of renewable and non-renewable energy consumption per capita among EU countries. Two types of convergence are studied: β convergence and σ convergence. The conclusion of the paper shows opinions on a convergence pattern from the perspective of both energy consumption per capita and renewable energy consumption per capita. The results are presented for six analysis models, of which four models are for energy consumption, and two models are for renewable energy consumption. Thus, our objective is to see if there is a convergence pattern of EU28 states. Furthermore, the results of the study show that there is a relationship between the convergence of conventional energy consumption and the convergence of renewable (unconventional) energy consumption.

The paper is structured as follows: the first part substantiates the scientific literature on the concepts used in the theoretical approach of the analysis; followed by methodological substantiation and presentation of research methods; and continuing with the results and discussion section; followed by conclusions, limitations, and future directions of research.

2. Literature Support and Hypothesis Development

The concept of convergence was introduced in the literature by Solow [14], later tested and developed by Baumol [15], Barro and Sala-i-Martin [16], Levine and Renelt [17], and others. Convergence studies have their origins in the theory of economic growth, developing around the core of research provided by Islam [18] and Abreu et al. [19] on income convergence. Convergence occurs mainly between homogeneous groups of countries, and divergence between heterogeneous groups of countries [20]. In terms of its forms, convergence is real, nominal, structural, absolute, unconditional, conditional, and club [21,22].

Convergence among European regions is somewhat ambiguous [23], but it is a priority process within the mutual policy. Innovation often explains the gaps and the convergence among European regions [24]. Innovations tend to highlight, not to diminish the inter-regional disparities, at least in the short term, so that persistent economic gaps continue to be a challenge across Europe [24,25], leading to the shaping of several convergence clubs.

Gáspár [21] studied omega convergence, which is calculated on a single or multivariate basis, being a modified standard deviation of cluster differences. According to Delgado et al. [26], convergence forces appear dominant at the microeconomic level.

However, long-term convergence is not ensured, poor regions become more homogeneous in terms of living standards, without achieving the performance of the rich ones [27]. The global economies are slowly converging towards their own equilibrium stage in the case of high- and low-income countries, indicating club-type convergence [20]. Convergent behavior is also described by the concept of weak σ -convergence, which can be conditional and unconditional [28]. Convergence takes the weak and the strong form.

However, economic, socio-political, and governmental differences among European member states reduce the convergence rate. Territorial proximity and similarity are those playing a positive role [29], especially the structural ones [30]. Economies which tend toward the same equilibrium are integrated into a convergence club, especially when the original conditions are similar [31].

Some studies refute the conclusions already mentioned. Thus, the crisis seems to have substantially slowed down the economic growth process, and the convergence calculated on the European area even stopped it, with situations characterized by the manifestation of divergence elements [32]. Therefore, the manifestation of different convergence rates among regions demonstrates insignificant growth rates [33]. Convergence reduces certain gaps, but highlights others, a European feature being the existence of economic, social, and geographical divergences [34,35].

In this context, the analysis of the convergence of energy consumption deserves both an integrative perspective, as a whole, and one at the level of the component, with the most promising growth rate (i.e., renewable energy). In the current context of sustainability concerns, we will refer to a few results, distinctly on the two components: energy consumption and renewable energy consumption. These components will be the starting point for formulating the hypotheses of our study.

Regarding the convergence of energy consumption, a research direction focused on the study of the convergence of energy variables between two groups of states. For example, for the period 1971–1992, it was agreed that developed and developing countries converged towards a common pattern in energy use [36]. Following the expansion of the EU to Eastern Europe, the study conducted by Markandya et al. [12] confirmed the convergence hypothesis.

Another direction of research aimed at confirming or refuting the convergence of energy variables or identifying patterns of convergence/divergence or convergence clubs, Fallahi and Voia (2015) [37]. The presence of β convergence, both absolute and conditional, in the energy consumption per capita,

using spatial dynamic econometric models, was analyzed among Chinese provinces [10] over a period of two decades (1994–2014). Using the dynamics of cross-section distributions, Kounetas [13] refuted the hypothesis of a convergence pattern of energy consumption and emissions for 23 European states between 1970 and 2010, while Mussini [38], with the help of a research on β -convergence of energy intensity and of the re-ranking of countries within the energy intensity distribution, found evidence of convergence in the first years of the period, and a slowdown in the second part of the interval.

The interest in renewable energy occurred during the energy crisis of the mid-1970s [39], when the risk of running out of fossil fuel led to the development of renewable energy sources [40,41]. More recently, the risks associated with CO₂ emissions [42] and global warming [43] have again aroused interest in renewable energy.

Regarding the convergence of renewable energy consumption, a study by Payne, Vizek and Lee [44] confirmed β and σ convergence in the USA. Berk, Kasman and Kılınc [45] obtained interesting results, according to which the contribution of renewable energy sources to primary energy consumption is characterized by a process of convergence, both absolute (unconditional) and conditional in EU core countries in the period 1990–2014. Another study, conducted by Reboredo [46], analyses the convergence for the period 1990–2010, and argues that only a small number of countries with significant and growing renewable energy sectors show convergence, the rest indicating mainly divergence and different temporal patterns. The hypothesis of convergence of renewable energy consumption was also tested by Solarin, Gil-Alana, and Al-Mulali [47] for 27 OECD countries with the help of parametric and semi-parametric methods. The results show evidence of convergence in both methods. Demir and Cergibozan [48] obtained similar results, showing that there is a statistically significant convergence process in OECD countries.

Based on the main tendencies and results regarding the convergence studies identified in the literature, the hypotheses of our study are:

Hypothesis 1 (H1): *Energy consumption per capita in EU member states shows a convergence pattern.*

Hypothesis 2 (H2): *Renewable energy consumption per capita in EU member states shows a convergence pattern.*

Hypothesis 3 (H3): *There is a nexus between the convergence of conventional energy consumption and the convergence of renewable energy consumption.*

3. Materials and Methods

The empirical analysis was performed for a long period of time, 1960–2015. The goal is to capture the processes analyzed in the dynamics of a significant period starting from the creation of the European Economic Community (EEC) since 1957. As the availability of statistical data and the division of the interval into subperiods did not allow us to achieve this goal, we decided to analyze the period 1960–2015. The chosen interval captures the issues investigated before the introduction of the euro in 1992 and on the entire period of geographical and economic metamorphosis of the EU. In this way we captured any changes as new members have joined the European system.

Considering the theoretical aspects of convergence and the studies on energy consumption per capita using convergence-based econometric analysis models [13,37], in the current research the calculation method for β -convergence considers the equation proposed by Baumol [15] and used in the research conducted by Hao and Peng [10] and Dumitrescu-Moroianu [49].

$$\frac{1}{T}[\ln(y_{i,T}) - \ln(y_{i,t_0})] = \alpha + \beta \ln(y_{i,t_0}) + \varepsilon_t \quad (1)$$

where T is the time interval analyzed, y_T is energy consumption (kg of oil equivalent per capita) at the end of the period of time, t_0 is the initial period of time, y_{t_0} is energy consumption (kg of oil equivalent per capita) at the beginning of the period of time, β is the slope parameter, and ε is the statistical error.

The studies conducted by Butnaru et al. [50], Butnaru and Haller [51], Goschin [52], Butnaru and Niță [53], and Dvoroková [54] used Baumol's [15] modified equation, as shown by the following model:

$$\frac{1}{T} \ln \left(\frac{y_{i,T}}{y_{i,t_0}} \right) = \alpha + \beta \ln(y_{i,t_0}) + \varepsilon_i \quad (2)$$

for which α is a constant level.

When measuring convergence, we can also calculate σ -convergence which uses as indicator the coefficient of variation of the energy consumption level (kg of oil equivalent per capita) [13,35,50–53], calculated according to the following model:

$$\sigma_t = \sqrt{\frac{\sum_i [\ln(y_{i,t}) - \ln(\bar{y}_t)]^2}{(N-1)}} \quad (3)$$

where N is the number of EU28 member states.

The model proposed by Equation (3) is used to analyze the level of convergence by measuring the dispersion of the energy consumption. The σ -convergence indicator is relevant when comparing certain countries in the analysis.

In our study we used data for “energy consumption” and for “renewable energy consumption”.

4. Results and Discussions

In our study we used data from the World Bank [55] for energy consumption (kg of oil equivalent per capita) and for renewable energy consumption.

4.1. Estimation of Econometric Model for β Convergence

4.1.1. β -Convergence of Energy Consumption

Mathematically, the model for β -convergence presented above can be written using Equation (4):

$$\frac{1}{T} \ln \left(\frac{\text{Energy consumption}_{T_i}}{\text{Energy consumption}_{t_0}} \right) = \alpha + \beta \ln(\text{Energy consumption}_{t_0}) + \varepsilon_i \quad (4)$$

where α is a constant, β is the slope, ε is the error, T is number of years corresponding to the time interval analyzed, t_0 is the initial period of time, T_i is the end of the period of time.

The energy consumption analysis was performed in four stages, proposing four analysis models. In Model 1, we included 16 EU member states (EU16) in the analysis, and the period of time analyzed was 1960–2015. We have lowered the number of countries from 28 to 16 due to some missing statistical data, such as for the years 1960–1970 and also for 2015 there are no data for Bulgaria, Cyprus, Malta, and Romania; for the years 1960–1970 there are no data for Slovak Republic and Czech Republic; for the years 1960–1989 and also for 2015 there are no data for Estonia, Croatia, Lithuania, and Latvia; for the interval 1960–1989 there are no data for Slovenia; and also for Hungary there are no data for the years 1960–1964. In Model 2, we included 19 EU member states (EU19) in the analysis, and the period of time analyzed was 1971–2015. We lowered the number of countries from 28 to 19 due to missing data for the year 2015 for Bulgaria, Cyprus, Malta, and Romania; and in the case of Estonia, Croatia, Lithuania, Latvia, and Slovenia, for the missing data for the years 1971–1989. In Model 3, we included 23 EU member states (EU23) in the analysis, and the period of time analyzed was 1971–2014. We added to the analysis Bulgaria, Cyprus, Malta, and Romania, countries with missing data for the year 2015, but we have narrowed the time frame from 1971–2015 to 1971–2014. In Model 4, we included all EU

member states (EU28) in the analysis, and the period of time analyzed was reduced from 1971–2014 to 1990–2014.

In the mathematical operations of Equation (4) we used the values of energy consumption (kg of oil equivalent per capita) corresponding to the time intervals analyzed. The results of the calculations for the values of natural logarithms are summarized in Table 1.

Table 1. β -convergence of energy consumption for the 4 models of analysis.

EU Member States	Model 1—UE16 1960–2015		Model 2—UE19 1971–2015		Model 3—UE23 1971–2014		Model 4—UE28 1990–2014	
	x_i	y_i	x_i	y_i	x_i	y_i	x_i	y_i
Austria	7.343595	0.016058	7.827449	0.009231	7.827449	0.009218	8.083363	0.005988
Belgium	7.831815	0.011088	8.318731	0.002977	8.318731	0.003144	8.478425	−0.000854
Bulgaria	-	-	-	-	7.709168	0.002407	8.082511	−0.010698
Cyprus	-	-	-	-	6.852053	0.013488	7.484762	−0.001570
Czech Republic	-	-	8.437805	−0.003986	8.437805	−0.003755	8.475734	−0.008125
Germany	7.576911	0.011972	8.267517	−0.000448	8.267517	−0.000686	8.394204	−0.006275
Denmark	7.561628	0.006815	8.223771	−0.006233	8.223771	−0.005927	8.124679	−0.006469
Spain	6.274131	0.028180	7.126813	0.016119	7.126813	0.015522	7.748234	0.002463
Estonia	-	-	-	-	-	-	8.737570	−0.012215
Finland	7.694827	0.017715	8.278736	0.009070	8.278736	0.010357	8.646742	0.003509
France	7.437943	0.013845	8.015598	0.004392	8.015598	0.004303	8.254952	−0.002002
United Kingdom	8.017324	−0.001659	8.225043	−0.006680	8.225043	−0.006727	8.187870	−0.010352
Greece	5.666624	0.036097	6.891669	0.017697	6.891669	0.017485	7.650967	0.000402
Croatia	-	-	-	-	-	-	7.591453	−0.001719
Hungary	-	-	7.515535	0.006250	7.515535	0.005259	7.928223	−0.007251
Ireland	7.184487	0.013571	7.716605	0.005063	7.716605	0.004538	7.944638	−0.001134
Italy	6.678111	0.020332	7.575148	0.005368	7.575148	0.004866	7.857051	−0.002712
Lithuania	-	-	-	-	-	-	8.376591	−0.023947
Luxembourg	9.261357	−0.008471	9.381187	−0.013205	9.381187	−0.012445	9.090893	−0.010291
Latvia	-	-	-	-	-	-	7.989318	−0.012147
Malta	-	-	-	-	6.545287	0.021362	7.581538	−0.003853
Netherlands	7.509847	0.015015	8.257185	0.002078	7.629918	−0.005850	8.388119	−0.000633
Poland	7.510943	0.005521	7.873606	−0.001189	8.257185	0.002616	7.903082	−0.003589
Portugal	5.819827	0.032944	6.587620	0.023934	7.873606	−0.001369	7.427122	0.007636
Romania	-	-	-	-	6.587620	0.023418	7.894758	−0.020889
Slovak Republic	-	-	8.048342	−0.000906	8.048342	−0.001388	8.300198	−0.012518
Slovenia	-	-	-	-	-	-	7.957725	0.004978
Sweden	7.900560	0.011375	8.400745	0.003040	8.400745	0.002493	8.615147	−0.004188

Source: Calculations performed by authors based on the data provided by World Bank 2019 [55].

As we can see in Figures 1–4, the linear equations have the form $y = \alpha + \beta x$:

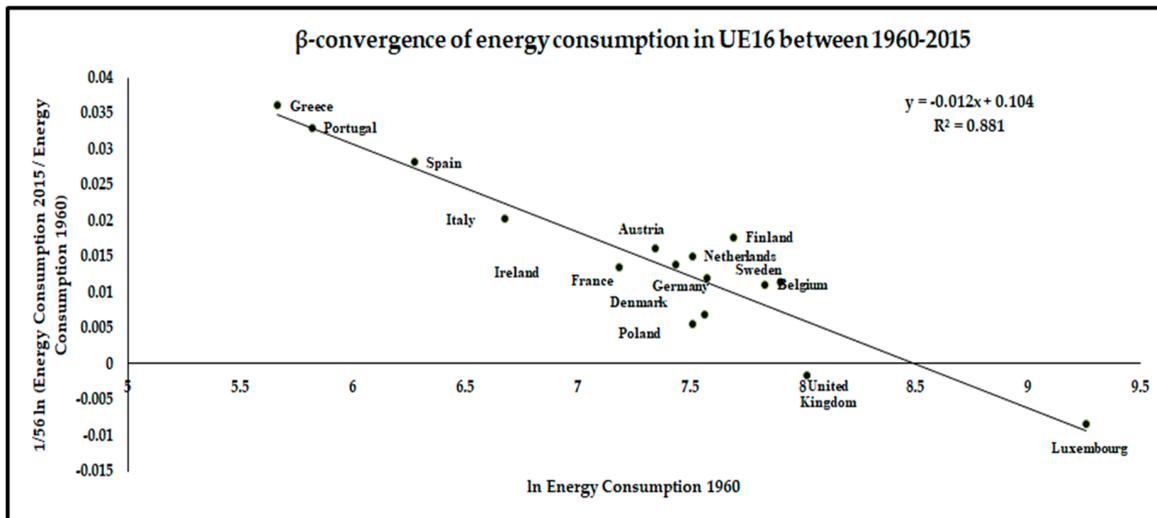


Figure 1. β-convergence of energy consumption in UE16 1960–2015 (Model 1).

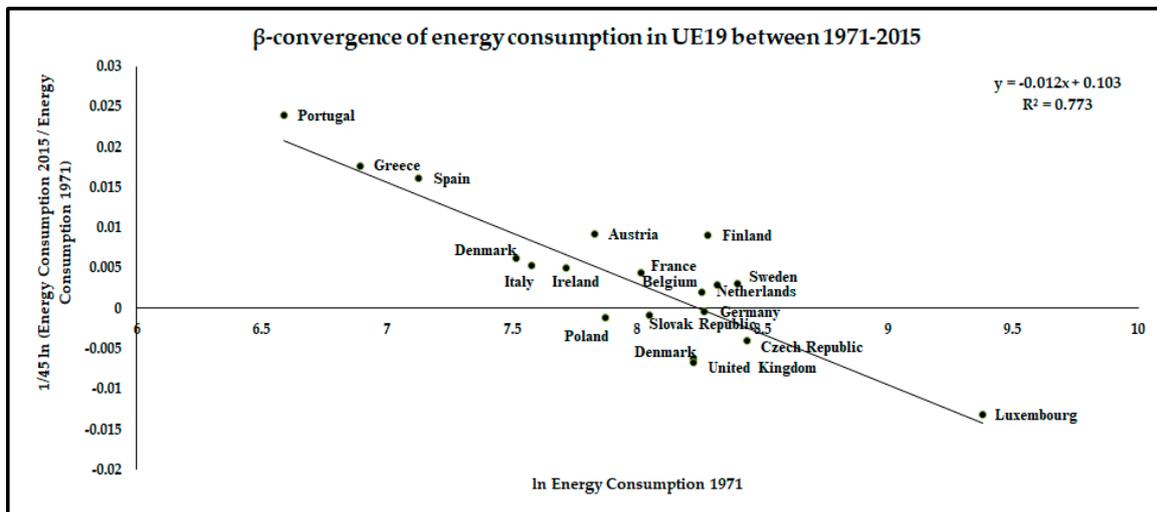


Figure 2. β-convergence of energy consumption in UE19 1971–2015 (Model 2).

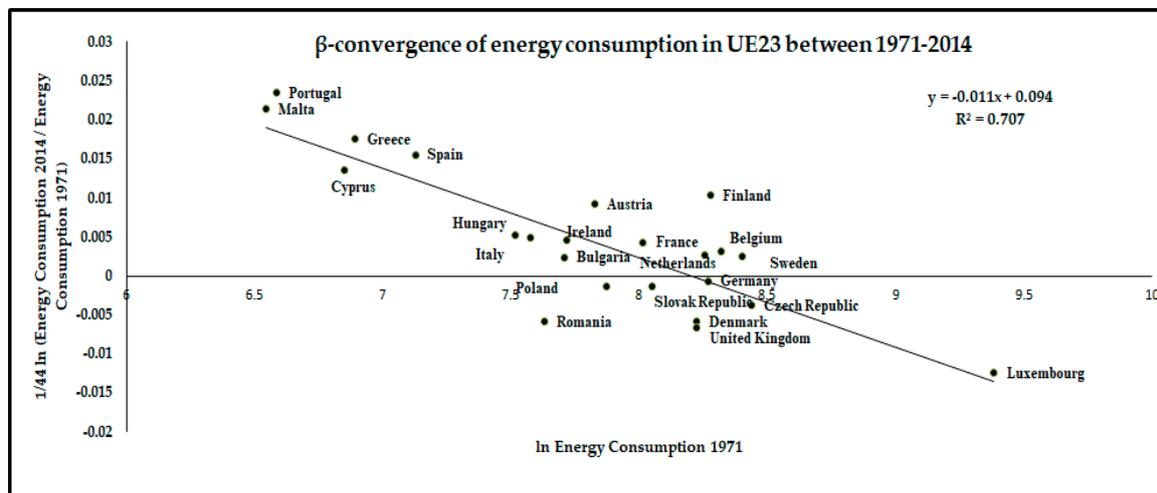


Figure 3. β-convergence of energy consumption in UE23 1971–2014 (Model 3).

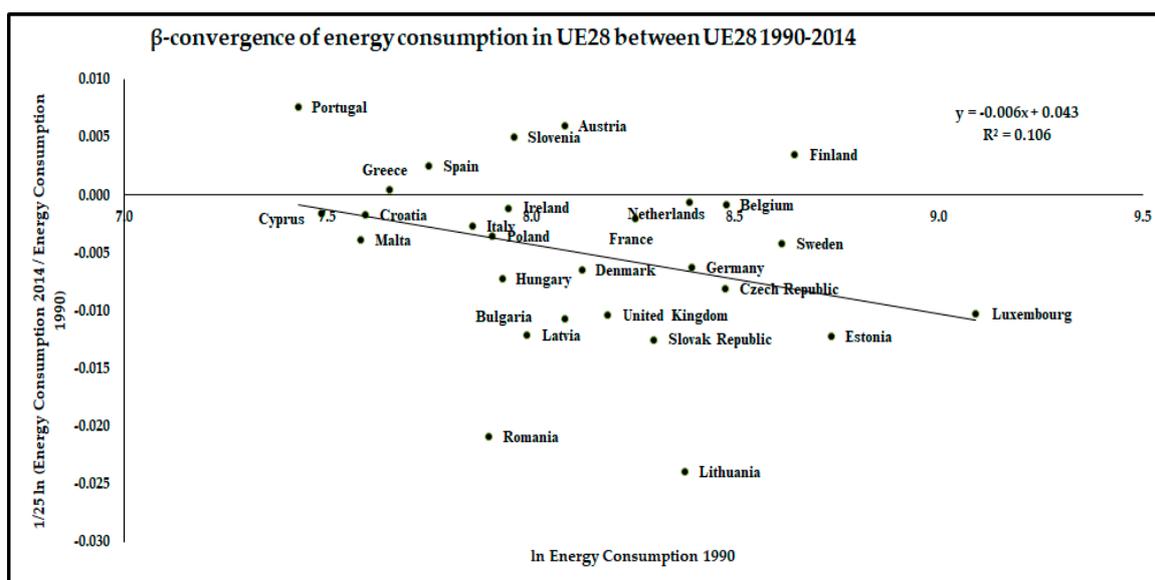


Figure 4. β-convergence of energy consumption in UE28 1990–2014 (Model 4).

Table 2 shows: R, R², and Fisher test, Durbin–Watson test, Pearson Correlation, β, α and T test sig. (p-value) for energy consumption (kg of oil equivalent per capita) in the EU countries corresponding to the time series of the 4 models analyzed:

Table 2. Results of econometric model for β-convergence of energy consumption for the 4 models of analysis.

Energy Consumption	Variables	Summary Model		Anova Sig.F.Test	Durbin-Watson	Pearson Correlation	Linear Equation	Coefficients	
		R	R ²					Value	Sig.t.Test
Model 1 UE16	Independent	0.939	0.881	0.000	2.083	-0.939 sig.0.000	y = -0.012x + 0.104	-0.012	0.000
	Dependent							0.104	0.000
Model 2 UE19	Independent	0.880	0.773	0.000	2.103	-0.880 sig.0.000	y = -0.012x + 0.103	-0.012	0.000
	Dependent							0.103	0.000
Model 3 UE23	Independent	0.841	0.707	0.000	2.332	-0.841 sig.0.000	y = -0.011x + 0.094	-0.011	0.000
	Dependent							0.094	0.000
Model 4 UE28	Independent	0.326	0.106	0.091	2.065	-0.326 sig. 0.045	y = -0.006x + 0.043	-0.006	0.091
	Dependent							0.043	0.127

Source: Calculations performed by authors in SPSS based on the data provided by World Bank 2019 [55].

Pearson correlation coefficient shows how strongly the variables in the model are correlated. R varies between -1 and +1. A correlation of -1 means that the two variables are in perfect opposition. One goes up and another goes down, in a perfectly negative way. If they are not correlated, then the correlation value will be 0. A value of 1 will represent a perfectly positive correlation. In Table 2, R value is between 0.326 and 0.939, which shows a positive correlation of average intensity (Model 4) towards a perfectly positive correlation (Model 1). For UE16 the correlation is -0.939 (sig.0.000), for UE19 it is -0.880 (sig. 0.000), for UE23 it is -0.841 (sig. 0.000), for UE28 it is -0.326 (sig. 0.045). The square of the correlation coefficient (R²) indicates the proportion of variation of one variable “explained” by the other variable [56] and varies from 0 to 1. Durbin–Watson test is a measure of the autocorrelation (also called serial correlation) of the residues in the regression analysis. The values of the test statistics are between 1.5 and 2.5. Values outside this range could be worrying. In Table 2,

the value of the Durbin–Watson test is between 2.065 and 2.332, which shows that the values obtained fall within this range. The calculation formula for the Durbin–Watson test is given in Equation (5):

$$d = \frac{\sum_{t=2}^T (e_t - e_{t-1})^2}{\sum_{t=1}^T (e_t)^2} \quad (5)$$

where T is the number of observations and e_t is the error.

The analysis of linear regression shows that for the EU16 countries there is a significant negative relationship between the two variables ($r = -0.012$, $p = 0.000$). This suggests that a change by one unit of the value of the independent variable x will lead to a change in the value of the dependent variable y by -0.012 . Sig. F. is also 0.000, which means that the model is statistically significant and more efficient than a model without a predictor. For the EU19 and EU23 countries there is a significant negative relationship between the two variables ($r = -0.012$, $p = 0.000$) and ($r = -0.011$, $p = 0.000$), while for the EU28 countries there is an insignificant negative relationship between the two variables ($r = -0.006$, $p = 0.091$).

Mathematically, β -convergence of energy consumption for the four analyzed models are presented in Table 3:

Table 3. Mathematical presentation for Equation (4).

Energy Consumption	β -Convergence
Model 1 UE16	$\frac{1}{56} \ln\left(\frac{\text{Energy consumption}_{2015}}{\text{Energy consumption}_{1960}}\right) = 0.104 - 0.012 \ln(\text{Energy consumption}_{1960})$
Model 2 UE19	$\frac{1}{45} \ln\left(\frac{\text{Energy consumption}_{2015}}{\text{Energy consumption}_{1971}}\right) = 0.103 - 0.012 \ln(\text{Energy consumption}_{1971})$
Model 3 UE23	$\frac{1}{44} \ln\left(\frac{\text{Energy consumption}_{2014}}{\text{Energy consumption}_{1971}}\right) = 0.094 - 0.011 \ln(\text{Energy consumption}_{1971})$
Model 4 UE28	$\frac{1}{25} \ln\left(\frac{\text{Energy consumption}_{2014}}{\text{Energy consumption}_{1990}}\right) = 0.043 - 0.006 \ln(\text{Energy consumption}_{1990})$

The negative values of the parameter β (-0.012 ; -0.012 ; -0.011 ; -0.006) are the expression of the inverse relationship between the average annual growth rate of energy consumption per capita for the time intervals T ($T = 56$ years for Model 1, $T = 45$ years for Model 2, $T = 44$ years for Model 3, and $T = 25$ years for Model 4), and the original level of energy consumption per capita in the year t_0 ($t_0 = 1960$ for Model 1, $t_0 = 1971$ for Model 2, $t_0 = 1971$ for Model 3, and $t_0 = 1990$ for Model 4). The positions of the United Kingdom and Luxembourg on the graph included in Figure 1 show that y_i has negative values, indicating that these countries do not indicate a β -convergence of energy consumption. Greece, Portugal, Spain, Austria, Netherlands, Germany, Sweden, Finland, and Belgium show a convergence from above, due to the fact that the values of the points corresponding to the model $\frac{1}{T} \ln\left(\frac{\text{Energy consumption}_{T_i}}{\text{Energy consumption}_{t_0}}\right)$ are above the curve corresponding to the linear correlation. The points under the curve correspond to Italy, Ireland, France, Denmark, and Poland, which indicate a convergence from below. These results test the hypothesis H1, according to which there is a convergence pattern for the EU16 countries. The graph in Figure 2 shows that for the United Kingdom, Luxembourg, Czech Republic, Denmark, Poland, Slovak Republic, and Germany, y_i has negative values, which indicates that for these seven countries there is no β -convergence of energy consumption. Greece, Portugal, Spain, Austria, France, Belgium, The Netherlands, Sweden, and Finland show a convergence from above due to the fact that the values of the points corresponding to the model analyzed are above the linear correlation curve. The points below the curve correspond to Italy, Ireland, and Denmark, which indicate a convergence from below. The results obtained test the hypothesis H1, according to which there is a convergence pattern for the EU19 countries. For Germany, Czech Republic, Poland, Romania, Slovak Republic, Denmark, United Kingdom, and Luxembourg, the graph in Figure 3 shows that y_i has negative values, i.e., these countries do not have a β -convergence of energy consumption.

Portugal, Malta, Greece, Spain, Austria, France, Netherlands, Sweden, Finland, and Belgium show a convergence from above, and Cyprus, Hungary, Italy, Ireland, and Bulgaria show a convergence from below, confirming the H1 hypothesis, stating that there is a convergence pattern for the EU23 countries. Figure 4 shows that y_i has negative values for 22 countries out of the 28 countries analyzed, indicating that Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, France, United Kingdom, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Romania, Slovak Republic, and Sweden do not show a β -convergence of energy consumption. Portugal, Greece, Spain, Slovenia, Austria, and Finland indicate a convergence from above, because the values of the points are above the curve corresponding to the linear correlation. In this case, since for 22 countries out of the 28 countries included in the analysis (EU28) there is no β -convergence, hypothesis H1 is not confirmed.

4.1.2. β -Convergence of Renewable Energy Consumption

Mathematically, the model for β -convergence presented above can be written with the help of Equation (6):

$$\frac{1}{T} \ln \left(\frac{\text{Renewable energy consumption}_{T_i}}{\text{Renewable energy consumption}_{t_0}} \right) = \alpha + \beta \ln(\text{Renewable energy consumption}_{t_0}) + \varepsilon_i \quad (6)$$

where α is a constant, β is the slope, ε is the error, T is number of years corresponding to the time intervals analyzed, t_0 is the initial period of time, T_i is the end of the period of time.

Our study included in the analysis 27 EU member states (EU27) consuming renewable energy, for the period of time between 1990–2014. In Model 5 we narrowed the number of countries from 28 to 27, because the statistical data for Malta for the period 1990–2001 are missing.

Considering the stages of establishing the sample of countries included in the analysis, the research hypothesis H2 will be tested further.

In the mathematical operations in Equation (4) we used the values of renewable energy consumption (kg of oil equivalent per capita) corresponding to the periods analyzed. The results of the calculations for the values of the natural logarithms are summarized in Table 4.

Table 4. β -convergence of renewable energy consumption for Model 5 of the analysis.

EU Member States	Model 5—UE27 1990–2014		EU Member States	Model 5—UE27 1990–2014	
	x_i	y_i		x_i	y_i
Austria	6.702484	0.019678	Hungary	4.672857	0.048838
Belgium	4.111847	0.077818	Ireland	4.163547	0.051603
Bulgaria	4.128023	0.076525	Italy	4.581991	0.057624
Cyprus	2.178270	0.115955	Lithuania	4.314810	0.031481
Czech Republic	5.143551	0.048823	Luxembourg	7.351898	0.022853
Germany	4.530034	0.067832	Latvia	2.970120	0.096599
Denmark	5.471338	0.051867	Malta	-	-
Spain	5.498662	0.022386	Netherlands	3.966612	0.061355
Estonia	5.343173	0.068628	Poland	4.214797	0.057670
Finland	7.240589	0.024320	Portugal	6.115730	0.012537
France	5.992358	0.007947	Romania	4.500267	0.058355
United Kingdom	3.153660	0.086843	Slovak Republic	4.494936	0.055683
Greece	5.100802	0.029319	Slovenia	5.866369	0.028609
Croatia	6.073827	0.015417	Sweden	7.538159	0.010920

Source: Calculations performed by authors based on the data provided by World Bank 2019 [55].

Figure 5 shows the linear equation with the form $y = \alpha + \beta x$, and Table 5 shows: R, R², Fisher test, Durbin–Watson test, Pearson Correlation, β , α , and T test sig. (*p*-value) for renewable energy consumption (kg of oil equivalent per capita):

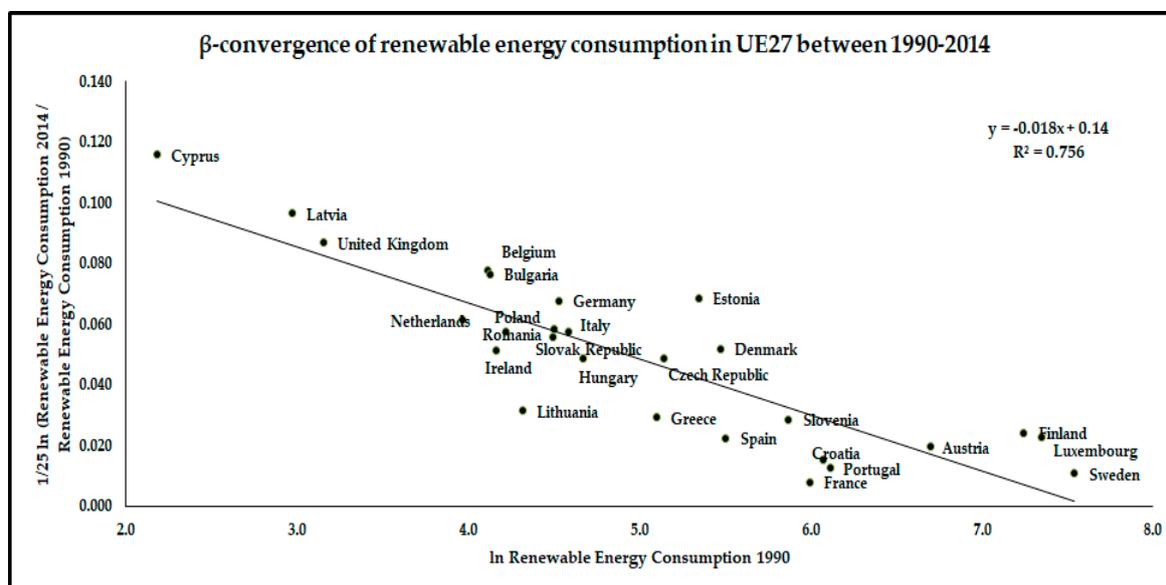


Figure 5. β -convergence renewable energy consumption in UE27 1990–2014 (Model 5).

Table 5. Results of econometric model for β -convergence of renewable energy consumption.

Renewable Energy Consumption	Variables	Summary Model		Anova	Durbin–Watson	Pearson Correlation	Linear Equation	Coefficients	
		R	R ²	Sig.F.Test				Value	Sig.t.Test
Model 5 UE27	Independent	0.870	0.757	0.000	2.055	−0.870 sig. 0.000	$y = -0.018x + 0.141$	−0.018	0.000
	Dependent							0.141	0.000

Source: Calculations performed by authors in SPSS based on the data provided by World Bank 2019 [55].

In Table 5, R value is 0.870, a value close to 1, which shows an almost perfectly positive correlation. R² is the square of the correlation coefficient, and varies from 0 to 1. The value of 0.757 is close to 1, which shows that the model explains more variation from the independent variables. Pearson correlation coefficient shows how strongly the variables in the model are correlated, in our case this correlation being −0.870 (sig.0.000). The value of Durbin–Watson test of 2.055 falls between 1.5 and 2.5 and shows the degree of autocorrelation. Linear regression analysis shows that for renewable energy consumption in the EU27 countries there is a significant negative relationship between the two variables ($r = -0.018, p = 0.000$), which suggests that a one-unit change in the value of the independent variable x will lead to a change in the value of the dependent variable y by −0.018. Sig. F. is also 0.000, which means that the model is statistically significant.

Mathematically, β -convergence of renewable energy consumption (kg of oil equivalent per capita) is showed in Table 6:

Table 6. Mathematical presentation for Equation (4).

Renewable Energy Consumption	β -Convergence
UE27	$\frac{1}{25} \ln \left(\frac{\text{Renewableenergy consumption}_{2015}}{\text{Renewableenergy consumption}_{1990}} \right)$ $= 0.141 - 0.018 \ln(\text{Renewableenergy consumption}_{1990})$

The negative values of parameter β (-0.018) also show in the case of renewable energy consumption the expression of the inverse relationship between the average annual growth rate of renewable energy consumption per capita for the time intervals T ($T = 25$ years for EU27) and the original level of renewable energy consumption per capita in the year $t_0 = 1990$. Over time, the countries included in the sample will reach equilibrium, i.e., they have a convergence tendency [35,50,51,53,54]. The graph in Figure 5 shows the position of Cyprus, Latvia, United Kingdom, Belgium, Bulgaria, Germany, Estonia, Denmark, Finland, Luxembourg, and Sweden, indicating a convergence from above, due to the fact that the values of the points corresponding to the model $\frac{1}{T} \ln\left(\frac{\text{Renewable energy consumption}_{T_i}}{\text{Renewable energy consumption}_{t_0}}\right)$ are above the curve corresponding to the linear correlation. The points below the curve correspond to Netherlands, Romania, Ireland, Hungary, Lithuania, Greece, Spain, Croatia, Portugal, and France, which indicate a convergence from below. In this case, according to this analysis, the EU27 countries show a convergence pattern, and hypothesis H2 is confirmed.

4.2. Estimation of Econometric Model for β Convergence

As we mentioned before, we used in our study data for both energy consumption and renewable energy consumption.

In the following, we will present the σ -convergence model, a semi-parametric method using the coefficient of variation σ_t [13,35,50–53]:

4.2.1. σ -Convergence of Energy Consumption

The mathematical model is the one proposed in Equation (3), which can be written as in Equation (7):

$$\sigma_t = \sqrt{\frac{\sum_i [\ln(\text{energy consumption}_T) - \ln(\bar{y}_t)]^2}{(N - 1)}} \quad (7)$$

The high values obtained for all countries show that for the period 1960–2015, in the countries of the EU16 group included in this analysis there is a high degree of dispersion of energy consumption. Consequently, we will analyze in more detail in the following, with the purpose of measuring the convergence or the divergence process, according to the values obtained for σ_t , this time calculated for the following pairs of time intervals: (1960–1965), (1966–1970), (1971–1975), (1976–1980), (1981–1985), (1986–1990), (1991–1995), (1996–2000), (2001–2005), (2006–2010), (2011–2015), and (1960–2015). For Luxembourg, the negative value (-0.007136287) of the equation $y = -0.012x + 0.104$ determined the narrowing of the group from 16 countries to 15 countries. For the group of the EU19 countries, we also obtained high values for σ -convergence, showing that for the period 1971–2015 there is a high degree of dispersion of energy consumption. To measure the convergence or the divergence process, we analyzed 10 pairs of time intervals, as follows: (1971–1975), (1976–1980), (1981–1985), (1986–1990), (1991–1995), (1996–2000), (2001–2005), (2006–2010), (2011–2015), and (1971–2014). For Luxembourg, the value of the equation $y = -0.012x + 0.103$ is also negative (-0.009574246), which determined the narrowing of the group from 19 countries to 18 countries. For the group of the EU23 countries, we obtained high values for σ -convergence, showing that for the period 1971–2014, there is a high degree of dispersion of energy consumption. To measure the convergence or the divergence process, we analyzed 10 pairs of time intervals, as follows: (1971–1975), (1976–1980), (1981–1985), (1986–1990), (1991–1995), (1996–2000), (2001–2005), (2006–2010), (2011–2014), and (1971–2014). For Luxembourg, the value of the equation $y = -0.011x + 0.094$ is also negative (-0.009193059), which determined the narrowing of the group from 23 countries to 22 countries. For all the countries in the EU28 group we obtained negative values by solving the equation $y = -0.006x + 0.043$, showing that for the period 1990–2014 a σ -convergence cannot be calculated for energy consumption. However, to measure the convergence or the divergence process, we continued the analysis on time intervals, and we analyzed

six pairs of time intervals, as follows: (1990–1994), (1995–1999), (2000–2004), (2005–2009), (2010–2014), and (1990–2014).

Figure 6 shows the curves corresponding to the total estimated values:

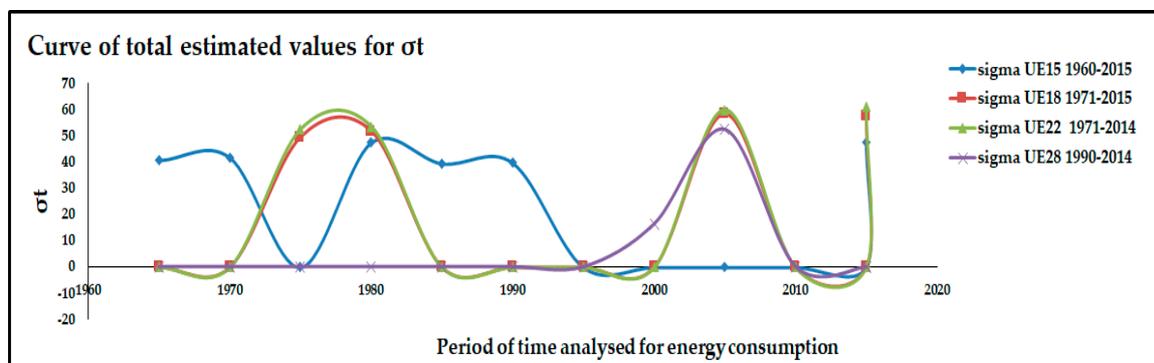


Figure 6. Graphical representation of total values obtained for σ_t energy consumption.

As we can see from Figure 6, the values obtained for σ_t on the four groups of EU countries are fluctuating. Analyzing σ_t on time interval pairs, we can see that a σ -convergence was obtained for UE15 only for 6 of the 12 pairs of time intervals. In the period 1960–1970, a convergence process takes place due to the fact that $\sigma_{1960-1965} < \sigma_{1966-1970}$. In the time period 1976–1990 there is both a divergence process due to the fact that $\sigma_{1976-1980} > \sigma_{1981-1985}$, and a convergence, because $\sigma_{1981-1985} < \sigma_{1986-1990}$. The time interval analyzed is characterized by the fact that $\sigma_{1976-1980}$ and $\sigma_{1960-2015}$ recorded the highest values. As a result, the countries analyzed in the period 1960–2015 indicated a convergence process, as shown by the negative value of the coefficient $\beta = (-0.012)$, indicating the same thing. In conclusion, energy consumption per capita in EU15 influences the convergence process, which takes place at a slower pace, and the countries included in the analysis show a convergence pattern, which means that hypothesis H1 is confirmed. Analyzing σ_t on pairs of time intervals, we can see that in the period 1971–2015, a convergence process took place in the EU18, due to the fact that σ_t on pairs of time intervals has high values, and $\sigma_{1971-1975} < \sigma_{1976-1980}$. However, for energy consumption, the time intervals 1981–2000 and 2006–2015 are considered critical, because no σ -convergence was obtained due to the negative values of $y = \alpha + \beta x$. Moreover, $\sigma_{1971-2015}$ has a high value, which leads us to the conclusion that for the countries analyzed in the period 1971–2015 a convergence process took place, as shown by the negative value of the coefficient $\beta = (-0.012)$, which indicates the same thing. In conclusion, energy consumption per capita in the EU18 countries also influences the convergence process which takes place at a slower pace, and the countries included in the analysis show a convergence pattern, which means that hypothesis H1 is confirmed. For the UE22, we can see that a σ -convergence was obtained for only 4 of the 10 pairs of time intervals. The critical time intervals are 1981–2000 and 2006–2014. However, due to the fact that σ_t on pairs of time intervals has high values for 1971–1980 and 2001–2005, and as $\sigma_{1971-1975} < \sigma_{1976-1980}$, we can conclude that a convergence process took place. The high value of $\sigma_{1971-2014}$ indicates a convergence process, as shown by the negative value of the coefficient $\beta = (-0.011)$, which means the same thing. As a result, the countries analyzed in the period 1971–2014 indicated a convergence process. In conclusion, energy consumption per capita in the EU22 countries also influences the convergence process which takes place at a slower pace, and the countries included in the analysis show a convergence pattern, which means that hypothesis H1 is confirmed. Analyzing σ_t on pairs of time intervals for the EU28, we can see that in the period 1990–2014 a convergence process took place only in the interval 2000–2004. However, the time interval analyzed is marked by critical periods because, as we previously explained, σ -convergence was not obtained due to the negative values of $y = \alpha + \beta x$. A negative value was obtained even for $\sigma_{1990-2014}$. Although σ -convergence has negative values, we can agree that the countries analyzed could indicate a convergence process at a slow pace only because the negative value of the coefficient $\beta = (-0.006)$

indicates it. In conclusion, energy consumption per capita in the EU28 countries does not influence the convergence process, and the countries included in the analysis do not indicate a convergence pattern, which means that hypothesis H1 is not confirmed.

4.2.2. σ -convergence of renewable energy consumption

The mathematical model is the one proposed in Equation (3), and it can be written as follows:

$$\sigma_t = \sqrt{\frac{\sum_i [\ln(\text{renewable energy consumption}_T) - \ln(\bar{y}_t)]^2}{(N-1)}} \quad (8)$$

The high values obtained for all countries show that for the period 1990–2014, in the countries of the EU27 group included in this analysis, there is a high degree of dispersion of the renewable energy consumption. Consequently, we will analyze in more detail in the following, with the aim of measuring the convergence or the divergence process, depending on the values obtained for σ_t , calculated this time for the following pairs of time intervals: (1990–1994), (1995–1999), (2000–2004), (2005–2009), (2010–2014), and (1990–2014). Since for Austria, Estonia, Finland, France, Croatia, Latvia, Luxembourg, Portugal, Slovenia, and Sweden the value of the equation $y = -0.018x + 0.141$ is negative for 4 of the 6 pairs of time intervals analyzed, we had to narrow the group from 27 countries to 17 countries (Model 6—EU17).

Considering the stages of establishing the sample of countries included in this analysis, the research hypothesis H2 will be tested further.

Figure 7 shows comparatively the curves obtained for the total values for renewable energy consumption and calculated for σ_t both for UE27 and for UE17:

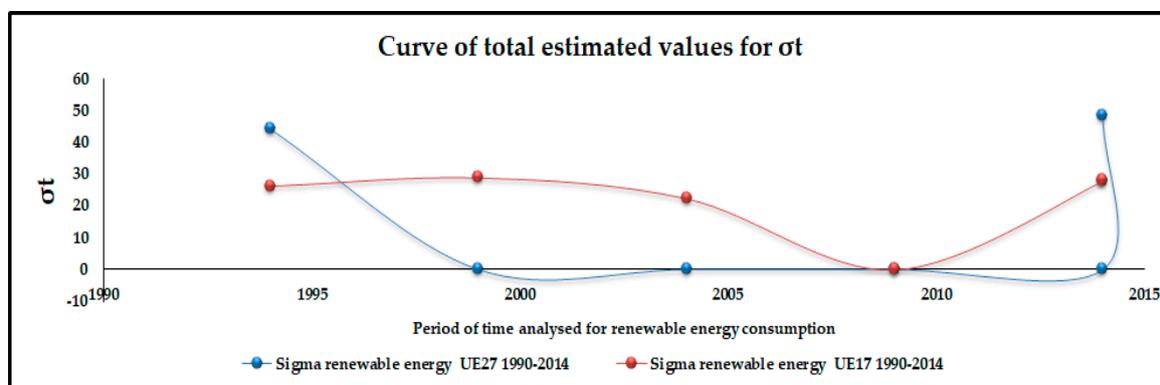


Figure 7. Graphical representation of total values obtained for σ_t for renewable energy consumption.

As we can see in Figure 7, the values obtained for σ_t for the EU27 and EU17 countries are fluctuating.

Analyzing the EU27 countries, we can see that the time interval studied is marked by critical periods in the period between 1995–2014, because no σ -convergence was obtained due to the negative values of $y = \alpha + \beta x$, even if for $\sigma_{1990-1994}$ and $\sigma_{1990-2014}$ there is a σ -convergence, which contradicts the negative value of the coefficient $\beta = (-0.018)$, indicating a convergence process. In conclusion, renewable energy consumption per capita in the EU27 countries influences the convergence process which takes place at a slow pace, and the countries included in the analysis show a convergence pattern, which means that hypothesis H2 is confirmed. For EU17, a σ -convergence was obtained for five of the six pairs of time intervals. Thus, in the period 1990–2014, there is a process of convergence due to the fact that $\sigma_{1990-1994} < \sigma_{1995-1999}$ and $\sigma_{2010-2014} < \sigma_{1990-2014}$, as well as a process of divergence because $\sigma_{1995-1999} > \sigma_{1990-2014}$. The time interval analyzed is characterized by the fact that $\sigma_{1995-1999}$ and $\sigma_{2010-2014}$ have the highest values. As a result, we can say that the countries analyzed in the period 1990–2014 had a convergence process, as shown by the negative value of the coefficient $\beta = (-0.018)$,

indicating the same thing. In conclusion, renewable energy consumption per capita in the EU17 countries influences the convergence process which takes place at a slow pace, and the countries included in the analysis show a convergence pattern, which means that hypothesis H2 is confirmed.

Based on the results obtained in this analysis, hypothesis H1 is demonstrated by the results of the empirical analysis with similar results in the literature. Several studies analyzed the “convergence of energy consumption” [37], confirming the hypothesis of convergence of energy consumption. However, there are studies that refuted the convergence of energy consumption in Europe [13]. The results obtained for the EU16, EU19, and EU23 countries are also confirmed by the study conducted by Fallahi and Voia [37], in which the countries show a convergence pattern. However, the countries in the EU28 group do not have a convergence pattern, a result which cannot be confirmed by Fallahi and Voia [37]. The period analyzed is the time interval between 1990 and 2014, when the consumption behavior changed, the consumers of conventional energy choosing an unconventional energy consumption, i.e., renewable energy. The results of the analysis are also confirmed by the study conducted by Fallahi and Voia [37]. Based on the results obtained in this analysis, hypothesis H2 is also demonstrated and confirmed. Therefore, renewable energy consumption per capita in the EU28 member countries shows a convergence pattern.

Analyzed comparatively, Figure 8 shows the curves of the total values estimated for energy consumption versus renewable energy consumption:

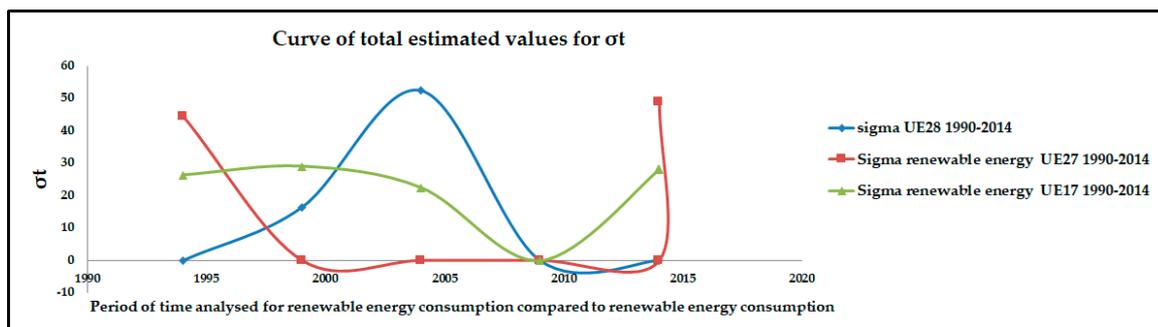


Figure 8. Graphical representation of total values obtained for σ_t energy consumption vs. renewable energy consumption.

Moreover, taking into account that β values are lower than R values ($\beta < R$) in all the cases studied, there is a σ -convergence [57]. The values of R2 show the existence of a relationship between variables, closer in the case of Models 1, 2, 3, and 5 and less close in the case of Model 4. The analysis of σ -convergence leads to conclusions similar to those obtained by β -convergence. In the following, based on the results achieved for β and σ -convergence, we will discuss the testing of hypothesis H3. In Table 3, could be observed that the β parameter values are: for UE16, $\beta = -0.012$, for UE19, $\beta = -0.012$, for UE23, $\beta = -0.011$, and for UE28, $\beta = -0.006$. These values show a low intensity negative relation as regards the energy consumption. Whatever model we choose, we note that between 1960 and 2015 there is a trend toward a reduction in European energy consumption, with 1.2% for UE 16 and UE 19, followed by UE23 with a decrease of 1.10% and UE28 with 0.60%. On the other hand, it could be observed from Table 5 that R value is 0.870, which is very close to 1, indicating an almost perfect positive correlation for the renewable energy consumption. All the directions studied offered the perspective of the convergence of energy consumption per capita and of renewable energy consumption per capita, and the results of the study show that there is a relationship between convergence of conventional energy consumption and convergence of renewable (unconventional) energy consumption. The change in consumption behavior leads us to the conclusion that for the period 1990–2014, specific to the group of the EU28 countries, though there is no convergence pattern for conventional energy consumption (see Figure 4), the tendency of renewable energy consumption has a convergence pattern for the EU27 countries (see Figure 5). In the light of the analysis of the results obtained and discussed above,

we consider that hypothesis H3 has been confirmed, which presently shows an existing relation between the convergence of conventional energy consumption and the convergence of renewable energy consumption for the EU member states (Malta is not included in the analysis). The results show that, in the EU perimeter, based on the reduction of the total energy consumption, the renewable energy consumption has increased. In other words, the Member States are taking measures to change their energy strategy, focusing on renewable energy consumption, albeit at the same pace.

5. Conclusions and Research Limitations

For the first three models used to accept the hypotheses of β -convergence, the results show that there is a significant negative relationship among the variables. As for Model 4, there is an insignificant negative relationship. We conclude that the convergence process of energy consumption per capita it shows a convergence pattern, which also confirms the results obtained by Fallahi and Voia [37]. With the exception of Luxembourg and the United Kingdom, there is a convergence of energy consumption per capita from above and from below. The analysis confirms the convergence of renewable energy consumption per capita, hypothesis also confirmed by the studies conducted by Payne, Vizek, and Lee for the USA [44] and Demir and Cergibozan [48], Solarin, Gil-Alanaand and Al-Mulali [47] for the OECD countries, and shows a convergence pattern also demonstrated by the study conducted by Fallahi and Voia [37]. The results obtained by σ -convergence show a fluctuating evolution likely to clarify the previous conclusions obtained by Butnaru et al. [50], Butnaru and Haller [51], Butnaru and Niță [53], Dvoroková [54], and Iancu [35], and they are confirmed by the studies conducted by Berk, Kasman and Kılınç [45], Solarin, Gil-Alanaand, and Al-Mulali [47], and Markandya et al. [12].

The empirical analysis by parametric and semiparametric methods using the β and σ convergence models shows the tendency of weak European convergence in terms of energy consumption and renewable energy consumption, nevertheless confirming convergence patterns. This study complements the literature and leaves room for further research. Technological innovations in the field of energy, the objectives of improving energy efficiency and reducing emissions will produce key changes in the convergence of European energy consumption. Moreover, in the long run, we consider that renewable energy will have the potential to replace conventional energy [3], this statement being supported both by the existence of multiple alternative energy sources (solar, wind, hydraulic, tidal energy, geothermal, biogas, etc.) and by the fact that energy from conventional sources tends to run out [40]. However, in the short and medium run, fossil fuels will continue to be the main source of conventional energy. These facts are supported both by the studied literature [1,3,8] and by the obtained results. Thus, we can say that for the time being the consumption of energy from alternative sources registers a rather low level, even if, especially for the analyzed period, respectively the years 1990–2014, important changes have occurred in the consumption behavior, and investments in new technology [2] leading to reducing carbon emissions, but also the use of fossil fuels and natural resources have become much more visible. Consequently, we believe that, in the future, conventional energy can be replaced by renewable energy; however, this requires much more sustained effort [4], reflected primarily in government policies [2,7]. The hallmark of the research is the approach of all EU member states regardless of the level of development of the energy sector, implementation stage, renewable energy production technologies, capacity to innovate, and investments in this field.

This research complements the literature, the subject of the analysis is also important because it demonstrates that there is a relationship between convergence of energy consumption from conventional sources and convergence of renewable energy consumption from unconventional sources. The results depend on the level of development of the countries analyzed, the homogeneity or heterogeneity of the states in the group, the economic policy measures taken by public administrations, and many other criteria.

The limitations of the research derive, from the multitude of relevant indicators impossible to study in the same research. The analysis needs to be continued using the data on energy consumption from different sources, with different states forming the target group and other time intervals. The relationship

between energy consumption–renewable energy consumption can also be studied in relation to other variables than those analyzed in this paper. This study allows future research in different contexts (temporary, spatial, and statistical), and the methodology selected as research tool will determine its results.

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