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Energy Security Risk Across the European Union: Converging or Diverging?

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Abstract

In this paper, we present the results of a study examining whether the European Union, where countries act in common on many issues such as monetary policy, abolition of borders and mobilization of labour and capital, also constitutes a union in terms of energy security. From this point of view, whether the energy security risk in the European Union has converged or not is tested by using various analysis methods covering the period 1980–2018 for 17 EU countries. The findings of the study not only reveal whether individual countries converge to the group average but also show whether the group as a whole forms a convergent outlook. The linear unit root analysis indicates that each country is in a stochastic convergence process towards the group average. In addition, time series beta convergence analysis, which takes into account country-specific structural break periods, is applied and the convergent-divergent situation of each country before and after the break is revealed. Following this determination of individual countries, whether the sample as a whole constitutes a convergent process is tested with sigma and panel beta convergence models and it is determined that the 17 countries subject to the analysis form a convergent outlook as a whole. A robustness check is also made via a nonlinear time series analysis and the previous findings are confirmed.

Keywords: Energy security, European Union, convergence, divergence, time series analysis

JEL Classification: C22, P18, Q40, Q47

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1. Introduction

Energy is one of the most important elements of modern life and sustainable development. In addition, the fact that energy has a very strong connection with national security increases this importance even further. For this reason, the uninterrupted supply of energy is of vital importance for all countries, both socially and economically. However, on a global scale, it was seen that the necessary importance was not given to energy policies until the two global oil crises in the 1970s. With the energy crises, it has been revealed that the existing energy policies and practices are insufficient, and the concept of energy security has started to take an important place in the world agenda. Energy security in this period largely referred to the security of the oil supply (Cohen *et al.*, 2011). After this time, energy policies started to take place at the top of countries' agendas and countries started to plan their energy policies in a way to ensure energy security. However, concerns about energy security almost completely disappeared due to the low oil prices in the 1980s. In the 2000s, developments such as the US invasion of Iraq, Iran's controversial nuclear programme, and the EU's increasing dependence on natural gas from Russia showed the importance of energy security once again (Hedenus *et al.*, 2010). The energy crises of the 1970s and 2000s were quite different from each other. The former was largely the result of political conflicts in the Middle East (mainly the 1973 Arab-Israeli war), while the latter was the result of bilateral trade disputes between energy companies in Russia and their neighbours (McGowan, 2011). The Russia-Ukraine gas crisis in 2006 and the Russia-Belarus oil crisis in 2007 were considered wake-up calls to improve energy security. Nevertheless, in 2009 Europe suffered a severe disruption of natural gas imports from Russia via Ukraine (Kitamura and Managi, 2017). In July 2008, oil prices rose sharply to 132.72 USD per barrel. Considering the previous year's average price of 72.46 USD per barrel, this represents a considerable increase. While political reasons were effective in the increase in prices back in the 1970s, speculative reasons were at the forefront this time (Conway, 2009). With economic power surpassing military power in the world, the sustainability of energy security has also been a key element in maintaining global economic leadership (Jun *et al.*, 2009). For this reason, ensuring energy security should be at the top of every country's economic policies. This is especially true for EU countries, whose economies are largely dependent on the foreign supply of energy resources such as coal, oil and gas (Misik, 2016; Brodny and Tutak, 2021). While the energy import dependence of the European Union is approximately 57% for 2020, this rate is 62% for the Euro Area.[1] Import dependence levels of EU member countries are also quite different within the union. While the energy import dependence of Malta, Cyprus,

1 We use the European Commission – Eurostat (2024) definition of energy dependence. It defines energy import dependence as the share of a country's total energy needs that are met by imports from other countries. When we refer to the EU total, intra-EU trade is excluded, whereas individual country data include intra-EU trade.

Luxembourg and Greece is more than 80%, the energy import dependence of Estonia and Romania is below 30% (Eurostat, 2022a). The high energy dependence is not the only problem that threatens the energy security of the European Union. In particular, the concentration of this dependence in a single country is an important problem in itself. Among the members of the European Union, Finland (100%), Latvia (93%), Bulgaria (79%), Estonia (79%), Austria (64%) and Hungary (61%) are countries with more than 50% dependence on Russian gas in 2019 (Eurostat, 2022b). In 2022, the European Union felt deeply the problems of being dependent on a single country for energy imports. Energy prices hit an all-time high in 2022, mainly due to Russia's invasion of Ukraine and its use of natural gas resources as a weapon of war. This situation caused a significant increase in electricity prices on the EU domestic market because EU electricity prices were heavily dependent on imported natural gas (European Council, 2022). This situation further deepened the economic problems created by the pandemic. Although the concept of energy security had been forgotten over time, it has once again taken the first place in policies for the whole world, especially for European countries, with the recent crisis. The recent energy crisis has brought up another important issue for the EU. Accordingly, the necessity of jointly determining the energy policies of a political and economic union, such as the European Union, has emerged. The debt crisis (2010–2012) experienced by the European Union in the past also supports this situation. The solution proposed by the European Commission during this period was to establish a fiscal union, a banking union and a political union, with strict rules on fiscal deficits and sovereign debt (Polito and Wickens, 2014). Despite the common determination of monetary policies in the European Union, the differences in fiscal policies according to countries caused the debt crisis (Polito and Wickens, 2014). For these reasons, to ensure the sustainability of the European Union, it is necessary to have a common structure in energy policies, which is one of the economic policies. In short, the sustainability of the European Union largely depends on whether it is a successful energy union. The importance of this article emerges at this point.

In this study, the energy security risk convergence of 17 EU member countries is analysed using different time series techniques for the period 1980–2018. In this way, it will be possible to analyse how successful the EU is in terms of energy security. Our study contributes to the literature in at least two ways. The first contribution is that, as far as we know, it is the first study to empirically test the energy security risk convergence for the European Union. The second contribution of our study is the use of several time series methods including both linear and nonlinear techniques in an energy security risk analysis. The richness of our findings is considerably enhanced by the fact that we do not limit the convergence test to the group as a whole but examines whether individual countries converge to the group average or not, and even take into account the structural breaks experienced by each country and reveal whether the convergent-divergent situation has changed before and after the break.

The rest of the study is organized as follows: in the next section, a comprehensive literature review on energy security will be presented, followed by the methodology and the dataset, and then a convergence analysis based on unit root tests to see whether countries converge to the group average on a disaggregated basis, a time series beta convergence analysis where break periods are decomposed, and finally a robustness analysis with nonlinear unit root tests for countries that are found to be nonlinear.

2. Literature Review

The fact that energy is an indispensable part of both modern life and the entire economic system has encouraged researchers to analyse the issue of energy security more deeply. The first studies in the literature dealt with the definition of energy security. Although energy security is one of the most important goals of energy policies of countries, it is not possible to say that there is a consensus in the literature on how to define energy security (Narula and Reddy, 2016). The International Energy Agency (IEA) defines energy security as "the uninterrupted availability of energy sources at an affordable price" (IEA, 2017). The Asia Pacific Energy Research Centre (APERC) defines energy security as "the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy". (APERC, 2007). Winzer (2012) expressed energy security as "the continuity of energy supplies relative to demand". At this point, while we find the IEA's definition inclusive, we also find other definitions useful as they broaden the scope of the issue.

Similar to the definition of energy security, there are quite different approaches to the measurement of energy security, but most studies measure it by constructing an index. In addition to studies using indices, there are methodological studies in the literature (Vivoda, 2010; Sovacool, 2012; Kisel *et al.*, 2016). Some studies select the indicators used in energy security indices according to basic policies. Zeng *et al.* (2017) determined its indicators for the Baltic countries, taking into account the European Union energy policy. Axon and Darton (2021) stated that the main key to assessing energy security is in the assessment of different types of risks in the energy system. Löschel *et al.* (2010) divided the indicators used to measure energy security into two ex-post and ex-ante indicators. They emphasized that researchers should focus on ex-ante indicators when assessing energy security, because while ex-post indicators show the past status of energy security, ex-ante indicators help determine the future energy policy. Sovacool (2013) analysed Denmark as a successful example in terms of energy security and advised other countries based on this country's policies. Some other studies have analysed energy security under different scenarios (Matsumo and Shiraki, 2018; Aized *et al.*, 2018; Martchamadol and Kumar, 2012).

Lu *et al.* (2019) proposed an emergy-based index system to address the problem of incomparability that arises when different types of quantities need to be compared in decision-making. There are studies in the literature comparing different indices to measure their consistency. Narula and Reddy (2015) compared three different indices (the Energy Sustainability Index, the International Index of Energy Security Risk and the Energy Architecture Performance Index). The study stated that the results of different indices are inconsistent. Gasser (2020) comparatively analysed 63 indices developed to measure energy security performance. In particular, the study reviewed their scope, geographical coverage, number of countries analysed, time frame covered, number of indicators considered, data treatment approach, multivariate analysis, normalization, weighting and aggregation of the indicators, and the assessment of uncertainty, sensitivity and robustness. Using the DEMATEL method, Ren and Sovacool (2014) concluded that the availability and affordability dimensions of energy security are the most influential dimensions of a country's overall energy security. Tutak and Brodny (2022), one of the more recent studies, utilized the grey relational analysis (GRA) method for the Three Seas Initiative countries and calculated the energy security levels of the countries using 17 different indicators covering the period 2009–2019. Similarly, Brodny and Tutak (2023) utilized the multi-criteria decision-making (MCDM) method to calculate energy security levels for 27 European Union countries for the period 2010–2020 and made a comprehensive assessment.

Some studies focus on variables that are affected by energy security. Iyke *et al.* (2021) claimed that energy security indices can predict returns. Le and Nguyen (2019) analysed the effects of energy security on economic growth for 74 countries over the period 2002–2013. The study concluded that energy security increases economic growth. Lee *et al.* (2022) analysed the impact of energy security on income inequality for 68 countries over the period 2001–2018. The results support the inverted U-shape impacts of energy security on income inequality with an improvement in economic development. Wang *et al.* (2018) stated that energy security makes a significant contribution to renewable energy development.

As mentioned above, there are many studies in the literature on the definition, effects and determinants of energy security. However, no study in the literature has analysed the energy security risk convergence of countries. However, in unions such as the European Union, which consists of countries with different structural characteristics, the energy security risk convergence of countries is a crucial issue that cannot be neglected. It is observed that the studies that constitute the relevant literature examine whether the country group under consideration as a whole forms a convergent image. Although this is an important question, the question of whether individual countries converge to the overall group – the group average – is also very important. From this point of view, this study aims to fill this gap in the energy security risk literature.

3. Methodology and Data

3.1 Data

The Energy Security Risk Index data used in the analyses of this study were obtained from the Global Energy Institute (GEI, 2022). The GEI Energy Security Risk Index is calculated for the top 75 energy-consuming countries. For this reason, we could not include the EU countries that are not listed in the GEI's index in our study due to the lack of data. We used the GEI Energy Security Risk Index to measure countries' energy security in this study, taking into account its advantages such as the period range, the number of countries and the number of indicators. The index value is calculated based on 29 different indicators covering the following categories: global fuels, fuel imports, energy expenditures, price and market volatility, energy use intensity, electric power sector, transportation sector and environmental conditions. Higher levels of the index imply higher levels of energy security risk. The descriptive statistics of the data are presented in Table 1. According to the statistics, Bulgaria has the highest risk (1.555) across the selected country group on average over the period 1980–2018 while Denmark has the lowest risk (0.802). The highest and lowest risk values for Bulgaria were in 1994 and 2018, namely 2.269 and 1.014 respectively. The highest and lowest risk values for Denmark, on the other hand, were in 1980 and 2000, namely 0.953 and 0.729 respectively. Over the whole period of the analysis, the lowest energy security risk was observed in Romania in 2018 (0.617). However, it is important to notice that at the beginning of the 1990s, the risk value for Romania was about 1.548, which implies that the country has reduced its energy security risk significantly.

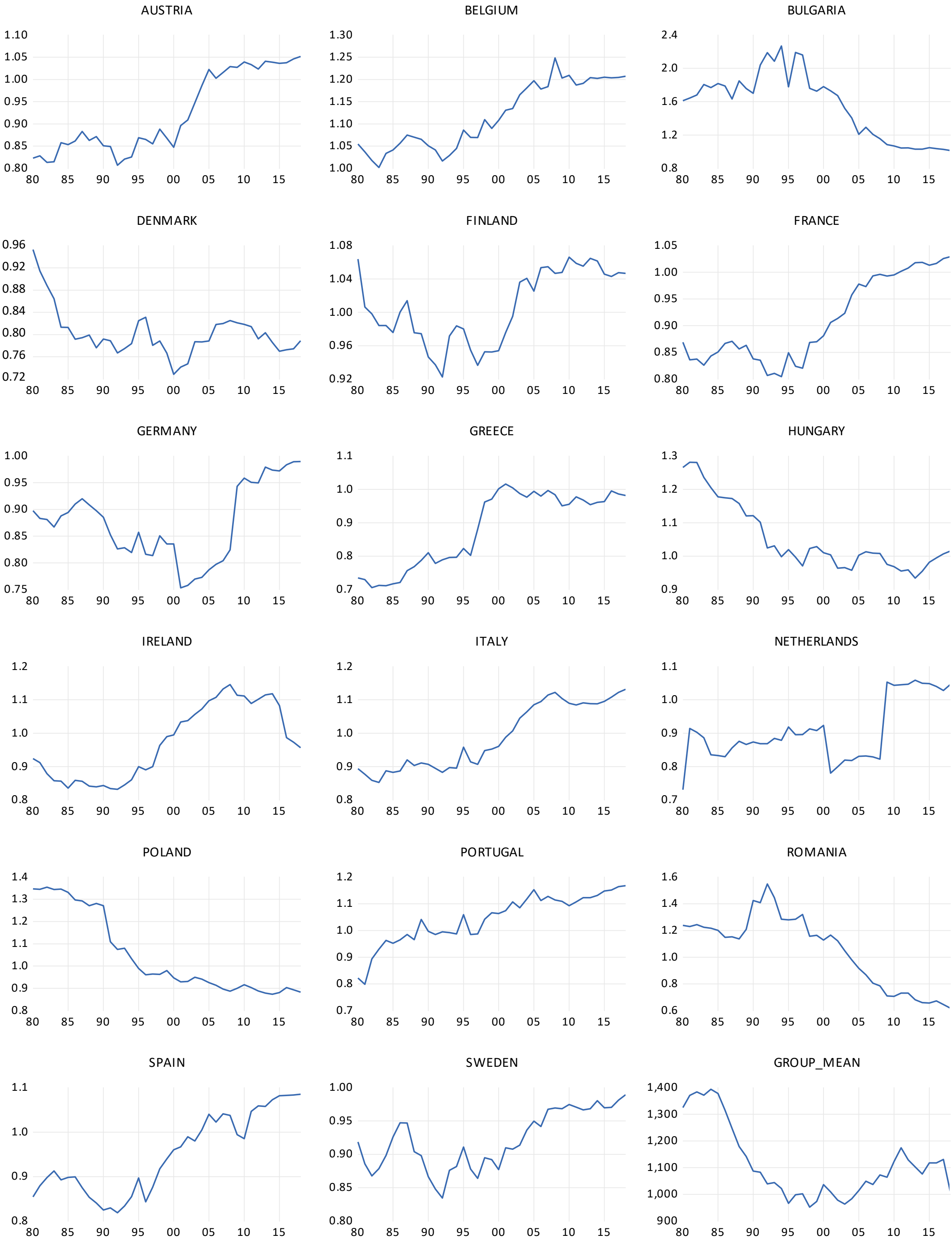
Many methods such as demeaning, measuring changes with logs or dividing by the group mean could have been used to determine whether individual countries converge towards the group as a whole. However, since this study aims to benefit from time series modelling, which takes structural breaks into account, and to present a unified set of results, we follow Ayala *et al.* (2013) and use the ratio of the energy security risk values of countries to the average risk value for the group for each year ($\gamma_{i,t}/\gamma_{mean,t}$). The relative energy security risk values of the countries are depicted in Figure 1.

Table 1: Descriptive statistics of Energy Security Risk Index (1980–2018)

	Mean	Max.	Min.	Std. dev.
Austria	0.923	1.052	0.807	0.089
Belgium	1.118	1.248	1.002	0.074
Bulgaria	1.555	2.269	1.014	0.396
Denmark	0.802	0.953	0.729	0.043
Finland	1.006	1.066	0.922	0.044
France	0.910	1.029	0.804	0.078
Germany	0.875	0.990	0.753	0.070
Greece	0.882	1.016	0.705	0.112
Hungary	1.053	1.281	0.934	0.102
Ireland	0.970	1.146	0.831	0.110
Italy	0.988	1.132	0.853	0.097
Netherlands	0.906	1.059	0.730	0.092
Poland	1.048	1.354	0.874	0.180
Portugal	1.043	1.167	0.798	0.092
Romania	1.049	1.548	0.617	0.269
Spain	0.949	1.085	0.819	0.089
Sweden	0.921	0.989	0.835	0.043

Source: Authors' own calculations using data obtained from GEI (2022)

Figure 1: Energy security risk for each country relative to group average



Note: The figure presents 17 EU countries' energy security risk values relative to the group average. The group average data calculated using the raw data are shown in the last row of the last column.

Source: Authors' own illustration based on calculations using data obtained from Global Energy Institute

3.1 Methodology

To test the convergence hypothesis across a country group, there are several empirical ways to follow. In this study, we try to provide satisfying findings obtained from different methods.

3.1.1 Linear unit root tests

By following Oxley and Greasley (1995), we decided to test the convergence hypothesis in terms of the stationarity of the series. The mentioned series here is the ratio of energy security relative to the group average (γ_i/γ_{mean}). In this approach, unit root tests are used. If the series has a unit root (is not stationary), this is considered a signal implying that there is no convergence process; otherwise, a stochastic convergence process exists (stationary). The null hypothesis of all these unit root tests is that the series has a unit root; in other words, is not stationary.

To test the stationarity of the series, we first used the augmented Dickey-Fuller unit root test developed by Dickey and Fuller (1979). Although this test is commonly used in the literature, it may yield inconsistent results in the case of structural breaks in the series. For this reason, we checked the stationarity of the series also via the Lee and Strazicich (2013) test, allowing one structural break, and the Lee and Strazicich (2003) test, allowing two structural breaks.

3.1.2 Time series beta convergence model

For series that give results favouring a stochastic convergence process, a time series-based convergence regression can be estimated for each country (Ayala *et al.*, 2013). As we show the reasons caused by the findings in the results section, we decided to estimate a regression model including two structural breaks as below:

$$y_t = \mu_1 D_{1t} + \mu_2 D_{2t} + \mu_3 D_{3t} + \beta_1 T_{1t} + \beta_2 T_{2t} + \beta_3 T_{3t} + u_t \,, \tag{1}$$

where $D_{1t} = 1$ if $t \leq T_{B1}$ and $D_{1t} = 0$ if $t > T_{B1}$; $D_{2t} = 1$ if $T_{B1} < t \leq T_{B1}$ and 0 otherwise; $D_{3t} = 1$ if $t > T_{B2}$ and $D_{3t} = 0$ if $t \leq T_{B2}$. For the time dummies, $T_{1t} = t$ if $t \leq T_{B1}$ and $T_{1t} = 0$ if $t > T_{B1}$; $T_{2t} = t - T_{B1}$ if $T_{B1} < t < T_{B2}$ and $T_{2t} = 0$ otherwise; $T_{3t} = t - T_{B2}$ if $t > T_{B2}$ and $T_{3t} = 0$ if $t \leq T_{B2}$.

By estimating this model for each country in the sample, we will obtain $\hat{\mu}_i$ and $\hat{\beta}_i$ values, which will allow us to decide whether there exists a converging, diverging or stable path for the series in question. If the signs of μ and β are opposite and they are statistically significant, we may suggest that there is a convergence process. If the signs of μ and β are the same and they are statistically significant, we may suggest that there is a divergence process. If μ is statistically significant while β is not, we may suggest that the series are constant at different levels. If β is statistically significant while μ is not, we may suggest that there is a divergence process from the same level. If neither μ nor β is statistically significant, we may suggest that the series are constant at the same level.

3.1.3 Nonlinearity tests and Fourier unit root tests

Although the methods above yield substantial evidence of the convergence/divergence process of the countries, the results might be biased and inconsistent in the case of nonlinearity. For this purpose, we decided to make a robustness check for the already obtained findings and tested the series to observe whether they were linear or nonlinear. The linearity tests developed by Harvey and Leybourne (2007) and improved by Harvey *et al.* (2008) are used to test linearity. The null hypothesis of these tests is that the series is linear.

For nonlinear series, checking the stationarity via the conventional unit root tests will not produce consistent results. In this case, the Fourier-based unit root test fulfils this duty. The interpretation of the results is the same with the linear unit root tests; rejection of the null hypothesis implies that the series is stationary (converging to the group average). We used three different unit root tests for robustness check: Fourier-ADF developed by Enders and Lee (2012a), Fourier-LM developed by Enders and Lee (2012b) and Fourier-GLS developed by Rodrigues and Taylor (2012).

3.1.4 Sigma and panel beta convergence

Following the methods that allow us to examine whether individual countries converge to the group mean, it would be appropriate to use sigma and panel beta convergence approaches to examine whether the group as a whole is convergent (or divergent). We use the sigma convergence technique, which is based on the standard deviation of the country group. This technique suggests that if the standard deviation of the group decreases over time, this can be considered a signal of a convergence process. The other method, panel beta convergence, is based on an autoregressive model of order one. A converging process exists if the lagged value of the dependent variable has a coefficient of less than one (for more details, see Barro and Sala-I-Martin, 2004). A basic beta convergence model in a panel data form is as follows:

$$y_{it} = \beta_0 + \beta_1 y_{it-1} + u_{it} \quad (2)$$

Since such an autoregressive model corresponds to a dynamic process including an endogenous condition, ordinary least square estimators may give biased and inconsistent results (Baltagi, 2005). To cope with this issue, we utilized the difference GMM and system GMM estimators, which are resistant to endogenous models. The difference GMM estimator was first developed by

Anderson and Hsiao (1981, 1982) and then improved by Holtz-Eakin *et al.* (1988) and Arellano and Bond (1991). By making an additional assumption suggesting that the instrumental variables are not correlated with the fixed effects, Arellano and Bover (1995) and Blundell and Bond (1998) then developed the system GMM estimator. The difference GMM estimator uses levels as the instruments of the differences, while the system GMM estimator uses differences as the instruments of the levels (Roodman, 2009).

4 Results and Discussion

4.1 Unit root test results

The convergence hypothesis was also tested via time series analyses. One of the methods is checking whether the series includes a unit root. Notice that we employ all the models with the ratio of energy security relative to the group average (γ_i/γ_{mean}). Table 2 presents three different unit root tests. According to the results of the first one, which is the Augmented Dickey-Fuller unit root test, the null hypothesis of the unit root was rejected only for Finland and Portugal. This implies that for these countries, the relative energy security level shows a stochastic convergence process. As mentioned above, in the case of structural breaks, unit root tests that ignore the existence of the breaks produce biased results. To check the existence and impacts of the possible structural breaks, we further tested the null hypothesis of the unit root by considering the breaks in the series. The unit root test of Lee and Strazicich (2013) allows one break in the model. By optimizing the movements of the series, the estimator detects the break date. Since ignoring a significant break may cause biased and inconsistent results of the test, considering the break is an important factor when checking stationarity. The results of the Lee and Strazicich (2013) test suggest that the null hypothesis of the unit root was rejected for Bulgaria, Denmark, Greece, Hungary, Portugal and Sweden, implying that the relative energy security level in these countries shows a stochastic convergence process. However, it is seen that the null hypothesis was rejected only for 6 out of 17 countries. For the other 11 countries, there might be more than one structural break in the series. To check this, we applied the unit root test of Lee and Strazicich (2003), which allows two structural breaks in the unit root testing process. The test results imply that when we consider two breaks detected by the estimator, the null hypothesis was rejected for all the countries in the analysis. Thus, one may suggest that all these countries have two significant breaks at different dates and the relative energy security levels of these countries show a stochastic convergence process.

Table 2: Unit root test results

	ADF	Lags	LS (2013)	Lags	Break	LS (2003)	Lags	Break 1	Break 2
Austria	−1.899	0	−3.399	4	1999	−5.911***	3	1990	2003
Belgium	−2.756	0	−3.449	0	2002	−6.959***	3	1996	2007
Bulgaria	−2.064	1	−4.001**	0	1996	−6.385***	0	1990	2003
Denmark	−3.576	0	−4.245**	3	1993	−5.000**	3	1993	2004
Finland	−3.33*	0	−2.845	1	2001	−4.817**	4	1995	2005
France	−2.339	0	−3.218	3	1996	−7.884***	4	1996	2004
Germany	−1.133	0	−2.933	0	2007	−5.938***	4	1995	2007
Greece	−1.146	0	−3.541*	0	1997	−6.257***	3	1995	2007
Hungary	−1.203	1	−4.246**	2	1990	−5.768***	3	1996	2011
Ireland	−1.058	1	−2.537	1	2000	−4.452*	1	1996	2010
Italy	−2.369	0	−3.002	4	1996	−5.249**	4	1994	2005
Netherlands	−2.143	1	−2.835	1	2000	−5.289**	3	1999	2009
Poland	−0.755	0	−3.992	1	1993	−7.713***	4	1989	1997
Portugal	−4.739***	1	−4.005**	1	1991	−5.596***	1	1991	2005
Romania	−1.727	0	−3.319	2	1997	−5.832***	4	1990	2006
Spain	−1.791	0	−3.435	3	1995	−4.566**	1	1988	1999
Sweden	−2.436	0	−4.933***	3	1991	−7.995***	4	1996	2009

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10%, respectively. The null hypothesis of the Augmented Dickey–Fuller, the Lee and Strazicich (2013) and the Lee and Strazicich (2003) unit root tests is that the series includes a unit root. The lag selections were optimized via the Akaike information criterion by choosing the number of maximum lags as 4 periods, which was calculated by following Newey and West (1994).

Source: Authors' own elaboration

4.2 Time series beta convergence model results

Since we found that all the countries have two significant structural breaks in the energy security series, we can now estimate individual country-specific β convergence regressions including the breaks. As shown in the methodology section, these regressions include break year dummies and time trends reflecting the behaviour before and after the breaks. Since the convergence/divergence of a country before and after a structural break may differ, this approach provides a much more comprehensive framework and reveals the transformation of countries in terms of energy security over time more clearly. Let us see the convergence/divergence situations of each country in Table 3 separately.

Austria: The first and second breaks of the energy security risk for Austria are 1990 and 2003. The estimation results suggest that during all three periods (before 1990, between 1990 and 2003, and after 2003), the energy security risk index for Austria diverges from the group average. It is seen that Austria's energy security risk has increased due to the instability that emerged after the US invasion of Iraq in 2003. The country's high energy dependence rate and the fact that this dependence is from a single country, Russia, increase the country's energy security risk.

Belgium: Although Belgium's energy security risk series has two significant structural breaks, this country's energy security risk diverges from the group average until the second break year, 2007. After the second break, the results imply that the index value for Belgium turns out to be stable. There is an increasing trend in Belgium's energy security risk after 2003. The country's energy dependence is about 99%. The country's high energy dependence significantly increases the security risk.

Bulgaria: Until the first structural break year, 1990, Bulgaria's energy security risk seems stable. However, just after the first break, until the end of the analysis period covering also the second break (2003), the energy security risk starts to converge to the sample average. Although the energy security risk for Bulgaria was quite high in the 1980s, it seems that it has decreased significantly over time. It is seen that the country's security risk does not increase significantly in energy crises, unlike the major energy-user countries.

Denmark: Starting from 1980, the energy security risk for Denmark converges to the group average. Although there was a significant second break in 2004, the converging situation of the energy security risk proceeds until the end of the analysis period. Denmark's world ranking in energy production is better than the world ranking in energy consumption. For this reason, it is possible to say that the energy security risk is lower than in other countries.

Finland: The first and second structural break dates for Finland are 1995 and 2005. Until the end of the second break, the estimated parameters imply that the energy security risk for Finland diverges from the group average. After the second break, a stable progress is observed which corresponds to neither convergence nor divergence.

France: Until 1996, the energy security risk for France converges to the group average. However, with the occurrence of the first structural break, the risk value for France starts to diverge from the average value for the sample until the end of the analysis period. Even though the country is at the forefront of energy consumption, its inability to show the same success in energy production is one of the factors that increase the country's energy security risk. Fuel import is the dimension with the highest share in the rise of energy security risk in France between 1980 and 2018.

Germany: Germany's energy security risk converges to the group average until 2007, which was estimated as the second structural break of the country. After the second break, 2007, the risk level for Germany starts to diverge from the group average. It is thought that the divergence that emerged after 2007 was caused by the energy crisis that occurred in those years. It is very important to state that prices increase significantly during this period. Germany's energy security risk increased after 2003, similar to that of France. Fuel imports and energy expenditures are the most important dimensions affecting the country's energy security risk during the period 1980–2018.

Greece: The first and second break dates for Greece are 1995 and 2007. Until the second break, the energy security risk for Greece diverges from the group average, which turns out to be stable after the second break, 2007. It is seen that the energy security risk for Greece was significantly affected by the energy crises in 2003 and 2008 and increased significantly after these periods. The energy dependence of Greece is 100% according to Eurostat 2018 data. In addition, the country's dependence on Russian natural gas is 71%. The country's high dependence on foreign energy is the most important problem that increases the country's energy security risk.

Hungary: During the period before the first structural break year, 1996, the energy security risk for Hungary converges to the group average. With the occurrence of the first structural break in 1996, a stagnant course was estimated. However, after 2011, which was the year of the second structural break, the energy security risk for Hungary started to diverge from the group average.

Ireland: Until 1996, Ireland's energy security converges to the group average but then starts to diverge until the second structural break date, 2010. After the second break, Ireland's energy security risk starts to converge to the group average again. Ireland's energy security risk has increased since the 1990s. According to Eurostat data, Ireland's energy dependence on natural gas is about 64%. The country's high energy dependence plays an important role in the divergence from the group average.

Italy: Although Italy's energy security risk series has two significant structural breaks (1994 and 2005), the risk value for Italy diverges from the group average until the end of the second structural break date. After 2005, the diverging process gives way to a stable course. Italy is a net importer of oil, natural gas and coal. The country's energy security risk seems to have increased after 2003. The most important factor that increases the country's energy security risk is the dimension of fuel imports.

Netherlands: During the first 30 years of the analysis period, the energy security risk value for the Netherlands demonstrates a diverging outlook. After the second structural break date, 2009, the risk value for this country became stable. The most important dimensions that increase the energy security risk for the country are fuel imports and energy expenditures. After the energy crisis in 2008, it was seen that the country behaved differently from the group average and was more affected by the increasing prices.

Poland: As a country that had a relatively higher energy security risk value at the beginning of the analysis period, Poland's risk value converges to the group average until the end of the analysis period. Neither the first nor the second structural breaks in 1989 and 1997 affected this process. Indeed, the country's security risk decreased after the 1990s. In this period, it is seen that the country showed a significant improvement in the energy use intensity dimension, which had a high share in the energy security risk in the 1980s.

Portugal: Although it has two significant structural breaks in terms of energy security risk, the estimation results suggest that Portugal's energy security risk diverges from the group average until the end of the analysis period. Portugal is a net importer of petroleum, natural gas and coal. It is seen that fuel imports are the dimension that has the most important share in the increase of the country's energy security risk during the period.

Romania: The energy security risk for Romania demonstrates a stagnant course until the first structural break date, 1990. However, after this year, including the second structural break date, 2006, the risk value for Romania starts to converge to the group average. While the energy security risk was quite high in the 1980s, Romania is one of the countries that managed to attain the group average by significantly reducing its risk during the period.

Spain: Although it had a stagnant process until the first structural break, 1988, after this date, the energy security risk value for Spain started to diverge from the group average until the end of the analysis period. Spain was a net importer of petroleum, natural gas and coal in 2018. Spain also ranks 17th in the world in total energy consumption. The energy security risk has increased since the country has not achieved the same ranking in energy production. The most important dimension that increases the energy security risk is fuel imports.

Sweden: Until the first structural break year, 1996, Sweden's energy security risk converges to the group average. Between the first and second structural break dates (1996 and 2009), the process becomes reversed and the risk value starts to diverge. Then, after the second structural break date, 2009, the relative risk value depicts a stagnant outlook. The energy security risk for the country was significantly affected by the 2003 and 2008 energy crises.

It should be noted that almost all the countries are similarly affected by the energy crises of 2003 and 2008. For this reason, it is very important for the sustainability of the union that countries act like an energy union by displaying a common attitude to the energy security risk.

Table 3: Time series based β convergence regression results for individual models with two structural breaks

	μ_1	β_1	Convergence or divergence	T_{B1}	μ_2	β_2	Convergence or divergence	T_{B2}	μ_3	β_3	Convergence or divergence
Austria	0.814*** (0.010)	0.005*** (0.001)	*D*	1990	0.808*** (0.009)	0.008*** (0.001)	*D*	2003	1.003*** (0.009)	0.003*** (0.001)	*D*
Belgium	1.031*** (0.009)	0.002* (0.001)	*D*	1996	1.067*** (0.012)	0.012*** (0.002)	*D*	2007	1.215*** (0.012)	−0.002 (0.002)	*n*
Bulgaria	1.673*** (0.069)	0.009 (0.010)	*n*	1990	2.266*** (0.062)	−0.050*** (0.007)	*C*	2003	1.292*** (0.058)	−0.022*** (0.006)	*C*
Denmark	0.915*** (0.013)	−0.012*** (0.001)	*C*	1993	0.807*** (0.015)	−0.004** (0.002)	*C*	2004	0.824*** (0.013)	−0.003** (0.001)	*C*
Finland	–1.019*** (0.010)	−0.004*** (0.001)	*D*	1995	0.917*** (0.013)	0.011*** (0.002)	*D*	2005	1.057*** (0.011)	−0.001 (0.001)	*n*
France	0.858*** (0.007)	−0.002*** (0.000)	*C*	1996	0.817*** (0.011)	0.016*** (0.002)	*D*	2004	0.975*** (0.008)	0.003*** (0.001)	*D*
Germany	0.910*** (0.015)	−0.004** (0.002)	*C*	1995	0.827*** (0.017)	−0.004* (0.002)	*C*	2007	0.892*** (0.018)	0.010*** (0.002)	*D*
Greece	0.695*** (0.015)	0.007*** (0.002)	*D*	1995	0.891*** (0.018)	0.011*** (0.002)	*D*	2007	0.959*** (0.019)	0.002 (0.003)	*n*
Hungary	1.311*** (0.011)	−0.019*** (0.001)	*C*	1996	1.006*** (0.011)	−0.002 (0.001)	*n*	2011	0.927*** (0.017)	0.012*** (0.003)	*D*
Ireland	0.877*** (0.014)	−0.002 (0.001)	*C*	1996	0.933*** (0.016)	0.016*** (0.001)	*D*	2010	1.159*** (0.022)	−0.023*** (0.004)	*C*
Italy	0.874*** (0.010)	0.002* (0.001)	*D*	1994	0.886*** (0.012)	0.016*** (0.002)	*D*	2005	1.095*** (0.011)	0.001 (0.001)	*n*
Netherlands	0.831*** (0.022)	0.004** (0.001)	*D*	1999	0.795*** (0.032)	0.010* (0.005)	*D*	2009	1.051*** (0.035)	−0.001 (0.006)	*n*
Poland	1.373*** (0.016)	−0.009*** (0.003)	*C*	1989	1.231*** (0.018)	−0.037*** (0.004)	*C*	1997	0.959*** (0.010)	−0.004*** (0.001)	*C*
Portugal	0.831*** (0.017)	0.017*** (0.002)	*D*	1991	0.962*** (0.015)	0.012*** (0.002)	*D*	2005	1.094*** (0.016)	0.005** (0.002)	*D*
Romania	1.202*** (0.037)	0.002 (0.005)	*n*	1990	1.517*** (0.030)	−0.037*** (0.003)	*C*	2006	0.793*** (0.036)	−0.014*** (0.005)	*C*
Spain	0.886*** (0.016)	−0.001 (0.003)	*n*	1988	0.800*** (0.014)	0.010*** (0.002)	*D*	1999	0.964*** (0.010)	0.007*** (0.001)	*D*
Sweden	0.909*** (0.011)	−0.002* (0.001)	*C*	1996	0.860*** (0.013)	0.009*** (0.002)	*D*	2009	0.966*** (0.016)	0.001 (0.002)	*n*

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10%, respectively. The letter *C* stands for convergence, the letter *D* stands for divergence and the letter *n* stands for "no discernible trend". T_{B1} and T_{B2} are the first and second break years respectively.

Source: Authors' own elaboration

4.3 Robustness check: A nonlinear approach

Up to this point, we employed several time series methods assuming that the series are linear. However, treating a nonlinear series as linear might reduce the power of the unit root test. To check this, we first applied linearity tests of Harvey and Leybourne (2007) and Harvey *et al.* (2008), which are presented in Table 4. The null hypothesis of these tests is that the series is linear. Since the simulation results of Harvey *et al.* (2008) imply that W_λ has more power compared to W_{10}, W_5 and W_1, we decided to make our linearity/nonlinearity decision based on the W_λ test. In this case, the test results imply that the energy security risk series of Belgium, Greece, Italy and the Netherlands are nonlinear. Although the null hypothesis was rejected for Bulgaria at 5%, Hungary at 10%, Poland at 5% and Portugal at 5% according to the W_{10} and W_5 test statistics, we cannot reject the null hypothesis according to the W_λ.

Table 4: Results of linearity tests of Harvey and Leybourne (2007) and Harvey *et al.* (2008)

	W_λ	W_{10}	W_5	W_1
Austria	2.09	4.27	4.43	4.73
Belgium	7.72**	8.75*	8.94	9.28
Bulgaria	1.57	11.49*	11.92**	12.73
Denmark	1.28	1.84	1.85	1.87
Finland	2.9	5.04	5.1	5.2
France	0.97	0.06	0.08	0.13
Germany	0.31	1.14	1.15	1.18
Greece	6.12**	15.95*	16.08**	16.31***
Hungary	2.35	9.43*	9.47	9.55
Ireland	1.91	3.9	3.95	4.04
Italy	7.47**	8.02*	8.51	9.45
Netherlands	7.89**	4.33	4.39	4.48
Poland	2.7	9.49*	9.55**	9.67
Portugal	3.31	10.83*	10.88**	10.96
Romania	2.82	2.47	2.64	2.97
Spain	2.31	0.88	0.92	0.99
Sweden	0.38	0.37	0.41	0.49

Notes: ***, ** and * indicate statistical significance at 1%, 5% and 10%, respectively. The null hypothesis of these tests is that the series is linear. The critical values for W_λ (see Harvey *et al.*, 2008) are 9.21, 5.99 and 4.6 while the critical values for W_{10}, W_5 and W_1 are 7.77, 9.48 and 13.27 (see Harvey and Leybourne, 2007).

Source: Authors' own elaboration

Table 5: Fourier-based unit root test results

	Fourier ADF	Lags	Fourier LM	Lags	Fourier GLS	Lags
Austria	*NA*		*NA*		*NA*	
Belgium	–3.076	0	–3.788	3	–3.925*	3
Bulgaria	*NA*		*NA*		*NA*	
Denmark	*NA*		*NA*		*NA*	
Finland	*NA*		*NA*		*NA*	
France	*NA*		*NA*		*NA*	
Germany	*NA*		*NA*		*NA*	
Greece	–3.344	3	–3.477	3	–3.677	3
Hungary	*NA*		*NA*		*NA*	
Ireland	*NA*		*NA*		*NA*	
Italy	–3.602	4	–3.126	4	–3.384	4
Netherlands	–1.929	1	–2.416	1	–2.648	1
Poland	*NA*		*NA*		*NA*	
Portugal	*NA*		*NA*		*NA*	
Romania	*NA*		*NA*		*NA*	
Spain	*NA*		*NA*		*NA*	
Sweden	*NA*		*NA*		*NA*	

Notes: ***, ** and * denote statistical significance at 1%, 5% and 10%, respectively. Since this table only presents the unit root test results for the nonlinear series, the cells for the other countries are shown as “not available” (*NA*). The null hypothesis of all three tests is that the series has a unit root. The lag selections were optimized via the Akaike information criterion by choosing the number of maximum lags as 4 periods, which was calculated by following Newey and West (1994).

Source: Authors’ own elaboration

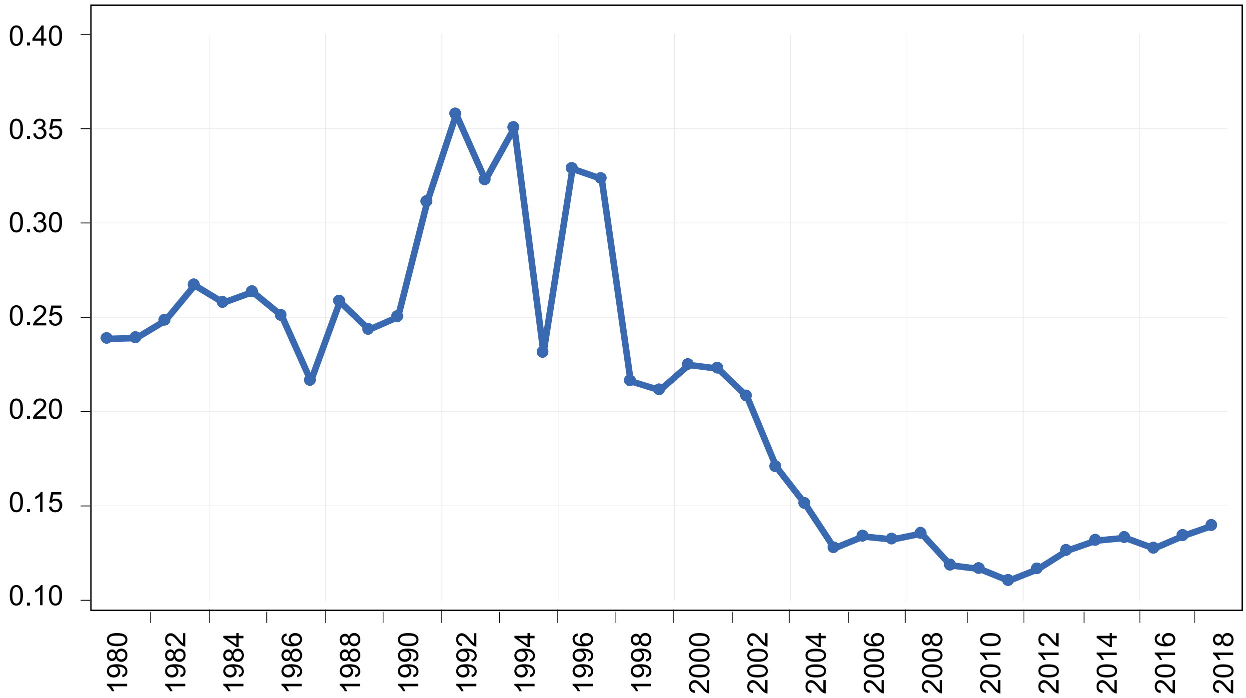
In the event of nonlinearity, the unit root test should be chosen among those that yield powerful results. Table 5 presents the results of Fourier-based unit root tests. Although we present three different test results here, the Fourier LM and the Fourier GLS tests have more power than the Fourier ADF test. All three tests assume that the series have structural breaks but the number of breaks is unknown. According to the results of the Fourier ADF unit root test, the energy security risks of Belgium, Greece, Italy and the Netherlands show a divergence process. The null hypothesis of a unit root (not stationary) was rejected only by the Fourier GLS test at 10% for Belgium, which might be taken as weak evidence. It is also important to state that the convergence/divergence decision based on these tests covers the entire period (1980–2018). However, in the previous analysis in Table 3, we had evidence for three different stages of the analysis period: before the first break, between the first and second breaks and after the second break. Thus, having the information obtained from the Fourier-based unit root test is an asset but combining the information of these results with the β convergence results for each country will present more comprehensive evidence.

The findings obtained from the Fourier-based unit root tests verify the previous β convergence analysis. We found that for 38 years out of the analysis period, Belgium diverged from the group average and the Fourier-based unit root tests, which give results for the whole analysis period, also speak in favour of divergence for this country. Similar findings were observed for Greece. Again, during the first 38 years of the analysis period, a divergence process was observed in Greece, which then turned to a stagnant course. The same results showed that Italy diverged from the group average during the first 26 years of the analysis period and then its course became stagnant. Lastly, the nonlinear unit root tests suggest that the Netherlands diverged from the group average during the whole analysis period. In the β convergence regressions, we found that the Netherlands diverged from the group average until 2009 and then became stagnant. Put briefly, the evidence obtained from the nonlinear analysis for the four countries following nonlinear paths confirms the findings of the previous time series β convergence analysis.

4.4 Convergence/divergence across the European Union as a whole

So far, we have presented comprehensive results on a time series basis, reflecting sub-periods for individual countries. Let us now examine whether the European Union also constitutes a union in terms of energy security risk, which was one of the questions we asked at the beginning of the study, using two additional methods. To do this, we checked for the sigma convergence and then estimated an unconditional panel β convergence model. Figure 2 demonstrates the sigma convergence of the selected countries' energy security risk. The sigma convergence is based on the ratio of the standard deviation of each year to the average value of that year (SD_t/AVE_t). The generally negative slope of the depicted series implies that the standard deviation converges to the group average over time. In other words, there is a significant convergence process in the European Union in terms of energy security risk. However, there were also some positive slopes and fluctuations in the 1990s.

Figure 2: Sigma convergence results



Source: Authors' own depiction and calculation

Subsequently, we went forward with the β convergence. According to the findings in Table 6, both the difference GMM and the system GMM estimation results suggest that the energy security risks of the selected European Union countries converge over time. The speed of convergence is 0.007 in the difference GMM model, while it is 0.021 in the system GMM model. The Hansen test and Arellano–Bond test suggest that the instruments used in the models are valid and there are no second-order autocorrelated disturbances. Since the difference GMM estimator does not include an intercept in the model, we preferred to not include the intercept in the system GMM model either. This is due to trying to compare the coefficient of the pure difference GMM model with the system GMM model without any bias. Additionally, both models include time dummies in the estimations. The findings briefly imply that the energy security risks of the selected countries converge to a path over time.

Table 6: Unconditional panel β convergence results

Dependent variable: Energy Security Index		
	Difference GMM	**System GMM**
Energy security risk in the previous period	0.943*** (0.012)	0.843*** (0.068)
Speed of convergence (implied λ)	0.007	0.021
Time dummies	Included	Included
Number of observations	102	119
Number of countries	17	17
Number of instruments	12	14
Wald test	9 812.18***	26 897.63***
Hansen test *p*-value	0.518	0.148
AR(2)	0.497	0.541

Notes: ***, ** and * denote statistical significance at 1%, 5% and 10% respectively. The null hypothesis of the Hansen test suggests that the instruments used in the models are valid, while the null hypothesis of the Arellano–Bond test, AR(2), suggests that there are no second-order autocorrelated disturbances.

Source: Authors' own elaboration

These additional findings from sigma and beta convergence analyses suggest that the European Union follows a convergent path in terms of energy security risk. Although time series linear and nonlinear estimation results suggest that individual countries show different trends in each sub-period, convergence is evident for the group as a whole. Nevertheless, policymakers should take into account that the country-specific findings in Table 3 vary from one period to another.

5. Discussion

There is no empirical study in the literature that directly analyses energy security risk convergence in the European Union. For this reason, to discuss the contribution of the present study within the existing literature, we compared our analysis results with the convergence studies on the indicators that are the components of our energy security risk index. Markandya *et al.* (2006) analysed the relationship between energy intensity in 12 transition countries in Eastern Europe and EU-15 countries. The results of their analysis, which is in accordance with our sigma and panel beta analysis, show a significant convergence of the transition countries to the EU countries. Jobert *et al.* (2010) examined whether there is a convergence in CO_2 emissions in 22 European countries. The results support the hypothesis of absolute convergence in CO_2 emissions per capita. Herrerias (2012) is yet another study that is in accord with our sigma and panel beta findings. The study investigated CO_2 per capita convergence among EU-25 countries and the findings reveal that there has been more convergence after the 1970s. Teixeira *et al.* (2014) demonstrated that European countries are converging towards a common energy policy, although some EU countries are lagging behind. Their findings show a similarity to our time series beta convergence analysis. The sample in our analysis constitutes a convergence club since it is comprised of 17 European Union countries. Thus, the findings reflecting the convergence process within the whole group imply the existence of a convergence club. Although their main indicators are different, there are studies revealing convergence clubs in Europe. Ulucak and Apergis (2018) investigated the convergence of the per capita ecological footprint for European Union countries and documented the existence of certain convergence clubs. Morales-Lage *et al.* (2019) analysed emissions in 28-EU countries. Their results indicate that there are convergence clubs with different patterns at the centre and periphery of the EU. Cialani and Mortazavi (2021) examined convergence clubs for CO_2 emissions per capita across 28 European countries. Their results strongly support the existence of convergence clubs. Llorca and Rodriguez-Alvarez (2024) proposed an improved approach to modelling the joint achievement of economic development, environmental sustainability and energy equity for EU-29 countries. Their results show convergence in the countries' performance.

6. Conclusion

In this study, we aimed to examine whether the countries within the European Union show a convergence process in terms of energy security risk. We applied a comprehensive time series analysis containing stochastic convergence tests, time series-based beta convergence estimations and nonlinear robustness checks. The results obtained from the unit root test allowing two structural breaks suggested that all the countries in the analysis show a stochastic convergence process. Since we detected two significant structural breaks for each country, we became suspicious about whether the processes varied before and after the structural breaks. To test this, we estimated a time series-based β convergence model for each country. Since this method allows convergence/divergence analysis by dividing the whole sample into three sub-periods, it provides different findings for different sub-periods for countries. The results obtained from this model revealed that country-specific converging and diverging paths vary before and after the break dates. To check the robustness of these findings, the convergence/divergence situations of countries were also checked via an additional nonlinear time series analysis. The linear unit root test results indicate that almost all the countries were similarly affected by the energy crises in 2003 and 2008. Linearity test results show that the energy security risk series of Belgium, Greece, Italy and the Netherlands are nonlinear. Fourier-based unit root test results demonstrate that these four countries diverged from the group average for almost the entire analysis period. We observed that these additional results confirmed the former findings.

Although there are eight main categories of the GEI index, fuel imports and energy expenditures are the prominent ones for many countries as discussed in the results section. The fuel import dimension consists of the indicators oil import exposure, gas import exposure, coal import exposure, total energy import exposure and fossil fuel import expenditure per GDP. The energy expenditure dimension consists of the indicators energy expenditure intensity, energy expenditures per capita, retail electricity prices and crude oil prices. For this reason, determining policies for reducing the energy security risk for the European Union countries according to these indicators will increase the success rate of the policies. The econometric analyses show that European Union countries have been affected by the energy crises quite similarly. This became clearer in 2022, when Russia used gas as a weapon against Europe. With Russia's cut off natural gas, energy prices in Europe increased at record levels, and the country's economies were hit hard. As a result, it was once again understood that the European Union also had to act as an energy union. At the same time, the high energy dependence of most of the EU member countries and the concentration of this dependence on a single supplier country (Russia) increases the energy security risk. Therefore, it is essential to determine energy policies jointly in the European Union, as well as to take measures such as reducing energy dependence and diversifying energy suppliers. Investing in alternative energy sources is very important for reducing energy dependence. In the literature, the importance of increasing the use of renewable energy and nuclear energy is emphasized especially for ensuring energy security. Of course, adopting different hybrid energy production methods by taking into account their internal dynamics will play an important role in reducing energy dependence. Thus, governments need to accelerate the processes of renewable energy projects, implement new financing programmes to increase energy efficiency and implement measures such as the rapid conversion of fossil fuel-intensive industrial processes to electricity (McKinsey & Company, 2022; European Climate Foundation, 2022). In addition to these applications, energy storage is also of great importance in ensuring energy security. The European Association for Storage of Energy (2022) proposes some targets for the member countries of the union. In addition, there are measures that local governments can take in the short term, such as heating, street lighting and mobility. Thanks to these measures, significant reductions in energy consumption can be achieved (Zaccaro, 2022).

Apart from all these measures, it is very important to plan energy security in a way that will ensure economic, social and environmental sustainability by considering it in a very broad framework. These plans are very important in preventing other potential energy security problems in the future. The EU has been taking various measures on energy security in the recent period. The EU Energy Platform was established on 7 April 2022. The platform aims to secure the EU's energy supply at affordable prices and to phase out dependence on Russian gas. We think that if this platform can enable EU member states to act in coordination with energy purchase agreements, it will play an important role in reducing the energy security risk for the EU member states.

Our study has some limitations. The main limitation is that we could not include all the EU countries in the analysis. The GEI's Energy Security Risk Index that we used includes the top 75 energy consumer countries. For this reason, only the EU countries included in this index were analysed in the study. In future research, analyses can be made to include all the EU countries. In addition, it may be important to compare the results of different energy security risk indices to check the consistency of the results. Moreover, in future studies, a new energy security risk index can be developed by taking the literature into account, and convergence analyses can be conducted on this index. In this study, we analysed the convergence of EU countries by considering time series. Panel data convergence techniques can also be used for the whole EU.

While testing the energy security risk convergence of countries in future studies, the convergence of different dimensions of energy security risk can also be analysed. In this way, it can be determined which dimension(s) of energy security risk converge or diverge. In this situation, it will be possible to develop policy analysis for the indicators that make up these dimensions. In addition, the factors affecting the speed of convergence can be determined by using control variables in the analysis.

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