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The Relationship Between Energy Dependency, Energy Diversification, and Economic Growth: Assessing Energy Resilience in Europe

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Abstract

Several successive crises during the first three decades of the third millennium created the premises for a world that, after expanding international relations, entered a new reality of slowbalization or deglobalization, shaping new development paradigms for national economies. In this context, where economic activity remains highly sensitive to energy market disruptions and strategic resource constraints, nations seek new opportunities to reduce their foreign dependencies through energy diversification and a green transition. Nations are seeking strategies to leverage their advantages and moderate their weaknesses. This research evaluates the relationship between energy-related features and economic growth in a complex context, describing dependency on foreign markets. Furthermore, the study discusses the effects of a selection of variables describing the green transition (energy import dependency, energy diversification, and the share of renewable energy) on economic growth. The data covers the period between 1995 and 2024 for 25 European countries. The study uses cross-sectionally ARD (CS-ARDL) for the main empirical analysis and augmented mean group (AMG) to check the robustness of the main results. Furthermore, the method of moments quantile regression (MMQR) is employed to capture the impact more precisely across various stages of countries' development. The findings suggest a direct relationship between employment and renewable energy adoption across all quantiles. Moreover, the negative coefficient for the energy dependency in the first quantile documents an increased sensitivity of less developed economies to energy market uncertainties.

Keywords: renewable energy; energy diversification; energy dependence; Europe

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1. Introduction

Once the trade wars and trade shrinkage become acute, the world enters a new era, the post-globalization era, some considering deglobalization or slowbalization as the new paradigms the nations must cope with. Under these circumstances, the national economies must enhance their ability to provide resources, including energy, to support social and economic welfare. The role of energy for economic and private activities in Europe has been widely and intensively debated in the literature from various perspectives [1]. While the demand for energy is constantly [2] increasing, energy access is associated with higher levels of social welfare or poverty mitigation outcomes. On the other hand, energy is closely linked to economic growth and output. Furthermore, the energy sector plays a significant role in the labor market, and transformations, including the energy transition and diversification, can create disturbances and challenges to income distribution if not effectively addressed.

Among the 25 countries selected for the empirical analysis, some are top performers in renewable energy and energy diversification [3]. Countries such as Sweden, Denmark, and Finland have increased the share of renewable sources in recent years, demonstrating greater depth in renewable energy. In contrast, others, such as France, Germany, and Spain, have diversified their energy sources, including nuclear energy production capacities. It is true that when specific aspects, such as the share of renewable energy in heating and cooling, are considered, some performers fall behind the EU average (Spain and Germany). Altogether, while the EU's average share of renewable energy in total consumption was 24.6% in 2024, some countries remain heavily dependent on fossil fuels and external suppliers (Figure 1).

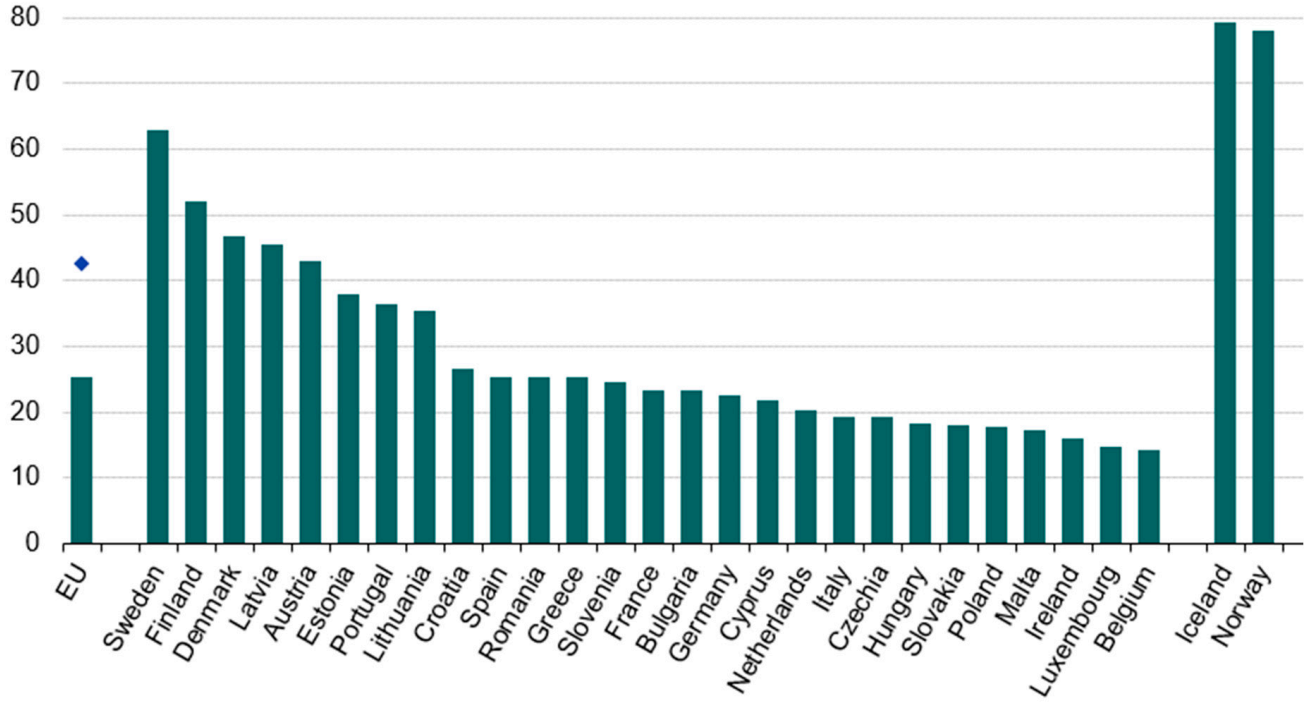


Figure 1. Share of energy from renewable sources in Europe (2024), Eurostat (online data code: nrg_ind_ren), ◆ 2030 target.

Building on previous research, this study focuses on SDG 1 and SDG 7 to document how uncertainties in energy markets affect social and economic outcomes in selected emerging economies, challenging nations to explore new options to ensure energy diversification and reduce their dependence on external energy markets.

The recent international context will not only change political allegiances, trade agreements, and international cooperation, but also reshape the global economy. The national economies will have to adapt to these new realities from many perspectives. For instance, countries may need to learn to be self-sufficient from an economic point of view. Given the highly volatile international context and limited capacity to supply the national economy from external sources, a larger share of resources, including energy, should come from domestic sources. The nations are diverse in terms of energy potential: some have access to traditional sources, while others have access to renewables. In a de-globalized context, nations' energy profiles will shape their economic profiles and levels of self-sufficiency. At the same time, efforts toward energy transition and diversification involve other economic and social transformations (Figure 2).

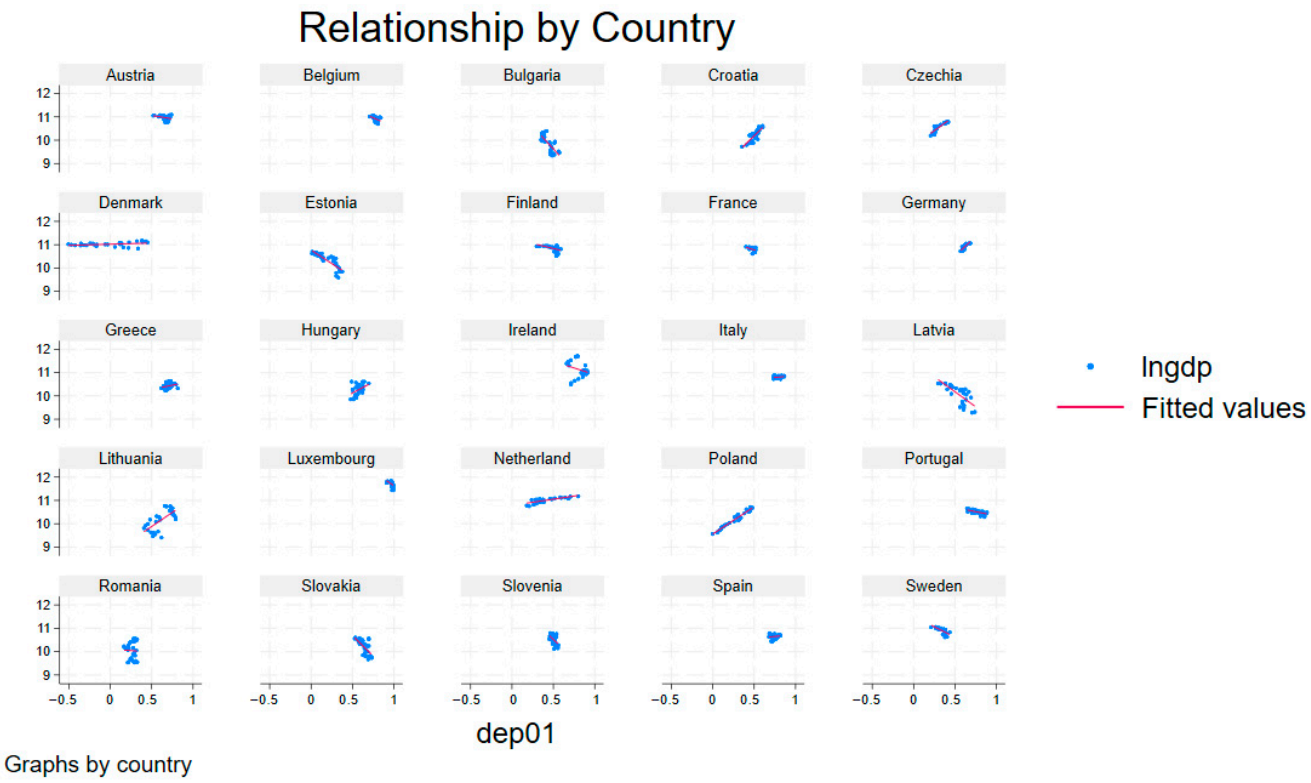


Figure 2. GDP and DEP relationship and country-specific dynamics.

This study used cross-sectionally ARD (CS-ARDL) as a baseline model and augmented mean group (AMG) as a robustness check, based on diagnostic tests for cross-sectional dependence, stationarity, cointegration, and slope homogeneity. To expand on the results from the CS-ARDL and AMG models, we further apply the method of moments quantile Regression (MMQR) to capture the impact at different stages of development across the countries included in the analysis. The results point to a direct relationship between the independent variables and the dependent variable, highlighting the direct impact of energy-related indicators on economic development, with particular implications for countries or periods with lower state development.

Specifically, this research explores the effects of energy diversification [4] and energy import dependency [5] on economic growth, unlike previous numerous studies that described the correlation between energy consumption and economic generation output without discussing the fragility of the energy-economy system in the context of foreign trade dependency. This study emphasizes the critical role of energy diversification in mitigating the economic risks posed by trade wars, geostrategic instability, and deglobalization. Unlike most of the existing literature that explores options for decoupling the

energy-economy system from carbon emissions, the aim of this study is to document energy diversification and energy transition as instruments to achieve not only environmental sustainability but also economic resilience and decreased energy dependency. The main results can provide valuable policy instruments for European nations to leverage their advantages and resiliently reshape the energy-economy system in response to global market uncertainties and deglobalization trends. Renewable energy plays a significant role in this context, contributing to carbon emissions mitigation and to ensuring the stability of internal energy markets. The differences between developed and less developed economies suggest that during the last couple of decades, besides ensuring faster development, globalization has also created dependency patterns. Under these circumstances, the results of this research indicate a higher likelihood of experiencing the effects of market instability for the less developed countries in our panel. Clearly, the trade and economic ties created by expanding global relations cannot be shattered overnight without significant effects, after many years of building economic capacities based on the free movement of investment capital and production resources, including energy. To effectively substantiate these results, the study uses several energy-related variables to determine their impact on economic growth. Briefly, these variables are renewable energy share, energy diversity index, and energy imports dependency (Table 1). The aim of recent energy policies is to increase the share of renewable energy sources until achieving the phasing out of fossil fuels. Using the variables that describe this process documents the stage reached by European countries and the impact of the expanding share of renewable energy sources on economic output generation. However, an increasing number of professionals and scholars recognize the gradual nature of this effort, discussing two major aspects: increased energy efficiency and the expansion of renewable sources within the energy mix. This study selected the diversity index of energy supply to describe the effects of energy diversification on economic development across European nations. Furthermore, to our knowledge, this research adds to the empirical analysis, beyond the first two energy-related variables, energy import dependency as a descriptor of energy independence. It is critical, in the current context characterized by trade wars, geopolitical instability, and market volatility, to understand the weight of energy import dependency on national economies and to provide policy recommendations aimed at increasing energy independence.

Table 1. Data and sources.

Variable	Abbrs.	Definition	Source
Economic growth	GDP	GDP per capita (constant 2015 USD)	World Bank
Labor market	EMPL	Employment to population ratio (15+, total %)	ILO
Energy transition	REN	Renewable energy (% equivalent primary energy)	Our World in Data
Energy diversification	DIV	Diversity index of energy supply (the composition of energy sources in the energy mix, with values between 0 and 1)	Eurostat
Energy independence	DEP	Energy import dependency (the share of total energy needs of a country met by imports from other countries)	Eurostat

The study continues with the literature review, while Section 3 presents the data and methods. Section 4 presents the main results and the discussion. The Section 5 is dedicated to drawing the conclusions and listing several policy recommendations.

2. Literature Review

2.1. Energy Diversification and the Labor Market

Previous research examined how the energy transition and energy diversification interact with various economic and social factors, creating a complex environment in which energy serves as the driver of significant transformations while also being influenced by markets and society. Expanding energy sources by increasing the share of renewables and diversifying the energy mix affects market volatility, economic cycles, and other components, such as the labor market and employment. Actually, previous research suggests that the transition towards renewable energy creates more jobs than traditional energy, boosting the number of new jobs across the whole energy generation cycle [6], for instance, in sectors such as transport and desalination [7]. Moreover, ref. [8] indicates that investments in the renewable energy sector will create new jobs and mitigate unemployment. However, the same research on the case of Spain underlines that the beneficial effects are not as high as expected for local communities where the investments are implemented. On the other hand, previous studies indicated that the cost of creating new jobs in the energy sector is high and challenging [9]. Under these circumstances, the net employment benefits are still under debate. Recent studies raise concerns regarding the regional discrepancies in employment gains, just transition, and fair green welfare allocation [10]. Furthermore, countries already struggling with social and economic challenges, low-income nations, and even less energy-independent emerging countries can experience negative economic effects and development downturns due to these transformations, especially in the short term [11]. Economically developed nations are not immune to energy-related risks and challenges. However, ref. [12] explains how energy diversification can mitigate energy risks, particularly in developed national economies. Additionally, the energy transition challenges the traditional energy sectors to adapt, a process that is costly and not smooth, as many workers are already highly specialized and would encounter difficulties in shifting to green jobs [13]. Another significant point is made by [14] in a study based on the case of the Netherlands. Their research claims that only a small proportion of the newly created jobs are strictly green, while the majority are non-green jobs that support the energy transition without directly contributing to environmental welfare. Another key point regarding the impact of energy transition and energy diversification on the labor market and its structure is made by [15]. They argue that there is a high probability that low-skilled workers lose their jobs as a result of the process, while new low-skilled jobs are less likely to be created. At the same time, demand for highly skilled labor increases due to stringent environmental regulations and new technologies. The perception that traditional energy sources represent the solid base for their social and economic welfare is present in communities that are historically connected to such sectors. They perceive renewable energy sources and technologies as unlikely to provide their future jobs and income source [16], making them reluctant to embrace the shift. On the other hand, when the final consumer is asked about their willingness to pay for energy transition and green jobs creation, the situation is slightly different, as emphasized by [17]. Generally, there is an agreement in previous research that energy diversification and adopting an increased share of renewable sources contribute to economic growth, create new jobs, ensure energy security, and enhance environmental welfare by mitigating emissions [18,19]. However, most of the studies debated on the long-term effects without fully explaining the immediate drawbacks and challenges.

2.2. Energy Market Uncertainty and Energy Diversification

The energy market is under complex pressure from net-zero carbon targets, climate change mitigation, energy dependence, and geopolitical challenges. Price volatility is challenging both economic activities and households' welfare, creating further frustration

regarding energy diversification targets and climate action. Recent research signals optimistic prospects for economic stability, green job creation, and reduced volatility, while promoting energy security and a renewable transition [20]. Furthermore, ref. [21] emphasized that increasing the contribution of renewable sources can mitigate market volatility and address turbulent periods, such as those generated by the war in Ukraine. Market projections incorporating renewable energy sources highlighted the significance of such options in addressing market challenges [22]. While some studies claim that trade openness does not necessarily promote energy diversification [23], it is generally believed that trade openness and global economic relations promote energy market stability and energy diversification. However, the new reality, characterized by deglobalization and difficulties in international trade, can further affect energy security and market stability. Recent studies documented the short-term impact of apparent deglobalization drivers, such as trade tariffs, on the potential for renewable energy generation [24].

2.3. Globalization and Its Effects

Globalization manifested as a natural process involving economic, social, and geopolitical systems and transforming international and national contexts. Over the last 20 to 30 years, opinions and empirical evidence have been divergent regarding globalization's impact on human society and development. For instance, various scholars linked globalization to economic inequality, increasing the asymmetries between developed and developing nations, skilled workers and unskilled ones, exacerbating development differences between urban and rural areas, and creating a world split between a wealthy Global North and a poor Global South [25,26]. The competition generated by the free movement of investment capital and the labor force due to expanding globalization supports major shifts in the labor market and deteriorates working conditions, resulting in job losses in developed countries and lowering labor standards in developing ones [27]. On the contrary, other studies have documented a different perspective, suggesting that free trade, foreign investment, and global financial relations are critical drivers of economic dynamics, significantly contributing to growth [28,29].

Numerous studies documented the environmental degradation generated by globalization. The mechanisms are diverse, including the substantial pollution due to economic globalization, the irrational natural resources exploitation in poor and developing countries, rapid industrialization and urbanization, and the occurrence of pollution havens leading to further environmental degradation by exporting the environmental issues freely from developed countries to Global South nations [30–32]. Nevertheless, some authors believe that globalization is also promoting technological development in economies that would otherwise have limited access to it, serving as a significant catalyst for innovation [33,34]. As such, globalization is considered to facilitate international cooperation on various issues, including environmental sustainability and the development of green technologies, and to be a promoter of the energy transition [35,36].

Last but not least, previous studies documented the so-called "cultural erosion" due to the expansion of globalization. Access to information and free contact with other cultures and communities can lead to cultural homogenization and the marginalization of indigenous identity and cultural ideals in favor of dominant ones imported from other regions [37].

All these previous findings leave significant room for further debate on how globalization and, more recently, deglobalization trends affect national economies generally and their energy positions specifically.

3. Data and Methods

3.1. Data Collection

This research selected a panel of 25 European countries (Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Romania, Sweeden, Slovenia, Slovakia) with diverse economic and energy profiles, using a dataset covering the 1995–2024 period to study the impact of labor-market and energy-related indicators on economic growth. The main independent variables are the energy import dependency, employment rate, and energy diversification, while renewable energy was selected as the control variable. The variable definitions and sources are given in Table 1. We have log-transformed the gross domestic product variable and also transformed employment, renewable energy, and the dependency ratio into decimal format to address scale consistency issues.

Energy import dependency reflects the share of a country's total energy needs met by imports from other countries. The rate shows the proportion of energy that an economy must import to cover domestic consumption needs. It is defined as net energy imports divided by gross available energy, expressed as a percentage (Energy dependence = (imports − exports)/gross available energy). A negative dependency rate indicates a net exporter of energy, while a dependency rate exceeding 100% indicates that energy products have been stockpiled.

The diversity index shows in one figure how varied energy sources used in a country are—the composition of energy sources in the energy mix. It is based on the Herfindahl–Hirschman index principle. This indicator can reach values only between 0 and 1. Lower values of this index indicate more varied sources (a fuel mix), while higher values indicate less variation (a tendency towards a limited set of dominant fuels). As most national economies use fossil fuels as their main energy source and are at different stages of diversification by expanding the role of renewable sources, the high values of this index suggest a predominant reliance on fossil fuels and limited shares of renewable sources. This indicator can help show how diversified the fuel mix is and how easily a single event can affect it, whether drought (hydropower shortage), high prices (natural gas, electricity), or another event.

3.2. Methodological Approach

To select the best econometric strategy, this study first evaluated cross-sectional dependence based on [38,39] recommendations using [40–42] tests. The test results highlighted cross-sectional dependence, and based on this, we decided to use the second-generation test [43] to assess the stationarity of the variables. Specifically, the cross-sectional augmented Dickey–Fuller (CIPS) test was applied, as it can handle serial correlation and cross-sectional dependence. Further, the cointegration was evaluated using [44] to verify the long-term relationship between the variables, and the next step was to apply [45] test to check the slope homogeneity for consistency and similarity across groups.

The econometric approach consists first of evaluating the mean long-run impact between independent variables and the dependent variable using cross-sectionally augmented ARD (CS-ARDL) and augmented mean group (AMG) as a robustness test, followed by a more in-depth analysis using the method of moments quantile regression (MMQR) to assess the impact by capturing the effects at different stages of development of the nations. MMQR examines the long-run distributional impact on levels.

The general model to investigate the impact of renewable energy, energy import dependency, diversity index of energy supply, and employment rate on economic growth is given by the equation below:

$$GDP_{it} = \beta_0 + \beta_1 REN_{it} + \beta_2 DIV_{it} + \beta_3 DEP_{it} + \beta_4 EMPL_{it} + \varepsilon_{it} \quad (1)$$

- Cross-Sectional Augmented ARDL (CS-ARDL)

The CS-ARDL model [46–48] remains a good approach for heterogeneous slopes and the presence of cross-sectional dependence in the panel, generating long-run estimates.

The CS-ARDL estimator is based on the following regression:

$$y_{it} = c_{yi}^{*} + \sum_{l=1}^{p_y} \varphi_{il} y_{i,t-l} + \sum_{l=0}^{p_x} \beta_{il}' X_{i,t-l} + \sum_{l=0}^{pz} \psi_{il}' \overline{Z}_{t-l} + e_{it}^{*} \quad (2)$$

In which the long-run coefficients are given by $N^{-1}\sum_{i=1}^{N} \hat{\theta}_{CS-ARDL,i}$ where the CS-ARDL estimator is given by $\hat{\theta}_{CS-ARDL,i} = \frac{\sum_{l=0}^{px} \hat{\beta}_{il}}{1-\sum_{l=1}^{py} \hat{\varphi}_{il}}$.

Thus, CS-ARDL includes the cross-sectional averages of the independent variables as well as the dependent variable, enabling slope heterogeneity and generating robust results for the case where the variables are I(0) or I(1).

- Augmented Mean Group (AMG)

The study implemented the approach introduced by [49,50] for heterogeneous slope and developed by [51], estimating the coefficients for a panel data with heterogeneous slope in the presence of cross-section dependence, which includes a common dynamic process going through two steps in the following equations:

$$\Delta y_{it} = b' \Delta x_{it} + \sum_{t=2}^{T} c_t \Delta D_t + e_{it} \quad (3)$$

$$y_{it} = a_i + b_i' x_{it} + c_i t + d_i \hat{\mu}_t^{\circ} + e_{it} \quad (4)$$

This estimator is robust to outliers and to cross-sectional dependence arising from multiple unobserved elements.

- Method of Moments Quantile Regression (MMQR)

The empirical analysis starts from a location-scale model for panel data [52,53], as presented in Equation (5).

$$y_{it} = \propto_i + x_{it}' \beta + (\delta_i + x_{it}' \gamma) u_{it} \quad (5)$$

where $\eta(\tau)_1 = \alpha_i + \delta_i \mathcal{Q}_u + (\tau)$ and $\beta(\tau) = \beta + \gamma \mathcal{Q}_u(\tau)$.

For this specific panel in which $n/T \leq 10$, the estimator will not be biased. Moreover, the method of moments quantile regression is useful in models with fixed effects and endogenous variables, allowing the estimation of conditional quantiles that account for heterogeneity and distributional effects. Additionally, this approach generates robust estimates even in the presence of outliers, endogeneity, and nonlinear relationships among the variables.

This method will highlight the impact of the independent variable while accounting for an economy's level of development.

4. Results and Discussion

4.1. Descriptive Statistics and Correlation

Table 2 presents the descriptive statistics of the initial version of the variables included in the model. In the analyzed countries, GDP per capita ranged from 10,707.515

to 138,677.96, while the maximum value of renewable energy was 50 higher than the minimum. Additionally, the figures show a high standard deviation for GDP, suggesting significant fluctuations in this indicator across European countries.

Table 2. Descriptive Statistics.

	N	Mean	SD	Min	Max
GDP	750	44,845.884	22,844.534	10,707.515	138,677.96
EMPL	750	52.822	5.656	37.288	66.509
DIV	750	0.2	0.060	0.117	0.402
DEP	750	53.827	24.207	−50.618	99.598
REN	750	12.557	10.631	0.024	52.459

Note: GDP = gross domestic product; EMPL = employment to population ratio; DIV = diversity index of energy supply; DEP = energy imports dependency; REN = renewable energy.

Table 3 and Figure 3 present the pairwise correlations among the variables, highlighting the absence of problematic correlations. Further, we have checked the variance inflation factor, and the test confirmed a non-problematic situation.

Table 3. Pairwise correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)
(1) GDP	1.000				
(2) EMPL	0.473 * (0.000)	1.000			
(3) DIV	−0.202 * (0.000)	−0.273 * (0.000)	1.000		
(4) DEP	0.288 * (0.000)	−0.255 * (0.000)	−0.038 (0.297)	1.000	
(5) REN	0.217 * (0.000)	0.206 * (0.000)	−0.324 * (0.000)	−0.069 (0.061)	1.000

Note: GDP = gross domestic product; EMPL = employment to population ratio; DIV = diversity index of energy supply; DEP = energy imports dependency; REN = renewable energy, * $p < 0.1$.

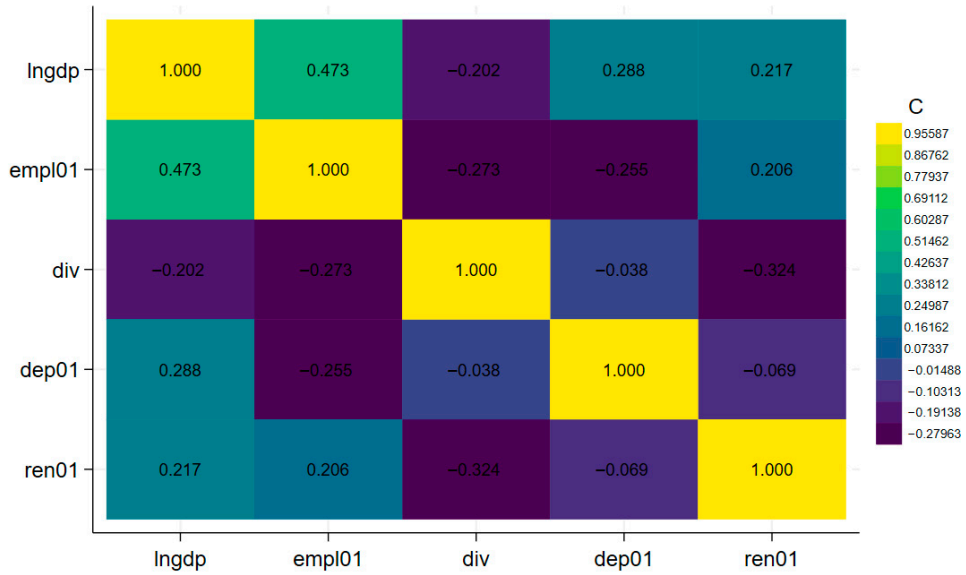


Figure 3. The correlation between the variables. C is the correlation coefficient.

4.2. Diagnostic Tests

Table 4 presents the results of cross-sectional dependence using Pesaran, Frees and Friedman tests. According to our results, our panel shows strong cross-sectional dependence: all tests are significant (Friedman and Pesaran at the 1% level of significance, while

Frees at the 10% level). Thus, stationarity will be tested using second-generation tests that account for cross-sectional correlation and dependence.

Table 4. Cross-sectional dependence tests.

Test Type	Value	Prob.
Friedman	189.373	0.0000
Pesaran	27.732	0.0000
Frees	6.001	0.086

The panel unit root test results are shown in Table 5. While the employment rate is stationary in level, the diversity index of energy supply, energy import dependency, and renewable energy consumption became stationary at the first difference. For GDP, we used the Fisher demeaned first difference, with 0.000 *p*-values for all tests, and set the integration order to 1.

Table 5. Panel unit root test results.

Variables	CIPS			
	Levels		First Difference	
	Constant	Constant &Trend	Constant	Constant &Trend
GDP	−1.616	−1.423	−3.448 ***	−3.652 ***
EMPL	−1.463 ***	−2.371	−3.538 ***	−3.613 ***
DIV	−2.803	−2.991	−5.622 ***	−5.875 ***
DEP	−1.554	−3.152	−5.630 ***	−5.835 ***
REN	−2.456	−2.813	−5.198 ***	−5.479 ***

Note: GDP = gross domestic product; EMPL = employment to population ratio; DIV = diversity index of energy supply; DEP = energy imports dependency; REN = renewable energy, *** indicate 1% level of significance, respectively.

Westerlund and Pedroni tests for cointegration are presented in Table 6. The results indicate the presence of long-term relationships among the variables, with the H0 of non-cointegration rejected.

Table 6. Panel cointegration.

	Westerlund Test for Cointegration	
	Statistic	**Prob.**
Variance ratio	1.4985	0.0670
	Pedroni Test for Cointegration	
	Statistic	**Prob.**
Modified Phillips–Perron t	2.6513	0.0040
Phillips–Perron t	−3.0728	0.0011
Augmented Dickey–Fuller t	−3.1774	0.0007

Table 7 presents the results of the homogeneity test. The null hypothesis of homogeneous slope coefficients was rejected; thus, the panel exhibits heterogeneous slope coefficients.

4.3. Estimation and Robustness Results and Discussion

The main results are presented in Table 8. According to it, the results of the CS-ARDL with a lagged dependent variable (GDP) highlight the direct impact of the employment rate, the diversity index of energy supply, energy import dependency, and renewable energy on economic growth in the long run. The robustness test (the AMG model, accounting also

for cross-sectional dependence) yields similar signs, while some variables have different statistical significance. The AMG model also considered the time-varying heterogeneity.

Table 7. Results of the homogeneity test.

	Statistic	Prob.
Delta	24.138	0.000
Delta adj.	26.987	0.000

Table 8. Long-run estimation results (CS-ARDL vs. AMG).

	(1)	(2)
	CS-ARDL	**AMG**
L.GDP	0.423 ***	
	(0.080)	
EMPL	7.243	1.276 ***
	(5.281)	(0.223)
DIV	3.654 *	0.079
	(2.135)	(0.205)
DEP	1.187 *	0.195 ***
	(1.124)	(0.075)
REN	0.979 *	0.172 *
	(1.670)	(0.114)
Constant		0.708
		(1.737)
Observations	675.000	750.000
Countries	25.000	25.000

Note: L.GDP = lagged gross domestic product; EMPL = employment to population ratio; DIV = diversity index of energy supply; DEP = energy imports dependency; REN = renewable energy; Standard errors in parentheses; * $p < 0.10$, *** $p < 0.01$.

Based on the results of the CS-ARDL and AMG models, one can identify the positive role of energy dependency in economic growth in the analyzed countries of the European Union. First, we should mention that for more than 60% of the European Union's development needs, member states are using external energy sources (extra-EU) because domestic energy sources are insufficient, or insufficiently exploited, if we are talking about renewable sources. However, after the war in Ukraine began, the European Union intensified its efforts to achieve energy security and independence, and the first moves focused on shifting imports from Russia to other, more reliable and stable alternatives. This being said, in 2023 [54], for example, the total extra EU natural gas imports came from Norway (27%), the United States (19%), and Algeria (14%), while in 2021 [55], 44% of the natural gas imports were from Russia, 16% from Norway and 12% from Egypt. Additionally, Russia accounted for 25% of crude oil and NGL imports in 2021 and 52% of hard coal imports. However, the data for the year 2023 highlight only irrelevant imports from Russia, while the most important countries are Australia, the United States, and Colombia for hard coal, and the United States, Norway, and Kazakhstan for crude oil. Second, the European Union pushed the capacity of renewable energy generation. From the table above, we can also observe the positive impact of renewable energy on economic growth, as confirmed by [56,57], but in contrast to [58]. Moreover, the energy supply diversity index is found to influence economic growth positively. Thus, lower values of the index indicate that a country has more varied sources of energy, which positively influences growth. Overall, the index level in the European Union during the analyzed period is rather low (below 0.4), indicating minimum

to average levels of energy concentration, suggesting that European countries are less vulnerable to various factors and possible disruptions (environmental or economic) [59,60]. The latest policy actions related to energy transition at the European level help diversify countries' energy profiles by balancing renewable and non-renewable energy sources and improve their potential to generate economic growth more sustainably [61], and link the energy quality profile of a country to higher national income.

Given the cointegration established by the Pedroni test, we estimate quantile regressions at the level to examine the long-run distributional effects. Table 9 presents the results of the MMQR model, estimating the quantile regression on levels, based on the presence of cointegration.

Table 9. Panel quantile regression results (MMQR).

	(1)	(2)	(3)	(4)
	Q25	**Q50**	**Q75**	**Q90**
EMPL	4.153 *** (0.371)	3.904 *** (0.225)	3.777 *** (0.267)	3.681 *** (0.340)
DIV	−0.632 (0.418)	−0.214 (0.254)	−0.000 (0.300)	0.160 * (0.382)
DEP	−0.019 (0.106)	0.004 (0.064)	0.017 * (0.076)	0.026* (0.097)
REN	1.484 *** (0.192)	1.637 *** (0.117)	1.715 *** (0.138)	1.774 *** (0.176)
Observations	750.000	750.000	750.000	750.000

Note: EMPL = employment to population ratio; DIV = diversity index of energy supply; DEP = energy imports dependency; REN = renewable energy; Standard errors in parentheses; * $p < 0.10$, *** $p < 0.01$.

The results from the MMQR method showcase several relevant threads of ideas.

First, a direct relationship between employment and renewable energy across all quantiles, with a different impact in Q25 than in Q90. Explicitly, the coefficients are higher in Q25 than in Q90 for the employment rate, but they evolve in the opposite direction for renewable energy. In this sense, we can affirm that national systems with higher economic growth benefit more from renewable energy than those with lower gross domestic product per capita. However, the impact of employment follows a distinct pattern, with a larger impact observed in countries or years with lower economic growth, helping developing countries more than developed ones.

Furthermore, the negative coefficient for energy dependency in the first quantile suggests that economies with low GDP per capita are more likely to be at risk and to be influenced by market volatility. Moreover, in the context of deglobalization, these economies should prioritize energy diversification and the exploitation of their own renewable energy sources to mitigate the risk of economic disruptions. The negative coefficient for the diversification coefficient supports this assertion. The countries in the first two quantiles, meaning those with weaker economic growth, will be influenced by the diversification and must seek to use this to their benefit. First, they can escape the energy dependency trap by using, as said earlier, their renewable energy potential. Second, they can respond resiliently to deglobalization trends and trade tariffs by moving towards energy independence and self-sufficiency in energy supply.

Second, the energy import dependency relationship moves from an indirect relationship in Q25, highlighting the negative impact on economic growth at lower levels of development, to a direct relationship as we move towards higher quantiles. The findings for higher quantiles are particularly valuable as they show that well-established national

economies can easily manage the relationship between economic growth and energy consumption. Specifically, even if there is still a direct connection between economic output generation and energy, they are close to decoupling the economic mechanisms from energy, as the coefficients describing the relationship are low. Furthermore, once a certain level of economic development is reached, these national economies can easily adjust their energy market positions without significantly affecting their output generation potential. Additionally, as fossil fuels still cover a significant share in total consumption, these countries can experience significantly fewer challenges in switching towards an increased share of renewable sources of energy and energy diversification. On the other hand, smaller, less developed economies are struggling with their energy dependency. They are prone to depend on a limited number of suppliers (or even a single one), and their market position is more fragile. Moreover, their reliance on imports can increase costs, leaving them at constant risk of shutting down economic processes at the supplier's whim. Uncertain events, such as geopolitical difficulties and conflicts, can raise further challenges for such national economies. Their dependency limits their willingness to join common political visions or decisions. For example, if an international commercial ban applies to their limited number of energy suppliers, they are reluctant to endorse it, or, if they do, they need to improvise further to fuel their economic processes and households' energy consumption.

Third, the MMQR results regarding the diversity index are also interesting. While in Q25, Q50, and Q75 it shows a negative but insignificant impact on economic growth, in the highest quantile (Q90), the coefficient shifts to a positive, statistically significant value. Thus, during slow economic growth periods or countries with lower levels of growth, the increase in the index values will affect the development of the state (although not in a significant measure), while in countries with higher levels of economic growth, even a less diversified mix of energy will influence the development positively, considering their intensive resource endowment.

The Figure 4 presents the comparative coefficients, showcasing the impact of the employment rate, the diversity index of energy supply, energy import dependency, and renewable energy, based on coefficients generated by the AMG estimator and MMQR. Thus, one should note that, for all energy-related indicators, the impact is stronger as the level of development increases; though the importance of employment is greater in lower quantiles, grounded in the relevance of work and productive employment as a main factor in economies at a lower level of development, according to SDG 8—decent work and economic growth.

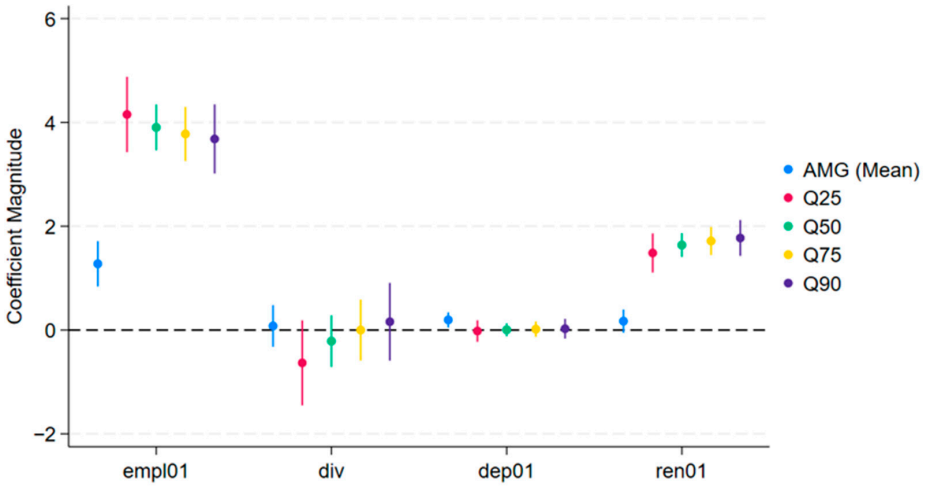


Figure 4. The impact of independent variables across the distribution. Note: Bars represent 95% confidence intervals.

5. Conclusions and Policy Recommendations

Globalization and trade openness can act in both ways regarding energy diversification and renewable energy expansion. First, it can create the premises and a favorable context for technological development, which supposedly promotes the development and transfer of green technologies, green investments, increased energy efficiency, and renewables. On the other hand, free trade can increase the dependence of countries with limited access to energy sources or limited renewable generation potential on fossil fuels, thereby increasing carbon emissions and creating energy security risks.

Different from previous research that extensively investigated the interactions between energy consumption and economic growth, this study explored the connections between energy diversification and energy import dependency on one hand, and economic growth on the other. To do this, the study uses data covering the period from 1995 to 2024 for 25 European countries. The cross-sectionally augmented ARD (CS-ARDL) is the main empirical analysis instrument, while the augmented mean group (AMG) is used to check the robustness of the main results. Furthermore, the method of moments quantile regression (MMQR) is employed to capture the impact more precisely across various stages of countries' development.

The findings fill a gap in understanding how European economies resiliently cope with deglobalization and adjust their energy-economy systems to maintain economic and social welfare unaltered. As reflected in the main results, expanding the role of renewable energy sources in total consumption, as part of diversification efforts, is significant to the overall picture. Moreover, the results showcase a direct impact of employment on economic growth in less developed nations. The reason may be that in such economies, economic output is more labor-intensive than in highly developed countries, which are supposedly more technologically advanced. This finding provides relevant support for public policies that encourage employment and attract investments that create new jobs and subsidize labor.

In a context that is rearranging the economic and global energy dependencies and market positions, this study provides valuable policy insights. For instance, policymakers should carefully consider the national energy potential, investing in developing this potential to increase energy independence. In the case of numerous European countries, such a policy orientation can lead to the expansion of renewable sources of energy due to the significant potential of some of the countries. It is recognized that the cost of initial investments in the renewable energy sector is high. The recent trends of nearshoring and friendly shoring accompanying deglobalization can also open new channels for the cooperative development of energy generation capacities, especially for renewable energy options.

As these models used to test the impact of economic and energy-related variables on economic growth included only a limited number of variables, the study's limitations are directly related to this aspect. In this sense, including key growth determinants, such as fixed capital formation, education level, trade openness, and the quality of institutions, could provide greater clarity on the economic context and the magnitude of the impact of energy-related indicators on economic growth. Furthermore, expanding the country selection or using different groups of countries would also expand the understanding on how economic dependencies work in a deglobalizing context. Also, using different econometric approaches, exploring a threshold model, and examining a moderating mechanism could expand the research's conclusions and relevance, and could be included in future research. Nevertheless, this study opens the floor for further research that will explore the transformations and economic repositioning that affect nations and regional economies.

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