

## RENEWABLE ENERGY AND ECONOMIC GROWTH: EVIDENCE FROM EUROPEAN UNION COUNTRIES

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(Received: December 2025; Accepted: February 2026; Published: April 2026)

**Abstract:** This study investigates the relationship between renewable energy and economic growth across European Union member countries between 2013 and 2023, considering cross-country differences. To address the mixed results in existing research, a two-step empirical

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approach is used. First, hierarchical cluster analysis groups EU countries based on their similar renewable energy and economic development patterns. Second, country-level linear regressions assess the connection between renewable energy and GDP. The findings reveal distinct clusters corresponding to different energy transition pathways, broadly differentiating more developed, long-standing EU Member States from catching-up, newer Member States. The regression analysis shows that the relationship between renewable energy and economic growth varies across these groups. While in some countries, renewable energy is positively associated with economic performance, in others, the relationship is weak or statistically insignificant. These results underscore the importance of tailored, context-specific energy policies. The study advocates for designing customized renewable energy strategies that align energy deployment with broader economic and institutional factors to foster sustainable growth.

**Keywords:** Renewable energy; energy transition; economic growth; cluster analysis; heterogeneity.

**JEL Codes:** Q43, O47.

## 1. Introduction

The shift toward renewable energy (RE) has become a key part of the European Union's economic and environmental policies, driven by the goals of reducing carbon emissions and promoting sustainable economic growth (EG). In the context of combating climate change, addressing energy security issues, and increasing volatility in fossil fuel markets, RE is viewed not only as an environmental necessity but also as a potential driver of long-term EG. As a result, understanding the relationship between RE and economic performance has gained significant attention in both research and policy discussions.

Sustainable economies strive to strike a balance between competitiveness and energy efficiency, thereby reducing reliance on non-renewable resources (OECD, 2020). The shift toward RE systems is widely recognized as a major driver of sustainable EG, climate change mitigation, and energy security (IRENA, 2015). Recent empirical research also supports this perspective, finding a positive link between RE and GDP growth (Wei & Huang, 2022; Ali & Raissi, 2024; Sari-Hassoun et al., 2025; Yin et al., 2025).

Despite growing interest, the empirical literature on the relationship between RE and EG has yielded mixed, often inconclusive results, particularly in the European context. While some studies find a positive link between RE use and EG, others show weak, insignificant, or neutral effects. These differing findings suggest that the impact of RE on economic performance is unlikely to be uniform across countries

and may depend on structural factors such as income level, energy intensity, economic structure, and policy design.

The EU offers a particularly relevant context for exploring this variability. Although EU Member States operate under a shared climate and energy policy framework, they vary significantly in terms of economic development, energy sources, technological capacity, and institutional quality. Consequently, countries follow different energy transition paths, leading to varied economic outcomes. Overlooking this variability risks oversimplifying the relationship between RE and EG, and may help explain the inconsistencies observed in previous empirical research.

The present study uses a cluster-based analytical approach to examine the relationship between RE development and EG in EU member countries. By grouping countries according to similarities in RE and economic features, the analysis explicitly considers structural diversity within the EU. This approach is supplemented by country-level linear regressions that allow investigation of the relationship between RE and GDP.

The aim of this study is to analyze the relationship between RE and EG in the EU, explicitly accounting for cross-country differences. The analysis seeks to identify groups of countries with similar RE and economic development profiles and to examine how the relationship between RE and growth varies across these groups. By combining cluster analysis with country-level linear regression models, the study aims to provide a more detailed understanding of the economic effects of RE in the EU.

The contribution of this study is threefold. First, it establishes a systematic classification of EU countries based on their RE and economic development profiles, highlighting various transition paths. Second, it provides empirical evidence on how the relationship between RE and EG varies across countries, contributing to the ongoing discussion about the growth effects of RE. Third, the results underscore the need for energy strategies tailored to specific contexts rather than one-size-fits-all policies.

The rest of the paper is organized as follows. The next section covers the relevant literature on RE and EG. Section 3 explains the data and methodology. Section 4 displays the empirical results. Section 5 interprets the findings in relation to existing studies, and Section 6 offers the conclusion.

## 2. Literature review

The literature on the relationship between RE and EG is extensive, showing various viewpoints and reaching different conclusions depending on the context. A survey of empirical studies on the causal relationship between RE consumption and EG, conducted by Cvijović et al. (2020), found no clear consensus in the existing

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research. However, Bhuiyan et al. (2022) conducted a systematic review that confirms that RE does not hinder EG in both developing and developed countries, although it has a minor impact on the EG of developed countries. Additionally, the bibliometric analysis by Chou et al. (2023) supports the positive links between RE adoption and key economic indicators, including GDP growth, industrial productivity, and technological innovation.

Several studies have examined the causal relationship between RE and EG. Matei (2018) confirms a long-term bidirectional causality between renewable and non-RE consumption and EG in OECD countries. Ahmed & Shimada (2019) found bidirectional causality between RE consumption and EG in 30 emerging and developing countries. Similar results were obtained by Perera et al. (2024), who used the Granger causality test to examine the relationship between energy consumption and EG across 152 nations from 1990 to 2019. These findings are also supported by Soava et al. (2018), who confirm the bidirectional causality between RE and EG in European Union countries and the United Kingdom. Kasperowicz et al. (2020) identified a positive long-term equilibrium relationship between RE consumption and EG. Studies from Central and Eastern Europe reveal bidirectional causality between RE consumption and EG in the long run (Marinaș et al., 2018; Neagu et al., 2021). On the other hand, Mutumba et al. (2024) reported support for the neutral hypothesis in Uganda.

Empirical literature consistently shows a positive link between RE use and EG worldwide. The study by Shahbaz et al. (2020) provided evidence of the long-term positive impact of RE consumption on economic development across 38 countries. Additionally, studies focusing on developing Asian economies (Mohsin et al., 2021) and Ghana (Gyimah et al., 2022) have confirmed that increasing RE consumption promotes EG. Similar findings are also observed in European contexts, where RE sources are positively correlated with GDP per capita, particularly in countries with higher GDP (Ntanos et al., 2018; Pegkas, 2020; Sahlian et al., 2021).

Research on the connection between RE use and EG yields complex, context-specific results. Thombs (2017) highlighted the "RE paradox," in which the carbon-reduction benefits of RE diminish at higher GDP levels, suggesting different policy approaches for developed and developing nations. Singh et al. (2019) found that RE production has a positive impact on EG in both developed and developing countries, although the effect is stronger in developed economies.

Research on OECD countries shows that the positive effect of RE on EG grows stronger once certain risk thresholds are surpassed (Wang et al., 2022). It also indicates that countries need to reach specific development levels to benefit from RE investments (Makiela et al., 2022). Similarly, Chen et al. (2020) found that this

relationship depends on threshold levels of RE use; developing countries see positive growth effects only after exceeding certain consumption thresholds.

Several studies have found that the relationship between RE use and EG is influenced by factors such as urbanization and per capita income (Wang & Wang, 2020). While RE promotes job creation, technological progress, and reduced dependence on imports (Dirma et al., 2024), causality often flows from EG to RE consumption rather than the other way around (Armeanu et al., 2017; Rahman & Velayutham, 2020).

The studies above suggest that RE can promote sustainable economic development; however, its effectiveness depends on various factors. Based on the literature reviewed, the following research hypotheses for this study were developed:

H1: The 27 EU member countries form distinct and internally consistent groups based on RE and EG, reflecting diverse but organized paths of energy transition and economic development.

H2: RE has a significant positive impact on EG across EU countries.

### 3. Research methodology

This article examines the relationship between RE and EG in EU member states. The first hypothesis aims to determine whether there are groups of EU countries with similar approaches and outcomes related to RE and economic development, given the numerous differences among the 27 EU member states.

To test the first hypothesis, hierarchical clustering was conducted using the Ward linkage method and squared Euclidean distance. This technique helps identify EU countries with similar RE and economic development profiles. Hierarchical clustering with Ward's method was chosen as the primary classification method because it is well-suited for small samples and can minimize within-cluster variance without imposing a priori assumptions about the number of clusters. To verify the robustness of the results, a k-means clustering procedure was later applied using the same number of clusters.

To verify differences between clusters, the ANOVA test was used to determine whether the mean values of the clusters are equal. The significance level is set at 10%, and values below this allow rejection of the hypothesis that the clusters are equal, indicating a significant difference between them. The cluster analysis was conducted using SPSS software both at the start and at the end of the observed period to see if any countries had shifted to different clusters. This enables the observation of countries' development and evolution.

Following the cluster analysis, the second research hypothesis aims to determine whether there is a significant positive correlation between RE and the EG of European Union countries. Based on the literature review, we compile a database

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that includes the most important variables used to examine this relationship: GDP per capita for EG, total energy production from all renewable sources, greenhouse gas emissions, employment rate, and total investment in fixed capital. The data for all variables across all EU countries cover the period from 2013 to 2023. A description of these variables is provided in Table 1.

**Table 1. Description of variables**

Variable		Description	Unit of measure	Source
GDP	GDP per capita	The ratio of Gross Domestic Product at market prices to the average population of a specific year	Chain-linked volumes (2020), euros per capita	Eurostat database
RE	Renewable Energy	Energy generated from the total renewable sources: solar photovoltaic, solar thermal energy, onshore wind energy, offshore wind energy, renewable hydropower, mixed hydro plants, marine energy, solid biofuels, renewable municipal waste, liquid biofuels, biogas, geothermal energy.	GWh	IRENA database
GHG	Greenhouse gas emissions	Greenhouse gases (CO <sub>2</sub> , N <sub>2</sub> O, CH <sub>4</sub> , HFC, PFC, SF <sub>6</sub> , NF <sub>3</sub> in CO <sub>2</sub> equivalent) of all economic activities.	Kilograms per capita	Eurostat database
EMP	Employment rate	Total employment of the population aged between 20 and 64 years old.	Percentage of the total population	Eurostat database
FCAP	Investments in fixed capital	Accumulation of fixed tangible or intangible assets.	Percentage of Gross Domestic Product	Eurostat database

To test the second research hypothesis, a linear regression analysis was performed for each EU country, with GDP as the dependent variable and RE, greenhouse gas emissions, employment rate, and investments in fixed capital as predictor variables. This approach enables the examination of the relationship between the dependent

variable and predictors in each country, helping to understand the direction, strength, and statistical significance of these relationships.

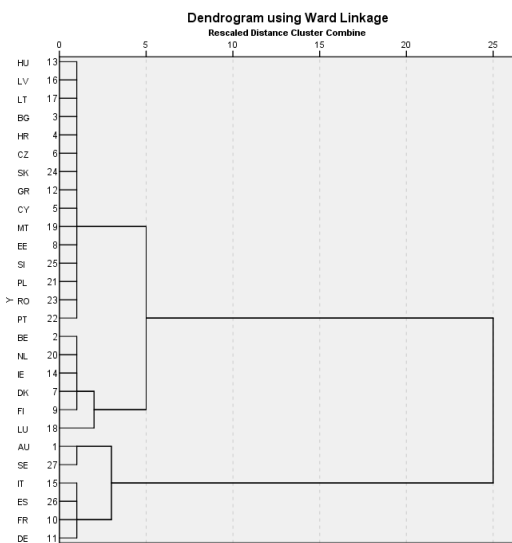
The regression equation used was:

$$GDP_t = \alpha + \beta_1 \times RE_t + \beta_2 \times GHG_t + \beta_3 \times EMP_t + \beta_4 \times FCAP_t \quad (1)$$

Where: GDP = GDP per capita; RE = Renewable energy; GHG = Greenhouse gas emissions; EMP = Employment rate; FCAP = Investments in fixed capital;  $\alpha$  = free coefficient;  $\beta_1, \beta_2, \beta_3, \beta_4$  = coefficients of the predictors.

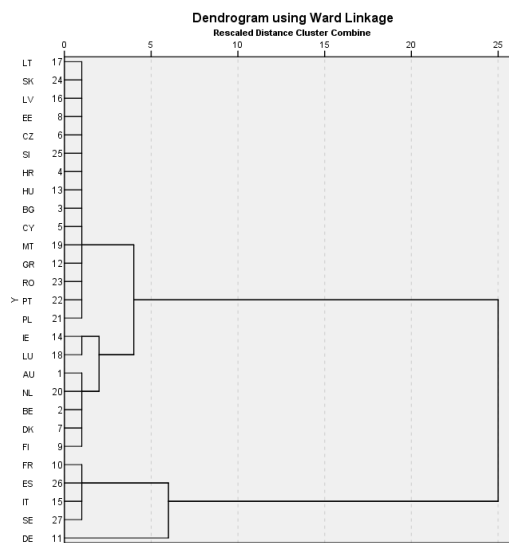
#### 4. Empirical results

Cluster analysis was employed to identify groups of EU countries with similar RE and EG. The results of hierarchical clustering using Ward’s method for the 2013 and 2023 datasets are shown in Figure 1 and Figure 2.



**Figure 1. Ward’s hierarchical clustering for 2013**

Source: Authors’ processing



**Figure 2. Ward’s hierarchical clustering for 2023**

Source: Authors’ processing

Hierarchical clustering using Ward’s method groups the EU countries with similar patterns in RE and EG into five clusters for both 2013 and 2023. The k-means clustering method was applied to these five clusters to test the robustness of the

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approach. Table 2 shows the composition of each cluster for the years included in the analysis.

**Table 2. K-means cluster composition**

2013			2023		
Cluster	No.	Countries	Cluster	No.	Countries
1	6	Austria, Belgium, Denmark, Finland, Ireland, Netherlands	1	4	France, Italy, Spain, Sweden
2	1	Luxembourg	2	1	Germany
3	1	Germany	3	13	Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Croatia, Hungary, Latvia, Lithuania, Malta, Romania, Slovenia, Slovakia
4	4	France, Italy, Spain, Sweden	4	7	Austria, Belgium, Denmark, Finland, the Netherlands, Poland, Portugal
5	15	Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Croatia, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovenia, Slovakia	5	2	Ireland, Luxembourg

Source: Authors' processing

While the overall clustering pattern stays consistent across methods, some countries show sensitivity to the clustering algorithm, highlighting their transitional profiles in RE and economic development. Countries with unstable cluster membership appear to be positioned between energy and economic development paths, emphasizing diversity within the EU and the non-linear nature of the energy transition.

A first cluster formed in 2013 includes Austria, Belgium, Denmark, Finland, Ireland, and the Netherlands. These countries share a common profile of RE and EG, characterized by high income levels, early adoption of RE policies, diversified energy sources, and strong institutional capacity. The results indicate that in these nations, the expansion of RE is closely linked with productivity-enhancing sectors, supporting sustainable EG.

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Although Poland and Portugal differ from high-income EU economies in terms of income levels, they exhibit similar trends in RE and EG. The fast deployment of renewables, strong policy alignment with EU climate goals, and increasing integration of renewables into productive sectors are moving these countries closer to advanced energy transition paths, justifying their grouping in the same cluster in 2023.

In 2013, the second and third clusters each included only one country: Luxembourg and Germany. These countries are often viewed as outliers with distinct profiles. Luxembourg is known for its exceptionally high GDP per capita, very low energy intensity, limited domestic renewable potential, and a strong decoupling of EG from energy consumption. In 2023, Ireland joined Luxembourg in the same cluster, characterized by similar RE and economic development profiles, featuring very high income levels, low energy intensity, and strong institutional capacity. In both cases, RE mainly plays a supportive role within a service-driven growth model, allowing both countries to be grouped together despite differences in the scale of RE deployment.

Germany maintains a unique profile in RE and EG within the EU, influenced by its economic size, industrial makeup, and comprehensive energy policy. These factors distinguish Germany from both high-income, service-oriented countries and catching-up Member States, justifying its separate classification in the clustering analysis.

The fourth cluster comprises France, Italy, Spain, and Sweden, which exhibit similar profiles in terms of RE and economic development. These countries feature diverse energy mixes, strong public policy coordination, and a middle stage of energy-growth decoupling. In each, RE growth supports their economies without being the only factor driving growth, which justifies grouping them together.

A fifth cluster includes Bulgaria, Cyprus, the Czech Republic, Estonia, Greece, Croatia, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovenia, and Slovakia. These countries form a group characterized by lower initial income levels, higher energy intensity, and rapidly expanding RE capacity driven by EU policy alignment. In these nations, RE serves a transitional role in economic development, supporting convergence rather than acting as a fully mature growth driver. Poland and Portugal exhibit transitional profiles of RE and economic development, positioning them between those of catching-up and advanced EU economies. Rapid renewable deployment, decreasing energy intensity, and increased policy stability contribute to their proximity to advanced transition countries, explaining their movement between clusters.

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The ANOVA test performed confirms the difference between clusters (Table 3). Based on these observations and findings, we conclude that the first research hypothesis is confirmed.

**Table 3. ANOVA test results**

2013	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
GDP	2443350228.935	4	26138328.409	22	93.478	.000
RE	10933566876.774	4	130986717.650	22	83.471	.000
2023	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
GDP	2582843710.880	4	97748512.500	22	26.423	.000
RE	24522372082.538	4	117901354.415	22	207.991	.000

Source: Authors' processing

Moving on to testing the second research hypothesis, the equation from the research methodology section was applied to the available data for each EU country. The results indicate that the model is marginally significant, with R-squared and Adjusted R-squared values exceeding 0.85 and 0.77, respectively. Luxembourg presents a unique case, with an R-squared of 0.276 and an Adjusted R-squared of -0.207, suggesting very limited explanatory power for such a complex economy. The results presented in Table 4 are organized according to the cluster analysis and the grouping of EU countries for 2023.

The results demonstrate the positive influence of RE, greenhouse gas emissions, and employment on EG in the countries of the first cluster. However, RE is not a significant predictor of EG in this cluster. Instead, employment and greenhouse gas emissions are key factors for EG, except in Sweden. Investments in fixed capital have a negative impact on EG in France and Spain. Nevertheless, they have a positive effect in Italy and Sweden, but are only significant factors in Italy and France.

Germany forms the second cluster, and the results demonstrate the positive impact of all predictors on EG. However, greenhouse gas emissions, employment, and investments in fixed capital continue to be significant factors affecting it.

**Table 4. Linear regression model results**

Cluster		Dependent Variable: GDP					R Square	Adjusted R Square
		Predictors						
		$\alpha$	RE	GHG	EMP	FCAP		
1	FR	-79183.898 ***	.000	2.966 **	1587.364 ***	-648.074 *	.901	.835
	IT	-31120.767 ***	.019	3.185 ***	565.639 ***	353.886 ***	.978	.964
	ES	-15222.396 *	.022	1.847 **	506.840 ***	-243.930	.971	.951
	SE	-12792.350	.063	.911	427.274	592.075	.896	.826
2	DE	-44606.982 **	.021	1.270 **	589.542 **	1242.858 *	.952	.921
3	BG	1761.967	.149 *	-.257 *	161.993 ***	-170.649 *	.976	.961
	CY	-15239.442	4.591 *	.711	428.846 ***	18.144	.980	.967
	CZ	-26554.259 ***	.470	.608	468.657 ***	8.503	.976	.961
	EE	-23728.284	1.197	.144	456.189 *	148.594	.901	.835
	GR	-2705.041	-.014	.614	207.725 **	200.163	.923	.871
	HR	-23135.551 **	.258 *	3.383	309.061 ***	-83.651	.953	.922
	HU	-5107.048 **	.500 *	1.322	100.488	85.260	.988	.980
	LT	-23673.448 ***	-.435	.587	222.172 **	982.099 **	.983	.971
	LV	-18831.795 *	.132	-.641	475.486 ***	57.144	.867	.779
	MT	-63450.364	-35.953	-.143	1342.347 *	-6.606	.952	.921
	RO	-11100.076 *	.005	-.044	350.243 ***	-3.057	.992	.987
	SI	-7389.719	.051	-.552	419.199 ***	106.138	.977	.961
SK	-7381.694	-.037	-.036	350.995 ***	-37.240	.943	.905	
4	AU	-45442.009 ***	-.084 *	.182	1231.363 ***	-4.371	.975	.958
	BE	-41638.329	-.402	-1.852	1210.266 **	902.664	.909	.848
	DK	-15666.689	.240	.568 **	603.548	421.214	.987	.978

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	<b>FI</b>	4257.372	.075	.347	245.330	609.645 **	.930	.884
	<b>NL</b>	-74205.744 ***	.132 *	2.604 **	1228.425 ***	-243.140	.968	.947
	<b>PL</b>	-12252.036 *	-.016	-.145	392.616	-15.377	.989	.982
	<b>PT</b>	8227.569	-.089	-1.576	519.402 **	-823.039	.900	.834
<b>5</b>	<b>IE</b>	-113188.743	1.550	-2.163	2697.802	-108.588	.950	.917
	<b>LU</b>	37094.485	2.628	1.210	562.112	418.800	.276	-.207

Note: \*\*\* p < 0.01 – Highly statistically significant; \*\* p < 0.05 – Statistically significant; \* 0.05 < p < 0.10 – Marginally statistically significant

Source: Authors' processing

The results for the third cluster show the positive effect of employment on EG across all countries. Employment is a significant factor for EG, with Hungary being the only exception. Differences can be seen in the other predictors. RE positively impacts EG, except in Greece, Lithuania, Malta, and Slovakia, but it is significant only in Bulgaria, Cyprus, Croatia, and Hungary. Greenhouse gas emissions show a positive effect on EG only in Cyprus, the Czech Republic, Estonia, Greece, Croatia, Hungary, and Lithuania, but are a significant factor only in Bulgaria. Investments in fixed capital have a positive influence on EG only in Cyprus, the Czech Republic, Estonia, Greece, Hungary, and Slovenia, whereas they negatively affect the other countries. However, they are significant only in Bulgaria and Lithuania.

The results for the fourth cluster are similar to those of the third cluster, highlighting the positive impact of employment on EG across all countries. However, it is a significant factor only in Austria, Belgium, the Netherlands, and Portugal. The other predictors display different effects. RE has a positive impact on EG in Denmark, Finland, and the Netherlands, but a negative impact in the other countries. However, it is significant only in Austria and the Netherlands. Greenhouse gas emissions have a positive effect on EG in Austria, Denmark, Finland, and the Netherlands; however, this effect is significant only in Denmark and the Netherlands. Investments in fixed capital have a positive influence on EG in Belgium, Denmark, and Finland, but this effect is significant only in Finland.

The last cluster highlights a positive effect of RE and employment on EG. Greenhouse gas emissions and investments in fixed capital have a positive influence on Luxembourg's EG, whereas they have a negative impact in Ireland. However, none of the predictors is statistically significant for EG.

Based on these results, the second research hypothesis is not confirmed. Even though some countries show that RE has a positive influence on EG, only in Bulgaria,

Cyprus, Croatia, Hungary, and the Netherlands, RE is a significant factor for economic development.

## 5. Discussion

This study aimed to examine the relationship between RE and EG in the EU, based on two research hypotheses. The first hypothesis explored whether groups of EU countries share similar approaches to RE and EG. Using cluster analysis, this research confirms this hypothesis and highlights significant diversity in the relationship between RE and growth. Our findings are consistent with other studies on RE in the EU, which show considerable heterogeneity across member states. Parobek et al. (2016), Scaramuzzino et al. (2019), and Zuev & Kanikhin (2024) identified distinct groupings of EU countries based on RE characteristics, while Polyanska et al. (2025) assessed the EU countries' energy transition efficiency and found that higher resource efficiency does not necessarily correspond with better transition indicators. Brodny & Tutak (2020) analyzed the structure and volume of RE production across EU countries, observing notable diversity among nations.

The second research hypothesis examined the effect of RE on EG across EU countries. The results of the linear regression analysis show that the expected positive relationship between RE and EG does not apply uniformly to all EU Member States. Nevertheless, a positive relationship is seen in most countries, indicating that Hypothesis 2 is partly supported. A negative impact was noted in Greece, Lithuania, Malta, Slovakia, Austria, Belgium, Poland, and Portugal. Other studies support the positive influence of RE consumption on GDP and competitiveness (Simionescu et al., 2020; Mehedintu & Soava, 2024). Additionally, multiple studies using panel data regression models have confirmed that RE consumption has a positive impact on EG across EU member states (Davidson et al., 2021; Buşu, 2020). However, Smolović et al. (2020) found that the relationship varies across traditional and new EU members: new members experience negative short-term impacts, whereas traditional members show no significant short-term effects.

## 6. Conclusions

This study examined the relationship between RE and EG across EU member countries, specifically addressing cross-country differences using a cluster-based analytical framework supplemented by country-level linear regression analyses. The findings confirm that the connection between RE and EG varies among EU countries.

The clustering results identify several coherent groups of countries distinguished by different stages of energy transition and economic development. Advanced

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economies with diverse energy systems and stable policy frameworks tend to incorporate RE more effectively into their growth models. Conversely, catching-up and transitional economies exhibit a more uneven relationship, in which RE expansion is often driven by EU policy compliance and investment support rather than productivity-boosting mechanisms. Countries identified by us as situated at the edges between clusters and transitioning among cluster profiles exemplify dynamic convergence processes and reflect the evolving nature of the EU's energy transition. Country-level regression results also show that the relationship between RE and GDP varies significantly among member countries. In some cases, RE development is positively associated with economic performance, while in others, the link is weak or not statistically significant. These findings support the view that RE should be considered part of a broader economic, institutional, and technological framework. From a policy perspective, the results highlight several important implications. EU energy and climate policy should focus more on tailored implementation strategies. While common targets are necessary for coordination, their success relies on alignment with national economic systems, energy sources, and institutional capabilities. Cluster-specific policy design can improve the economic efficiency of RE investments.

This study has several limitations. The analysis relies on a limited set of macroeconomic and energy indicators and examines linear relationships rather than causal mechanisms. Additionally, country-level regressions are limited by data availability and sample size. Future research could expand this framework by employing non-linear models, longer time horizons, or sector-specific data, as well as by explicitly examining the roles of innovation, finance, and institutional quality in shaping the RE–growth relationship.

Overall, the findings indicate that RE development can stimulate EG in the EU if specific structural and policy conditions are met. Recognizing and addressing differences among EU member countries is thus crucial to creating effective, economically sustainable energy transition strategies.

### Acknowledgments

The author thanks the anonymous reviewers and editors for their valuable contributions.

### Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**Author Contributions**

The authors contributed equally to this work.

**Disclosure Statement**

The author declares no competing financial, professional, or personal interests.

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