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Renewable Energy Transitions in the EU: A Comparative Panel Data Perspective

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Abstract

Considering the contemporary, rapidly evolving society, renewable energy emerges as a key element in advancing both environmental resilience and energy independence. The current study aims to undertake a comparative analysis of the renewable energy adoption between the Old Member States (OMSs) and New Member States (NMSs) of the European Union (EU). This study focuses on regional heterogeneity as well as the role of economic, social, and environmental determinants in shaping effective energy transition policies. This study uses advanced long-term panel estimates such as Dynamic Ordinary Least Squares (DOLS), Fully Modified Least Squares (FMOLS) and Canonical Cointegration Regression (CCR) on a dataset covering the 2010–2023 period. Moreover, this study utilizes quantile regression methods such as Quantile Regression (QREG) and Method of Moments Quantile Regression (MMQR). Finally, this study employs the Dumitrescu–Hurlin test to assess panel causality. The empirical findings reveal notable discrepancies between the two samples when it comes to fossil fuel reliance, income inequality, financial and economic development, the existing level of greenhouse gas emissions, and green finances influencing renewable energy adoption. In the OMS region, a 1% increase in GHG and income inequality reduces the adoption of renewable energy by 0.80–1.14% and 0.61–0.67%, respectively, while a 1% increase in GDP increases the adoption of renewable energy by 0.72–0.92%. In the NMS region, GHG inhibits renewable energy transition by 0.27–0.30%, while fossil fuel energy share, income inequality, green finance, GDP and financial development do not have a significant effect. These results highlight economic development as the key to renewable energy transition in OMSs, while in NMSs, GHG and financial development are key levers. This research seeks to support the developing and restructuring of the existing green framework to enhance its overall effectiveness.

Keywords: renewable energy; DOLS; FMOLS; CCR; quantile regression; European Union; panel data analysis

Academic Editor: Alina Cristina Nuta

Received: 27 August 2025
Revised: 6 September 2025
Accepted: 9 September 2025
Published: 11 September 2025

Citation: Dincă, G.; Netcu, I.-C.; Ungureanu, C. Renewable Energy Transitions in the EU: A Comparative Panel Data Perspective. *Energies* **2025**, *18*, 4836. https://doi.org/10.3390/en18184836

1. Introduction

Over the last few decades, economies, societies, and scholars have placed a significant emphasis on environmental sustainability, climate change mitigation, renewable energy consumption, and energy efficiency. This emphasis is unsurprising considering the pressing climate challenges faced by today's society, with the transition to renewable energy sources viewed as a critical requirement for protecting ecological systems and for achieving long-term energy independence and sustainable economic development in an increasingly digitalized world. At the same time, however, the global economy continues to depend significantly on fossil fuels, which not only deepens environmental degradation but also imposes challenges in energy security and energy independence. In this context, and particularly in the light of the recent geopolitical conflict regarding energy dependency sparked by the Russo-Ukrainian war, investigating the development of renewable energy adoption is essential for understanding the path to a more resilient and sustainable future. The EU has made decarbonizing the energy system a top priority, aiming to reach carbon neutrality by 2050 [1]. These efforts position Europe to be the first continent to reach carbon neutrality [2]. Reaching zero emissions and significantly lowering greenhouse gases requires an exclusive adoption of renewable energy sources [3]. The EU has set a minimum objective of 42.5% for the share of renewable energy in the energy mix by 2030 [4]. In 2023, EU's investment in renewable energy totaled $110 billion, representing a 6% increase during a one-year time period. Moreover, the investment in modernizing and optimizing the energy grid has totaled $65 billion, representing a 20% increase [5]. The surge in investment was driven by the Russia–Ukraine conflict started in 2022. By 2024, renewable energy had become the primary energy source for electricity in the EU, representing 50% of overall energy consumption, while fossil fuels made up roughly 25% [6]. The REPowerEU initiative, developed by the EU in 2022, is designed to promote the adoption and diversification of clean energy alternatives, as well as energy efficiency. In addition, in response to the Russia–Ukraine conflict, REPowerEU has successfully reduced oil imports by 24%, gas imports by 26%, and coal imports to 0% over a period of three years [7]. Between 2005 and 2023, Denmark, Sweden, and Estonia exhibited the largest increase in renewable energy share, followed by Croatia, Slovenia, and Romania. Bulgaria also demonstrated a rapid increase in its renewable energy share, although over a shorter timeframe. Conversely, Latvia, Slovakia, Luxembourg, and Poland are experiencing a decline in their renewable energy share compared to 2022 [8]. While the policy framework, financial incentives, and strategy for supporting the clean energy transition in the EU is theoretically well-founded, the approach has been challenging in practice. Despite the notable investment in renewable energy, using the current outdated grid results in energy inefficiency, rising energy costs, and possible collapses of the power systems [9]. The European power grid will require an investment of $2–2.3 billion by 2050 to prevent a major blackout similar to the one experienced in Spain in 2025, with repercussions also felt in Portugal, regions of France, and Andorra [10]. The ageing infrastructure, combined with a rapid rise in the share of renewable energy, is contributing to the occurrence of blackouts. The growth in the adoption, production, and utilization of renewable energy started exceeding the capabilities of the electrical grid, highlighting the urgent necessity for improvements and maintenance [11]. Furthermore, the EU's energy transition strategies may not align effectively with the economic conditions of the member states. Although many countries are increasing their efforts towards green transition, scholars emphasize on the need of policy framework restructuring and improvement [12–15]. Despite substantial investment and ongoing renewable adaptation, unexpected economic and global events continuously reshape the renewable energy landscape. The NMS and OMS region of the EU exhibit different economic contexts, and levels of development underscore the need for region-specific strategies [16].

Previous studies have assessed the implications of renewable energy transition in all EU member states focusing on renewable energy network optimization [17], energy productivity [18], the role of energy taxes, energy productivity in clean energy transition [19], and the impact of energy poverty [20]. A large portion of existing research focuses on the EU as a whole [21–23]; however, few studies address the differences in renewable energy adoption considering the two main samples of the EU. The novelty of the research lies in examining the determinants of renewable energy consumption through a comparative framework between OMSs and NMSs, thereby capturing the social, environmental, and economic heterogeneity that shapes the transition to a greener future, providing region-specific perspectives. By employing a combination of robust long-term estimators (FMOLS, DOLS, and CCR) alongside quantile-based approaches (MMQREG and QREG), together with panel causality analysis, this paper captures the impact of key determinants such as fossil fuel consumption, income inequality, greenhouse gas emissions, green finance, and economic and financial development on renewable energy adoption. The differences in governance structures as well as economic contexts between the member states underscore the need for tailored approaches in the development of policies aimed at facilitating the green transition. By conducting a comparative approach between OMSs and NMSs, the current study makes a valuable contribution to the specialty literature by identifying the best practices and offering nuanced, regionally appropriate insights regarding the drivers and barriers of the green transition, that may prove more relevant for policymaking rather than aggregate EU-level results. The importance of the research is reinforced by the unexpected events that reshaped the renewable energy transition. Understanding the particularities of the studied regions is critical in addressing the current challenges of the renewable transition.

The current study is meant to respond to the following questions, which also highlight its contributions to the existing literature on the topic of renewable energy:

1. Do OMSs and NMSs exhibit comparable patterns in the shift towards renewable energy?
2. Are there variations in the adoption of renewable energy based on regions? Is that the case, and does it impact the efficacy of the policy framework adopted by the EU?
3. How significantly do economic, social, and environmental elements influence the adoption of renewable energy?

The purpose of this study is to provide insight into the effect that fossil fuel energy, income inequality, financial development, greenhouse gases, and green finance impact the energy transition. This study employs a panel data analysis from 2010 to 2023, covering the OMS and NMS regions of the EU. Moreover, this study is meant to illustrate the discrepancy in clean energy transition between the NMSs and OMSs of the EU. The unexpected events, such as the COVID-19 pandemic, Russia–Ukraine conflict, and the Spain 2025 blackout have emphasized the need for a resilient, sustainable, and secure green transition. Current policies must be restructured to align with long-term sustainability objectives. This study introduces an innovation based on analyzing long-term relationships among the variables, examining distributional data, and investigating causality for two separate regions. To accomplish this, the analysis employs several advanced econometric techniques such asDOLS, FMOLS, and CCR to evaluate the long-term relationships between the variables. Additionally, MMQR and QREG are used to examine the dynamics at different distributional levels, along with the Dumitrescu–Hurlin panel causality test to evaluate the interactions among the variables. The research aims to assist in developing and reorganizing the existing green framework to enhance its efficiency. Additionally, the document seeks to highlight the distinctions between the various regions of the EU and stress the importance of avoiding one-size-fits-all strategies.

The subsequent parts of the analysis are structured as follows: the Section 2, the literature review, offers a summary of the current research landscape and the existing body of literature. Section 3 provides information about the data used in this study along with the econometric methods applied. Following Section 3, Section 4 outlines the empirical results of the research. The interpretation of the findings is discussed in Section 5, while Section 6 concludes this study and the resulting policy implications.

2. Literature Review

The topic of climate change remains a fundamental area of research, considering its vast implications upon the environment, economies around the world—including agricultural losses and infrastructure damages—and for human health and social stability. Taking these into account, the literature and the international organisms [24–28] agreed upon the call for urgent and coordinated global action in combating climate change. According to the climate change literature, transitioning to renewable energy is one of the most commonly acknowledged and agreed-upon techniques for combating climate change and its externalities [29–31], establishing itself as a key research area across multiple disciplines.

Renewable energy is widely regarded in the literature as a key strategy for addressing climate change [32–34]. The paper by Yu et al. [31] explains the urgency of shifting from fossil fuels to renewable energy, emphasizing both the encountered and expected challenges of the transitions as well as the importance of global collaboration in meeting the renewable energy goals. analyzing the global trends regarding renewable energy consumption and carbon emissions, Attanayake et al. [30] emphasize the importance of investments in R&D in developed economies. The authors further argue that developing countries should focus on increasing investments on renewable energies sources, while highlighting the importance of international cooperation between countries in mitigating climate change. Authors Panwar et al. [35] review different sources of renewable energy, accounting especially for solar energy, wind energy, and bioenergy, and the impact they have on mitigating CO_2 emissions. Maintaining the same technical note, the paper by Moriarty and Honnery [36] argues that although renewable energy mitigates the effects of climate change, the global shift to renewable energy must be accompanied by reductions in overall energy use to achieve environmental sustainability, considering mainly the imposed costs of transition. Similarly, the paper by Bogdanov et al. [37] emphasizes that in addition to the increasing share of renewable energy, the process also requires complementary investments and research in some complementary innovations that have to accompany the process to renewable energy transition, implying other significant costs. However, cost-effective proposals for this specific green transition are also proposed by the literature, given the example of the research of authors such as Bogdanov et al. [37], Babayomi et al. [38], Go et al. [39], Patrocinio et al. [40], and Gaudiana [41].

When it comes to the implications of renewable energy consumption, the literature offers a multi-faced perspective on this subject. More precisely, the impact of renewable energy is mainly studied in relation to climate risk, but without being limited to this link. For example, the paper by Shang et al. [42] ends with the conclusion that an increase in the share of renewable energy sources can reduce the climate risk by reducing emissions using a fixed effects regression model for 84 countries, including the G20 grouping and EU states. Similar results are met in the paper by Ilyas et al. [43] under observation of South East Asian countries. Their result proved robust for different samples, variables employed, methodologies, and statistical tests. More importantly, authors Shang et al. [42] explain that the impact of renewables on climate change depends on the level of economic performance, population density, and also perceived corruption. Similarly, authors Solangi and Magazzino [44], while analyzing China's commitment regarding Sustainable Development Goals, sustain the urgent shift to renewable energy sources, providing a set of criteria and policy strategies for renewable energy development. In relation to energy security, the study by Bashir et al. [45] emphasizes with the help of AMG, CCEMG, and CS-ARDL regressions that investments in renewable energy and energy transitions impact the energy security risk, using a sample of the 25 largest energy-consuming countries for a period of 31 years. Similar remarks are also met in the work of Tugcu and Menegaki [46], who concluded using a panel ARDL approach that renewable energy generation and economic wellbeing, together with encouraging research and innovation, can mitigate energy security risks. Huynh and Phan [47] focus on the link between climate change, renewable energy, and income inequality. The above-mentioned authors proved, when analyzing a panel dataset of 36 Asian countries over the 1990–2923 period, that renewable energy not only mitigates income inequality but also diminishes the adverse effects of climate change on income equality through job creation. When considering the impact of renewable energy on economic growth, the meta-analysis by Sebri [48] carefully points to the conclusion that direction of causality between renewable energy consumption and economic growth significantly differs in the long-term and short-term analyses, in terms of estimation techniques and considered samples. For example, Lahrech et al. [49] emphasize the significant and negative relationship between global renewable energy consumption and economic growth, focusing on the Gulf Cooperation Council Countries. However, the paper by Dirma et al. [50] demonstrates that renewable energy does not hinder economic growth in the long run. The results from Dilanchiev et al. [51] join the debate regarding economic performance and renewable energy, highlighting that renewable energy positively impacts economic growth, while negatively influencing CO_2 emissions.

Regarding global trends in renewable energy consumptions, the article by Ritchie et al. [52] details data regarding renewable energy generation and consumption across the globe. Starting from 1965, the global level of renewable energy consumption was around 6.09%, and at the end of 2024, the share of primary energy consumption from renewable sources was around 14.82%, according to data from Energy institute [53]. As Ritchie et al. [52] point out, one-seventh of the world's primary energy is now sourced from renewable technologies, such as the combination of hydropower, solar, wind, geothermal, tidal, and other biofuels. Focusing on the EU states, data from Eurostat [54] emphasize that the share of energy from renewable sources almost tripled from 2004 to 2023, from 9.6% to 24.5%. Classifying the EU countries according to their overall share of green energy consumption, Sweden ranks first, with around 66.4% of its energy consumption coming from renewables such as biofuels, hydro, and wind at the end of 2023, followed by Finland (50.8% energy consumption from renewables) and Denmark (44.9% energy consumption from renewables). On the opposite pole, we find countries such as Luxemburg, Belgium, and Malta, which, at the end of 2023, did not use individually more than 15.1% of overall energy consumption derived from renewable sources.

With regard to the determinants of renewable energy usage, Bourcet [55] enriches the literature with a consistent review paper, focused on 48 papers that target empirical determinants of renewable energy. According to Bourcet's [55] literature review, the main independent variables considered in the explored papers can be grouped into six main categories: economic variables, environmental variables, energy variables, regulatory variables, political variables, and demographic variables. The article ends with the author's remark that further studies in green energy should be developed, considering the mixed results in the literature. Examining the determinants of renewable energy in EU countries, Papież et al. [56] explain that renewable energy developments are stimulated by the level of economic development per capita, concentration of energy supply, and costs associated with fossil fuel energy sources. On the same note, the authors remarked that countries with low levels of their own fossil fuel resources are the ones that are focusing on the development of renewable energy sources. Xu et al. [57] also conclude that especially for non-OECD countries, GDP can be considered a driver for renewable energy consumption. Regarding energy consumption levels, the paper by Aguirre and Ibikunle [58] highlights that countries with high energy consumption that also face pressures to ensure energy supply are more likely to employ less renewable energy and focus more on fossil fuels. Also focusing on macroeconomic indicators to assess the levels of renewable energy, researchers Tu et al. [59] conclude that economic development and high employment rates are promoters of renewable energy sector development. Furthermore, the aforementioned authors also focus on the relationship between institutional quality, democracy coordinates, and renewable energy usage, demonstrating that increased economic freedom and political participation are positively related to higher levels of renewable energy levels, alongside the influence of geographical location. Another important metric considered in the literature regarding the development of renewable energy consumption is the degree of financial development. In the paper by Shahbaz et al. [60], the results of the FMOLS regression show that financial development promotes green energy demand while economic growth discourages it. Similarly, the paper by Anton and Nucu [61] shows that financial development can contribute to the development of renewable energy consumption for the EU countries sample. The results are in accordance with the conclusion from Mukhtarov et al. [62], who focus on data from Turkey, and Dimnwobi et al. [63], who analyzed renewable energy trends in Nigeria. Regarding the environmental determinants, papers in the field mostly focus on greenhouse gas emissions and investments in climate change mitigation. The paper by Ghezelbash et al. [64] examines 63 countries for the 1990–2021 period in terms of greenhouse gas emissions and energy investments. The panel data model results indicate that CO_2 emissions drive solar, wind, and geothermal investments in all countries, whereas higher levels of non-CO_2 greenhouse gas emissions demonstrated a negative influence on solar and geothermal energy investments. In the case of wind energy, however, the effect differs across considered countries. On the same note, the study by Idroes et al. [65] illustrates through the Granger causality test the unidirectional causality from CO_2 emissions to renewable energy. When it comes to investments on climate change mitigation, the paper by Rasoulinezhad and Taghizadeh-Hesary [66] shows that, considering a sample of the top ten economies that support green finance, green bonds are an efficient method of promoting renewable energy projects. Similarly, authors Li and Umair [67] conclude that green finance as well as financial inclusions are positively contributing to renewable energy developments when analyzing China's situation. The findings are consistent with Lin et al. [68], who concluded that renewable energy advancements in China significantly benefit from green financing. Moreover, Kurbatova and Perederi [69] show that governmental support is essential for promoting and encouraging the prominent use of renewable energy, highlighting policy factors and support mechanisms as main drivers of renewable energy sector growth. Furthermore, the literature also considers the link between concepts such as income inequality and green energy consumption. For example, Uzar [70] analyses the link between income inequality and renewable energy consumption for 43 countries using an ARDL-PMG model, considering also dimensions such as economic growth, corruption, CO_2 emissions, and trade openness. The conclusion points to the fact that income equality can contribute to increased renewable energy consumption. The same results are sustained by the works of Mahalik et al. [71] and Eyuboglu and Uzar [72], while the paper by Churchill et al. [73] shows mixed results regarding the impact of inequality on renewable energy consumption over time. Digitalization as well as artificial intelligence are also important topics that the current literature considers when analyzing the levels of renewable energy consumption. For example, Zheng and Wong [74] claim that digital economy positively influences the renewable energy development in China, while the study by Tian et al. [75] draws attention to the positive link between AI and renewable energy, adding more dimensions to the research in the field of renewable energies.

3. Materials and Methods

This study utilizes data containing the 27 European Union countries. The data has been sourced from Eurostat and World Bank, providing complete and dependable information for the empirical investigation. The data pertaining to the 27 countries is classified into the NMS and OMS regions. The OMSs are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and Sweden, while the NMSs are Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. The timeframe of the analysis spans 13 years, from 2010 to 2023, with more recent years excluded due to data limitations. By analyzing the relationship between fossil fuel energy, income inequality, greenhouse gas emissions, GDP growth, green finance, and financial development in the EU's NMS and OMS regions, this article aims to demonstrate the green transition's advancement. This study aims to identify the factors that promote and hinder the shift towards clean energy by concentrating on the unique characteristics of the two regions. The study utilizes three long-term estimating methods: Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), and Canonical Cointegration Regression (CCR). FMOLS, developed by Pedroni [76], is designed for small sample sizes and corrects for heteroskedasticity, autocorrelation, and endogeneity, effectively eliminating these issues. This study employs FMOLS as an estimator based on its capability of eliminating endogeneity as well as any sample-related error [77], thereby making the estimator suitable for panel data analysis [78]. In contrast, DOLS, introduced by Stock and Watson [79], addresses potential correlations between parameters and error terms [80]. Similarly to FMOLS, DOLS is widely employed in empirical analyses based on its properties of addressing potential endogeneity issues and disregarding individual dependence, making it more effective than regular OLS methodology by reducing potential bias [81,82]. Both DOLS and FMOLS are employed to examine the long-run elasticity of the variables and are used in tandem to validate the consistency of the results [83]. These models are particularly valuable when the unit root tests are present, extending the traditional OLS framework by integrating lagged variables to account for potential non-stationarity. CCR estimates the cointegrated vectors while considering the presence of endogeneity. The findings from FMOLS, DOLS, and CCR yield robust results [84]. The study uses an MMQR and QREG analytical mean to capture long-term effects throughout the conditional distribution, although FMOLS, DOLS, and CCR offer trustworthy long-term estimates. This study may demonstrate the impacts of distributional variability across several stages of the green energy transition by utilizing MMQR and QREG. The Dumitrescu–Hurlin test is used in the study to determine if the variables exhibit a unidirectional or bidirectional connection in order to evaluate the panel causality between variables. By using these methodologies, the research offers a deeper understanding of the long-term impacts as well as the interactions between variables at various levels. Figure 1 depicts the framework of the methodology utilized in this study. The figure presents details about the stages undertaken in the analysis that underpins the comprehensive methodological discourse.

The EU region has been chosen for its role as a frontrunner in the renewable energy transition, while fostering economic growth. The EU is projected to be the first partnership between 27 member countries to achieve carbon neutrality by 2050 [2]. The distinction between NMSs and OMSs is made to assess whether the longer membership of OMSs is a competitive advantage in today's market, or whether the rapid exposure of NMSs to mature technology targeting renewable energy serves as a differentiating factor. The information necessary for the analysis has been sourced from the Eurostat database. Table 1 provides a description of the data used in the analysis.

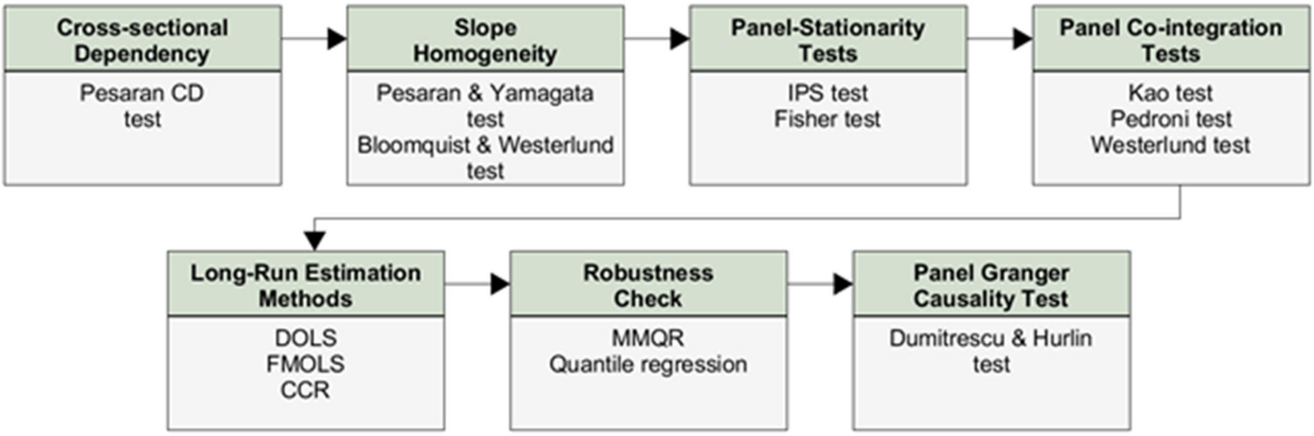

Figure 1. Analysis framework. Source: processed by the authors based on the sources [85–93].

Table 1. Variables employed in the model.

Dependent Variable	Abbreviation	Definition	Unit	Source
Renewable energy share	RE	Gross final energy consumption in a country derived from renewable energy sources [94]	% Of total energy consumption	Eurostat 2010–2023
Independent variables				
Fossil fuel share	FE	Gross final energy consumption in a country derived from fossil fuel energy sources [95]	% Of total energy consumption	Eurostat 2010–2023
Gini Index	G	Income inequality within a population [96]	points	Eurostat 2010–2023
Greenhouse gas emissions	GHG	% Change in GHG excluding LULUCF [97]	% Change from 1990 baseline	World Bank Indicator 2010–2023
Real GDP per capital	GDP	Change on total output of a country adjusted for inflation and divided by its population [98]	% Chain link change	Eurostat 2010–2023
Investments in climate change mitigation	GF	Financial resources targeting the reduction in climate change externalities [99]	% GDP	Eurostat 2010–2023
Monetary sector credit to private sector	FD	Financial resource provided by the banks and financial institutions to households and business [100]	% GDP	World Bank Indicator 2010–2023

Source: processed by the authors.

The present study utilizes panel data analysis methods. These types of analyses incorporate both cross-sectional and time-series dimensions. Utilizing such an approach yields precise outcomes and econometric estimates, effectively capturing intricate relationships compared to time-series analysis [84]. The model used is derived from the research of Fatima et al. [101] and is structured as follows:

$$RE_{it} = \vartheta_0 + \vartheta_1 FE_{it} + \vartheta_2 G_{it} + \vartheta_3 GHG_{it} + \vartheta_4 GDP_{it} + \vartheta_5 GF_{it} + \vartheta_6 FD_{it} + \varepsilon_{it} \quad (1)$$

In the equation mentioned above, "i" and "t" denote the time periods and countries, while "ε" signifies the error term. The "ϑ" symbols represent the coefficients of the parameters. This study employs one mathematical equation for both NMS and OMS regions. This approach facilitates comparability between the two regions.

The variable that is relied upon for evaluating the clean energy transition is renewable energy (RE). The variables considered independent in this research are financial development (FD), fossil fuel share (FE), investment in climate change and mitigation (GF), greenhouse gas emissions (GHG), Gini Index (G), and gross domestic product (GDP). The choice of the aforementioned variables is based on the reasoning presented below.

Renewable energy share (RE) has been utilized as a dependent variable and serves as a proxy for a clean and sustainable energy transition. Relying on renewable energy rather than fossil fuels is fundamental to addressing climate change, given its ability to decrease greenhouse gas emissions linked to fossil fuel energy use [102]. Furthermore, the initiatives to adopt and implement green energy, along with the formulation of policies like the European Green Deal and RePowerEU, aimed at facilitating the green transition, have notably intensified [4]. Renewable energy is essential for achieving carbon neutrality and fostering a sustainable future. Employing renewable energy as a dependent variable aids in comprehending how various factors considered in this analysis influence the share of renewable energy.

Although substantial progress has been made in improving the speed and effectiveness of renewable energy, fossil fuels continued to be the most prevalent energy source in the EU in 2022. Furthermore, the dependence on fossil fuel energy differs among member countries, with consumption rates ranging from 20% to 55.2% [103]. While research indicates that renewable energy adoption is gradually reducing fossil fuel usage and Europe has seen a notable decline in fossil fuel consumption [104–106], some member nations still rely heavily on conventional energy sources [107]. Evaluating the impact of fossil fuel energy on renewable energy, particularly in relation to both NMSs and OMSs, could provide valuable insights for developing future policies or strategies tailored to specific regions. The Gini Index (G), a measure of income inequality, has gained traction in recent academic research. Recent studies [47,108–111] demonstrate a connection between income inequality and the adoption and use of renewable energy. Consequently, utilizing the Gini Index enhances the understanding of how socioeconomic factors influence the transition to greener practices. Additionally, when analyzing the shift towards green energy, employing the Gini Index accounts for income disparities between both NMSs and OMSs, yielding insights that are specific to the respective regions. The impact of financial development (FD) on renewable energy has been examined in various studies [60–62,112]. The analysis illustrates the effect of financial development on green transitions, and subsequently renewable energy share, while accounting for the differences between NMSs and OMSs. Furthermore, by analyzing financial development, it is possible to determine whether NMSs have effectively leveraged the experience and robust institutional frameworks of OMSs to promote renewable energy. Using the monetary sector credit to private sector has been used as a proxy by multiple authors [113–116]. Investment aimed at mitigating climate change (GF) serves as an indicator of green finance based on its capabilities of reducing GHG emissions, safeguarding the environment, and minimizing negative externalities [117]. According to Fleming [118], any financial activity intended to improve the environment qualifies as green finance. UNEP [119] defines green finance as any financial effort geared towards sustainable development. Additionally, Spinaci [120] describes green finance as funds allocated to tackle environmental challenges and climate change, making investment in climate change mitigation a fitting representative of green finance. The GDP growth rate has been utilized to evaluate the economic development rate of both NMSs and OMSs. GDP serves as a measure to analyze the impact of economic performance on the transition to green energy.

4. Results

To gain a deeper understanding of the particularities of OMSs and NMSs, Tables 2 and 3 are illustrating the results of the summary statistics. Both tables contain descriptive statistics such as mean, standard deviation, minimum, and maximum values.

Table 2. Summary statistics in the OMS sample.

Variables	Obs.	Mean	Std. Dev.	Min	Max
RE	196	22.2589	14.1455	2.851	66.393
FE	196	71.6888	17.2859	30.3	95.53
G	196	50.6076	4.1847	44	61.6
GHG	196	−11.1228	16.0939	−44.8317	26.0324
GDP	196	1.0438	3.7260	−11.4	23.5
GF	196	0.5829	0.4432	0.09	2.6
FD	196	100.604	31.5891	25.4313	192.8299

Source: processed by the authors.

Table 3. Summary statistics in the NMS sample.

Variable	Obs.	Mean	Std. Dev.	Min	Max
RE	182	20.2235	9.0969	0.979	43.72
FE	182	74.9601	11.9216	52.9	99.79
G	182	47.0637	4.1230	37.2	55.2
GHG	182	−27.0265	32.6004	−67.6946	90.5840
GDP	182	2.8313	3.4173	−7.5	13.4
GF	182	0.7587	0.4341	0.06	2.08
FD	182	62.4406	41.8273	23.0502	254.6681

Source: processed by the authors.

The data presented in Table 2 reveals that financial development has the highest average value, followed closely by fossil fuel energy, which ranks second. The high values of financial development and fossil fuel energy, compared to other factors, indicate that economies are advanced and have a strong reliance on credit. The substantial share of fossil fuel energy underlines an ongoing dependence on pollution-heavy energy sources rather than clean options. These two variables also display the greatest standard deviation, demonstrating substantial variability within the dataset across OMSs. Greenhouse gases and renewable energy also show similar high variability among the countries, highlighting the inconsistent emphasis on clean alternative energy in OMSs. The negative mean value of greenhouse gases indicates a general decline in emissions compared to the 1990 baseline, although there is considerable variation among state members. The variable with the smallest positive mean is green finance, which suggests limited availability of green financial options and a consistent presence within the dataset. The mean and standard deviation indicate that OMSs show overall modest economic development. The Gini Index reflects that, despite relatively high-income inequality, this trend appears to be consistent across all member states.

Table 3 presents the summary statistics of the NMSs in the EU. The variables with the highest average are fossil fuel energy and financial development. These variables also illustrate notable variation across NMSs. The credit market and its availability are substantially smaller than in OMS, while the dependence on fossil fuels is greater. Furthermore, the dependence on fossil fuel energy is more consistent across member countries compared to OMS. The smallest average and standard deviation are observed in green finance and GDP. Although the amount of green finance available is lower than in OMSs, NMSs display stronger economic growth and less variability. Greenhouse gas emissions display a high negative mean and standard deviation. NMSs have experienced a greater reduction in

GHGs relative to the 1990 baseline in comparison to OMSs. While income inequality levels remain high, it is lower than that in OMSs and relatively consistent across the member states. The adoption and utilization of renewable energy share is less prevalent in NMSs compared to OMSs, yet it exhibits greater consistency across member states.

4.1. Correlation Matrix

Table A1 from Appendix A illustrates the correlation analysis for OMSs. The results show that renewable energy is negatively correlated with fossil fuel energy, highlighting the substitutive nature of clean energy sources. Additionally, a rise in renewable energy usage markedly decreases greenhouse gas emissions. The greater adoption of renewable energy fosters the growth of green finance and contributes to the advancement of the financial system. However, an increase in renewable energy tends to worsen income inequality, whereas reliance on fossil fuels tends to reduce it. Moreover, there is a weak negative correlation between income inequality and greenhouse gasses. Unlike renewable energy, the use of fossil fuels hampers the progress of the financial system and the financial instruments designed to address climate change's adverse effects, promoting clean technologies. Both financial development and green finance significantly worsen income inequality. Furthermore, economic growth constrains the evolution of the financial sector and the accessibility of the credit market.

The correlation analysis of the NMS summary represented by Table A2 shows similar interactions as OMSs. Renewable energy inhibits the usage of fossil fuel energy as well as the emission of greenhouse gasses. Moreover, compared to OMSs, in NMSs, renewable energy negatively affect financial development; on the other hand, fossil fuel energy positively increases the credit market, facilitating financial development. Moreover, fossil fuel energy facilitates greenhouse gas emission while reducing green finance. In NMSs, income inequality, compared to OMS, decreases the greenhouse gas emission and inhibits financial development. In addition, in NMSs, income inequality is also associated with increased economic development as well as green finance. Similarly to OMS, economic development decreases the development of the financial sector and instruments, while green finance and financial development have an inverse and significant relationship.

4.2. VIF

Table A3 presents the output of the VIF (Variance Inflation Factor) for OMSs and NMSs. VIF is utilized to evaluate the existence of multicollinearity within the dataset. Examining the dataset for multicollinearity is crucial for determining whether the variables exhibit identical linear relationship. The presence of multicollinearity renders the variables insignificant [121]. Although it is commonly recommended that values should not surpass a limit of 10 [122], values that are lower than 5 effectively alleviate worries about multicollinearity [123]. To address variables that exceed the 5–10 value range, they are excluded from the model [124]. The output from the OMSs and NMSs yields a mean VIF of 1.47 and 1.93, respectively. No single variable exceeds a value of 2.91; thus, there are no issues concerning the variables of the European Union states exhibiting identical relationships.

4.3. Slope Homogeneity

To evaluate the existence of slope homogeneity in the dataset, this research employs the slope homogeneity tests established by Pesaran & Yamagata [85] and Blomquist and Westerlund [86]. These tests assess the level of variation among the regression estimators pertaining to the unique characteristics of each country. Both tests provide trustworthy outcomes; however, the method introduced by Blomquist and Westerlund [86] successfully overcomes the shortcomings of the Pesaran and Yamagata [85] test—particularly its assumptions of homoskedasticity—by utilizing HAC-adjusted estimators [86,125]. The results obtained from both tests are presented in Table A4 from the Appendix A. The study's outcomes for OMSs and NMSs align consistently. Irrespective of the classification, both delta and adjusted delta reject the null hypothesis. Consequently, the tests affirm the existence of slope heterogeneity among OMS and NMS countries.

4.4. Panel-Stationary Test

To conduct long-panel estimates, it is essential that all variables are stationary, either at level l (0) or at first difference l (1). The analysis employs first-generation tests such as Im-Pesaran-Shin (IPS) test and the Fisher-type unit root test. The IPS first generation unit root test provides robust results in even in panels that have small sample size (N and T < 10) [87]. Moreover, IPS results are more accurate compared to alternative tests such as Levin, Lin, and Chu (LLC) tests [88]. Table A5 from the Appendix A presents the results of the tests employed in the analysis for the OMS and NMS regions. In the OMS regions, the variables that exhibit stationarity at the first level are economic development and green finance, whereas all variables become stationary at the first difference, according to the IPS unit root test. The results remain constant when employing the Fisher-type unit root test. Looking at the NMS region, the results provided by the IPS test are similar to the ones illustrated in the OMS region. The difference relies on the Fisher-type test, which shows that while economic development remains strongly stationary at level, greenhouse gasses exhibit moderate significance while financial development shows low significance. At first difference, however, all variables become significant.

4.5. Cross-Dependence

The cross-section dependency test developed by Pesaran [89] has been utilized to demonstrate the existence of cross-sectional dependence across two different regions. In Appendix A, Table A6 presents the analysis of cross-dependence for the variables used in the study pertaining to the OMS and NMS regions. The findings reveal that financial development and green finance in the OMS region show insignificant *p*-values, suggesting that these variables do not exert any influence across different regions, with their development being specific to their respective region. The remaining variables in the OMS region reinforce the conclusion that policy changes in one member country led to spill over effects on other member countries. In the NMS region, all variables and member countries indicate the presence of cross-dependence. Consequently, policy changes in any member state have a spill over impact on the economic wellbeing of other members. The results of regions indicate that the null hypothesis is dismissed, signifying that the countries are interdependent within each region.

4.6. Cointegration Test

To assess the presence of a long-run relationship between the variables in the OMS and NMS regions, the Kao [90], Pedroni [91], and Westerlund [92] tests were utilized. In contrast to other testing approaches, the Kao [90] test demonstrates stable dynamics in both the short run and long run, despite not accounting for heterogeneity [126]. Although the Kao [90] test focuses on homogeneous cointegration, the Pedroni [127] test employs a robust framework that incorporates heterogeneous errors and cross-sectional dependence, while the Westerlund [92] test loosens assumptions and presumes no integration [128]. The Westerlund [92] test has been employed for its simplistic approach that requires no corrections and accounts for short-term dynamics.

Tabel A7 provides the results of the three panel cointegration tests in the OMS and NMS regions. The results for both regions are consistent across all tests. The cointegration findings indicate a long-term relationship among the member countries of OMSs and NMSs at various significance levels. The Pedroni [91] test validates a long-run association between variables in both regions. Although the Westerlund [92] test shows no significance in the NMS region, it supplies moderate evidence of a long-run relationship in the OMS region. The Kao [90] test does not provide strong evidence of a long-run association in the OMS region and presents mixed results for the NMS region. In summary, the heterogeneity-based test offers robust and consistent evidence, supporting cointegration in both regions. Following these results, we proceed with FMOLS, DOLS, and CCR long-run estimation.

4.7. DOLS, FMOLS, CCR

To evaluate the long-term relationships among the variables, the study applied FMOLS, DOLS, and CCR estimation methods. The analysis utilizes the renewable energy share, representing the green transition, as the dependent variable for both OMS and NMS regions, while using fossil fuel energy share, Gini index, greenhouse gas emissions, GDP, financial development, and green finance as independent variables. The findings of the analysis for the OMS and NMS regions are presented in Table 4.

Table 4. DOLS, FMOLS, and CCR analysis on OMS and NMS samples.

	OMS			NMS		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variables	**DOLS**	**FMOLS**	**CCR**	**DOLS**	**FMOLS**	**CCR**
FE	0.5343 (0.3584)	0.5196 *** (0.0969)	0.9334 * (0.4892)	0.2023 (0.2228)	0.1173 * (0.0629)	0.0890 (0.1411)
G	−0.6360 *** (0.2260)	−0.6110 *** (0.0665)	−0.6743 *** (0.1706)	0.1340 (0.3363)	0.2740 *** (0.0956)	0.3213 (0.2160)
GHG	−0.8020 *** (0.2563)	−0.8298 *** (0.0707)	−1.1410 *** (0.3537)	−0.2955 *** (0.0812)	−0.2846 *** (0.0220)	−0.2702 *** (0.0545)
GDP	0.7599 ** (0.3409)	0.7182 *** (0.0977)	0.9183 *** (0.3011)	−0.0087 (0.1083)	−0.0368 (0.0299)	−0.0462 (0.0837)
GF	5.4663 (4.7192)	5.2505 *** (1.2453)	3.4686 (2.3771)	0.6730 (2.9229)	0.7942 (0.7885)	0.6915 (2.3724)
FD	0.3528 * (0.1928)	0.3423 *** (0.0519)	0.2185 (0.2090)	0.0116 (0.0486)	0.0002 (0.0133)	−0.0001 (0.0287)
R-squared	0.9396	0.9132	0.9163	0.7376	0.6843	0.7395

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: processed by the authors.

Upon reviewing the OMS member state, the long-term analysis reveals a consistent pattern across all three methodologies, producing robust results. The results of the analysis indicate that greenhouse gasses exert a constraining effect on green energy transition. The DOLS, FMOLS, and CCR estimators indicate that a 1% increase in GHG emissions hinders the adoption of renewable energy by 0.8020%, 0.8292, and 1.1410%, respectively. Similarly, income inequality displays an adverse effect on the green transition and renewable energy adoption. While its impact effect is less substantial than greenhouse gasses, it remains significantly negative. According to the DOLS, FMOLS, and CCR analysis output, one 1% increase in income inequality is consistent with a diminution in renewable energy adoption of 0.6360%, 0.6110%, and 0.6743%, respectively. The analysis highlights consistent positive associations between renewable energy share and economic development, emphasizing the substantial impact of economic growth on the adoption and use of renewable energy technologies as well as green transition. In the OMS region, GDP and economic growth are pivotal drivers of the adoption of green energy and green transition. Specifically, a 1% increase in GDP corresponds to an increase in renewable energy usage by 0.7599% in the DOLS model, and 0.7182% and 0.9783% in FMOLS and CCR estimations, respectively.

Relative to other variables, GDP exhibits a positive and robust impact. While fossil fuel energy, financial development, and green finance yield mixed significance results, all variables are significant in the FMOLS estimation; fossil fuel energy loses its significance in the DOLS model, green finance is insignificant in the DOLS and CCR models, and financial development lack is not significant in the CCR model.

In the NMS group, greenhouse gasses exhibit an inhibiting effect on renewable energy adoption as well as green transition. An increase of 1% in GHGs leads to reductions in renewable energy usage of 0.2955%, 0.2846%, and 0.2702% in the DOLS, FMOLS, and CCR models, respectively. The inhibiting effect of GHG on renewable energy adoption remains consistent in OMSs and NMSs; however, the effect is more prominent in the OMS region compared to the NMS region, underscoring its pivotal role in achieving sustainable development. GDP, financial development, and green finance do not exhibit any long-term association with renewable energy, suggesting a limited role that does not effectively support the adoption of renewable energy as well as green transitioning. Fossil fuel energy and income inequality present mixed results, with both variables being significant only in the FMOLS model. Although fossil fuel energy shows a weak and positive correlation, income inequality reveals a strong and positive statistical connection. The results highlight a complex dynamic between fossil fuel, income inequality in facilitating the green transition, and clean energy adoption in the NMS region.

4.8. MMQR and QREG

Given the varied outcomes demonstrated by the DOLS, FMOLS, and CCR estimations, using a MMQR estimation will shed light on the dynamic relationship among the variables. Since the results include details about the interaction between variables across different quantiles, the analysis presents a more thorough understanding of these interactions. Table 5 displays the results of the MMQR analysis across various quantiles (Q 0.25, Q 0.50, Q 0.75, Q 0.95) in the OMS and NMS areas.

Table 5. MMQR analysis for the OMS and NMS samples.

	OMS				NMS			
	Quantile 0.25	**Quantile 0.50**	**Quantile 0.75**	**Quantile 0.95**	**Quantile 0.25**	**Quantile 0.50**	**Quantile 0.75**	**Quantile 0.95**
FE	−0.4758 *** (0.0698)	−0.6314 *** (0.0444)	−0.7067 *** (0.0399)	−0.7960 *** (0.0434)	−0.2788 *** (0.0436)	−0.2979 *** (0.0473)	−0.3323 *** (0.0723)	−0.3574 *** (0.0965
G	0.2664 (0.1945)	0.2557 *** (0.1233)	0.2506 *** (0.1091)	0.2445 ** (0.1200)	0.4568 *** (0.1133)	0.3271 *** (0.1232)	0.0942 (0.1888)	−0.0755 (0.2489)
GHG	−0.0349 (0.0517)	0.0296 (0.0328)	0.0608 ** (0.0292)	0.0979 *** (0.0320)	−0.0081 (0.0193)	−0.0114 (0.0209)	−0.0175 (0.0320)	−0.0218 (0.0428)
GDP	0.2478 (0.2207)	0.0674 (0.1401)	−0.0197 (0.1241)	−0.1232 (0.1363)	−0.1660 (0.1250)	−0.0974 (0.1355)	0.0257 (0.2072)	0.1155 (0.2762)
GF	0.0877 *** (0.0380)	0.0238 (0.0242)	−0.0070 (0.0215)	−0.0437 ** (0.0236)	0.0117 (0.0114)	0.0080 (0.0124)	0.0013 (0.0189)	−0.0034 (0.0253)
FD	1.2114 (3.2152)	3.6198 * (2.0404)	4.7835 *** (1.8073)	6.1658 *** (1.9861)	5.7783 *** (1.4024)	6.6914 *** (1.5208)	8.3313 *** (2.3264)	9.5270 *** (3.0966)
_cons	27.0172 *** (12.3390)	51.7080 *** (7.8539)	63.6379 *** (7.0203)	77.8096 *** (7.6768)	9.8156 (6.3332)	20.0963 *** (6.9153)	38.5599 *** (10.6039)	52.0227 *** (13.8265)

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: processed by the authors.

In the OMS region, fossil fuel energy is notably influential across all quantiles, with the negative correlation intensifying as the quantiles increase. Greater amounts of fossil fuel energy correspond to decreased levels of renewable energy. At the lowest quantile, the negative effect is measured at 0.4758, whereas at the highest quantile, the effect nearly doubles to −0.7960, suggesting that an increase in fossil fuel energy hinders the renewable energy transition. Income inequality significantly and positively impacts clean energy adoption, starting with Q 0.50 and Q 0.75. At the lowest quantile the significance becomes moderate, although its impact remains relatively stable across all quantiles. The role of greenhouse gases is to enhance renewable energy at the highest quantile; as greenhouse gas levels rise, so does their impact and significance in promoting clean energy. The results of MMQR emphasize that an increase in greenhouse gasses facilitates green transition, while the DOLS, FMOLS, and CCR exhibit that greenhouse gasses hinder green transition. The counterintuitive findings illustrate the complex relationship and dynamic between GHGs and renewable energy. While the average effects of long-term-run equilibrium analysis of the variables emphasize a negative effect, the MMQR analysis reveals how the variables interact at different quantiles, capturing heterogeneous responses to current variations. Financial development similarly exerts a positive influence on renewable energy, with higher levels leading to greater impacts. Green finance only facilitates renewable energy transition at the lowest quantile; however, its effect becomes significantly negative at the highest quantile, hindering its potential in supporting green energy transition and adoption of renewable energy. The outcomes from DOLS, FMOLS, and CCR estimates highlight that GDP serves as a key driver in the long-term equilibrium relationship with the adoption of renewable energy and clean energy transition. However, the results from MMQR, which show no significant impact between variables, underscore that prioritizing economic growth alone does not support the shift to clean alternative energy sources.

In the NMS region, greenhouse gas emissions, GDP, and green finance do not play a role in promoting the adoption and use of renewable energy. Within the NMS region, financial development is a crucial factor driving the transition to green practices. In contrast to the OMS region, the impact of financial development remains strongly positive across all quantiles in the NMS region. Increased financial development enhances the adoption of renewable energy. Fossil fuel energy demonstrates its adverse and significant effects in OMSs, similar to its behaviour in NMSs; however, unlike OMSs, the impact remains stable across all quantiles. The output from the MMQR analysis emphasizes on the consistent and significant effect fossil fuel energy share has on hindering renewable adoption. The opposing evidence provided by the long-term FMOLS estimator emphasizes the importance of considering country-specific economic conditions within the NMS region. Income inequality shows a notable positive effect only at the lowest quantiles, specifically at quantile 0.25 and 0.50. Therefore, after surpassing the median value of income inequality, the variable no longer demonstrates an effect on green energy transition and renewable energy share. The results are consistent with the findings from employing the FMOLS estimator. The discrepancy in the results exhibits the dynamic effect that social aspects have on speeding the green transition.

To gain a comprehensive understanding, quantile regression has been employed alongside MMQR. Table A8 from Appendix A presents the results of the quantile regression the OMS and NMS regions. The results of the quantile regression align with the MMQR findings. In the OMS and NMS regions, fossil fuel energy significantly hinders renewable energy share as well the progress towards clean sources of energy. In the OMS region, higher usage of fossil fuel energy amplifies the decrease in renewable energy adoption, while in the NMS region, its restraining effect remains constant. The pattern for income inequality mirrors that of MMQR, with the distinction that in the NMS region, elevated levels of income inequality significantly hinder the adoption of renewable energy. Economic development continues to show an insignificant influence on renewable energy regardless of regions. In line with the MMQR findings, the quantile regression analysis shows that

GHGs only exhibit positive significant impact on renewable energy adoption, in both the NMS and OMS regions. Financial development continues to exhibit a significant and positive trend, consistent with the MMQR findings, demonstrating a progressive effect on promoting renewable energy at higher quantiles of the distribution. The insignificant effect of green finance on the adoption of renewable energy in NMSs is consistent with the results provided by the MMQR analysis. In the OMSs, however, the quantile regression shows that at high levels, green finance hinders the adoption of renewable energy.

4.9. Panel Causality

To formulate efficient policy recommendations, in addition to analyzing the long-term relationship estimators and conditional effects, it is essential to utilize panel causality to assess the directional influence of variables on renewable energy adoption across regions. The Dumitrescu & Hurlin [93] test has been employed to establish the presence of Granger causality within the panel. In Appendix A, Table A9 displays the results of the test.

In the OMS region, renewable energy and financial development display a highly significant bidirectional causality, while renewable energy and fossil fuel energy display a moderately significant bidirectional relationship. The relationship between renewable energy and Gini index mirrors the relationship between renewable energy and greenhouse gases. While renewable energy displays a moderate effect on greenhouse gases and income inequality, the effect of the two variables on the adoption of renewable energy is highly significant. Conversely, there is no evidence of a long-term relationship between economic development, green finance, and renewable energy. Regarding the NMS region, renewable energy and GHGs are the only variables that display the presence of a highly significant bidirectional causality. Additionally, green finance and economic development show a highly significant unidirectional relationship with renewable energy, whereas a moderate unidirectional significance exists between fossil fuel energy, financial development, and renewable energy.

5. Discussion

The present research aimed at exploring the link between economic, financial, and environmental dimensions and the levels of employed renewable energy sources as a percentage of total energy consumption focusing on the two main clusters of the EU structure, namely the old and new member states. Employing the long-term panel estimation models such as DOLS, FMOLS, and CCR, the results of the study emphasize that the results are mainly robust for all three methodologies, for both OMS and NMS groups.

The results emphasize that greenhouse gas emissions are negatively and significantly associated with renewable energy for both OMS and NMS samples, considering all three long-term methodologies. Even though the literature primarily validates the negative impact of renewable energy consumption on greenhouse gas emissions [129–133], the link between greenhouse gas emissions and renewable energy is also studied. The results regarding the GHG and renewable energy consumption nexus are in line with the remarks of Lucas et al. [134] and Marques et al. [135], who proved the negative and significant link between CO_2 emissions and renewable energy deployment. The authors Hao and Shao [136] further argue that carbon-intensive economies which generate high levels of GHGs are less likely to prioritize climate change mitigation and the investments in renewable energy, and countries with high carbon dependence, like the EU states, often lean toward fossil fuels due to lobbying pressures, which might slow the adoption of renewables. Also, consistent with our results, Cui et al. [137] proved the bidirectional causal link between greenhouse gas emissions and renewable energy, pointing to the feedback from GHG emissions to RE. Moreover, researchers Kiesecker et al. [138] explain that if renewable energy projects are poorly located, they can harm habitats and ecosystems, and may even produce unintended greenhouse gas emissions that offset their environmental advantages. However, when analyzing the link between greenhouse gas emissions and renewable energy consumptions at quantile levels, we find significant positive links between the variables; in the case of Q75 and Q97 quantiles of the MMQR methodology for the OMSs and Q50, Q75 for the OMSs, and Q50 for the NMSs in the QREG scenarios. The positive associations are in line with the work of Ghezelbash et al. [64], who focused their study on the CO_2 emissions and their positive link to green investments in all countries considered. Idroes et al. [65] through the Granger causality test point to the unidirectional positive causality from CO_2 emissions to renewable energy. Similarly, Altin [129] also explores the loops between emissions and renewable energy consumption and highlight the positive correlation between renewable energy use and carbon emissions, arguing that investments and developments of renewables may be driven as a response to rising emissions, not necessarily to prevent them. Furthermore, the paper of Silva and Raadal [139] summarizes that GHG emissions shape the adoption and the implementation of renewable energy technologies.

Also considering the environmental dimension, fossil fuel share is, according to the current study's results, positively associated with increased levels of renewable energy usage for both OMSs and NMSs at an average level; however, significant levels are only met in the case of FMOLS regressions and CCR in the case of OMSs. Still, at a quantile level, for both OMSs and NMSs, considering both methodologies, the link proved negative and significant for all quantiles, meaning that an increased level in fossil fuel consumption decreases the consumption of renewable energy. Thus, the empirical evidence highlights that as the share of energy produced from fossil fuels increases, the deployment of renewable energy tends to decrease, consistent with the findings of Marques et al. [135]. The negative impact is most felt in European countries that already have higher renewable shares, in accordance with the paper of Chavda and Mehta [140], who point to the same remark when analyzing the impact of fossil fuels subsidies on renewable energy consumption in OECD countries. On the same note, Papież et al. [56] point out that countries that do not rely on their own fossil fuel sources are the countries that tend to maximize renewable energy development. Moreover, a significant body of literature sustains that increased fossil fuel consumption hinders renewable development and consumption [141–145].

Investments in climate change mitigation proved a positive link with the levels of renewable energy consumption, however only significant for the OMS sample using the FMOLS regression. The significant results are sustained by the existing literature in the field [146–149] and in line with the expected results. The results are also maintained in the MMQR scenario, and are positive and significant in relation to renewable energy only for the first quantile, while being negative for the highest quantile in the OMS sample. Similar observations regarding the quantiles can also be made for the QREG results, namely that investments in climate change mitigation positively impact renewable energy development in the smaller quantiles, while for the upper quantiles it slightly hinders green energy consumption, pointing to the fact that states that do not have significant green infrastructure benefit most from investment in climate change mitigation when it comes to renewable energy development. This can be explained through the fact that high investment environments might redirect some mitigation funds to other areas besides renewable energy that might help fight climate change. However, also using the MMQR technique, Javed et al. [150] highlight that innovation in terms of green technologies benefits the transition to green energy in the analyzed countries, for all quantiles. On the same note, using similar quantile regressions techniques, Muhammad and Hoffman [151] demonstrated that in the case of Germany, green investment is positively significant on renewable energy consumption for higher quantiles, thusly indicating its positive impact in the long run.

Monetary sector credit to private sector, which was used as a proxy for financial development, positively impacts renewable energy consumption in all samples, with the exception of the CCR scenario for the NMSs. However, its statical significance is emphasized only for the DOLS and FMOLS methodologies considering the OMS grouping. Zahan and Chuanmin [149] also highlight that financial development increases environmental quality through reduced CO_2 emissions. Comparable results are also reported by Wang and Xu [152], showing that financial development portrayed through the financial development index positively and significantly influences renewable energy deployment. Similarly, a wide body of literature supports the conclusion that financial development is a key driver of renewable energy infrastructure [60–63,153]. Following quantile regression approaches, for both OMSs and NMSs, for all quantiles except the first one the relation between financial development and renewable energy is positive and significant, consistent with the results of the quantile regression conducted by Javed et al. [150].

When it comes to economic variables such as economic growth and Gini index, they manifest mirror-like influences. To be more precise, an increased inequality negatively and significantly influences renewable energy consumption in the OMSs in all three scenarios, while for the NMSs, an increased level of income inequality is positively linked to increased levels of renewable energy consumption, significant only for the FMOLS scenario. Following the same topic, using Tobit regressions and different proxies for income inequality, authors Asongu and Odhiambo [110] concluded that the impact of inequality on renewable energy consumption depends on the level of the Atkinson index, when analyzing Sub-Saharan Africa, with equitable income distribution promoting renewable energy use. Uzar [70], when considering renewable energy consumption in 43 countries across the world, concludes that more equitable income distribution contributes to an increased use of renewable energy consumption. On the same line, authors Mahalik et al. [71] highlight that income inequality negatively impacts renewable energy consumption in Asian economies. Similarly, the same conclusion is drawn by Sharma and Rajpurohit [154] for India, and Eyuboglu and Uzar [72] for Italy. Also considering the EU countries dataset, Buis [155], using an ARDL-PMG methodology, emphasizes the negative effect of inequality on green energy development. In the quantile regressions scenarios, for the majority of quantiles, in both MMQR and QREG, results show that higher levels of inequality contribute to renewable energy development. Mixed results regarding the impact of inequality on renewable energy consumption are also emphasized in the paper of Churchill et al. [73].

In terms of the economic growth variable, it positively and significantly influences the consumption of renewable energy in the OMS sample for all regression scenarios; however, in the NMSs, the influence is negative and lacks significance for all DOLS, FMOLS, and CCR models. Moreover, the quantile analysis proves no significant impact of economic growth on renewable energy consumption at any level of green energy consumption. Considering the results of long-term regressions in the OMS sample, they converge with the hypothesis validated by numerous papers in the field, namely that economic expansion creates a favourable environment for renewable energy investments and adoption [56,57,156,157].

The investigation ends with the results of the Dumitrescu and Hurlin [93] causality analysis for both samples. The results prove strong evidence of bidirectional causality between renewable energy consumption and greenhouse gas level variables in both groups, just like the results of Cui et al. [137], and also a highly significant bidirectional causality in the OMS sample between financial development and renewable energy, in line with the remarks of Wang et al. [158]. Similarly, in the OMS sample, the significant bidirectional causality is valid for renewable energy and fossil fuel variables, in accordance with the results of Apergis and Payne [159], who point to the substitutability of the two energy sources in the short run, as well as for renewable energy consumption and income inequality variables, similar to the results of Mehmood et al. [160]. In other words, OMSs shows deeper feedback loops between renewable and environmental system and the economic and financial sector, while, in contrast, NMSs could rely more on the interplay between the two systems to promote green energy developments. The NMS sample had primarily unidirectional causalities, with the ones that were particularly significant being those involving fossil fuels, inequality, economic growth, financial development, and investments targeted at mitigating climate change, sharing some similarities with the work of Eren et al. [161] and Vo et al. [162] for specific determinants.

Renewable energy is part of many circular economy frameworks which are targeting climate change mitigation, benefiting the population and environment. Its role is reducing the reliance on polluting and finite resources, while decreasing GHG emissions [163]. The importance of the circular economy is based on its restorative and regenerative design that eliminates waste while maintaining resource at high values. Circular economy is a solution framework addressing the challenges posed by climate change [164]. Integrating renewable energy in the circular economy facilitates sustainable economic and environmental development [165]. Moreover, renewable energy is a key driver to facilitate economic development and reduce reliance on polluting energy, as well as mitigating environmental harm and energy efficiency [166].

6. Conclusions

This paper analyses green transition and the usage of clean energy alternative shares within the OMSs and NMSs of the EU over 13 years, from 2010 to 2023. The study uses a dynamic panel analysis by employing DOLS, FMOLS, and CCR methodologies to assess the long-term relationship between renewable energy share and GDP growth, financial development, income inequality, green finance, and GHGs. Moreover, the study takes a deeper dive in how the independent variables influence renewable energy share and clean energy transition, capturing the heterogeneous effects of the distribution using the MMQR and QREG techniques. To assess efficient and effective policy recommendations, the Dumitrescu and Hurlin [93] test has been employed. The test complements the analysis by providing insight on the direction and significance of the relationship between the variables. The novelty of the study consists of illustrating the heterogenous effects of the OMS and NMS. Unlike the existing literature that treats the EU as a homogeneous body and emphasizes that economic development and green finance are the key drivers of the green transition, our analysis yields divergent findings. The paper demonstrates that economic development, in itself, is not a predictor for a sustainable future. Moreover, the two regions of the EU exhibit different long-term relationships as well as distributional heterogeneity and causal linkage between the variables. The varied results of the interaction between fossil fuel reliance and renewable energy highlight the differences among countries, which are influenced by distinct policies and economic conditions. When considering the overall effect, consistent reliance on a larger share of fossil fuel energy hampers the transition to green energy. The research emphasizes the connection between income inequality and the adoption of renewable energy. In the OMSs, the long-term association between income inequality and renewable energy adoption is found to be negative, whereas in NMSs, no significant long-term relationship exists. The distinctive results highlight the diverse economic conditions of the two regions. Nevertheless, when examining the heterogeneous effects, it becomes clear that countries with high income inequality tend to adopt renewable energy at a greater rate. The importance of financial development proxied by the monetary sector credit to private sector plays a pivotal role in facilitating the transition towards clean energy. In the long-term, the effect is pronounced in the OMSs that already have the necessary financial infrastructure and instruments to support the innovation and adaptation of renewable energy, especially in countries where higher levels of adoption are exhibited. On the other hand, although NMSs display a positive impact of financial development on renewable adoption across different distributions, long-term, the variables do not exhibit any relation, underscoring country-specific economic and financial dimensions. Compared to the existing body of literature, this study does not find robust evidence that economic development alone is a key driver in renewable energy adoption. However, GDP growth facilitates the deployment of renewable energy in long-term within OMSs, specifically. The results emphasize that focusing exclusively on economic development to facilitate the green transition may be insufficient. In OMSs, elevated levels of GHGs lead to greater adoption of renewable energy; however, in NMSs, GHGs do not exert a notable influence. Additionally, the long-term interaction between GHGs and renewable energy is significantly negative, indicating that GHGs hinder the transition to clean energy. The findings indicate that the connection between greenhouse gas emissions and the advancement and execution of renewable energy is tailored to the distinct traits of each nation. The interaction results between green finance and renewable energy reveal that in the OMS region, long-term green financing aids in increasing the share of renewable energy; however, the quantile analysis demonstrates that while green finance promotes the green transition at the lowest quantiles, and it hinders it at the highest quantile. Conversely, in NMSs, green finance has an insignificant influence on the adoption of clean energy techniques. To ensure credibility of the obtained results, several steps were taken to validate the numerical findings. First of all, the methodological approach provides multiple estimation techniques, such as advanced long-term panel estimates (DOLS, FMOLS, and CCR), to ensure the robustness of the results, as well as quantile regression models such as quantile regression (QREG) and Methods of Moments Quantile Regression (MMQR). Secondly, the results align with existing empirical evidence on the determinants of renewable energy consumption in both the EU sample as well as other regions, supporting the validity of the findings, as detailed in the discussion section. Thus, the convergence of results across different estimators and their agreement with the broader literature confirm the reliability of the findings presented in this current study.

EU policy changes that are meant to facilitate the development and adaptation of clean energy must take into consideration the economical context and particularities of each region. One size-fits-all solutions to facilitate the green transition in the EU is unlikely to be effective. To maximize the impact of renewable energy, shared adaptive strategies are the basis of a sound policy framework. Policy interventions should account for heterogenous effects displayed by income inequality within both the NMS and OMS regions. The divergent evidence highlights the need to account for the distinct economic context in the process of developing a policy framework. Based on the difference in significance as well as long-run estimators and distributional effects, it is important to develop accommodating policies. To enhance the adoption rate of renewable energy and design of effective policies, the approach should be adaptable to the specific requirements of each country as well as distinct economic contexts. Uniform policies designed to promote clean energy alternatives may be hindering the transition process. Particularly considering income inequality as measured by the Gini index, policies must consider the unique characteristics of both regions. While both areas exhibit higher adoption of renewable energy in the context of significant income inequality, income inequality in NMSs does not impede the advancement of renewable energy development as it does in OMSs. As a result, policies aimed at fostering economic growth while neglecting the implementation and advancement of renewable energy in underdeveloped members may hinder the transition to renewable energy sources. The conflicting evidence regarding the relationship between fossil fuels, GHGs, and renewable energy highlights the necessity for a reform of the prevailing policy framework to effectively encourage the decarbonization of the energy system. Given the key role that financial development has on facilitating the green transition, developing or adjusting the policy framework demands careful consideration. In the OMS region, policies should target emission reduction actions as well as facilitate social equity programmes. Since economic growth has a significant positive effect on renewable energy adoption, aligning economic development strategies with clean energy initiatives may support the green transition. Based on the mixed results exhibited by financial development and green finance, financial instruments designed at facilitating renewable energy transition must be carefully designed. On the other hand, in the NMS region, financial development emerges as a key driver for renewable energy transition. Such results highlight the importance of policies that strengthen financial institutions as well as the development of financial instruments that support green initiatives. Moreover, policies aiming to reduce fossil fuel dependence while adapting to different social contexts are particularly useful in the region. The results also emphasize that in the NMS regions, policies focusing on economic development as well as green finance are not sufficient to support the green transition.

This study presents several limitations. Data availability presents a limitation of study. While the study spans over a period of 13 years, using additional data may enhance the reliability and robustness of the results. Expanding the time frame could improve the understanding of the long-term interactions within the analysis. Moreover, the study does not include recent years due to lack of data. Furthermore, the methodology utilized in this analysis is inadequate for capturing the short-term shocks, as well as variations in economic conditions. The study primarily focuses on aggregated data at the country level, limiting its ability to capture the individual nuances of each country. The generalized results pinpoint the need of assessing the individual effects of each country. Furthermore, the research could also account for additional socio-economic and political factors that influence the clean energy transition. The current research emphasizes the role of monetary sector credit to the private sector as an indicator of financial development, alongside investments in climate change mitigation as a metric for green finance. These indicators may face inconsistencies and limitations in accurately reflecting the complete effects and more extensive implications of the two variables. Collectively, these limitations highlight future directions for research. The sample period considered for analysis overlaps with major global events in terms of energy, such as the Paris Agreement, The COVID-19 Pandemic, and The Russia–Ukraine war. The Paris Agreement signed in 2016 marks the global policy shift towards climate commitments, while the COVID-19 Pandemic disrupted the global economic cycle that led to temporary reduction in emissions. Moreover, the Russia–Ukraine war that caused global energy shocks highlights the importance of energy security and independence. Although these events are not explicitly modelled in our estimators as dummy variables, their influence is indirectly manifested and absorbed through the values of the considered variables in the model. However, since the shocks are not explicitly modelled, their specific contribution cannot be isolated, which can be considered a limitation of the study.

Future studies could extend this analysis by explicitly accounting for these particular shocks, using different econometric techniques such as including dummy variables, using sub sample regressions (e.g., pre-pandemic and post-pandemic samples), or using a difference-in-difference methodology, to particularly assess the impact of the above-mentioned events on renewable energy consumption. Further investigation may examine how the correlation between renewable energy share and the explanatory variables varies between urban and rural settings. The upcoming studies might utilize it as a data sub-sample. Considering that rural regions often lack adequate infrastructure, factors such as accessibility and affordability of green transitioning may account for differential effects. In addition to analyzing the data split between rural and urban areas, the examination could be expanded to investigate the impact specific to each country, which would aid in formulating effective policy recommendations. Additionally, leveraging MMRQ and QREG analyses on the sub-groups may reveal heterogeneous responses between less developed and industrialized rural areas as well as country-specific effects. Moreover, future research could undertake a comparison of the EU's progress in green transition against a similar regional bloc to assess its unique dynamics. Additionally, upcoming research could explore alternative measures for financial development and green finance to more effectively capture the intricate impacts of green finance. Employing a wider range of indicators strengthens the validity of the empirical findings and reduces discrepancies.

Author Contributions: Conceptualization, G.D. and I.-C.N.; methodology, I.-C.N. and C.U.; software, I.-C.N. and C.U.; validation, G.D., I.-C.N. and C.U.; formal analysis, I.-C.N.; investigation, I.-C.N. and C.U.; resources, I.-C.N. and C.U.; data curation, I.-C.N.; writing—original draft preparation, I.-C.N. and C.U.; writing—review and editing, G.D.; visualization, G.D. and I.-C.N.; supervision, G.D.; project administration, G.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Dataset available on request from the authors. The raw data supporting the conclusions of this article will be made available by the authors on request. The original contributions presented in the study are included in the manuscript and in Appendix A.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AMG	Augmented Mean Group
CCEMG	Common Correlated Effects Estimation for Dynamic Heterogeneous Panels
CCR	Canonical Cointegration Regression
CS-ARDL	Cross-Sectionally Augmented Autoregressive Distributed Lag model
DOLS	Dynamic Ordinary Least Squares
EU	European Union
FMOLS	Fully Modified Ordinary Least Squares
MMQR	Method of Moments Quantile Regression
NMS	New Member States
OMS	Old Member States
QREG	Quantile Regression
VIF	Variance Inflation Factor

Appendix A

Table A1. Correlation matrix for the OMS sample.

	RE	FE	G	GHG	GDP	GF	FD
RE	1.0000						
FE	−0.8075 ***	1.0000					
G	0.2112 ***	−0.1562 ***	1.0000				
GHG	−0.2506 ***	0.3108 ***	−0.1157 *	1.0000			
GDP	−0.0319	0.0555	0.0332	0.1068	1.0000		
GF	0.4764 ***	−0.4656 ***	−0.0122	−0.3138 ***	−0.0354	1.0000	
FD	0.3523 ***	−0.2781 ***	0.2806 ***	−0.0592	−0.2374 ***	0.5378 ***	1.0000

*** $p < 0.01$, * $p < 0.1$; Source: processed by the authors.

Table A2. Correlation matrix for the NMS sample.

	RE	FE	G	GHG	GDP	GF	FD
RE	1.0000						
FE	−0.5932 ***	1.0000					
G	0.3251 ***	−0.1029	1.0000				
GHG	−0.5007 ***	0.5720 ***	−0.3209 ***	1.0000			
GDP	0.0079	0.0422	0.2103 ***	−0.0893	1.0000		
GF	0.6083 ***	−0.4980 ***	0.4623 ***	−0.6201 ***	0.0798	1.0000	
FD	−0.3781 ***	0.5363 ***	−0.1810 ***	0.7191 ***	−0.2138 ***	−0.4233 ***	1.0000

*** $p < 0.01$; Source: processed by the authors.

Table A3. VIF analysis for OMS and NMS samples.

	OMS		NMS	
Variable	**VIF**	**1/VIF**	**VIF**	**1/VIF**
FE	1.37	0.7324	2.03	0.4930
G	1.23	0.8112	1.38	0.7268
GHG	1.24	0.8057	1.76	0.5691
GDP	1.13	0.8871	1.14	0.8806
GF	2.00	0.5010	2.91	0.3431
FD	1.84	0.5445	2.36	0.4238
Mean VIF	1.47		1.93	

Source: processed by the authors.

Table A4. Slope homogeneity for OMS and NMS samples.

	OMS		NMS	
	Pesaran and Yamagata [85]		Pesaran and Yamagata [85]	
Delta	3.028	0.002	3.328	0.001
Delta adj	4.625	0.000	5.084	0.000
	Blomquist and Westerlund [86]			
Delta	3.767	0.000	2.483	0.013
Delta adj	5.754	0.000	3.793	0.000

Source: processed by the authors.

Table A5. Unit root test for OMS and NMS samples.

	OMS				NMS			
	IPS Unit Root Test		**Fisher-Type Unit Root Test**		**IPS Unit Root Test**		**Fisher-Type Unit Root Test**	
	Level	**Difference**	**Level**	**Difference**	**Level**	**Difference**	**Level**	**Difference**
RE	0.0344	−4.2660 ***	−2.3188	9.2728 ***	−0.8107	−3.0394 ***	−0.7732	4.1009 ***
FE	−1.0090	−3.5905 ***	−0.8179	11.5456 ***	−1.1423	−3.2440 ***	−0.0845	9.7627 ***
G	−1.8480	−3.8563 ***	−0.3080	9.3629 ***	−1.2963	−4.2632 ***	−1.3254	5.9394 ***
GHG	−1.2200	−4.0243 ***	−2.6692	9.7567 ***	−1.4294	−3.1690 ***	1.5012 **	8.5414 ***
GDP	−3.9926 ***	−5.3735 ***	13.9716 ***	23.4364 ***	−3.8871 ***	−5.6563 ***	7.2314 ***	24.9255 ***
GF	−2.1742 **	−3.5976 ***	−3.3924 ***	12.4979 ***	−1.8445 **	−4.0404 ***	0.8765	13.5678 ***
FD	−0.8855	−2.5307 ***	−1.3972	1.8294 ***	−2.2191	−2.6824 ***	1.3013 *	3.6165 ***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: processed by the authors.

Table A6. Cross-dependence for OMS and NMS samples.

	OMS				**NMS**			
	CD-Test	***p*-Value**	**corr**	**Abs(corr)**	**CD-Test**	***p*-Value**	**corr**	**Abs(corr)**
RE	32.62	0.000	0.914	0.914	23.47	0.000	0.710	0.710
FE	26.28	0.000	0.736	0.736	23.94	0.000	0.724	0.724
G	5.70	0.000	0.160	0.391	9.93	0.000	0.300	0.528
GHG	25.74	0.000	0.721	0.752	11.03	0.000	0.334	0.549
GDP	22.94	0.000	0.643	0.643	20.33	0.000	0.615	0.615
GF	1.30	0.735	0.036	0.380	5.51	0.000	0.167	0.371
FD	1.28	0.202	0.036	0.662	12.51	0.000	0.379	0.742

Source: processed by the authors.

Table A7. Panel cointegration for OMS and NMS samples.

	OMS		**NMS**	
Kao Test	Statistic	*p*-Value	Statistic	*p*-Value
MDFt	0.8593	0.1951	0.6172	0.2686
DFt	0.5874	0.2785	0.8405	0.2003
ADFt	−0.3793	0.3522	2.5081	0.0061
UMDFt	−1.2602	0.1038	−2.1802	0.0146
ADFt	−1.0472	0.1475	−1.1146	0.1325
Pedroni Test				
MPPt	4.7850	0.0000	5.0072	0.0000
PPt	−3.9009	0.0000	−3.0026	0.0013
ADFt	−3.0846	0.0010	−2.8041	0.0025
Westerlund Test				
Variance ratio	1.6118	0.0535	1.2491	0.1058

Source: processed by the authors.

Table A8. QREG analysis for OMS and NMS samples.

	OMS				**NMS**			
	Quantile 0.25	**Quantile 0.50**	**Quantile 0.75**	**Quantile 0.95**	**Quantile 0.25**	**Quantile 0.50**	**Quantile 0.75**	**Quantile 0.95**
FE	−0.5647 *** (0.0903	−0.6598 *** (0.0374)	−0.7053 *** (0.0414)	−0.8722 *** (0.0335)	−0.2567 *** (0.0626)	−0.3679 *** (0.0710)	−0.3093 *** (0.1161)	−0.2963 *** (0.0867)
G	0.4582 (0.3545)	0.3417 *** (0.1468)	0.5015 *** (0.1626)	0.4051 *** (0.1317)	0.5857 *** (0.1602)	0.4126 * (0.1818)	0.1098 (0.2971)	−0.9185 *** (0.2218)
GHG	−0.1045 (0.0924)	0.0637 * (0.0383)	0.0990 *** (0.0424)	0.0376 (0.0343)	0.0165 (0.0295)	0.0594 ** (0.0334)	0.0263 (0.0546)	−0.0357 (0.0408)
GDP	0.4367 (0.3807)	−0.1031 (0.1577)	−0.0683 (0.1747)	−0.0834 (0.1414)	−0.3184 * (0.1756)	−0.1434 (0.1992)	−0.0701 (0.3257)	0.2001 (0.2431)
GF	0.1055 ** (0.0573)	−0.0334 (0.0237)	−0.0589 *** 0.0263	−0.0372 * 0.0213	−0.0080 0.0206	−0.0293 0.0234	−0.0223 0.0383	−0.0150 0.0286
FD	−0.3814 (4.2586)	6.1759 *** (1.7642)	7.9674 *** (1.9542)	3.5629 *** (1.5827)	5.3830 *** (1.8483)	6.3585 *** (2.0963)	10.9273 *** (3.4266)	9.5699 *** (2.5582)
_cons	23.2399 (19.4621)	54.3714 *** (8.0627)	55.1135 *** (8.9307)	75.2533 *** (7.2332)	4.8608 (7.8844)	26.4035 *** (8.9426)	36.6066 *** (14.6172)	87.5718 *** (10.9126)

Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: processed by the authors.

Table A9. Causality analysis for OMS and NMS samples.

	OMS		NMS	
	W-stat	**Z-stat**	**W-stat**	**Z-stat**
RE = FE	2.4016 **	1.9903	1.3262	0.1369
FE = RE	2.5102 **	2.1779	2.4273 **	1.9606
RE = G	2.3626 **	1.9228	2.0192	1.2810
G = RE	2.6393 ***	2.4010	2.2430 *	1.6536
RE = GHG	2.3351 **	0.0608	2.7867 ***	2.5592
GHG = RE	2.8154 ***	2.7054	2.8677 ***	2.6940
RE = GDP	1.7644	0.8890	1.5560	0.5096
GDP = RE	1.5044	0.4397	2.9949 ***	2.9058
RE = GF	1.3207	0.1222	1.3614	0.1856
GF = RE	1.9723	1.2483	3.2724 ***	3.3680
RE = FD	3.4744 ***	3.8442	1.1583	−0.1527
FD = RE	2.8589 ***	2.7806	2.5033 **	2.0872

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Source: processed by the authors.

References

1. European Commission. The European Green Deal. Available online: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed on 20 August 2025).
2. European Commission. In Focus: EU Leading the Global Energy Transition. Directorate-General for Energy. 2024. Available online: https://energy.ec.europa.eu/news/focus-eu-leading-global-energy-transition-2024-11-18_en (accessed on 24 August 2025).
3. Solar Power Europe; L.U.T University. 100% Renewable Europe Study. 2025. Available online: https://www.solarpowereurope.org/insights/market-outlooks/100-renewable-europe-study (accessed on 21 August 2025).
4. European Environment Agency (EEA). Renewable Energy. European Environment Agency. Last Modified 26 June 2025. Available online: https://www.eea.europa.eu/en/topics/in-depth/renewable-energy (accessed on 24 August 2025).
5. International Energy Agency. World Energy Investment 2024: European Union. 2024. Available online: https://www.iea.org/reports/world-energy-investment-2024 (accessed on 20 August 2025).
6. International Energy Agency. *World Energy Investment 2025*; Section on European Union; IEA: Paris, France, 2025. Available online: https://www.iea.org/reports/world-energy-investment-2025 (accessed on 20 August 2025).
7. European Commission. REPowerEU: Affordable, Secure and Sustainable Energy for Europe. Available online: https://commission.europa.eu/topics/energy/repowereu_en (accessed on 20 August 2025).
8. European Environment Agency (EEA). *Share of Energy Consumption from Renewable Sources in Europe*; European Environment Agency: Copenhagen, Denmark, 2025. Available online: https://www.eea.europa.eu/en/analysis/indicators/share-of-energy-consumption-from (accessed on 20 August 2025).
9. Bousso, R. The Path to Cheap Power Will Be Very Expensive. *Reuters*. 2025. Available online: https://www.reuters.com/business/energy/path-cheap-power-will-be-very-expensive-2025-06-09/ (accessed on 20 August 2025).
10. Ray, S.; Roush, T. Spain and Portugal Power Outages: Electricity Restored in Some Regions (Live Updates). *Forbes*. 2025. Available online: https://www.forbes.com/sites/siladityaray/2025/04/28/spain-and-portugal-power-outages-electricity-restored-in-some-regions-live-updates/ (accessed on 20 August 2025).
11. Chestney, N. EU Power Grid Needs Trillion-Dollar Upgrade to Avert Spain-Style Blackouts. *Reuters*. 2025. Available online: https://www.reuters.com/sustainability/climate-energy/eu-power-grid-needs-trillion-dollar-upgrade-avert-spain-style-blackouts-2025-05-05/ (accessed on 20 August 2025).
12. De Lange, D.E. Climate Action Now: Energy Industry Restructuring to Accelerate the Renewable Energy Transition. *J. Clean. Prod.* **2024**, *443*, 141018. [CrossRef]
13. Tijanić, L.; Kersan-Škabić, I. Tracking the Green Transition in the European Union within the Framework of EU Cohesion Policy: Current Results and Future Paths. *Economies* **2025**, *13*, 37. [CrossRef]
14. Andersson, M.; Köhler-Ulbrich, P.; Nerlich, C. Green Investment Needs in the EU and Their Funding. European Central Bank. ECB Economic Bulletin. 2025. Available online: https://www.ecb.europa.eu/pub/economic-bulletin/articles/2025/html/ecb.ebart202501_03~90ade39a4a.en.html (accessed on 20 August 2025).
15. Ollier, L.; Metz, F.; Nuñez-Jimenez, A.; Späth, L.; Lilliestam, J. The European 2030 Climate and Energy Package: Do Domestic Strategy Adaptations Precede EU Policy Change? *Policy Sci.* **2022**, *55*, 161–184. [CrossRef]
16. Bocquillon, P.; Maltby, T. The More the Merrier? Assessing the Impact of Enlargement on EU Performance in Energy and Climate Change Policies. *East Eur. Politics* **2017**, *33*, 88–105. [CrossRef]

17. Potrč, S.; Čuček, L.; Martin, M.; Kravanja, Z. Sustainable Renewable Energy Supply Networks Optimization—The Gradual Transition to a Renewable Energy System within the European Union by 2050. *Renew. Sustain. Energy Rev.* **2021**, *146*, 111186. [CrossRef]
18. Soto, G.H.; Nghiem, X.-H.; Martinez-Cobas, X. Analyzing the Role of Main Energy Transition Policies upon Renewable Energy Penetration in the EU: An Assessment of Energy Productivity and Low Carbon Economies. *Struct. Change Econ. Dyn.* **2025**, *25*, 100573. [CrossRef]
19. Aydin, M.; Degirmenci, T.; Ahmed, Z.; Apergis, N. Do the Energy Taxes, Green Technological Innovation, and Energy Productivity Enable the Green Energy Transition in EU Countries? Evidence from Novel Panel Data Estimators. *Renew. Energy* **2025**, *249*, 123236. [CrossRef]
20. Śmiech, S.; Karpinska, L.; Bouzarovski, S. Impact of Energy Transitions on Energy Poverty in the European Union. *Renew. Sustain. Energy Rev.* **2025**, *211*, 115311. [CrossRef]
21. Diaconescu, M.; Marinas, L.E.; Marinoiu, A.M.; Popescu, M.-F.; Diaconescu, M. Towards Renewable Energy Transition: Insights from Bibliometric Analysis on Scholar Discourse to Policy Actions. *Energies* **2024**, *17*, 4719. [CrossRef]
22. Vezzoni, R. Green Growth for Whom, How and Why? The REPowerEU Plan and the Inconsistencies of European Union Energy Policy. *Energy Res. Soc. Sci.* **2023**, *101*, 103134. [CrossRef]
23. Chen, J.; Huang, S.; Kamran, H.W. Empowering Sustainability Practices through Energy Transition for Sustainable Development Goal 7: The Role of Energy Patents and Natural Resources among European Union Economies through Advanced Panel. *Energy Policy* **2023**, *176*, 113499. [CrossRef]
24. Amen, M.; Bosman, M.M.; Gills, B.K. Editorial:The Urgent Need for Global Action to Combat Climate Change. *Globalizations* **2008**, *5*, 49–52. [CrossRef]
25. Schenck, L. Climate Change Crisis-Struggling for Worldwide Collective Action. *Colo. J. Int. Environ. Law Policy* **2008**, *19*, 319.
26. Javadinejad, S.; Dara, R.; Jafary, F. Taking Urgent Actions to Combat Climate Change Im-Pacts. *Ann. Geogr. Stud.* **2019**, *2*, 1–13. [CrossRef]
27. World Bank Group. Climate Change Action Plan 2021–2025: Supporting Green, Resilient, and Inclusive Development (Report No. 160888). 2021. Available online: https://openknowledge.worldbank.org/entities/publication/ee8a5cd7-ed72-542d-918b-d72e07f96c79#:~:text=The%20Climate%20Change%20Action%20Plan,prosperity%20with%20a%20sustainability%20lens (accessed on 27 August 2025).
28. International Monetary Fund. *Finance & Development: The Climate Issue*; International Monetary Fund: Washington, DC, USA, 2021; Volume 58. Available online: https://www.imf.org/external/pubs/ft/fandd/2021/09/pdf/fd0921.pdf (accessed on 25 August 2025).
29. Sahadevan, D.; Irfan, M.T.; Luo, C.; Moyer, J.D.; Mason, C.; Beynon, E. *Charged for Change: The Case for Renewable Energy in Climate Action (Climate Promise Report)*; United Nations Development Programme: Ulaanbaatar, Mongolia; Pardee Institute for International Futures: Denver, CO, USA; Octopus Energy: London, UK, 2025. Available online: https://climatepromise.undp.org/sites/default/files/research_report_document/UNDP_Charged%20for%20Change_July%202025_Final.pdf (accessed on 27 August 2025).
30. Attanayake, K.; Wickramage, I.; Samarasinghe, U.; Ranmini, Y.; Ehalapitiya, S.; Jayathilaka, R.; Yapa, S. Renewable Energy as a Solution to Climate Change: Insights from a Comprehensive Study across Na-Tions. *PLoS ONE* **2024**, *19*, 0299807. [CrossRef]
31. Yu, H.; Wen, B.; Zahidi, I.; Chow, M.F.; Liang, D.; Madsen, D.Ø. The Critical Role of Energy Transi-Tion in Addressing Climate Change at COP28. *Results Eng.* **2024**, *22*, 102324. [CrossRef]
32. Krey, V.; Clarke, L. Role of renewable energy in climate mitigation: A synthesis of recent scenarios. *Clim. Policy* **2011**, *11*, 1131–1158. [CrossRef]
33. Fawzy, S.; Osman, A.I.; Doran, J.; Rooney, D.W. Strategies for mitigation of climate change: A review. *Environ. Chem. Lett.* **2020**, *18*, 2069–2094. [CrossRef]
34. Sompolska-Rzechuła, A.; Bąk, I.; Becker, A.; Marjak, H.; Perzyńska, J. The use of renewable energy sources and environmental degradation in EU countries. *Sustainability* **2024**, *16*, 10416. [CrossRef]
35. Panwar, N.L.; Kaushik, S.C.; Kothari, S. Role of Renewable Energy Sources in Environmental Protection: A Review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1513–1524. [CrossRef]
36. Moriarty, P.; Honnery, D. What Is the Global Potential for Renewable Energy? *Renew. Sustain. Energy Rev.* **2012**, *16*, 244–252. [CrossRef]
37. Bogdanov, D.; Ram, M.; Aghahosseini, A.; Gulagi, A.; Oyewo, A.S.; Child, M.; Breyer, C. Low-Cost Renewable Electricity as the Key Driver of the Global Energy Transition towards Sustainabil-Ity. *Energy* **2021**, *227*, 120467. [CrossRef]
38. Babayomi, O.O.; Dahoro, D.A.; Zhang, Z. Affordable Clean Energy Transition in Developing Countries: Pathways and Technologies. *Iscience* **2022**, *25*, 104178. [CrossRef]
39. Go, R.; Kahrl, F.; Kolster, C. Planning for Low-Cost Renewable Energy. *Electr. J.* **2020**, *33*, 106698. [CrossRef]

40. Patrocínio, A.O.D.T.; Mizoguchi, S.K.; Paterno, L.G.; Garcia, C.G.; Iha, N.M. Efficient and Low Cost Devices for Solar Energy Conversion: Efficiency and Stability of Some Natural-Dye-Sensitized Solar Cells. *Synth. Met.* **2009**, *159*, 2342–2344. [CrossRef]
41. Gaudiana, R. Third-Generation Photovoltaic Technology—The Potential for Low-Cost Solar Energy Conversion. *J. Phys. Chem. Lett.* **2010**, *1*, 1288–1289. [CrossRef]
42. Shang, Y.; Sang, S.; Tiwari, A.K.; Khan, S.; Zhao, X. Impacts of Renewable Energy on Climate Risk: A Global Perspective for Energy Transition in a Climate Adaptation Framework. *Appl. Energy* **2024**, *362*, 122994. [CrossRef]
43. Ilyas, M.; Mu, Z.; Akhtar, S.; Hassan, H.; Shahzad, K.; Aslam, B.; Maqsood, S. Renewable Energy, Economic Development, Energy Consumption and Its Impact on Environmental Quality: New Evidence from South East Asian Countries. *Renew. Energy* **2024**, *223*, 119961. [CrossRef]
44. Solangi, Y.A.; Magazzino, C. Evaluating Financial Implications of Renewable Energy for Climate Action and Sustainable Development Goals. *Renew. Sustain. Energy Rev.* **2025**, *212*, 115390. [CrossRef]
45. Bashir, M.F.; Pata, U.K.; Shahzad, L. Linking Climate Change, Energy Transition and Renewable Energy Investments to Combat Energy Security Risks: Evidence from Top Energy Consuming Economies. *Energy* **2025**, *314*, 134175. [CrossRef]
46. Tugcu, C.T.; Menegaki, A.N. The Impact of Renewable Energy Generation on Energy Security: Evidence from the G7 Countries. *Gondwana Res.* **2024**, *125*, 253–265. [CrossRef]
47. Huynh, C.M.; Phan, T.N. Climate Change and Income Inequality: Does Renewable Energy Matter? *Renew. Energy* **2024**, *233*, 121147. [CrossRef]
48. Sebri, M. Use Renewables to Be Cleaner: Meta-Analysis of the Renewable Energy Consumption–Economic Growth Nexus. *Renew. Sustain. Energy Rev.* **2015**, *42*, 657–665. [CrossRef]
49. Lahrech, A.; Abu-Hijleh, B.; Aldabbas, H. The Impact of Global Renewable Energy Demand on Economic Growth–Evidence from GCC Countries. *Arab Gulf J. Sci. Res.* **2024**, *42*, 498–511. [CrossRef]
50. Dirma, V.; Neverauskienė, L.O.; Tvaronavičienė, M.; Danilevičienė, I.; Tamošiūnienė, R. The impact of renewable energy development on economic growth. *Energies* **2024**, *17*, 6328. [CrossRef]
51. Dilanchiev, A.; Umair, M.; Haroon, M. How Causality Impacts the Renewable Energy, Carbon Emissions, and Economic Growth Nexus in the South Caucasus Countries? *Environ. Sci. Pollut. Res.* **2024**, *31*, 33069–33085. [CrossRef]
52. Ritchie, H.; Roser, M.; Rosado, P. *Renewable Energy*; Our World in Data: Oxford, UK, 2020. Available online: https://ourworldindata.org/renewable-energy (accessed on 29 July 2025).
53. Energy Institute. *Statistical Review of World Energy 2025*; Our World in Data, Ed.; Our World in Data: Oxford, UK, 2025. Available online: https://www.energyinst.org/statistical-review/ (accessed on 29 July 2025).
54. Eurostat. Renewable Energy Statistics. In *Statistics Explained*; European Commission: Luxembourg, 2025. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics (accessed on 29 July 2025).
55. Bourcet, C. Empirical Determinants of Renewable Energy Deployment: A Systematic Literature Review. *Energy Econ.* **2020**, *85*, 104563. [CrossRef]
56. Papież, M.; Śmiech, S.; Frodyma, K. Determinants of Renewable Energy Development in the EU Countries. A 20-Year Perspective. *Renew. Sustain. Energy Rev.* **2018**, *91*, 918–934. [CrossRef]
57. Xu, C.; Gao, Y.; Qin, Z.; Li, Z.; Pan, S.; Qi, L. Historical Characteristics and Projection of Global Renewable Energy Consumption. *Renew. Energy* **2024**, *234*, 121222. [CrossRef]
58. Aguirre, M.; Ibikunle, G. Determinants of Renewable Energy Growth: A Global Sample Analysis. *Energy Policy* **2014**, *69*, 374–384. [CrossRef]
59. Tu, Y.X.; Kubatko, O.; Piven, V.; Sotnyk, I.; Kurbatova, T. Determinants of Renewable Energy Development: Evidence from the EU Countries. *Energies* **2022**, *15*, 7093. [CrossRef]
60. Shahbaz, M.; Topcu, B.A.; Sarıgül, S.S.; Vo, X.V. The Effect of Financial Development on Renewable Energy Demand: The Case of Developing Countries. *Renew. Energy* **2021**, *178*, 1370–1380. [CrossRef]
61. Anton, S.G.; Nucu, A.E.A. The Effect of Financial Development on Renewable Energy Consumption. A Panel Data Approach. *Renew. Energy* **2020**, *147*, 330–338. [CrossRef]
62. Mukhtarov, S.; Yüksel, S.; Dinçer, H. The Impact of Financial Development on Renewable Energy Consumption: Evidence from Turkey. *Renew. Energy* **2022**, *187*, 169–176. [CrossRef]
63. Dimnwobi, S.K.; Madichie, C.V.; Ekesiobi, C.; Asongu, S.A. Financial Development and Renewable Energy Consumption in Nigeria. *Renew. Energy* **2022**, *192*, 668–677. [CrossRef]
64. Ghezelbash, A.; Khaligh, V.; Fahimifard, S.H.; Liu, J.J. A Comparative Perspective of the Effects of CO_2 and Non-CO_2 Greenhouse Gas Emissions on Global Solar, Wind, and Geothermal Energy Investment. *Energies* **2023**, *16*, 3025. [CrossRef]
65. Idroes, G.M.; Hardi, I.; Rahman, M.H.; Afjal, M.; Noviandy, T.R.; Idroes, R. The Dynamic Impact of Non-Renewable and Renewable Energy on Carbon Dioxide Emissions and Ecological Footprint in Indonesia. *Carbon Res.* **2024**, *3*, 35. [CrossRef]
66. Rasoulinezhad, E.; Taghizadeh-Hesary, F. Role of Green Finance in Improving Energy Efficiency and Renewable Energy Development. *Energy Effic.* **2022**, *15*, 14. [CrossRef]

67. Li, C.; Umair, M. Does Green Finance Development Goals Affects Renewable Energy in China. *Renew. Energy* **2023**, *203*, 898–905. [CrossRef]
68. Lin, C.Y.; Chau, K.Y.; Tran, T.K.; Sadiq, M.; Van, L.; Phan, T.T.H. Development of Renewable Energy Resources by Green Finance, Volatility and Risk: Empirical Evidence from China. *Renew. Energy* **2022**, *201*, 821–831. [CrossRef]
69. Kurbatova, T.O. Global Trends in Renewable Energy Development. In Proceedings of the 2020 IEEE KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 5–10 October 2020; IEEE: Kharkiv, Ukraine, 2020; pp. 1–5. Available online: https://scispace.com/pdf/global-trends-in-renewable-energy-development-49ghf7uyxk.pdf (accessed on 26 August 2025).
70. Uzar, U. Is Income Inequality a Driver for Renewable Energy Consumption? *J. Clean. Prod.* **2020**, *255*, 120287. [CrossRef]
71. Mahalik, M.K.; Patel, G.; Sahoo, B.K.; Rahman, M.M. Impact of Income Inequality on Renewa-Ble Energy Demand in South Asian Economies. *Energy Policy* **2023**, *180*, 113628. [CrossRef]
72. Eyuboglu, K.; Uzar, U. The Social, Economic, and Environmental Drivers of Renewable Energy: Is Income Inequality a Threat to Renewable Energy Transition? *J. Clean. Prod.* **2025**, *490*, 144780. [CrossRef]
73. Churchill, S.A.; Ivanovski, K.; Munyanyi, M.E. Income Inequality and Renewable Energy Con-Sumption: Time-Varying Non-Parametric Evidence. *J. Clean. Prod.* **2021**, *296*, 126306. [CrossRef]
74. Zheng, M.; Wong, C.Y. The Impact of Digital Economy on Renewable Energy Development in China. *Innov. Green Dev.* **2024**, *3*, 100094. [CrossRef]
75. Tian, L.; Li, X.; Lee, C.W.; Spulbăr, C. Investigating the Asymmetric Impact of Artificial Intelligence on Renewable Energy under Climate Policy Uncertainty. *Energy Econ.* **2024**, *137*, 107809. [CrossRef]
76. Pedroni, P. Fully Modified OLS for Heterogeneous Cointegrated Panels. In *Advances in Econometrics*; Panels, N., Cointegration, P., Panels, D., Baltagi, B.H., Fomby, T.B., Carter Hill, R., Eds.; Emerald Group Publishing Limited: Leeds, UK, 2001; Volume 15. [CrossRef]
77. Ali, H.S.; Nathaniel, S.P.; Uzuner, G.; Bekun, F.V.; Sarkodie, S.A. *Trivariate Modelling of the Nexus Between Electricity Consumption, Urbanization and Economic Growth in Nigeria: Fresh Insights from Maki Cointegration and Causality Tests*; AGDI Working Paper 2020, WP/20/010; African Governance and Development Institute (AGDI): Yaoundé, Cameroon, 2020. Available online: https://hdl.handle.net/10419/227988 (accessed on 1 September 2025).
78. Khan, M.W.A.; Panigrahi, S.K.; Almuniri, K.S.N.; Soomro, M.I.; Mirjat, N.H.; Alqaydi, E.S. Investigating the Dynamic Impact of CO_2 Emissions and Economic Growth on Renewable Energy Production: Evi-Dence from FMOLS and DOLS Tests. *Processes* **2019**, *7*, 496. [CrossRef]
79. Stock, J.H.; Watson, M.W. A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems. *Econometrica* **1993**, *61*, 783–820. [CrossRef]
80. Yahyaoui, I.; Bouchoucha, N. The Long-Run Relationship between ODA, Growth and Governance: An Application of FMOLS and DOLS Approaches. *Afr. Dev. Rev.* **2021**, *33*, 38–54. [CrossRef]
81. Månsson, K.; Kibria, B.M.G.; Shukur, G. Some Liu Type Estimators for the dynamic OLS estimator: With an application to the carbon dioxide Kuznets curve for Turkey. *Commun. Stat. Case Stud. Data Anal. Appl.* **2017**, *3*, 55–61. [CrossRef]
82. Mark, N.C.; Ogaki, M.; Sul, D. *Dynamic Seemingly Unrelated Cointegrating Regression*; NBER Technical Working Papers, No. 292; National Bureau of Economic Research: Cambridge, MA, USA, 2003. Available online: http://www.nber.org/papers/T0292 (accessed on 5 September 2025).
83. Hardi, I.; Afjal, M.; Can, M.; Idroes, G.M.; Noviandy, T.R.; Idroes, R.S.E. Energy Con-Sumption, and Ecological Footprint in Indonesia. *Sustain. Futures* **2024**, *8*, 100343. [CrossRef]
84. Hsiao, C. Panel Data Analysis—Advantages and Challenges. *TEST* **2007**, *16*, 1–22. [CrossRef]
85. Pesaran, M.H.; Yamagata, T. Testing slope homogeneity in large panels. *J. Econ.* **2008**, *142*, 50–93. [CrossRef]
86. Blomquist, J.; Westerlund, J. Testing Slope Homogeneity in Large Panels with Serial Correlation. *Econ. Lett.* **2013**, *121*, 374–378. [CrossRef]
87. Barbieri, L. Panel Unit Root Tests: A Review (Serie Rossa: Economia–Quaderno No. 43). Quaderni del Dipartimento di Scienze Economiche e Sociali, Università Cattolica del Sacro Cuore. 2006. Available online: https://dipartimenti.unicatt.it/dicdr-dipartimenti/dises-wp_rossa_06_43.pdf (accessed on 26 August 2025).
88. Westerlund, J.; Breitung, J. *Myths and Facts about Panel Unit Root Tests*; Working Papers in Economics, No. 380; University of Gothenburg, Department of Economics: Gothenburg, Sweden, 2009. Available online: https://gupea.ub.gu.se/handle/2077/21050 (accessed on 26 August 2025).
89. Pesaran, M.H. *General Diagnostic Tests for Cross Section Dependence in Panels, Cambridge Working Papers in Economics*; No. 0435; University of Cambridge, Faculty of Economics: Cambridge, UK, 2004. [CrossRef]
90. Kao, C. Spurious Regression and Residual-Based Tests for Cointegration in Panel Data. *J. Econom.* **1999**, *90*, 1–44. [CrossRef]
91. Pedroni, P. *Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the PPP Hypothesis*; Department of Economics Working Papers, No. 2004-15; Department of Economics, Williams College: Williamstown, MA, USA, 2004. Available online: https://web.williams.edu/Economics/wp/pedronipanelcointegration.pdf (accessed on 26 August 2025).

92. Westerlund, J. New Simple Tests for Panel Cointegration. *Econom. Rev.* **2005**, *24*, 297–316. [CrossRef]
93. Dumitrescu, E.-I.; Hurlin, C. Testing for Granger non-causality in heterogeneous panels. *Econ. Model* **2012**, *29*, 1450–1460. [CrossRef]
94. Eurostat. Share of Energy from Renewable Sources; Dataset Code: nrg_ind_ren. Available online: https://ec.europa.eu/eurostat/databrowser/product/view/nrg_ind_ren (accessed on 6 September 2025). [CrossRef]
95. Eurostat. Share of Fossil Fuels in Gross Available Energy; Dataset Code: nrg_ind_ffgae. Available online: https://ec.europa.eu/eurostat/databrowser/product/view/nrg_ind_ffgae (accessed on 6 September 2025).
96. Eurostat. Gini Coefficient of Equivalised Disposable Income by Age; Dataset Code: ilc_di12__custom_16040149. Available online: https://ec.europa.eu/eurostat/databrowser/product/view/ilc_di12__custom_16040149 (accessed on 6 September 2025).
97. World Bank. Total Greenhouse Gas Emissions Excluding LULUCF (% Change from 1990); Indicator Code: EN.GHG.TOT.ZG.AR5. Data Sourced from EDGAR (Emissions Database for Global Atmospheric Research), Joint Research Centre (JRC)—European Commission. Available online: https://data.worldbank.org/indicator/EN.GHG.TOT.ZG.AR5 (accessed on 6 September 2025).
98. Eurostat. Sustainable Development Indicators: Goal 8—Decent Work and Economic Growth, Real GDP per Capita; Dataset Code: sdg_08_10; Source: Eurostat (nama_10_pc). Available online: https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10 (accessed on 6 September 2025). [CrossRef]
99. Eurostat. Investments in Climate Change Mitigation by NACE Rev. 2 Activity; Dataset Code: env_ac_ccminv. Available online: https://ec.europa.eu/eurostat/databrowser/view/env_ac_ccminv (accessed on 6 September 2025).
100. World Bank. Monetary Sector Credit to the Private Sector (% of GDP); World Development Indicators; Indicator Code: FM.AST.PRVT.GD.ZS. Last Updated 24 March 2025. Available online: https://databank.worldbank.org/source/world-development-indicators (accessed on 6 September 2025).
101. Fatima, N.; Xuhua, H.; Alnafisah, H.; Akhtar, M.R. Synergy for Climate Actions in G7 Countries: Unravel-Ing the Role of Environmental Policy Stringency Between Technological Innovation and CO2 Emission Interplay with DOLS, FMOLS and MMQR Approaches. *Energy Rep.* **2024**, *12*, 1344–1359. [CrossRef]
102. UNDP. What Is the Sustainable Energy Transition and Why Is It Key to Tackling Climate Change? *Clim. Promise Explain.* 2025. Available online: https://climatepromise.undp.org/news-and-stories/what-sustainable-energy-transition-and-why-it-key-tackling-climate-change (accessed on 8 July 2025).
103. Eurostat. Shedding Light on Energy in Europe—2024 Edition. Interactive Publication. 14 March 2024. Available online: https://ec.europa.eu/eurostat/web/interactive-publications/energy-2024 (accessed on 8 July 2025).
104. Bocca, R. Europe's Record Fall in Fossil Fuels–Plus Other Top Energy Stories. World Economic Forum. Published 14 February 2024. Updated 3 June 2025. Available online: https://www.weforum.org/stories/2024/02/europe-record-fall-fossil-fuels-other-energy-stories (accessed on 8 July 2025).
105. Igliński, B.; Kiełkowska, U.; Mazurek, K.; Drużyński, S.; Pietrzak, M.B.; Kumar, G.; Veeramuthu, A.; Skrzatek, M.; Zinecker, M.; Piechota, G. Renewable Energy Transition in Europe in the Context of Re-Newable Energy Transition Processes in the World. A Review. *Heliyon* **2024**, *10*, 40997. [CrossRef] [PubMed]
106. SolarPower Europe. Solar Overtakes Coal in EU Power Sector. Available online: https://www.solarpowereurope.org/news/solarovertakes-coal-in-eu-power-sector (accessed on 8 July 2025).
107. Kosowski, P. From Fossil Fuels to Renewables: Clustering European Primary Energy Production from 1990 to 2022. *Energies* **2024**, *17*, 5596. [CrossRef]
108. Sahu, A.K.; Mahalik, M.K. The Linkage between Income Inequality, Opportunity and Renewable Energy Demand: Panel Evidence from OECD Economies. *Renew. Energy* **2025**, *243*, 122588. [CrossRef]
109. Simionescu, M.; Cifuentes-Faura, J. Evaluating the Relationship between Income Inequality, Renewable Energy and Energy Poverty in the V4 Countries. *Energy Res. Soc. Sci.* **2024**, *115*, 103640. [CrossRef]
110. Asongu, S.A.; Odhiambo, N.M. Inequality and Renewable Energy Consumption in Sub-Saharan Africa: Implication for High Income Countries. *Int. J. Green Energy* **2021**, *18*, 382–398. [CrossRef]
111. Simionescu, M. The Impact of Income Inequality on Energy Poverty in the European Union. *Int. J. Financ. Stud.* **2025**, *13*, 54. [CrossRef]
112. Zhen, Z.; Ullah, S.; Irfan, M. How Do Renewable Energy Consumption, Financial Development, and Tech-Nical Efficiency Change Cause Ecological Sustainability in European Union Countries? *Sustainability* **2022**, *14*, 12345. [CrossRef]
113. Beck, T.; Demirgüç-Kunt, A.; Levine, R. A New Database on the Structure and Development of the Fi-Nancial Sector. *World Bank Econ. Rev.* **2000**, *14*, 597–605. [CrossRef]
114. Caporale, G.M.; Sova, A.D.; Sova, R. The Direct and Indirect Effects of Financial Development on Inter-National Trade: Evidence from the CEEC-6. *J. Int. Financ. Mark. Inst. Money* **2022**, *78*, 101550. [CrossRef]
115. Bist, J.P. Financial Development and Economic Growth: Evidence from a Panel of 16 African and Non-African Low-Income Countries. *Cogent Econ. Financ.* **2018**, *6*, 1449780. [CrossRef]
116. Struthmann, P. Financial Development and Growth Volatility Revisited. *Financ. Res. Lett.* **2025**, *78*, 107175. [CrossRef]

117. Ali, M.; Seraj, M.; Turuc, F.; Tursoy, T.; Uktamov, K.F. Green Finance Investment and Climate Change Mitigation in OECD-15 European Countries: RALS and QARDL Evidence. *Environ. Dev. Sustain.* **2024**, *26*, 27409–27429. [CrossRef]
118. Fleming, S. What Is Green Finance and Why Is It Important? World Economic Forum. 9 November 2020. Available online: https://www.weforum.org/stories/2020/11/what-is-green-finance/ (accessed on 26 August 2025).
119. UNEP. Green Financing. United Nations Environment Programme. Last Update: 23 January 2018. Available online: https://www.unep.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-financing (accessed on 25 August 2025).
120. Spinaci, S. *Green and Sustainable Finance*; EPRS (BRIEFING); European Parliament: Brussels, Belgium, 2021. Available online: https://www.europarl.europa.eu/RegData/etues/BRIE/2021/679081/EPRS_BRI%282021%29679081_EN.pdf (accessed on 8 July 2025).
121. Akinwande, M.O.; Dikko, H.G.; Samson, A. Variance Inflation Factor: As a Condition for the Inclusion of Suppressor Variable(s) in Regression Analysis. *Open J. Stat.* **2015**, *5*, 754–767. [CrossRef]
122. O'Brien, R.M. A Caution Regarding Rules of Thumb for Variance Inflation Factors. *Qual. Quant.* **2007**, *41*, 673–690. [CrossRef]
123. Kalnins, A.; Praitis Hill, K. What Is It Good For? Absolutely Nothing. *Organ. Res. Methods* **2023**, *28*, 58–75. [CrossRef]
124. Kim, J.H. Multicollinearity and Misleading Statistical Results. *Korean J. Anesth. Anesthesiol.* **2019**, *72*, 558–569. [CrossRef] [PubMed]
125. Bersvendsen, T. Testing for slope heterogeneity in Stata. *Stata J.* **2021**, *21*, 51–80. [CrossRef]
126. Pedroni, P. *Panel Cointegration Techniques and Open Challenges*; Department of Economics Working Papers; No. 2018-09; Williams College: Williamstown, MA, USA, 2018. Available online: https://web.williams.edu/Economics/wp/Pedroni_PanelCointegration.pdf (accessed on 26 August 2025).
127. Pedroni, P. Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxf. Bull. Econ. Stat.* **1999**, *61*, 653–670. [CrossRef]
128. Sultana, N.; Rahman, M.M.; Khanam, R.; Kabir, Z. Environmental Quality and Its Nexus with Informal Economy, Corruption Control, Energy Use, and Socioeconomic Aspects: The Perspective of Emerging Economies. *Heliyon* **2022**, *8*, 09569. [CrossRef] [PubMed]
129. Altın, H. The Impact of Energy Efficiency and Renewable Energy Consumption on Carbon Emissions in G7 Countries. *Int. J. Sustain. Eng.* **2024**, *17*, 134–142. [CrossRef]
130. Vasylieva, T.; Lyulyov, O.; Bilan, Y.; Streimikiene, D. Sustainable Economic Development and Greenhouse Gas Emissions: The Dynamic Impact of Renewable Energy Consumption, GDP, and Corruption. *Energies* **2019**, *12*, 3289. [CrossRef]
131. Bölük, G.; Mert, M. Fossil & Renewable Energy Consumption, GHGs (Greenhouse Gases) and Economic Growth: Evidence from a Panel of EU countries. *Energy* **2014**, *74*, 439–446. [CrossRef]
132. Bilgili, F.; Koçak, E.; Bulut, Ü. The Dynamic Impact of Renewable Energy Consumption on CO_2 Emis-Sions: A Revisited Environmental Kuznets Curve Approach. *Renew. Sustain. Energy Rev.* **2016**, *54*, 838–845. [CrossRef]
133. Dong, K.; Dong, X.; Jiang, Q. How Renewable Energy Consumption Lower Global CO_2 Emissions? Evidence from Countries with Different Income Levels. *World Econ.* **2020**, *43*, 1665–1698. [CrossRef]
134. Lucas, J.N.V.; Francés, G.E.; González, E.S.M. Energy Security and Renewable Energy Deployment in the EU: Liaisons Dangereuses or Virtuous Circle? *Renew. Sustain. Energy Rev.* **2016**, *62*, 1032–1046. [CrossRef]
135. Marques, A.C.; Fuinhas, J.A.; Manso, J.P. Motivations Driving Renewable Energy in European Countries: A Panel Data Approach. *Energy Policy* **2010**, *38*, 6877–6885. [CrossRef]
136. Hao, F.; Shao, W. What Really Drives the Deployment of Renewable Energy? A Global Assessment of 118 Countries. *Energy Res. Soc. Sci.* **2021**, *72*, 101880. [CrossRef]
137. Cui, N.; Nketiah, E.; Ma, X. Do Green Energy and Information Technology Influence Greenhouse Gas Emitting Countries to Attain Sustainable Development? *Sustainability* **2023**, *15*, 13685. [CrossRef]
138. Kiesecker, J.; Baruch-Mordo, S.; Kennedy, C.M.; Oakleaf, J.R.; Baccini, A.; Griscom, B.W. Hitting the Target but Missing the Mark: Unintended Environmental Consequences of the Paris Climate Agreement. *Front. Environ. Sci.* **2019**, *7*, 151. [CrossRef]
139. Silva, M.; Raadal, H.L. *Life Cycle GHG Emissions of Renewable and Non-Renewable Electricity Generation Technologies*; Ostfoldforskning: Krakeroy, Norway, 2019.
140. Chavda, P.; Mehta, D. Assessing the Impact of Fossil Fuel Subsidies and Environmental Tax on Re-Newable Energy Consumption of OECD Countries: A Panel Quantile Approach. *Next Energy* **2025**, *8*, 100313. [CrossRef]
141. İçen, N.M.E. What Are the Determinants of Renewable Energy Consumption? An Application for Variable Selection. *Renew. Energy* **2025**, *239*, 122029. [CrossRef]
142. Hoa, P.X.; Xuan, V.N.; Thu, N.T.P. Determinants of the Renewable Energy Consumption: The Case of Asian Countries. *Heliyon* **2023**, *9*, e22696. [CrossRef] [PubMed]
143. Asratie, T.M. Determinants of Electricity Production from Renewable Source Excluding Hydroelectricity in Selected East African Countries: Panel ARDL Approach. *Cogent Econ. Financ.* **2022**, *10*, 2080897. [CrossRef]
144. Akarsu, G.; Gümüşoğlu, N.K. What Are the Main Determinants of Renewable Energy Consumption? A Panel Threshold Regression Approach. *Anadolu Üniv. Sos. Bilim. Derg.* **2019**, *19*, 1–22. [CrossRef]

145. Bekun, F.V.; Alola, A.A. Determinants of renewable energy consumption in agrarian Sub-Sahara African economies. *Energy Ecol. Environ.* **2022**, *7*, 227–235. [CrossRef]
146. Alharbi, S.S.; Al Mamun, M.; Boubaker, S.; Rizvi, S.K.A. Green finance and renewable energy: A worldwide evidence. *Energy Energy Econ.* **2023**, *118*, 106499. [CrossRef]
147. Lyeonov, S.; Pimonenko, T.; Bilan, Y.; Štreimikienė, D.; Mentel, G. Assessment of Green Investments' Impact on Sustainable Development: Linking Gross Domestic Product per Capita, Greenhouse Gas Emissions and Renewable Energy. *Energies* **2019**, *12*, 3891. [CrossRef]
148. Xu, P.; Zhang, J.; Mehmood, U. How Do Green Investments, Foreign Direct Investment, and Renewable Energy Impact CO_2 Emissions? Measuring the Role of Education in E-7 Nations. *Sustainability* **2023**, *15*, 14052. [CrossRef]
149. Zahan, I.; Chuanmin, S. Towards a Green Economic Policy Framework in China: Role of Green investment in Fostering Clean Energy Consumption and Environmental Sustainability. *Environ. Sci. Pollut. Res.* **2021**, *28*, 43618–43628. [CrossRef]
150. Javed, A.; Shabir, M.; Rao, F.; Uddin, M.S. Effect of Green Technological Innovation and Financial Development on Green Energy Transition in N-11 Countries: Evidence from the Novel Method of Moments Quantile Regression. *Renew. Energy* **2025**, *242*, 122435. [CrossRef]
151. Muhammad, S.; Hoffmann, C. From Investment to Impact: The Role of Green Finance and Technological Innovation on German Energy Transition. *Renew. Energy* **2024**, *237*, 121665. [CrossRef]
152. Wang, Y.; Xu, A. Green Investments and Development of Renewable Energy Projects: Evidence from 15 RCEP Member Countries. *Renew. Energy* **2023**, *211*, 1045–1050. [CrossRef]
153. Kim, J.; Park, K. Financial Development and Deployment of Renewable Energy Technologies. *Energy Econ.* **2016**, *59*, 238–250. [CrossRef]
154. Sharma, R.; Rajpurohit, S.S. Nexus between Income Inequality and Consumption of Renewable Energy in India: A Nonlinear Examination. *Econ. Change Restruct.* **2022**, *55*, 2337–2358. [CrossRef]
155. Buis, J. The Effect of Income Inequality on Renewable Energy Consumption in Europe. Master's Thesis, Nijmegen School of Management, Radboud University, Nijmegen, The Netherlands, 2023. Available online: https://theses.ubn.ru.nl/bitstreams/7fd41140-de80-4e20-8ca9-edcc322b1cca/download (accessed on 26 August 2025).
156. Dai, X.; Qian, S.; Zhang, J. Sustainable Financial Inclusion as a Source of Green Environment? Evidence from Selected Regional Comprehensive Economic Partnership Countries. *Econ. Res.-Ekon. Istraž.* **2022**, *35*, 5719–5738. [CrossRef]
157. Humbatova, S.I.; Hajiyeva, N.; Fodor, M.G.; Sood, K.; Grima, S. The Impact of Economic Growth on the Ecological Environment and Renewable Energy Production: Evidence from Azerbaijan and Hungary. *J. Risk Financ. Manag.* **2024**, *17*, 275. [CrossRef]
158. Wang, Z.; Pham, T.L.H.; Sun, K.; Wang, B.; Bui, Q.; Hashemizadeh, A. The Moderating Role of Financial Development in the Renewable Energy Consumption-CO_2 Emissions Linkage: The Case Study of Next-11 Countries. *Energy* **2022**, *254*, 124386. [CrossRef]
159. Apergis, N.; Payne, J.E. Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. *Energy Econ.* **2012**, *34*, 733–738. [CrossRef]
160. Mehmood, U.; Agyekum, E.B.; Tariq, S.; Ul Haq, Z.; Uhunamure, S.E.; Edokpayi, J.N.; Azhar, A. Socio-Economic Drivers of Renewable Energy: Empirical Evidence from BRICS. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4614. [CrossRef]
161. Eren, B.M.; Taspinar, N.; Gokmenoglu, K.K. The Impact of Financial Development and Economic Growth on Renewable Energy Consumption: Empirical Analysis of India. *Sci. Total Environ.* **2019**, *663*, 189–197. [CrossRef]
162. Vo, D.H.; Tran, Q.; Tran, T. Economic Growth, Renewable Energy and Financial Development in the CPTPP Countries. *PLoS ONE* **2022**, *17*, e0268631, Correction in *PLoS ONE* **2022**, *17*, e0314387. [CrossRef]
163. Wang, K.; Costanza-van den Belt, M.; Heath, G.; Walzberg, J.; Curtis, T.; Berrie, J.; Schröder, P.; Lazer, L.; Altamirano, J. *Circular Economy as a Climate Strategy: Current Knowledge and Calls-to-Action*; National Renewable Energy Laboratory: Golden, CO, USA, 2022. Available online: https://www.nrel.gov/docs/fy23osti/84141.pdf (accessed on 6 September 2025).
164. U.S. Department of Energy. *Circularity for Secure and Sustainable Products and Materials: A Draft Strategic Framework*; Office of Energy Efficiency & Renewable Energy: Washington, DC, USA, 2024. Available online: https://www.energy.gov/sites/default/files/2024-10/circularity-for-secure-sustainable-products-materials-report.pdf (accessed on 6 September 2025).
165. Wang, Y.; He, Y.; Gao, X. Synergizing Renewable Energy and Circular Economy Strategies: Pioneering Pathways to Environmental Sustainability. *Sustainability* **2025**, *17*, 1801. [CrossRef]
166. Liao, Z. Assessing Sustainable Impacts of Green Energy Projects for the Development of Renewable Energy Technologies: A Triple Bottom Line Approach. *Processes* **2023**, *11*, 2228. [CrossRef]