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# Do the Energy-Related Uncertainties Stimulate Renewable Energy Demand in Developed Economies? Fresh Evidence from the Role of Environmental Policy Stringency and Global Economic Policy Uncertainty

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**Abstract:** Despite earlier research on green energy, there is still a significant gap in understanding how energy-related uncertainties affect renewable energy consumption (REN), especially in developed nations. Thus, this study explicitly looks into how the energy-related uncertainty index (EUI) can promote (or diminish) REN in sixteen wealthy nations between 2000 and 2020. Furthermore, we attempt to specify the factors of REN and explore whether environmental policy stringency (EPS) and global economic policy uncertainty (GEPU) could help moderate (or intensify) the EUI-REN nexus. To achieve this, we employ different panel data methods. The results underscore that the EUI significantly impacts REN, denoting that higher uncertainties related to energy markets lead to promoting REN. Additionally, the (EUI × EPS) underlines that EPS has a favorable role in increasing the positive effect of the EUI on REN in sample developed countries while (EUI × GEPU) has a detrimental effect. Remarkably, the findings underline that the effect of the EUI on REN is more positive in high EPS countries and that the positive effect of the EUI is more moderate when GEPU is high. The findings also underscore that the development of the financial market, FDI, personal remittances, and EPS positively stimulate REN whereas $CO_2$, total natural resources rents, economic activity, and GEPU have a detrimental impact. The results are robust, and authorities and policymakers are advised to implement a wide range of policy proposals to accomplish sustainable development goals (SDGs) 7 and 13.

**Keywords:** renewable energy demand; energy-related uncertainty; ecological policy; economic policy uncertainty; developed countries; SDGs; panel quantile regression

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## 1. Introduction

The issue of renewable energy (RENE) has garnered substantial interest from scholars and decision-makers across the globe as a result of the deteriorating state of the air and the expanding consequences of climate change. Ref. [1] found that ecological pollution negatively impacts human health; as a result, declining air quality was associated with 5.5 million early deaths. According to [2], the use of RENE caused carbon emissions to drop from 2.1% in 2018 to 0.5% in 2019. Furthermore, RENE issues have gained more importance due to fluctuating fossil fuel prices and increasing global warming. Remarkably, about 80% of the world's primary energy consumption is derived from fossil fuels, which contributes to an increase in greenhouse gas emissions, climate change, and global warming. Transitioning nations from conventional fossil fuels to RENE sources contributes to mitigating climate change and expediting the achievement of the SDGs. When opposed to traditional energy, RENE offers advantages that are both ecologically friendly and replenishable. According to [3], promoting RENE is a better way to accomplish the goal of the Paris Climate Conference (COP-21) and is more appropriate for economic development.

In the last two decades, authorities and policymakers have implemented several laws and initiatives to expedite the transition from conventional to green energy. These initiatives include standardization, tax breaks, incentive programs, and less expensive credits, among many others. To lower greenhouse gas emissions, slow down climate change, and achieve ecological sustainability, these initiatives seek to increase household REN, boost R&D in the green energy sector, and invest in RENE [4,5]. Ref. [6] reported that these actions contributed to a 3% global increase in REN in 2020 and investments in RENE increased from less than $50 billion in 2004 to over $300 billion in 2015. Ref. [7] emphasized that green funding for RENE projects needs to rise to $1.1 trillion between 2021 and 2030 to meet the SDGs and reduce greenhouse gas emissions.

The increased debate regarding global warming and the role of clean energy has led to research examining the major factors influencing the decline or increase of REN in various nations employing the demand modeling method. Studies suggest, for instance, that the development of the financial markets promotes REN [8,9] and that investors can access external funds at lower costs more easily when the capital market is more developed. In addition, the development of a financial market might promote more R&D efforts in clean energy, improve ecological knowledge, and raise the level of RENE planning due to the easier accessibility of various financial facilities. Furthermore, research has demonstrated (e.g., [9,10]) that economic openness is one of the major factors that stimulate REN and an increased inflow of FDI increases access to external funds and enables firms and investors to borrow at lower costs to invest in RENE plans. In previous studies (e.g., [11]), it has also been found that increasing economic openness enables improved managerial expertise and cleaner technologies to be transmitted, which ultimately contributes to the growth of renewable energy. Furthermore, prior studies have demonstrated that economic activity either positively (e.g., [12]) or negatively impacts REN (e.g., [8]).

In the same vein, several studies (e.g., [8,13]) have revealed that technological innovations promote REN and that a higher level of ecological technology could improve energy productivity and hasten a nation's transition to green economies. Furthermore, technological improvements allow for significant reductions in the investment costs of new RENE installations [14]. Additionally, some research has shown that the influx of international remittances encourages the development of REN [15]. A greater inflow of remittances encourages households to finance RENE programs and makes it easier for them to adopt homes with green systems. Nevertheless, several studies have shown that GEPU reduces REN (e.g., [9,16]). As EPU increases worldwide, consumers (demand side) are less encouraged to switch to RENE sources because of the reduction in their income [17]. Ref. [9] revealed that a 1% increase in GEPU declines REN by 0.16% in OECD nations. As a consequence, it also has a negative effect on the supply side by increasing the price of private-sector investment [18].

Likewise, several studies have shown that $CO_2$ ([12]) and natural resources rents [9] diminish REN. In particular, Ref. [12] demonstrated that in OECD countries, a 1% increase in natural resources rents and $CO_2$ results in a decrease in REN of 0.03% and 0.35%, respectively. Previous research has demonstrated that in contexts with higher rents for natural resources, the switch from conventional energy to RENE occurs more slowly [19]. Previous studies [9,20] have also emphasized the importance of green ecological strategies in contributing to the rise in REN. The authors contended that the adoption of ecologically friendly strategies contributes to the expansion of RENE capacity. In general, previous research indicates that authorities and policymakers should develop a range of approaches to persuade householders and investors to switch from fossil fuels to RENE to achieve the SDGs and ecological quality.

What about the elements of REN in the setting of developed countries? Although some works have studied REN in different blocks like BRICS (e.g., [8]), limited studies have uncovered the elements of REN in general and developed countries specifically. As shown in Figure 1, fossil fuels will remain the leading energy source in the world whereas RENEs have a small supply share of 5%. Since countries attempt to achieve carbon neutrality, environmental quality, and also attain SDGs, identifying the elements of REN could be an effective approach to promoting RENEs globally.

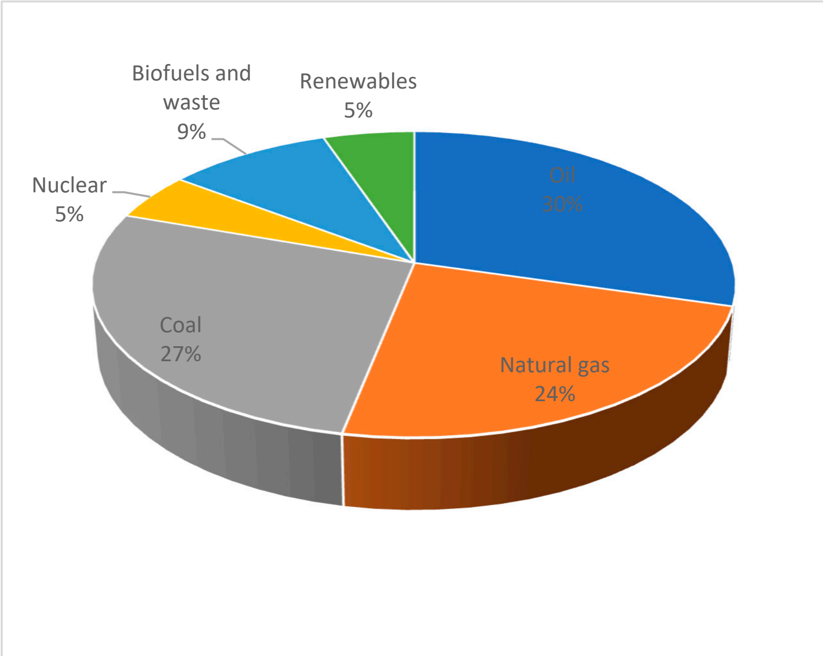



**Figure 1.** Global total energy supply by source (2021). Authors' calculations (Source: https://www.iea.org/data-and-statistics/, accessed on 1 June 2024).

By classifying countries, Figure 2 shows that the developed countries accounted for 66% of the world's total supply of RENE in 2021, a substantial percentage higher than that of developing countries (34%). The higher share of RENE supply by the developed countries emphasizes the significance of this work. Since clean energy could be used as a substitute for conventional energy sources, it is essential to identify the important elements of REN mostly in the developed countries, which have the higher share of RENE supply, directing to plan climate change policies, achieve ecological quality, and eventually attain the SDGs. In light of the aforementioned arguments, the developed economies are an important case for scrutinizing.

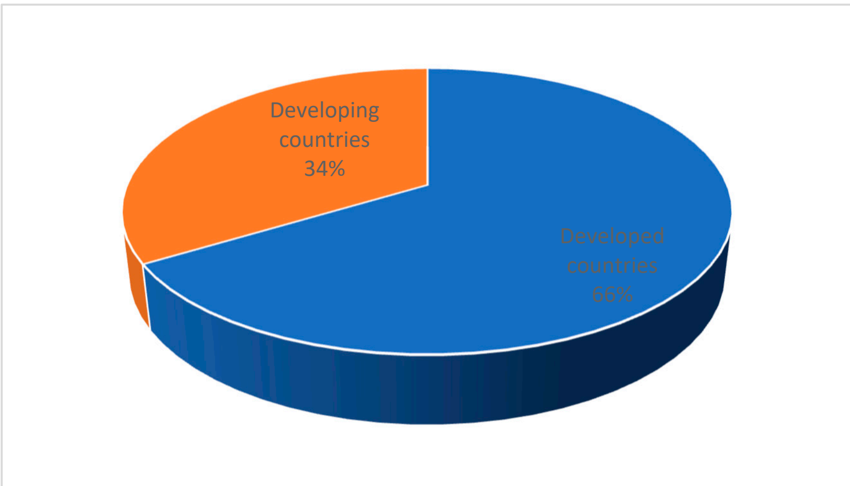



**Figure 2.** Total RENE supply by developing and developed countries (2021); Authors' calculations (Source: https://www.iea.org/data-and-statistics/, accessed on 1 June 2024).

It is important to conduct this study for several reasons. First, policymakers and governments can increase the supply and demand of RENE by identifying REN factors in developed countries, thus reducing fossil fuel usage and achieving SDG 7 and SDG 13.

Second, by highlighting the role of EUI, EPS, and GEPU policymakers could plan and improve more efficient plans in developed economies for encouraging REN, reducing the adverse effect of GEPU, adopting stricter ecological policies, and eventually attaining SDGs in the future.

Several contributions are made by the present study. First, in contrast to previous recent studies (e.g., [8,9,12]), which examined REN in OECD and BRICS countries, this study probed the factors contributing to REN in developed countries comprising more control factors. This study is particularly noteworthy for its consideration of EUI effects on REN. Despite the majority of recent studies investigating the EUI's impact on oil volatility forecasting [21] and stock market returns [22], no study has examined the EUI's impact on REN. The current research will contribute to the literature by using a novel country-based EUI, as suggested by [23]. The index may aid policymakers in comprehending the intricate and interconnected relationships between different elements in energy markets, as it aggregates energy-related and economic uncertainty across a wide range of words. Unlike uncertainty indicators, the EUI is particularly built to capture information on uncertainties linked with energy markets like energy price shocks and war risk. Furthermore, we employ a novel country-based EPS index, which is widely used for policy evaluation focusing on climate change and air pollution lessening plans. Second, despite prior works (e.g., [9,24]) that tested the effects of EPS and GEPU on REN in high- and middle-income and OECD economies, this work contributes by probing the moderator or catalyst role of EPS and GEPU on the EUI–REN association in 16 developed nations. Third, this study estimates models and finds robust results by using advanced panel data estimation techniques based on fixed effects and quantiles. Notably, the quantile panel data technique offers a more comprehensive explanation of the data since it allows us to examine a covariate's impact on y's entire distribution as opposed to simply its conditional mean.

Overall, the purpose of this research is to identify factors contributing to REN in developed countries. Particularly, the current study aims to analyze the role of the EUI in promoting REN (or diminishing it). In addition, we seek to discover whether either EPS or GEPU attenuates or exacerbates the impact of the EUI on REN. The current research can be reviewed as follows: (i) What are the significant factors of REN, and which factors have a positive or negative impact on REN? (ii) How does the EUI influence REN? (iii) Is the EUI–REN nexus moderated or exacerbated by EPS and GEPU?

This research yields some noteworthy highlights. First, the results uncover that the EUI positively affects REN, denoting that rising uncertainties related to the energy market stimulate developed countries to increase their REN. Second, the results unearth that EPS positively affects REN, implying that stricter ecological strategies encourage developed countries to increase REN. This is while GEPU has a detrimental effect and leads to diminishing REN. Third, the interaction results underscore that EPS has a catalyst role in triggering REN by increasing the EUI ($EUI \times EPS > 0$), although GEPU has a moderator role ($EUI \times GEPU < 0$). This implies that stricter ecological plans could be an important channel to upsurge REN when the EUI is high. In contrast, GEPU moderates the increase in REN while the EUI is high. More specifically, the findings underscore that the effect of the EUI on REN is more positive in high EPS countries and that the positive effect of the EUI is more moderate when GEPU is high. Our results recommend that policymakers should focus on scheming effective clean ecological policy instruments and reducing uncertainties related to economic policy to help trigger the REN by increasing EUI and eventually help achieve SDGs in the future. Fourth, the positive and negative determinants of REN provide insight for policymakers to enhance REN, which ultimately helps decrease the potential negative consequences of climate change and attain a clean environment.

The study's remaining is organized as follows. In Section 2, the literature review is explained. The data and technique are explained in Section 3. The results are discussed and the robustness check is shown in Sections 4 and 5. Section 6 is the summary.

## 2. Uncertainties and Renewable Energy: A Literature Review

Numerous studies explored the effects of uncertainties on RENE. In the literature, prior works used various measurements for measuring uncertainties like GEPU, geopolitical risk (GPR), and climate policy uncertainty (CPU). For example, Refs. [12,20,25] found that GEPU decreases RENE. From the demand side, GEPU increases adversely affect the income levels of consumers, thereby delaying the transition to a clean economy in the long run [17]. From the supply side, the GEPU reduces RENE supply by increasing private investment costs [18]. Ref. [26] revealed a negative long-run nexus between EPU and REN, indicating that higher levels of the country's vulnerability reduce its REN. Ref. [27] showed a negative effect of EPU on REN in G7 countries. Ref. [28] also showed that EPU has a significant negative impact on REN in most subperiods.

Furthermore, Ref. [29] documented that GPR is a significant positive driver in developing RENE in the U.S. and GPR encourages economies to rely on RENE sources to decrease fossil fuel inflows' risk. Ref. [17] underscored that GPR positively impacted REN in developing countries between 1996 and 2015 and that its effect is more prominent in the long run. Ref. [30] underscored that GPR shocks positively affect the growth of REN over time. Ref. [31] in a global study uncovered that GPR has a significantly considerable impact on green investments both in the short and in the long run. Ref. [12] discovered that increased GPR diminishes REN and undermines climate change mitigation efforts.

Moreover, some works indicated that the global CPU plays an important role in encouraging both the demand and the supply of RENE. According to works by Refs. [32,33], when CPUs rise, firms invest more in clean energy schemes (supply side) and promote the clean energy sector as a consequence of climate change. Furthermore, Ref. [34] demonstrated that the CPU promotes RENs (demand side) for a long time. Ref. [35] revealed that the CPU has a greater ability to forecast RENE volatility than other uncertainty indices, including the EPU and GPR variables. In a study by Ref. [28], the causal relationship between REN and CPU is both positive and negative. When the Administration is supportive of climate change alleviation, the correlation between REN and CPU is positive, but when it is not, the correlation is negative. Ref. [36] also showed that when extreme climate events or major climate policy changes are faced, the causal nexus between CPU and RENE will increase significantly. Ref. [37], using the novel Fourier augmented autoregressive distributed lag model, found that CPU diminishes REN across the long and short run. Ref. [38] highlighted that CPU has a significant negative effect on the long-term clean energy market's volatility. Ref. [39] found that CPU favorably affects REN in the U.S. in the short and long term between 2005–2021.

In contrast to conventional uncertainty indicators, Ref. [23] recently created the energy-related uncertainty index (EUI), which is based on energy and economic uncertainty components specifically designed to capture information on uncertainties related to energy markets (e.g., war risk, energy price shocks). Ref. [23] created EUIs for 28 advanced and developing nations by examining words associated with energy and uncertainty in The Economist Intelligence Unit's (EIU) monthly national reports. When it comes to the other uncertainty indicators, the EUI is unique and has specific benefits. First, the EUI is built by looking for the relevant terms using the text search method. Second, the EUI's construction is predicated on the EIU's monthly nation reports, which aid in distinguishing the EUI's regional variations. Third, compared to when it comprised information on a single nation or category, the EUI can more accurately reflect significant information like oil crises, military crises, etc.

Given the specific advantages, some studies using the EUI attempted to delve into forecasting oil price volatility and stock market return. For example, Ref. [21] discovered evidence of information spillovers from the EUI to the oil market in a recent study. According to their findings, the EUI can foresee oil price volatility, and figuring out this connection enables response to international political and economic issues as well as the promotion of ecological protection and sustainable growth (e.g., [40–42]). Moreover, Ref. [22] uncovered that the EUI has a significant role in predicting stock market returns in China and that the

EUI outperforms economic factors. Using the ARCH model, Ref. [43] concluded that the global EUI is highly volatile, so a shift from fossil fuels to RENE and a clean economy is essential for achieving SDGs. As RENE is less susceptible to exogenous shocks and price fluctuations, it can reduce energy dependency and uncertainty in energy markets.

It has been evident from several studies that the EUI is a better uncertainty indicator to use and has relatively greater advantages than other uncertainty indicators. Nevertheless, there has not been sufficient literature to use the EUI and examine the EUI–REN nexus. Moreover, no prior research has examined the EUI–REN nexus in light of EPS and GEPU's role. Therefore, the current research efforts are designed to illuminate these research gaps in the framework of developed economies between 2000 and 2020.

## 3. Data and Methodology

### *3.1. Data*

The following research initially focuses on developed economies between 2000 and 2022 to examine the factors of REN. However, 16 developed countries between 2000 and 2020 make up the final sample because of data shortages and mismatches across different data sources. The sample economies are shown in Table A1 in Appendix A.

Based on the results of earlier studies (e.g., [9,34]), the traditional factors were selected. Data for the control variables were gathered from the World Bank for the current study. Furthermore, data were obtained from the websites of the OECD and policy uncertainty, respectively, for the GEPU and the EPS. Thirteen policy tools targeted at mitigating air pollution and climate change make up the EPS index. In particular, this work collects data from the policy uncertainty website, which was built by Ref. [38] for the EUI. Table 1 provides clarifications on the factor descriptions.

**Table 1.** Variables explanations.

| Variables | Codes | Measurements | Links |
|---|---|---|---|
| Renewable energy consumption | REN | Renewable energy consumption (% of total final energy consumption) | World Bank |
| Financial market development | STV | Stocks traded, total value (% of GDP) | World Bank |
| Economic openness | FDI | Foreign direct investment, net inflows (% of GDP) | World Bank |
| Remittances | REMIT | Personal remittances received (% of GDP) | World Bank |
| Carbon dioxide emissions | $CO_2$ | $CO_2$ emissions (kt) | World Bank |
| Natural resources rents | TNRR | Total natural resources rents (% of GDP) | World Bank |
| Economic activity | GDPC | GDP per capita (current US$) | World Bank |
| Energy-related uncertainty | EUI | Energy-related uncertainty index | www.policyuncertainty.com, 20 May 2024 |
| Global economic policy uncertainty | GEPU | Global economic policy uncertainty index | www.policyuncertainty.com, 20 May 2024 |
| Environmental policy stringency | EPS | Environmental policy stringency index | https://stats.oecd.org/, 20 May 2024 |

Note: Table 1 presents the codes, measurements, and links of variables.

Figure 3 illustrates the expected signs for each determinant. Based on the findings of prior works, we expect that STV, FDI, REMIT, EPS, and the EUI positively impact REN whereas TNRR has a negative effect. Furthermore, Figure 3 shows that GDPC, $CO_2$, and GEPU impact REN either negatively or positively.

Furthermore, the Scatterplot Matrix was plotted in Figure 4 to show the distribution of data between the examined variables. Meanwhile, Figure 5 plots REN, EUI, EPS, and GEPU for the entire economies during 2000 and 2020. As illustrated in Panel A, there is a positive movement between REN and the EUI, denoting that a rise in the EUI leads to an increase in REN. In addition, it shows that EPS and GEPU positively move together and that developed countries improve their environmental policies by increasing GEUP, particularly after 2004.

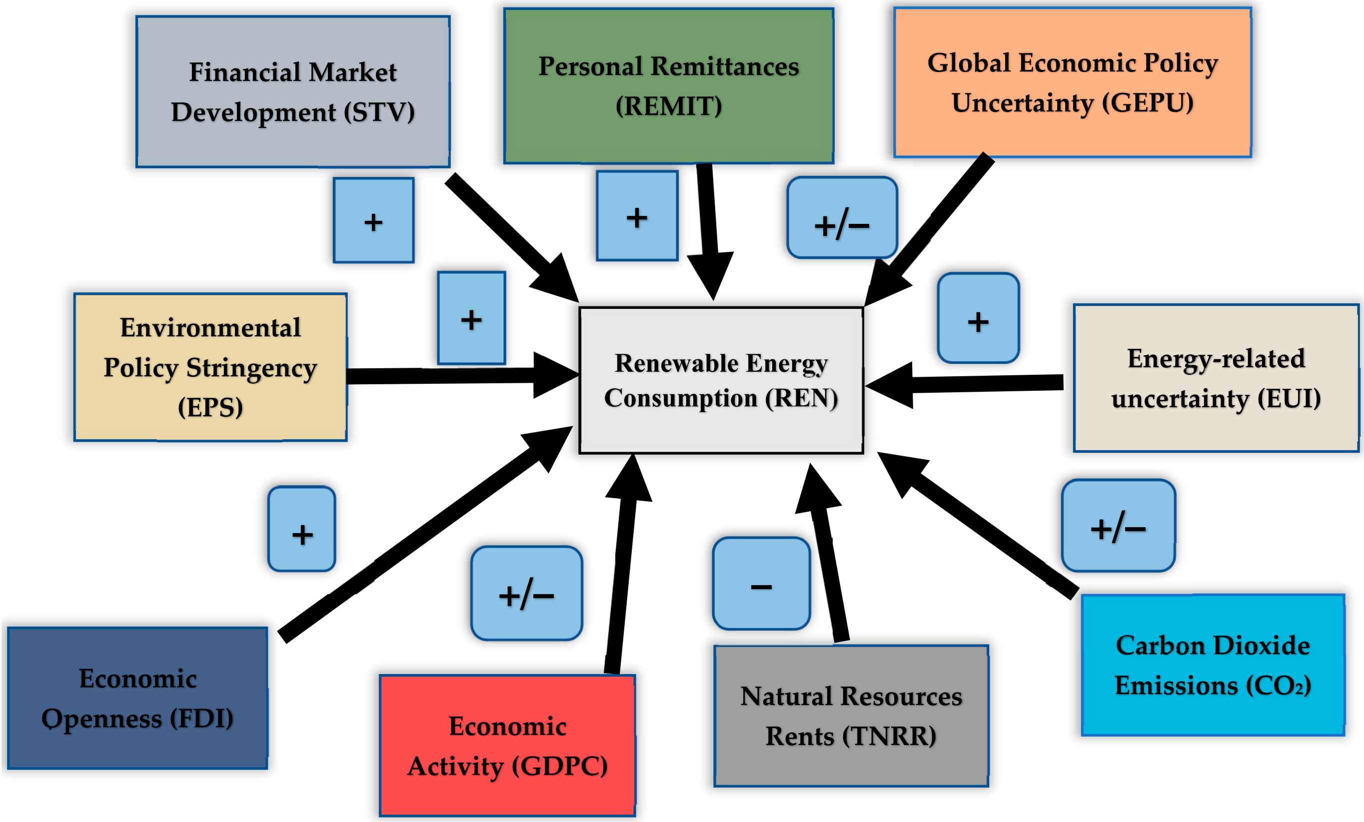



**Figure 3.** Variables' Expected signs.

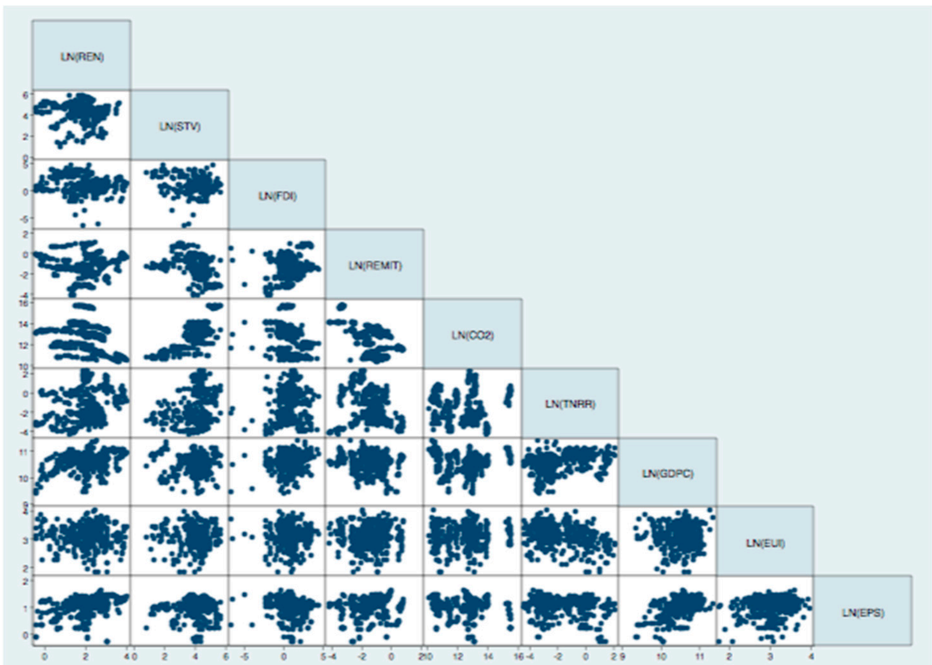



**Figure 4.** Scatterplot matrix.

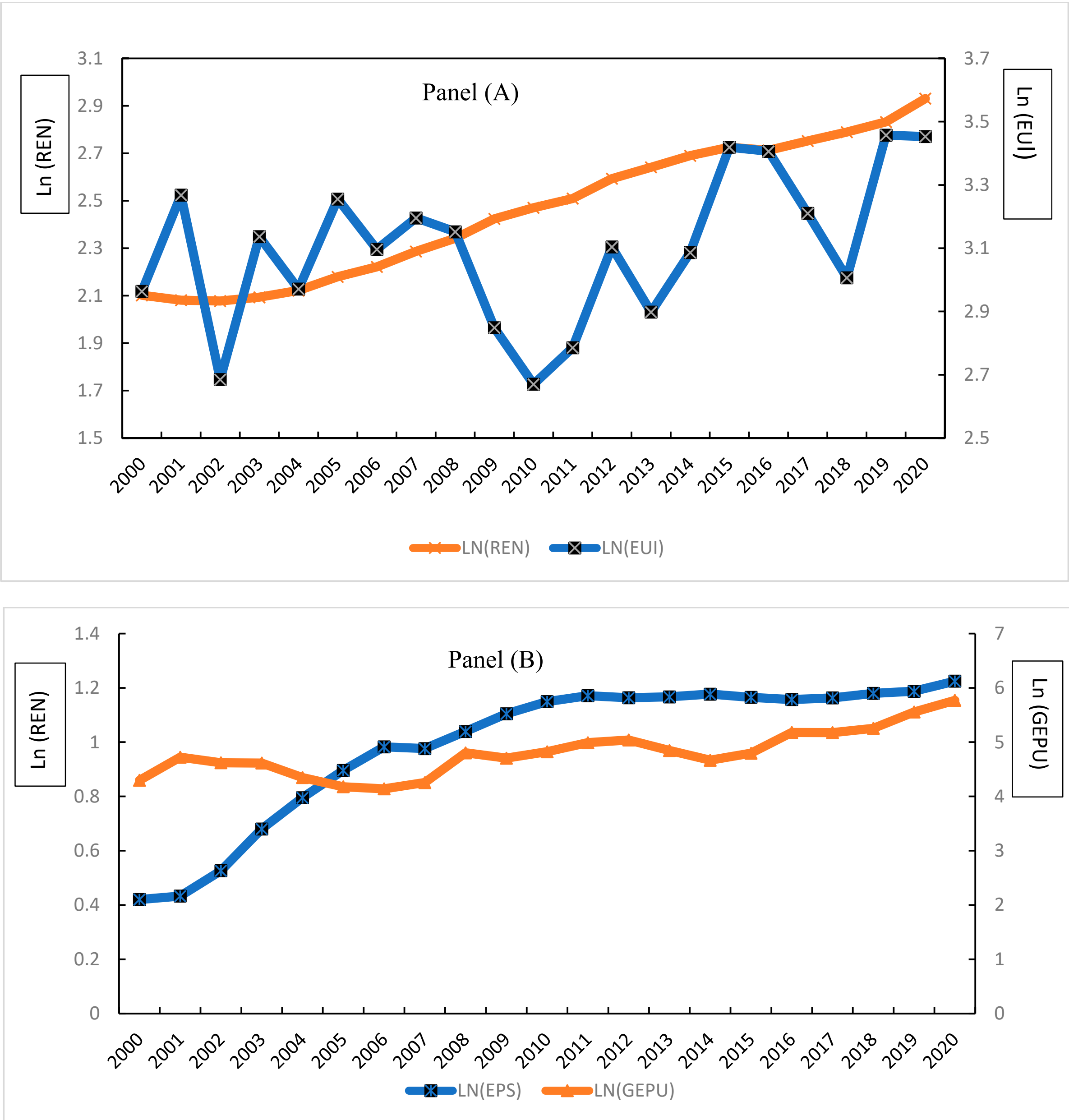



**Figure 5.** Panel (**A**,**B**) Time series plot of Ln(REN), Ln(EUI), Ln(EPS), and Ln(GEPU) for the years 2000–2020.

Multicollinearity is not present among the factors, as Table 2 illustrates, and the equation can be estimated by integrating all feasible determinants.

**Table 2.** Pearson correlation matrix.

| | STV | FDI | REMIT | $CO_2$ | TNRR | GDPC | EUI | EPS | GEPU | VIF |
|---|---|---|---|---|---|---|---|---|---|---|
| STV | 1.000 | | | | | | | | | 1.04 |
| FDI | 0.066 | 1.000 | | | | | | | | 1.01 |
| REMIT | −0.248 * | 0.051 | 1.000 | | | | | | | 1.08 |
| $CO_2$ | −0.041 | −0.135 * | −0.273 * | 1.000 | | | | | | 1.09 |
| TNRR | 0.229 * | −0.038 | −0.248 * | 0.022 | 1.000 | | | | | 1.14 |
| GDPC | −0.192 * | 0.134 * | −0.078 | 0.137 * | 0.234 * | 1.000 | | | | 1.03 |
| EUI | −0.113 * | 0.002 | 0.013 | 0.048 | −0.317 * | 0.036 | 1.000 | | | 1.11 |
| EPS | −0.294 * | −0.133 * | 0.081 | −0.212 * | −0.136 * | 0.245 * | 0.14 6* | 1.000 | | 1.05 |
| GEPU | −0.188 * | −0.162 * | 0.052 | −0.121 * | −0.057 | 0.264 * | 0.292 * | 0.261 * | 1.000 | 1.12 |

Note: Table 2 presents the Pearson correlation matrix and Variance Inflation Factor (VIF). * is statistically significant at 1%.

### 3.2. Model and Methodology

In examining the research questions and identifying the elements of REN, this work follows the prior works (e.g., [9,12]) and applies the linear model. Thus, we use the baseline Equation (1) to scrutinize the effect of the EUI for each investigated country (i) on REN during the period of the work (t) by including the controlling factors. In estimating Equation (1), we use the time and country dummies, but, for parsimony, the coefficients do not present it.

$$\mathbf{REN_{it}} = \alpha_0 + \alpha_1\mathbf{STV_{it}} + \alpha_2\mathbf{FDI_{it}} + \alpha_3\mathbf{REMIT_{it}} + \alpha_4\mathbf{CO_{2it}} + \alpha_5\mathbf{TNRR_{it}} + \alpha_6\mathbf{GDPC_{it}} + \alpha_7\mathbf{EUI_{it}} + \alpha_8\mathbf{GEPU_{t}} + \alpha_9\mathbf{EPS_{it}} + \varepsilon_{it} \quad (1)$$

A winsorization of all variables at the top and bottom 1% was carried out before estimating Equation (1). Additionally, the natural logarithm was used to normalize each factor. Next, by clustering standard errors at the national level, this work assessed the reliability of findings using the fixed effects (FE) panel data approach. In the FE, all time-invariant disparities between individuals are controlled so that omitted time-invariant characteristics cannot bias the estimate of coefficients. Furthermore, in addition to improving estimation efficiency [44], using the panel data method helps manage multicollinearity and heterogeneity issues. As part of the present study, a Hausman test result was used to choose between fixed and random effects, and a cross-sectional dependence (CD) post-estimation test was also applied to test robustness [45] to ensure that findings are robust.

Aside from the FE method, the study follows prior research (e.g., [9]) by estimating Equation (1) using quantile regression at multiple points in the distribution of the LnREN. This approach allows for estimating the model by describing the relationship at distinct points in the conditional distribution of the LnREN. A quantile is the intersection of a continuous, smaller interval with equal probabilities in a probability distribution. Using quantile regression, we can understand the associations between factors at different quantile levels rather than the mean. This method is useful for investigating outcomes that do not follow a normal distribution and are not linear.

Quantile regression estimator for quantile q, therefore, minimizes the objective function for a linear function ($y = \beta X' + \varepsilon$) by;

$$\mathbf{Q}\left(\beta_{\mathbf{q}}\right) = \sum_{i:y_i \geq X_i'\beta}^{N} \mathbf{q}|\mathbf{y_i} - \mathbf{X_i'}\beta_{\mathbf{q}}| + \sum_{i:y_i < X_i'\beta}^{N} (\mathbf{1} - \mathbf{q})|\mathbf{y_i} - \mathbf{X_i'}\beta_{\mathbf{q}}| \quad (2)$$

## 4. Results

### 4.1. Univariate Results

A descriptive summary of the 16 developed countries is presented in Table 3. It shows that $LnCO_2$ has the highest mean (12.515), ranging from 10.217 to 15.569. The second highest mean (10.536) is for LnGDPC, which ranges from 9.355 to 11.362. Meanwhile, LnREMIT (−1.408) and LnTNRR (−1.566) have the lowest means. Additionally, the descriptive statistics reveal that LnFDI, with a standard deviation of 1.474, and LnTNRR, with a standard deviation of 1.659, have the highest variation of all other variables but that LnEPS and LnGDPC, with their respective standard deviations of 0.350 and 0.368, exhibit the lowest variation.

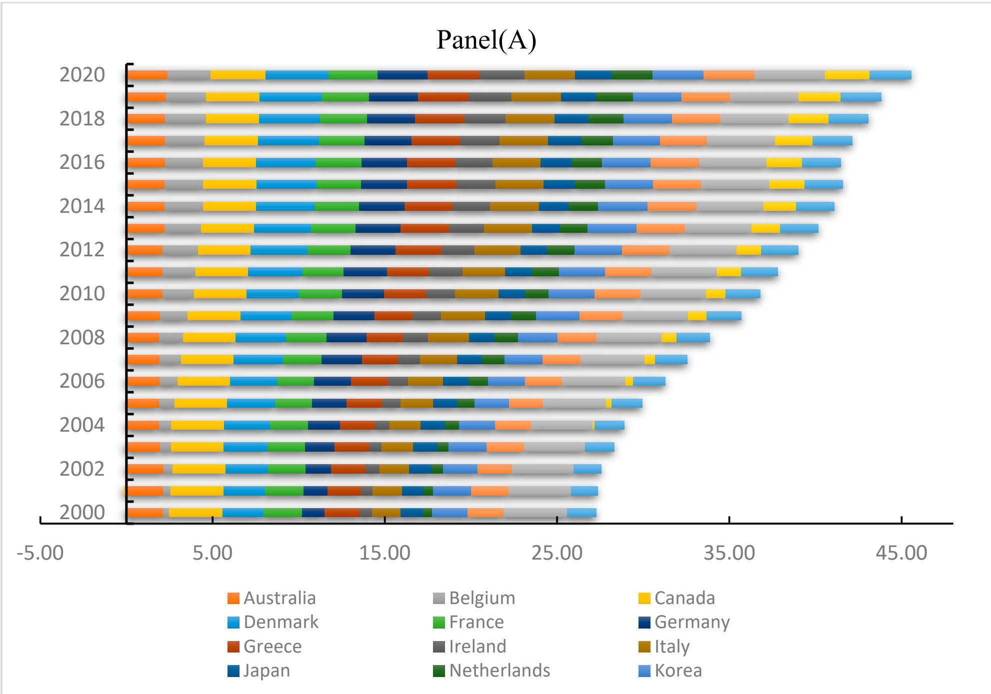
Table A1 displays descriptive statistics for the variables of the sample of developed countries. Korea has the lowest mean LnREN (0.379), whereas Sweden has the highest mean (3.796). Furthermore, with a mean of 5.366 for LnSTV and a mean of 15.479 for $LnCO_2$, the United States leads the other sample countries in both of these categories. Likewise, Australia has the lowest LnEUI on average at 2.682, and France has its highest LnEUI on average at 3.329. Moreover, the United States has the lowest LnEPS on average at 0.671, and Japan has the highest on average at 1.196.

LnREN and LnEUI are specifically compared in Figure 6 for developed economies between 2000 and 2020. According to Figure 6 panel A and Figure 6 panel B, Sweden has the highest LnREN and Korea has the lowest LnREN. Australia and France also have the lowest and highest LnEUI, respectively, as shown in Figure 6B.

**Table 3.** Descriptive summary (2000–2020).

| Variables | No. of Obs. | Mean | Median | St.dev | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Ln(REN) | 336 | 2.114 | 2.182 | 0.931 | −0.371 | 4.067 |
| Ln(STV) | 336 | 4.010 | 4.203 | 0.980 | 0.893 | 5.768 |
| Ln(FDI) | 336 | 0.839 | 0.837 | 1.474 | −6.524 | 4.460 |
| Ln(REMIT) | 336 | −1.408 | −1.425 | 1.083 | −4.163 | 0.900 |
| Ln($CO_2$) | 336 | 12.515 | 12.758 | 1.296 | 10.217 | 15.569 |
| Ln(TNRR) | 336 | −1.566 | −1.976 | 1.659 | −4.343 | 2.166 |
| Ln(GDPC) | 336 | 10.536 | 10.612 | 0.368 | 9.355 | 11.362 |
| Ln(EUI) | 336 | 3.050 | 3.072 | 0.400 | 1.782 | 3.997 |
| Ln(EPS) | 336 | 0.965 | 1.051 | 0.350 | −0.325 | 1.587 |
| Ln(GEPU) | 336 | 4.799 | 4.797 | 0.425 | 4.140 | 5.771 |

Note: Table 3 presents the descriptive statistics of variables.



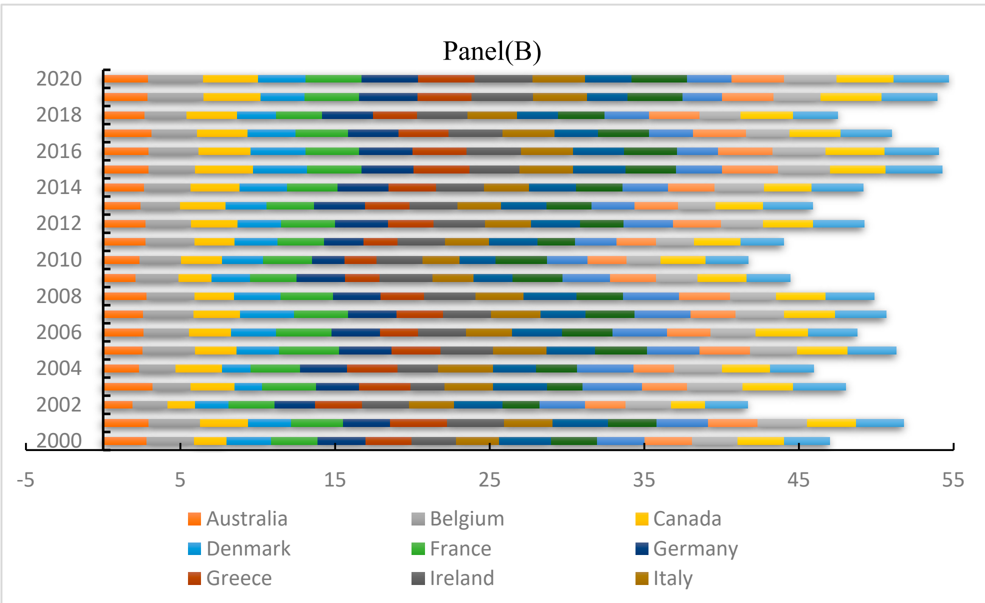




**Figure 6.** Panel (**A**): Average of Ln(REN) among the selected developed countries. Panel (**B**): Average of Ln(EUI) among the selected developed countries.

### *4.2. Empirical Results*

A CD test, a unit root test, and a direction of relations test were performed before estimating models in this research. The CD test was conducted according to Ref. [45] to accomplish this. The CD-tests indicate that any variation in one country will undoubtedly impact the other countries in the sample, as shown in Table 4.

**Table 4.** Cross-sectional dependence.

| | REN | STV | FDI | REMIT | $CO_2$ | TNRR | GDPC | EUI | EPS |
|---|---|---|---|---|---|---|---|---|---|
| Pesaran's test | 11.588 ** | 20.537 * | 34.216 ** | 22.447 * | 18.634 * | 22.548 * | 14.822 ** | 25.413 ** | 18.488 * |

Note: * and ** denote statistical significance at the 1% and 5% levels, respectively.

Furthermore, as shown in Table 5, all factors are stationary, and the panels do not contain unit roots using the Ref. [46] (Panel A) and Ref. [47] (Panel B) panel unit root tests.

**Table 5.** Panel unit root test.

| Variables | Panel (A): LLC (2002) | | Panel (B): IPS (2003) | |
|---|---|---|---|---|
| | With Trend | With Cross-Sectional Dependence | With Trend | With Cross-Sectional Dependence |
| LnREN | −5.436 * | −4.354 * | −4.314 * | −4.283 * |
| LnSTV | −3.551 * | −5.285 * | −5.621 * | −5.556 * |
| LnFDI | −6.546 * | −3.669 * | −4.232 * | −4.332 * |
| LnREMIT | −4.258 * | −5.261 * | −3.182 * | −3.106 * |
| $LnCO_2$ | −2.218 ** | −2.115 ** | −2.926 * | −4.258 * |
| LnTNRR | −3.689 * | −2.226 ** | −2.218 ** | −3.324 * |
| LnGDPG | −2.026 ** | −6.753 * | −4.565 * | −2.214 ** |
| LnEUI | −3.448 * | −2.288 ** | −6.637 * | −5.652 * |
| LnEPS | −5.386 * | −3.395 * | −5.765 * | −6.448 * |
| LnGEPU | −2.135 ** | −4.522 * | −4.391 * | −4.523 * |

Note: * and ** denote statistical significance at the 1% and 5% levels, respectively.

Moreover, the Granger causality test is used to examine how the relationship between the variables is directed. Based on the results of Table 6, it can be concluded that the model does not suffer from endogeneity problems and that there is no reverse causality between the independent and dependent factors. For developed economies, this means historical information about explanatory variables can be used to predict future changes to REN.

**Table 6.** Granger causality test.

| | $H_0$ | | F-Statistics | [Probability] | Decision |
|---|---|---|---|---|---|
| LnSTV | → | LnREN | 6.363 * | [0.000] | ✓ |
| LnFDI | → | LnREN | 4.425 * | [0.000] | ✓ |
| LnREMIT | → | LnREN | 2.224 ** | [0.023] | ✓ |
| $LnCO_2$ | → | LnREN | 5.348 * | [0.000] | ✓ |
| LnTNRR | → | LnREN | 4.856 * | [0.001] | ✓ |
| LnGDPG | → | LnREN | 2.151 ** | [0.019] | ✓ |
| LnEUI | → | LnREN | 6.653 * | [0.000] | ✓ |
| LnEPS | → | LnREN | 5.846 * | [0.000] | ✓ |
| LnGEPU | → | LnREN | 2.252 ** | [0.026] | ✓ |

Note: * and ** imply 1% and 5% statistical significance levels, correspondingly.

#### 4.2.1. Multivariate Results

The estimation results of Equation (1) are presented in Table 7. The findings highlight that LnSTV positively affects LnREN, with significant coefficient in Q.25 (α = 0.381), Q.75 (α = 0.205), and Q.95 (α = 0.264) at a 1% and 10% significance level. Likewise, Table 7 reveals that LnFDI, LnREMIT, and LnEPS positively affect LnREN at the various quantiles in the sample developed economies. Nevertheless, the results indicate that $LnCO_2$, LnTNRR, and LnGDPC negatively impact LnREN at the various quantiles. Furthermore, as expected, LnEUI positively impacts LnREN with significant coefficient at the quantiles Q.25 (α = 0.042), Q.50 (α = 0.378), Q.75 (α = 0.237), and Q.95 (α = 0.108) in the sample developed nations. According to the FE method, the results reveal that a 1% rise in EUI upsurges REN by 0.03%. Moreover, the results underscore that LnGEPU negatively impacts LnREN with significant coefficient at the quantiles Q.25 (α = −0.515), Q.50 (α = −0.419), Q.75 (α = −0.486), and Q.95 (α = −0.506) in the sample developed nations. The results show that REN is lowered by 0.27% for every 1% rise in GEPU based on the FE method.

**Table 7.** The impact of the EUI on REN (2000–2020).

| Independent Variables | Quantile Estimated Coefficients | | | | FE |
|---|---|---|---|---|---|
| | Q.25 | Q.50 | Q.75 | Q.95 | Coefficients |
| LnSTV | 0.381 * | 0.064 | 0.205 *** | 0.264 * | 0.087 ** |
| | (4.70) | (0.41) | (1.67) | (3.35) | (2.03) |
| LnFDI | 0.052 | 0.037 ** | 0.007 | 0.018 * | 0.036 ** |
| | (0.80) | (2.06) | (0.16) | (4.39) | (2.15) |
| LnREMIT | 0.164 | 0.045 | 0.019 ** | 0.077 * | 0.009 *** |
| | (1.41) | (0.43) | (2.13) | (4.18) | (1.73) |
| $LnCO_2$ | −0.171 ** | −0.061 | −0.213 ** | −0.317 * | −1.049 * |
| | (−2.07) | (−0.41) | (−2.18) | (−4.22) | (−5.56) |
| LnTNRR | −0.163 * | −0.216 * | −0.212 * | −0.237 | −0.074 |
| | (−3.36) | (−3.74) | (−5.91) | (−1.22) | (−1.07) |
| LnGDPC | −0.124 | −0.393 ** | −0.533 * | −0.176 | −0.941 * |
| | (−0.774) | (−2.04) | (−3.09) | (−0.62) | (−4.78) |
| LnEUI | 0.042 * | 0.378 ** | 0.237 ** | 0.108 * | 0.035 ** |
| | (4.24) | (2.05) | (2.12) | (3.04) | (2.14) |
| LnGEPU | −0.515 * | −0.419 * | −0.486 * | −0.506 ** | −0.271 ** |
| | (−2.65) | (−3.01) | (−3.79) | (−2.02) | (−2.14) |
| LnEPS | 0.441 ** | 0.657 ** | 0.827 * | 0.251 * | 0.109 *** |
| | (2.03) | (2.40) | (3.73) | (5.63) | (1.73) |
| CD-test (*p*-value) | --- | --- | --- | --- | (0.339) |
| Time dummy | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country dummy | ✓ | ✓ | ✓ | ✓ | ✓ |

Note: Table 7 specifically presents the impact of the EUI on REN by considering the control variables. Table 1 reveals the variables' explanations. The 25th, 50th, 75th, and 95th percentiles of the LnREN are reported. *, **, and *** denote the significance level at 1%, 5%, and 10%, respectively.

The positive and significant effect of LnSTV, LnFDI, and LnREMIT underscore the important role of internal and external financing in promoting REN in developed countries. Following prior research (e.g., [8,48]), investors and companies developing the financial market are more able to borrow loans at lower funding costs. This encourages them to shift from using conventional energies to green energies and to stimulate them to invest in RENE projects which ultimately results in increasing REN and helping achieve ecological quality [49]. In addition, the development of the capital market could ease the accessibility of various financial facilities, leading to motivating firms to upsurge R&D activities in renewable energy, advancing ecological technologies, and developing RENE plans.

Furthermore, following prior works (e.g., [8,9,50]), the positive and significant effect of LnFDI uncovered that increasing economic openness leads to inflowing massive amounts of capital, which helps to facilitate the accessibility of external finances for investors for RENE plans, to transmit better cleaner know-how, and eventually to increase the share of RENE in providing worldwide energy. Similarly, consistent with the findings of prior studies (e.g., [15]), rising personal remittances (LnREMIT) are a significant positive driver in financing RENE schemes, providing knowledge and skills related to renewable energy, and promoting REN.

Furthermore, the study by Ref. [12], which found that a 1% increase in $CO_2$ produced a fall in REN by 0.35% in OECD nations, is corroborated by the negative and substantial effect of $LnCO_2$, in contrast to Ref. [16]. Moreover, following past research (e.g., [19,51]), the negative and significant effects of LnTNRR suggest that REN is lower in countries with higher TNRR, and in such environments, the transition of conventional energy to RENE has a low speed. In this line, Ref. [12] unearthed that a 1% rise in TNRR causes a decrease in REN by 0.03% in OECD economies.

Likewise, the adverse and significant impact of LnGDPC confirms some research (e.g., [8,10]) which found that economic development adversely impacts REN. However, the finding is in contradiction with prior studies (e.g., [12,52]). Additionally, the negative and significant effect of LnGEPU is consistent with prior research (e.g., [16,25]), indicating that an increasing economic policy uncertainty results in decreasing investors' and households' income levels causing less motivation to replace traditional fuels with RENEs and diminish REN.

In addition, the results reveal that LnEUI has a positive statistically significant effect on REN. This implies that rising uncertainties related to the energy market are an important driver to stimulate the consumption of RENE and vice versa. Consistently, Ref. [43] stressed that due to the high volatility of the global EUI, using RENEs could be vital for economies to attain ecological sustainability and diminish climate change threats. As RENE is less susceptible to exogenous shocks and price fluctuations, a higher supply and consumption of RENE could help decrease energy dependency and uncertainty in energy markets.

Moreover, the favorable and significant effect of LnEPS supports earlier studies (e.g., [9,20]) that uncovered that the adoption of clean ecological techniques led to an increase in REN. The primary objective of EPS is to achieve a clean environment without compromising the goal of economic expansion. Strict ecological policies are essential to promoting ecological sustainability [53,54]. Some works indicated that EPS is effective in developing RENE capacity development and that the productivity of ecological plans is associated with the type of RENE sources (e.g., [55,56]). Nevertheless, Ref. [57] indicated a mixed effect of EPS on REN in different quantiles.

#### 4.2.2. Further Analysis: Do the GEPU and EPS Play a Moderator or Catalyst Role?

Specifically, Table 8 scrutinizes the interaction effects of (EUI $\times$ EPS) and (EUI $\times$ GEPU) on REN in developed economies by including the control factors and classifying economies based on the level of EPS and GEPU. As presented in Table 8, (LnEUI $\times$ LnGEPU) is negative and statistically significant in developed economies. This implies that the positive effect of the EUI on REN is moderated by an increase in GEPU. Additionally, the findings indicate that the EUI has relatively less positive effects on REN when GEPU is high and vice versa.

**Table 8.** The role of GEPU and EPS between EUI and REN (2000–2020).

| Independent Variables | Global Economic Policy Uncertainty (GEPU) | | | Environmental Policy Stringency (EPS) | | | Sample Countries |
|---|---|---|---|---|---|---|---|
| | Low GEPU | High GEPU | Sample Countries | Low EPS | High EPS | Sample Countries | |
| LnEUI | 0.455 * | 0.638 ** | 0.951 | 0.254 ** | 0.286 * | 0.342 | 0.126 ** |
| | (3.64) | (2.02) | (1.17) | (2.11) | (4.66) | (1.24) | (2.07) |
| LnGEPU | −0.143 | −0.165 | −0.175 ** | −0.086 | −0.194 ** | −0.515 * | −0.316 |
| | (−1.16) | (−1.44) | (−2.08) | (−0.64) | (−2.05) | (−5.56) | (−0.58) |
| LnEPS | 0.363 | 0.462 ** | 0.628 * | 0.197 | 0.213 | 0.441 ** | 0.144 |
| | (1.12) | (2.18) | (4.49) | (1.44) | (0.69) | (2.03) | (1.22) |
| LnEUI × LnGEPU | −0.093 ** | −0.126 * | −0.213 *** | --- | --- | --- | −0.088 *** |
| | (−2.22) | (−5.17) | (−1.89) | --- | --- | --- | (−1.71) |
| LnEUI × LnEPS | --- | --- | --- | 0.014 ** | 0.032 * | 0.009 *** | 0.023 ** |
| | --- | --- | --- | (2.01) | (3.18) | (1.73) | (2.16) |
| Control variables | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time dummy | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country dummy | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Adj $R^2$ | 0.26 | 0.32 | 0.41 | 0.23 | 0.29 | 0.36 | 0.43 |

Note: Table 8 reveals the interaction effects of GEPU and EUI and also EPS and EUI on REN using the fixed effects method. *, **, and *** present the significance level at 1%, 5%, and 10%, respectively.

The findings of the study also confirm that (LnEUI × LnEPS) is positive and statistically significant in developed economies, suggesting that the positive impact of the EUI on REN is intensified by stricter environmental policies. Further, the findings reveal that in countries with high EPS, the EUI has a relatively greater impact on REN than in countries with low EPS and vice versa. In general, the EUI promotes REN, but its positive impacts can either be moderated by increasing GEPU (moderator role) or intensified by increasing EPS (catalyst role) in developed countries. Therefore, in light of the increased uncertainty related to energy markets (EUI), policymakers should refocus their efforts on reducing uncertainty related to economic policy and on designing and implementing clean ecological strategies to stimulate REN.

## 5. Robustness Check

As part of the robustness tests, technological innovation (LnTINV) was added as a control variable to estimate baseline Equation (1) following Refs. [8,9]. To gauge the development of the financial market, we also used the "stock market turnover ratio" (LnSMT) as a new alternative measurement. We obtained the data from the World Bank database. Furthermore, we employ panel quantile and FE methods to confirm the accuracy and coherence of the findings. To find out if the estimated model depends on other models, the CD post-estimation test [45] is used. Moreover, by Refs. [9,12], we estimate Equation (1) by the use of the dynamic panel data technique (SYS-GMM) to assess the dependability of the results in the event that endogeneity concerns may arise. It is interesting to note that many tests, including the Sargan, Hansen, and serial correlation tests, are used by SYS-GMM to verify the correctness of the calculated equations.

The robustness test results in Table 9 corroborate the above findings presented in Tables 7 and 8. The findings stress the beneficial role of LnSMT, LnFDI, LnREMIT, LnEUI, and LnEPS in promoting REN. Meantime, the results show that LnTINV positively impacts REN. This finding supports the prior research (e.g., [8,9,13]) and indicates that ecological technology, by increasing energy efficiency and accelerating replacing fossil fuels with RENEs, has a significant role in reducing carbon emissions and attaining ecological quality [58]. However, Table 9 reveals that $LnCO_2$, LnTNRR, LnGDPC, and lnGEPU have an adverse effect and diminish REN. This indicates that increasing $CO_2$, TNRR, GDPC, and GEPU results in lessening REN in developed countries.

**Table 9.** Robustness test.

| **Independent Variables** | **Quantile Estimated Coefficients** | | | | **FE** | **GMM-SYS** |
|---|---|---|---|---|---|---|
| | **Q.25** | **Q.50** | **Q.75** | **Q.95** | **Coefficients** | **Coefficients** |
| Lag dependent variable | --- | --- | --- | --- | --- | 0.138 |
| | --- | --- | --- | --- | --- | (1.33) |
| LnSMT | 0.147 * | 0.093 | 0.219 ** | 0.185 *** | 0.066 ** | 0.244 *** |
| | (4.46) | (1.24) | (2.05) | (1.73) | (2.13) | (1.69) |
| LnFDI | 0.013 | 0.074 ** | 0.138 * | 0.105 | 0.042 *** | 0.028 * |
| | (0.55) | (2.02) | (4.56) | (0.94) | (1.71) | (3.63) |
| LnREMIT | 0.262 | 0.087 | 0.066 * | 0.138 *** | 0.075 | 0.163 ** |
| | (0.88) | (1.11) | (5.58) | (1.68) | (1.37) | (2.03) |
| Ln$CO_2$ | −0.242 * | −0.009 | −0.356 *** | −0.118 ** | −0.007 | −0.115 |
| | (−5.33) | (−0.46) | (−1.69) | (−2.16) | (−1.22) | (−0.83) |
| LnTNRR | −0.063 | −0.124 ** | −0.252 ** | −0.153 | −0.337 * | −0.078 |
| | (−1.03) | (−2.05) | (−2.22) | (−1.41) | (−4.67) | (−1.43) |
| LnGDPC | −0.233 * | −0.141 | −0.473 ** | −0.126 | −0.351 * | −0.094 |
| | (−5.12) | (−1.57) | (−2.06) | (−0.77) | (−6.33) | (−1.26) |
| LnEUI | 0.058 * | 0.342* | 0.151 *** | 0.276 ** | 0.128 * | 0.304 ** |
| | (3.66) | (4.72) | (1.73) | (2.08) | (5.31) | (2.24) |
| LnGEPU | −0.362 * | −0.453 ** | −0.278 * | −0.541 *** | −0.342 * | −0.248 ** |
| | (−4.26) | (−2.11) | (−5.43) | (−1.73) | (−4.55) | (−2.13) |
| LnEPS | 0.362 * | 0.441 | 0.426 * | 0.251 ** | 0.133 | 0.425 ** |
| | (4.43) | (1.06) | (4.77) | (2.13) | (1.16) | (2.19) |
| LnTINV | 0.238 * | 0.344 ** | 0.179 ** | 0.212 | 0.286 | 0.166 *** |
| | (4.22) | (2.06) | (2.13) | (1.17) | (0.88) | (1.69) |
| CD-test (*p*-value) | --- | --- | --- | --- | (0.428) | --- |
| $M_1$-test | --- | --- | --- | --- | --- | (0.026) |
| $M_2$-test | --- | --- | --- | --- | --- | (0.451) |
| Sargan-test | --- | --- | --- | --- | --- | (0.366) |
| Hansen-test | --- | --- | --- | --- | --- | (0.477) |
| FC dummy | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time dummy | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country dummy | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Note: Table 9 presents the robustness test results. T-values are presented for the quantile and fixed effect in the parentheses while Z-values reported for the SYS-GMM. *, **, and *** denote the significance level at 1%, 5%, and 10%, respectively.

## 6. Conclusions

Although many studies have focused on exploring the determinants of environmental sustainability, less attention has been paid by scholars to scrutinizing the drivers of RENE. Particularly, limited studies have attempted mainly to delve into the impact of the EUI on REN in general and advanced economies in particular. Furthermore, there is a lack of research in the literature on the potential effects of EPS and GEPU changes on the EU–REN nexus. Thus, this research endeavors to fill this gap by testing particularly the EUI–REN relationship by considering the traditional control variables. We also aim to examine whether EPS and GEPU attenuate or intensify the effect of the EUI on REN.

The results underscore that the EUI significantly impacts REN, suggesting that higher uncertainties related to energy markets lead to promoting REN. Furthermore, the interaction (EUI × EPS) findings underline that EPS has a favorable role in increasing the positive effect of the EUI on REN in sample developed countries while (EUI × GEPU) has a detrimental impact. Remarkably, the findings underscore that the effect of the EUI on REN is more positive in high-EPS countries and that the positive impact of the EUI is more moderate when GEPU is high. This finding indicates that by soaring EUI, countries should establish stricter environmental policies (EPS) and decrease uncertainties related to economic policies to be able to promote REN and attain climate change-alleviating targets. Interestingly, as discussed in Ref. [9], the strengthening of EPS is not only a useful channel to promote REN, but it helps to some extent to control the adverse effect of GEPU on REN. Therefore, enhancing environmental policies could be a beneficial approach to stimulate REN particularly when energy and economic uncertainties are high.

The findings also reveal that the STV, FDI, REMIT, and EPS positively promote REN while $CO_2$, TNRR, GDPC, and GEPU have an unfavorable impact. The results also stress that developed countries, to attain energy and ecological sustainability targets (SDG 7, SDG 13) and mitigate climate change, should replace conventional energies by promoting REN, particularly by focusing on inflowing FDI and REMIT, STV, scheming effective EPS, improving TINV, and reducing TNRR. The results, which are based on several measurements and approaches, are reliable and provide a significant contribution to the literature on sustainability and green energy.

### *6.1. Policy Suggestions*

The findings suggest numerous policy recommendations. First, the findings of the traditional determinants emphasize the importance of internal and external financing to promote REN, suggesting that policymakers in developed countries should take steps forward to develop the financial market, inflow FDI (by increasing a country's competitiveness [59,60], and encourage personal remittances to enable investors and households to have easier access to borrowing funds. This causes conventional energies to be gradually replaced with RENEs and persuades consumers to spend more on RENE developments, which ultimately results in attaining SDG 7 and SDG 13. In addition, the findings stress that policymakers in advanced nations, to achieve energy and ecological sustainability goals (SDG 7, SDG 13) and reduce climate change, should promote REN by designing effective EPS, enhancing ecological innovation, reducing uncertainties related to economic policies, and decreasing total natural resources rents. To achieve a clean environment, governments in developed economies should also regulate $CO_2$ emissions.

Second, the positive interaction effect (EUIxEPS) recommends that policymakers, by increasing uncertainties related to energy markets, should focus on scheming and developing effective clean ecological policy instruments through market-based plans (e.g., taxes on $CO_2$), non-market-based plans (e.g., performance standards), and high-tech support plans (e.g., R&D support, feed-in tariffs) to be able to replace RENE and promote REN. Particularly, for the non-market-based plans, policymakers can also focus on socio-economic factors (e.g., education, income) to improve and achieve stricter environmental strategies. Having stricter environmental policies (high EPS) causes the beneficial impact of the EUI on REN to intensify in advanced countries compared to low EPS. Furthermore, the negative interaction effect (EUIxGEPU) recommends that policymakers should take steps forward to reduce economic instability and uncertainties related to economic policies to be able to promote REN and attain climate change mitigation plans when the EUI rises. All in all, enhancing EPS and reducing GEPU lead to promoting REN and intensifying the positive effect of the EUI on REN in advanced economies. To sum up, our discussion of the important potential and obstacles in promoting REN helps policymakers and decision-makers better understand how to support REN, which ultimately helps to reduce climate change and achieve the energy and ecological sustainability targets (SDG 7, SDG 13).

### *6.2. Study Limitations and Future Directions*

It would be helpful to investigate the impact of the EUI on REN for emerging economies in future studies. It would also be worth scrutinizing the effect of other moderators such as the country's political instability, financial instability, and institutional quality on the EUI–REN nexus. In addition, further research can focus on probing the effect of the EUI on REN in the short and long term in developed and developing countries. Likewise, future studies could also test the impact of other potential factors such as monetary policy, economic complexity, GPR, sovereign ESG [61,62], and climate policy uncertainty [63] on REN. Moreover, wavelet and time-varying Granger causality (e.g., [64]) can be used in future research to determine the direction of causality between the variables and determine whether a non-linearity relationship exists.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

| | |
|---|---|
| REN | Renewable energy consumption |
| RENE | Renewable energy |
| EUI | Energy-related uncertainty index |
| EPS | Environmental policy stringency |
| GEPU | Global economic policy uncertainty |
| SDGs | Sustainable development goals |
| GPR | Geopolitical risk |
| CPU | Climate policy uncertainty |
| FE | Fixed effects |
| CD | Cross-sectional dependence |

## Appendix A

**Table A1.** List of samples of developed economies and the average of variables (2000–2020).

| Sample Economies | Ln(REN) | Ln(STV) | Ln(FDI) | Ln(REMIT) | Ln($CO_2$) | Ln(TNRR) | Ln(GDPC) | Ln(EUI) | Ln(EPS) |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 2.115 | 4.302 | 1.250 | −1.957 | 12.845 | 1.554 | 10.660 | 2.682 | 0.767 |
| Belgium | 1.564 | 3.106 | 2.740 | 0.724 | 11.529 | −3.492 | 10.581 | 2.972 | 0.924 |
| Canada | 3.079 | 4.379 | 0.901 | −2.574 | 13.209 | 0.807 | 10.597 | 2.913 | 0.820 |
| Denmark | 3.062 | 3.379 | 0.581 | −1.017 | 10.674 | −0.033 | 10.854 | 2.792 | 1.187 |
| France | 2.433 | 4.088 | 0.537 | −0.234 | 12.737 | −3.075 | 10.499 | 3.329 | 1.195 |
| Germany | 2.301 | 3.875 | 0.817 | −1.096 | 13.545 | −2.108 | 10.564 | 3.145 | 1.053 |
| Greece | 2.434 | 2.636 | −0.588 | −0.738 | 11.317 | −2.099 | 9.932 | 3.024 | 0.793 |
| Ireland | 1.634 | 1.761 | 2.938 | −1.531 | 10.606 | −2.726 | 10.871 | 3.218 | 0.817 |
| Italy | 2.380 | 3.955 | −0.146 | −1.145 | 12.871 | −2.316 | 10.366 | 3.102 | 1.100 |
| Japan | 1.612 | 4.439 | −1.418 | −3.244 | 13.976 | −3.736 | 10.575 | 3.052 | 1.196 |
| Netherlands | 1.389 | 4.457 | 3.040 | −1.649 | 11.979 | −0.691 | 10.713 | 3.049 | 1.011 |
| Korea | 0.379 | 4.759 | −0.141 | −0.608 | 13.202 | −2.950 | 10.010 | 3.103 | 0.944 |
| Spain | 2.493 | 4.389 | 1.034 | −1.934 | 12.551 | −2.997 | 10.176 | 3.056 | 0.801 |
| Sweden | 3.796 | 4.500 | 0.979 | −0.628 | 10.695 | −0.560 | 10.769 | 2.964 | 1.192 |
| United Kingdom | 1.151 | 4.419 | 1.179 | −1.606 | 13.031 | −0.374 | 10.599 | 3.241 | 0.971 |
| United States | 2.005 | 5.366 | 0.479 | −3.287 | 15.477 | −0.264 | 10.806 | 3.162 | 0.671 |

## References

1. World Bank. *World Development Indicators 2016*; World Bank Publications: Chicago, IL, USA, 2016.
2. BP. *Statistical Review of World Energy 2020*; BP: London, UK, 2020.
3. Doğan, B.; Balsalobre-Lorente, D.; Nasir, M.A. European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. *J. Environ. Manag.* **2020**, *273*, 111146. [CrossRef]
4. Adams, S.; Nsiah, C. Reducing carbon dioxide emissions; Does renewable energy matter? *Sci. Total Environ.* **2019**, *693*, 133288. [CrossRef]
5. Zhou, A.; Li, J. Heterogeneous role of renewable energy consumption in economic growth and emissions reduction: Evidence from a panel quantile regression. *Environ. Sci. Pollut. Res.* **2019**, *26*, 22575–22595. [CrossRef]
6. Bloomberg New Energy Finance. *Global Trends in Clean Energy Investment*; Bloomberg: New York, NY, USA, 2019.
7. World Irena. *Energy Transitions Outlook: 1.5 °C Pathway*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2021; pp. 1–352. Available online: www.irena.org/publications (accessed on 1 June 2024).

8. Athari, S.A. The impact of financial development and technological innovations on renewable energy consumption: Do the roles of economic openness and financial stability matter in BRICS economies? *Geol. J.* **2024**, *59*, 288–300. [CrossRef]
9. Athari, S.A. Global economic policy uncertainty and renewable energy demand: Does environmental policy stringency matter? Evidence from OECD economies. *J. Clean. Prod.* **2024**, *450*, 141865. [CrossRef]
10. Tiwari, A.K.; Nasreen, S.; Anwar, M.A. Impact of equity market development on renewable energy consumption: Do the role of FDI, trade openness and economic growth matter in Asian economies? *J. Clean. Prod.* **2022**, *334*, 130244. [CrossRef]
11. Ferrier, G.D.; Reyes, J.; Zhu, Z. Technology diffusion on the international trade network. *J. Public Econ. Theory* **2016**, *18*, 291–312. [CrossRef]
12. Zhao, Z.; Gozgor, G.; Lau, M.C.K.; Mahalik, M.K.; Patel, G.; Khalfaoui, R. The impact of geopolitical risks on renewable energy demand in OECD countries. *Energy Econ.* **2023**, *122*, 106700. [CrossRef]
13. Alam, M.M.; Murad, M.W. The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renew. Energy* **2020**, *145*, 382–390. [CrossRef]
14. Saeed, T.; Bouri, E.; Alsulami, H. Extreme return connectedness and its determinants between clean/green and dirty energy investments. *Energy Econ.* **2021**, *96*, 105017. [CrossRef]
15. Subramaniam, Y.; Masron, T.A.; Loganathan, N. Remittances and renewable energy: An empirical analysis. *Int. J. Energy Sect. Manag.* 2022, *ahead-of-print*. [CrossRef]
16. Lei, W.; Liu, L.; Hafeez, M.; Sohail, S. Do economic policy uncertainty and financial development influence the renewable energy consumption levels in China? *Environ. Sci. Pollut. Res.* **2022**, *29*, 7907–7916. [CrossRef]
17. Alsagr, N.; van Hemmen, S. The impact of financial development and geopolitical risk on renewable energy consumption: Evidence from emerging markets. *Environ. Sci. Pollut. Res.* **2021**, *28*, 25906–25919. [CrossRef]
18. Gozgor, G.; Lau, M.C.K.; Zeng, Y.; Yan, C.; Lin, Z. The impact of geopolitical risks on tourism supply in developing economies: The moderating role of social globalization. *J. Travel Res.* **2022**, *61*, 872–886. [CrossRef]
19. Gozgor, G.; Paramati, S.R. Does energy diversification cause an economic slowdown? Evidence from a newly constructed energy diversification index. *Energy Econ.* **2022**, *109*, 105970. [CrossRef]
20. Lei, W.; Xie, Y.; Hafeez, M.; Ullah, S. Assessing the dynamic linkage between energy efficiency, renewable energy consumption, and $CO_2$ emissions in China. *Environ. Sci. Pollut. Res.* **2021**, *29*, 19540–19552. [CrossRef]
21. Zhang, X.; Guo, Q. How useful are energy-related uncertainty for oil price volatility forecasting? *Financ. Res. Lett.* **2024**, *60*, 104953. [CrossRef]
22. Wang, Y.; Huang, X.; Huang, Z. Energy-related uncertainty and Chinese stock market returns. *Financ. Res. Lett.* **2024**, *62*, 105215. [CrossRef]
23. Dang, T.H.-N.; Nguyen, C.P.; Lee, G.S.; Nguyen, B.Q.; Le, T.T. Measuring the energy-related uncertainty index. *Energy Econ.* **2023**, *124*, 106817. [CrossRef]
24. Chu, L.K.; Doğan, B.; Ghosh, S.; Shahbaz, M. The influence of shadow economy, environmental policies and geopolitical risk on renewable energy: A comparison of high-and middle-income countries. *J. Environ. Manag.* **2023**, *342*, 118122. [CrossRef]
25. Shafiullah, M.; Miah, M.D.; Alam, M.S.; Atif, M. Does economic policy uncertainty affect renewable energy consumption? *Renew. Energy* **2021**, *179*, 1500–1521. [CrossRef]
26. Ivanovski, K.; Marinucci, N. Policy uncertainty and renewable energy: Exploring the implications for global energy transitions, energy security, and environmental risk management. *Energy Res. Soc. Sci.* **2021**, *82*, 102415. [CrossRef]
27. Khan, K.; Su, C.W. Does policy uncertainty threaten renewable energy? Evidence from G7 countries. *Environ. Sci. Pollut. Res.* **2022**, *29*, 34813–34829. [CrossRef]
28. Li, Z.Z.; Su, C.W.; Moldovan, N.C.; Umar, M. Energy consumption within policy uncertainty: Considering the climate and economic factors. *Renew. Energy* **2023**, *208*, 567–576. [CrossRef]
29. Sweidan, O.D. The geopolitical risk effect on the US renewable energy deployment. *J. Clean. Prod.* **2021**, *293*, 126189. [CrossRef]
30. Cai, Y.; Wu, Y. Time-varying interactions between geopolitical risks and renewable energy consumption. *Int. Rev. Econ. Financ.* **2021**, *74*, 116–137. [CrossRef]
31. Flouros, F.; Pistikou, V.; Plakandaras, V. Geopolitical risk as a determinant of renewable energy investments. *Energies* **2022**, *15*, 1498. [CrossRef]
32. Pommeret, A.; Schubert, K. Intertemporal emission permits trading under uncertainty and irreversibility. *Environ. Resour. Econ.* **2018**, *71*, 73–97. [CrossRef]
33. Antoniuk, Y.; Leirvik, T. Climate change events and stock market returns. *J. Sustain. Financ. Invest.* **2024**, *14*, 42–67. [CrossRef]
34. Shang, Y.; Han, D.; Gozgor, G.; Mahalik, M.K.; Sahoo, B.K. The impact of climate policy uncertainty on renewable and non-renewable energy demand in the United States. *Renew. Energy* **2022**, *197*, 654–667. [CrossRef]
35. Liang, C.; Umar, M.; Ma, F.; Huynh, T.L. Climate policy uncertainty and world renewable energy index volatility forecasting. *Technol. Forecast. Soc. Chang.* **2022**, *182*, 121810. [CrossRef]
36. Ren, X.; Li, J.; He, F.; Lucey, B. Impact of climate policy uncertainty on traditional energy and green markets: Evidence from time-varying granger tests. *Renew. Sustain. Energy Rev.* **2023**, *173*, 113058. [CrossRef]
37. Syed, Q.R.; Apergis, N.; Goh, S.K. The dynamic relationship between climate policy uncertainty and renewable energy in the US: Applying the novel Fourier augmented autoregressive distributed lags approach. *Energy* **2023**, *275*, 127383. [CrossRef]

38. Zhang, H.; Hong, H.; Ding, S. The role of climate policy uncertainty on the long-term correlation between crude oil and clean energy. *Energy* **2023**, *284*, 128529. [CrossRef]
39. Zhou, D.; Siddik, A.B.; Guo, L.; Li, H. Dynamic relationship among climate policy uncertainty, oil price and renewable energy consumption—Findings from TVP-SV-VAR approach. *Renew. Energy* **2023**, *204*, 722–732. [CrossRef]
40. Zhang, L.; Wang, L.; Wang, X.; Zhang, Y.; Pan, Z. How macro-variables drive crude oil volatility? Perspective from the STL-based iterated combination method. *Resour. Policy* **2022**, *77*, 102656. [CrossRef]
41. Zhang, L.; Li, Y.; Yu, S.; Wang, L. Risk transmission of El Niño-induced climate change to regional Green Economy Index. *Econ. Anal. Policy* **2023**, *79*, 860–872. [CrossRef]
42. Dai, Z.; Wu, T. The impact of oil shocks on systemic risk of the Commodity markets. *J. Syst. Sci. Complex.* **2024**. [CrossRef]
43. Işık, C.; Kuziboev, B.; Ongan, S.; Saidmamatov, O.; Mirkhoshimova, M.; Rajabov, A. The volatility of global energy uncertainty: Renewable alternatives. *Energy* **2024**, *297*, 131250. [CrossRef]
44. Hsiao, C. *Analysis of Panel Data (No. 54)*; Cambridge University Press: Cambridge, UK, 2014.
45. Pesaran, M.H. *General Diagnostic Tests for Cross Section Dependence in Panels*; Cambridge Working Papers in Economics, 0435; University of Cambridge: Cambridge, UK, 2004.
46. Levin, A.; Lin, C.F.; Chu, C.S.J. Unit root tests in panel data: Asymptotic and finite-sample properties. *J. Econom.* **2002**, *108*, 1–24. [CrossRef]
47. Im, K.S.; Pesaran, M.H.; Shin, Y. Testing for unit roots in heterogeneous panels. *J. Econom.* **2003**, *115*, 53–74. [CrossRef]
48. 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]
49. Ma, Y.; Zhao, Y.; Jia, R.; Wang, W.; Zhang, B. Impact of financial development on the energy intensity of developing countries. *Heliyon* **2022**, *8*, e09904. [CrossRef] [PubMed]
50. Kutan, A.M.; Paramati, S.R.; Ummalla, M.; Zakari, A. Financing renewable energy projects in major emerging market economies: Evidence in the perspective of sustainable economic development. *Emerg. Mark. Financ. Trade* **2018**, *54*, 1761–1777. [CrossRef]
51. Dogan, E.; Majeed, M.T.; Luni, T. Analyzing the impacts of geopolitical risk and economic uncertainty on natural resources rents. *Resour. Policy* **2021**, *72*, 102056. [CrossRef]
52. Shahzad, U.; Doğan, B.; Sinha, A.; Fareed, Z. Does Export product diversification help to reduce energy demand: Exploring the contextual evidences from the newly industrialized countries. *Energy* **2021**, *214*, 118881. [CrossRef]
53. Allan, G.; Lecca, P.; McGregor, P.; Swales, K. The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. *Ecol. Econ.* **2014**, *100*, 40–50. [CrossRef]
54. Bashir, M.F.; Ma, B.; Bashir, M.A.; Radulescu, M.; Shahzad, U. Investigating the role of environmental taxes and regulations for renewable energy consumption: Evidence from developed economies. *Econ. Res.-Ekon. Istraživanja* **2021**, *35*, 1262–1284. [CrossRef]
55. Johnstone, N.; Haščič, I.; Poirier, J.; Hemar, M.; Michel, C. Environmental policy stringency and technological innovation: Evidence from survey data and patent counts. *Appl. Econ.* **2012**, *44*, 2157–2170. [CrossRef]
56. Jenner, S.; Groba, F.; Indvik, J. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy* **2013**, *52*, 385–401. [CrossRef]
57. Li, X.; Ozturk, I.; Raza Syed, Q.; Hafeez, M.; Sohail, S. Does green environmental policy promote renewable energy consumption in BRICST? Fresh insights from panel quantile regression. *Econ. Res.-Ekon. Istraživanja* **2022**, *35*, 5807–5823. [CrossRef]
58. Saliba, C.B.; Hassanein, F.R.; Athari, S.A.; Dördüncü, H.; Agyekum, E.B.; Adadi, P. The Dynamic Impact of Renewable Energy and Economic Growth on $CO_2$ Emissions in China: Do Remittances and Technological Innovations Matter? *Sustainability* **2022**, *14*, 14629. [CrossRef]
59. Athari, S.A.; Adaoglu, C. Nexus between institutional quality and capital inflows at different stages of economic development. *Int. Rev. Financ.* **2019**, *19*, 435–445. [CrossRef]
60. Athari, S.A.; Shaeri, K.; Kirikkaleli, D.; Ertugrul, H.M.; Ozun, A. Global competitiveness and capital flows: Does stage of economic development and risk rating matter? *Asia-Pac. J. Account. Econ.* **2020**, *27*, 426–450. [CrossRef]
61. Athari, S.A. Does the sovereign environmental, social, and governance sustainability activities jeopardize the banking sector's stability: Evidence from the Arab economies. *Sustain. Futures* **2024**, *7*, 100204. [CrossRef]
62. Athari, S.A.; Saliba, C.; Abboud, E.; El-Bayaa, N. Examining the Quadratic Impact of Sovereign Environmental, Social, and Governance Practices on Firms' Profitability: New Insights from the Financial Industry in Gulf Cooperation Council Countries. *Sustainability* **2024**, *16*, 2783. [CrossRef]
63. Athari, S.A.; Kirikkaleli, D. How do climate policy uncertainty and renewable energy and clean technology stock prices co-move? evidence from Canada. *Empir. Econ.* **2024**. [CrossRef]
64. Athari, S.A.; Khalid, A.A.; Syed, Q.R. Twitter-Based Economic Uncertainty and US Energy Market: An Investigation Using Wavelet Coherence. *Energy Res. Lett.* **2023**, *5*. [CrossRef]