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The Effect of Energy Policy Risk on Renewable Energy

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ABSTRACT

This study explores the association among renewable energy, energy policy risk, economic development, ESG (Environmental, Social, Governance) performance and institutional quality in the panel of 137 nations from 2000 to 2022. For the econometric estimations, Method of Moments Quantile Regression (MMQR) approach is employed which is robust for the heteroscedasticity. The findings reveal that energy policy risk curbs renewable energy development which is in line with the theoretical linkage. Moreover, the robustness checks conducted by dividing the sample into developed and developing economies also validate that energy policy risk leads to a decline in renewable energy transition. Regarding control variables, economic development, ESG performance and institutional quality, their effects vary depending on the sample of countries.

Keywords: Energy Policy Risk, Renewable Energy, Environmental, Social, Governance, Economic Development
JEL Classifications: Q42, Q43, Q48, Q56

1. INTRODUCTION

In recent years, renewable energy has experienced rapid growth, driven by a combination of factors, including heightened environmental awareness, strong governmental support and incentives, and significant technological advancements that have sharply reduced production costs (Ariza and Ferrer, 2025). Renewable energy, defined by its non-polluting and sustainable nature, plays a key role in fostering cleaner manufacturing and attaining environmental sustainability (Lee et al., 2022). Increasing environmental risks have prompted numerous countries to implement measures aimed at enhancing the integration of sustainable and renewable energy solutions. In addition, the G7 nations are taking the lead in achieving net zero greenhouse gas emissions by 2050 by dramatically raising the proportion of renewable energy in their energy supply system (Khan and Su, 2022). According to the International Energy Agency (IEA), in 2023, renewable energy sources accounted for 30% of global electricity supply. By 2035, the share of solar PV and wind in electricity generation is projected to surpass 40% globally under the STEPS scenario, and by 2050, it is expected to rise to nearly 60% (IEA, 2024). In this regard, renewable energy derived from various self-renewing sources has become a significant concept in the fight against climate change and in energy policy (Salman and Wang, 2024).

Numerous topics are covered by energy policy, such as climate change mitigation, renewable energy development, energy security, affordability, and efficiency. According to Kanna (2024), in energy policy, it is important to set goals and objectives, choose strategies based on available resources, and minimize risks in energy policy. The recent energy crisis, which was brought on by hostilities between Russia and Ukraine, has demonstrated that nations' reliance on imports of fossil fuels will have detrimental political and economic effects. The growing focus on sustainable energy and the transition to low-carbon technologies have made energy policy a critical aspect of national and global agendas. However, policy decisions in the energy sector carry inherent risks that can affect energy security, economic stability, and the achievement of environmental goals. In this context, Countries must lessen their reliance on other nations and boost their investments in renewable energy and choose the right direction in energy policy (Pata et al., 2023).

Evidence of the economic influence of energy policy can be found in the literature. Furthermore, in the majority of economies, investing in renewable energy may support low-carbon growth. The body of research on the connection between renewable energy and energy policy risk is, nevertheless, rarely cited. Thus, the effect of energy policy risk on renewable energy is confirmed in this article.

2. LITERATURE REVIEW

In literature, to study the interrelationships between energy variables is growing. However, there is no evidence to examine the effect of energy policy risk on renewable energy. Because energy policy risk is a novel variable. Even though this variable has not been applied in previous studies, the relation from energy policy risk on renewable energy can be justified through the composites of energy policy risk. Energy policy risk contains mismatches in supply and demand, geopolitical hazards, stop-go policies, lack of investment signals insufficient technological progress, bottlenecks from a lack of infrastructure, market tightening, over-investment leading to underutilized assets, grid transformation, and extreme weather events.

In academia, the scholars examine the relation between renewable energy and the variables associated with geopolitical hazards. More precisely, Yasmeen and Shah (2024) investigate the unstudied relationships between the militarization index, energy uncertainty, and geopolitical conflict with renewable and non-renewable energy in the G7 between 1997 and 2022. According to their results, the geopolitical environment currently in place does not present good conditions for the growth of the use of renewable energy. In their research, Chu et al. (2023) analyse the various impacts on renewable energy for 30 economies with high and middle incomes of the underground economy, the stringency of environmental regulations, geopolitical risk, GDP, carbon emissions, population, and oil prices. The study's findings indicate that while geopolitical risks have a detrimental effect on renewable energy in middle-income nations, they have a favourable effect on the deployment of renewable energy in high-income countries.

There are also studies that explore the association of renewable energy with financial and other economic variables, proxies for stop-go policies, and lack of investment signals. More specifically, Jiang et al. (2025) find that governmental, social, and economic environmental risks severely affect foreign investments in renewable energy, and that these effects are exacerbated in nations with high per capita GDP and low use of renewable energy due to the risk susceptibility of renewable energy projects. Shao et al. (2024) explain that renewable energy financing encompasses both energy and financial characteristics. In order to achieve a universal modern energy supply in the future, it is necessary to invest a large amount of funds in renewable energy technologies. In particular, Amuakwa-Mensah and Näsström (2022) estimate the relationship between a global panel's use of renewable energy and five banking sector performance metrics: Return on asset, market capitalization, asset quality, managerial effectiveness, and financial stability. The results emphasize the crucial role of a healthy banking sector in securing the funds required for renewable energy to face future energy demands. Dunbar and Treku (2025) investigate a positive relationship between energy transition investment flows and the issuance of green bonds, suggesting that higher investments in energy transitions drive the expansion of green bond markets. This connection highlights the importance of impact investments in promoting the green finance market and fostering climate resilience efforts.

The development of renewable energy sources is one of the most effective ways to ensure sustainable and long-term growth. Therefore, many countries around the world are trying to update their economic and industrial structures and adapt technological processes to support green growth. In this regard, there are a number of studies on the assessment of the impact of technological processes on renewable energy sources. Solarin et al. (2022) evaluate the impact of green growth-related technical innovation in the BRICS nations between 1993 and 2018. The empirical results of this study, which used a new panel quantile regression, demonstrate that innovation in renewable energy has a considerably favourable impact on the production of renewable energy across all quantiles. Oryani et al. (2021) suggested that the development of solar PV technology faces fewer constraints, followed by wind turbines and biomass. Consequently, it is essential to design and implement effective policies and strategies to promote the widespread adoption of renewable energy technologies.

Many researchers are working on the effects of climate change on renewable energy sources. According to researchers Shao and Hao (2024), perception of climate change as a major concern affects public support for renewable energy, and carbon dependency reduces support for renewable energy. The connection between climate change and extreme weather occurrences should be the main emphasis of policymakers. Solaun and Cerdá (2019) estimate the impact of climate change on solar, wind, hydro, and other renewable energy technologies based on quantitative data. This study shows that the impact of climate change on renewable energy is increasing. Tang et al. (2025) conducted research on the impact of climate change on energy demand and supply in China. The results show that 9.8 TW of renewable electricity must be added by 2060, with storage capacity reaching 0.9 TW and wind and solar power providing 4.2 and 5.0 TW, respectively. In the North, 56% of wind power, 42% of solar power, and 48% of storage are concentrated. It can be seen climate affects the optimal combination of energy generation technology, grid infrastructure, and storage technology. Karlilar Pata (2024) studies the effects of government efficiency, energy policy uncertainty, climate policy uncertainty, and economic policy uncertainty on renewable energy in the US. According to the results, energy policy uncertainty serves as a barrier to the long-term adoption of renewable energy sources while simultaneously effectively promoting renewable energy in the near term. Furthermore, the shift to low-carbon energy sources is accelerated by the uncertainty surrounding climate policy.

The impact of infrastructure on renewable energy is crucial in determining how effectively renewable energy sources can be integrated into existing energy systems and how they can reach their full potential. Alsayegh (2021) researches the existing system structure in Kuwait's pursuit of a sustainable energy transition, with an emphasis on renewable energy. The model's foundation is a "push-pull" idea that pinpoints the primary weaknesses in the current framework and the obstacles to the adoption of renewable energy technology. According to Greiner and Klagge (2024), large-scale renewable energy projects cannot be realized without auxiliary facilities like roads, labour camps, or water management systems. According to their results, these infrastructures are particularly crucial during the exploration and development stages since they are necessary to initiate energy infrastructure. Cui and Aziz (2024) highlight that a hydrogen-based renewable energy infrastructure may bridge the gaps between energy supply and demand over a large geographic area if it is well designed. In addition to applying market principles, enhancing the infrastructure for power, and increasing the use of renewable energy sources are crucial for fostering industrial and overall economic growth. Pinjaman et al. (2024) examines the relationship between renewable energy generation, economic factors, infrastructure, and governance quality in ASEAN countries. Based on the fixed effects regression model on panel data spanning the years 2002-2021, results demonstrate that infrastructure and economic expansion are positively correlated, suggesting that these elements serve as catalysts for the production of renewable energy in the area. Schnidrig et al. (2023) predict that as the amount of renewable energy increases and fossil fuel imports decrease, demand for energy infrastructure, which includes grids and storage technologies, would rise, perhaps necessitating grid reinforcement. Another important component to ensure supply security is the energy infrastructure.

Literature shows that risks associated with the composites of energy policy negatively impacts on renewable energy. More specifically, energy policy risk is a promoter to renewable energy development.

3. DATA AND METHODOLOGY

3.1. Data

To study the impact of energy policy risk on renewable energy, the work applies the annual data, spanning from 2000 to 2022, of a panel of 137 countries due to the availability of the data. The outcome variable, renewable energy (RENERGY), is measured as a percentage of electricity generation from renewables in total electricity generation. It is obtained from the Our World in Data website (https://ourworldindata.org/renewable-energy). The core explanatory variable is energy policy risk score (ENPORISK), measured as a score, and downloaded from Refinitive[1]. The score of energy policy risk ranges from 0 to 100. Higher values of the score represent low risk, whereas lower values denote high risk.

The control variables are gross domestic product per capita to capture economic development (ECDEV), measured in US dollars, environment score of ESG, measured as an index to consider environmental quality[2], and the index of government effectiveness[3] as a proxy for institutional quality (IQ). ESG environment score (ESG). The data of GDP per capita and government effectiveness index are downloaded from World Bank Open Data (https://data.worldbank.org). The data of ESG environment score energy risk is obtained from Refinitive.

Table 1 contains the descriptive statistics of the studied variables. Overall, 3151 observations are considered for each of the 5 variables: RENERGY, ENPORISK, ECDEV, ESG, and IQ. Respectively, with mean values of 38.497, 66.272, 12869.2, 52.552, and 0.024. Normality measures in terms of skewness highlight that while RENERGY is positively skewed, ENPORISK is negatively skewed. In contrast, ECDEV is highly positively skewed and the data distribution of ESG with IQ are nearly symmetrical. With regards to kurtosis figures, negative (platykurtic) kurtosis is observed among all of the variables except ECDEV in case of which positive (leptokurtic) kurtosis is detected.

The variables, ENPORISK, ECDEV and ESG are transformed into natural logarithm for data smoothing such as LOGENPORISK, LOGECDEV and LOGESG. RENERGY and IQ cannot be used in logarithmic transformation since the former is given in percentage while the latter contains negative values.

As a next step, the heteroscedasticity test is run. Since the main estimations of the study are run by MMQR, justifying the existence of the heteroscedasticity is crucial. Because the application of the MMQR method requires the presence of heteroscedasticity. To this end, White's test (1980) and Breusch–Pagan test (1980) for heteroscedasticity is employed. The results are provided in Table 2. According to the results, there is a heteroscedasticity in the regression model.

3.2. Methodology

3.2.1. Baseline model

In order to empirically examine the effect of energy policy risk on renewable energy, the general specification of the regression model can be prescribed as follows:

$$RENERGY_{it} = \alpha_0 + \alpha_1\, LOGENPORISK_{it} + \alpha_2\, LOGECDEV_{it} + \alpha_3\, LOGESG_{it} + \alpha_4\, IQ_{it} + \varepsilon_{it} \quad (1)$$

1. Accessed by Prof. A. Nazif Catik, Department of Economics, Ege University, Turkiye. email: a.nazif.catik@ege.edu.tr
2. The index ranges from 0 to 100, meaning high environmental performance for high value.
3. The index ranges from approximately -2.5 to 2.5, meaning higher value for high institutional quality.

Table 1: Descriptive statistics

Variable	Observations	Mean	Minimum	Maximum	Skewness	Kurtosis
RENERGY	3151	38.497	0.037	100	0.601	2.021
ENPORISK	3151	66.272	0.43	100	−0.996	2.840
ECDEV	3151	12869.2	110.461	133712	2.390	9.589
ESG	3151	52.552	0.19	100	−0.242	2.153
IQ	3151	0.024	−2.226	2.469	0.495	2.329

Table 2: White's test and Breusch-Pagan test for heteroscedasticity

Test name	Chi-square	P-value
White's test	134.31	0.000
Breusch-Pagan test	6.10	0.013

***P<0.01; **P<0.05

where, $RENERGY_{it}$ is renewable energy. α_0 represents an intercept, α_1, α_2, α_3 and α_4 denote the elasticity coefficients for $LOGENPORISK_{it}$ (a natural logarithm of energy policy risk), $LOGECDEV_{it}$ (a natural logarithm of economic development), $LOGESG_{it}$ (a natural logarithm of ESG environmental score) and IQ_{it} (institutional quality), respectively. ε shows an error term. i expresses countries, t indicates time.

Equation (1) is considered as a specification of the pooled ordinary least-squares (POLS) method, which is based on assumptions such as normal distribution, homoscedasticity and mean values. However, in reality, the conventional assumptions of POLS are distorted by the influence of economic fluctuations caused by wars, pandemics, financial crises and etc. Therefore, to cope with the heteroscedastic nature of the data, quantile approach is applied.

Since energy markets are sensitive and vulnerable to global shocks and economic fluctuations Boubaker et al., quantile approach is most common. More specifically, Zhang et al. (2023) explores how country risks and government subsidies affect the performance of renewable energy firms employing quantile regression. Alharbey and Ben-Salha (2024) explore the effect of the U.S. climate policy uncertainty on renewable energy applying a quantile-based (a) symmetric causality analysis. Following previous studies who examine the interrelationship between renewable energy and the proxies for energy policy risk such as country risks and climate policy uncertainty, this work also applies quantile regression approach to explore the effect of energy policy risk on renewable energy.

3.2.2. Method of moments of quantile regression (MMQR)

Since the POLS model shown in Equation (1) presumes the application of mean regression, it is affected by outliers. To avoid these drawbacks, the research employs MMQR. This is considered as a robust method to explore the effect of explanatory variables ($LOGENPORISK_{it}$, $LOGECDEV_{it}$, $LOGESG_{it}$, IQ_{it}) on the various quantiles of the explained variable ($RENERGY_{it}$). For this reason, MMQR specification for Equation (1) can be described after the conversion as the following (Machado and Silva, 2019):

$$RENERGY_{it} = \alpha_i + X_{it}'\beta + (\delta_i + Z_{it}'\gamma)U_{it} \quad (2)$$

In Equation (2), β is the vector that includes the coefficients for the respective variables. α_i is the individual fixed effect, whereas δ_i is the ith country's fixed effect which is specific to the quantile. Z_{it} is a vector that has developed differentiable transformations of the right-hand side variables satisfying the probability of $P\{\delta_i + Z_{it}'\gamma > 0\} = 1$. U_{it} denotes a random factor which is not observed and correlated with independent factors. It has been moved to the normalization for meeting the moment conditions, given following: The expected value is zero for U_{it} which is $E(U_{it}) = 0$. And, the expected absolute value is equal to one for U_{it} that is $E(|U_{it}|) = 1$.

Equation (2) s parameters, α_i, β, δ_i $\gamma' q(\tau)$, are calculated applying the first moment conditions which consider the independent variables' exogeneity. The current approach complies with the method developed by Machado and Silva (2019). Therefore, the model in the representation of the model in the conditional quantile is given in the following:

$$Q_{RENERGY_{it}}\left(\tau \mid X_{it}\right) = \left(\alpha_i + \delta_i q(\tau)\right) + X_{it}'\beta + Z_{it}'\gamma q(\tau) \quad (3)$$

Equation (3) calculates the conditional quantiles of the outcome variable ($RENERGY_{it}$) in association to the explanatory variables, it takes a panel of individuals into account which is observed across multiple time periods. The τ^{th} fixed effect quantile for i^{th} individual, in other words the distributional impact at τ, is described by the scalar parameter $i(\tau) \equiv (\alpha_i + \delta i\, q(\tau))$ given in parenthesis. For the estimation of the model given above, one-step version of GMM estimator[4] is applied.

3.2.3. Additional tests

3.2.3.1. Cross-sectional dependence and panel unit roots

As a prerequisite for the panel time series analysis, this paper applies a battery of tests to analyze cross-sectional dependence and variable heterogeneity. Breusch and Pagan (1980) proposed the following Lagrange Multiplier (LM) test statistic for analyzing cross-sectional dependence:

$$CD_{LM} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \quad (4)$$

Where $\hat{\rho}_{ij}^2$ represents the estimated pairwise correlation coefficients of the residuals obtained through ordinary least squares regressions. This test has an asymptotic chi-square distribution (x^2) with N (N−1)/2 degrees of freedom. A test statistic that is statistically significant provides compelling evidence against the null hypothesis of no cross-sectional dependence, indicating that the residuals exhibit correlation across units. The existence of cross-sectional dependency indicates that the standard errors of the OLS could be biased, necessitating the use of alternative estimation methods.

4. For more information on the model's estimation steps, refer to Machado and Silva (2019).

LM test may generate biased results in the case of large sample. Pesaran (2004) proposed a cross-sectional dependence (CD) test to address this issue as both number of cross-sections (N) and time period (T) approach infinity. The CD statistics serve to evaluate the null hypothesis regarding the absence of cross-sectional dependency among panel units, and its calculation is as follows:

$$CD = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^2 - 1)} \quad (5)$$

The null hypothesis indicates that there is no cross-sectional dependence present.

The existence of cross-sectional dependency necessitates that panel time series methodologies address this issue appropriately. This study utilizes the cross-sectional CIPS panel unit root test to analyze the unit root properties of the variables, while considering cross-sectional dependence. To compute CIPS statistics, the regression model used for the cross-sectional augmented Dickey-Fuller (CADF) test is estimated as follows:

$$\Delta Z_{it} = \alpha_i + \rho_i Z_{i,t-1} + \beta_i \overline{Z}_{t-1} + \sum_{j=0}^{k}\gamma_{ij}\Delta\overline{Z}_{i,t-1} + \sum_{j=0}^{k}\delta_{ij}Z_{i,t-1} + v_{it} \quad (6)$$

The final step involves computing the CIPS statistics, which is the average of CADF statistics, using the formula:

$$IPS = \frac{1}{N}\sum_{i=1}^{N}t_i(N,T) \quad (7)$$

3.2.3.2. Panel cointegration test

If unit root tests indicate the same level of integration of the series, the presence of long-run association among the variables can be investigated with panel cointegration tests. In this paper we employ Westerlund (2005) panel cointegration test to analyze cointegration. This test utilizes variance ratio statistics to ascertain whether the residuals from an estimated panel data regression have a unit root, based on the null hypothesis of no cointegration. The test is capable of accommodating individual-specific short-run relationships, intercept and trend specifications, and slope parameters without necessitating the precise specification of the data generation process.

To apply the Westerlund (2005) test, firstly the residuals are obtained from the estimation of Equation (1). Then they are tested for a unit root based on the following model following AR(1) process:

$$\hat{\varepsilon}_{it} = \rho_i\hat{\varepsilon}_{it-1} + u_{it} \quad (8)$$

The variance ratio statistics used for the analysis of cointegration are defined as follows:

$$VR_G = \frac{1}{N}\sum_{i=1}^{N}\frac{\sum_{t=1}^{T}E_{it}^2}{R_i} \quad (9)$$

$$VR_p = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}E_{it}^2}{R_i} \quad (10)$$

Where $E_{it} = \sum_{j=1}^{t}\varepsilon_{ij}$ and $R_i = \sum_{t=1}^{t}\varepsilon_{it}^{\,2}$. The test statistics' asymptotic distributions are derived under the null hypothesis of no cointegration, and the tests are demonstrated to be free of nuisance parameters. Cointegration of the entire panel is assessed by the panel statistic, VR_p, whereas cointegration of a subset of the panel is investigated with the group mean statistic, VR_G. Therefore, Westerlund (2005) panel cointegration test allows us to analyze the long-run equilibrium relationship between renewable energy (RENERGY) and its determinants under the presence of cross-sectional dependence and heterogeneity within the panel data.

4. EMPIRICAL RESULTS

4.1. Panel Time Series Results

In this section the first cross-sectional dependency among the residuals of the model is investigated with various cross-sectional dependence tests. The tests presented in Table 3 include the Lagrange Multiplier (LM) test, the adjusted LM test (LM adj*), and the cross-sectional dependence (CD) test. The results indicate significant cross-sectional dependence among the panel units, as evidenced by the significant test statistics of the three tests at one percent level of significance. This suggests that the residuals across different cross-sections are correlated, which is a common characteristic in panel data involving multiple countries or regions.

After evidencing for cross-sectional dependence unit root test and cointegration analysis are conducted to determine the long-run relationship among the variables. Table 4 reports the results of the CIPS unit root test. CIPS unit root test results reported in the panel (a) contain the results for the variables at both levels and first differences. The results show that all variables are non-stationary at levels but become stationary after first differencing, as indicated by significant test statistics obtained for the first differences. This indicates that the variables are integrated of order one, I(1).

As the variables have the same integration, Westerlund (2005) cointegration test is applied results reported in Table 5 indicate the presence of cointegration among the variables, as the variance ratio statistic is found to be significant at one percent level. This corroborates the presence of long-run equilibrium relationship between renewable energy and the explanatory variables, including energy policy risk, economic development, ESG environmental performance and institutional quality.

4.2. MMQR Results

Table 6 provides MMQR results exploring the link between RENENERGY and the core explanatory variable LOGENPORISK, controlling LOGECDEV, LOGESG, and IQ variables. Overall, the coefficients vary across given quantiles, showing that the effect of these variables differs at varying degrees of renewable energy utilization. According to the estimations, LOGENPORISK positively impacts RENERGY across the quantiles from 50% to 90%. Since a higher value of the score means less risk, the findings are in line with the theoretical linkage in the medium and high quantiles. More specifically, a decrease in energy policy risk promotes renewable energy. This could aim policymakers in steering towards energy transition and energy security by suggesting they consider energy policy-related risks when attempting to promote investment in renewable energy. To the best of our knowledge, this relationship has been overlooked by scholars; hence, we can only relate to other risks impacting renewable energy. In this regard, it aligns with the results of Jiang et al. (2019), Ivanovski and Marinucci (2021), who analyze economic policy uncertainty, and Wang et al. (2022), who consider political risk.

As regards LOGECDEV, it has a positive relation with RENERGY in lower and middle quantiles from 10% to 50%. It is consistent with the findings of Sadorsky (2009a), Sadorsky (2009b), Aguirre and Ibikunle (2014), Omri and Nguyen (2014), and Gozgor et al. (2020), uncovering that an increase in GDP per capita enhances renewable energy consumption regarding different contexts comprising both emerging and advanced economies. This might imply that the primary stage of renewable energy adoption is highly improved by a rise in GDP, while developed nations can encounter the effect of saturation or make a priority of tackling other energy challenges. In emerging countries, policymakers should utilize this impact of economic growth in order to foster renewable energy usage, while developed nations could be required to be more innovative in their policy establishment to achieve sustainable adoption of renewables. In contrast, there is a contradiction with the findings of Chen et al. (2021), who examine this connection in 97 nations, concluding that the increment in renewable energy consumption is inversely correlated with higher degrees of economic development.

LOGESG has a growing and significant positive effect on RENERGY in the high quantiles of 75-90%. This result has an alignment with such studies as Lu and Li (2024) and Shahzad et al. (2024), who research the same or proxy variables. This could be viewed as an implication for policymakers to ensure sustainable adherence to ESG principles at later adoption stages. However, alignment is not present with the result of Bashir et al. (2021), who establish that environmental policies within OECD member states hinder the exploitation of renewable energy sources. Conversely, IQ has a significant and negative effect on RENERGY in the quantiles 10-75%. This finding is in contradiction with that of Cadoret and Padovano (2016), Sequeira and Santos (2018), Uzar (2020), and Mukhtarov et al. (2023), who indicate a positive long-term effect of IQ on RENERGY.

Figure 1 shows that the marginal effect of LOGENPORISK on RENERGY is also in line with the theory. More precisely, a decrease in an additional unit of energy policy risk also enhances renewable energy. The marginal effect of LOGESG on RENERGY is also positive. The marginal effects of LOGECDEV on RENERGY are also positive, but the effect is decreasing. IQ has a negative marginal effect on RENERGY, but the effect is increasing.

4.3. Sub-sample Testing

The findings reported in Table 6 are estimated with the panel data of 137 countries, which validate the theoretical relation between renewable energy and energy policy risk. Conducting the estimations based on the development stage of the countries also sheds light on the analysis. More specifically, the nexus of energy policy risk and renewable energy might be affected due to the economic development stage of the nations. Therefore, sub-sample tests are run, dividing the sample into developed and developing countries.

Table 7 presents MMQR results for the sample of developed countries, revealing how RENENERGY reacts to LOGENPORISK, LOGECDEV, LOGESG, and IQ across different levels of renewable energy utilization. Overall, impacts of all variables show high statistical significance across almost all quantiles, except for LOGESG at 50%, where significance is not detected.

The main independent variable, LOGENPORISK, consistently provides a strong, significant, and positive influence over RENERGY across all quantiles, underscoring its predominant importance for renewable energy adoption in advanced economies.

Table 3: Cross-sectional dependence test

Test name	Statistic	P-value
LM	1.30	0.000
LM adj*	35.94	0.000
LM CD*	8.687	0.000

***Denote statistical significance at 1% level. Trend is included

Table 4: CIPS unit root test

Variable	Level	First difference
RENERGY	−1.902	−4.342***
LOGENPORISK	−1.616	−3.038***
LOGECDEV	−2.477***	−3.686***
LOGESG	−1.617	−3.694***
IQ	−1.860	−4.485***

***Denote statistical significance at 1% level

Table 5: Westerlund cointegration test

Measure	Statistic	P-value
Variance ratio	4.558	0.000

***Denote statistical significance at 1% level. Trend is included

Table 6: MMQR results of the whole sample

Variables	10%	25%	50%	75%	90%
Dependent variable: RENENERGY					
LOGENPORISK	0.533	1.358	2.644***	4.369***	5.519***
LOGECDEV	1.739***	1.416***	0.913**	0.238	−0.211
LOGESG	0.554	0.826	1.251*	1.820**	2.200***
IQ	−3.147**	−2.978***	−2.714***	−2.360**	−2.124*
Constant	11.140**	12.521***	14.675***	17.564**	19.491**

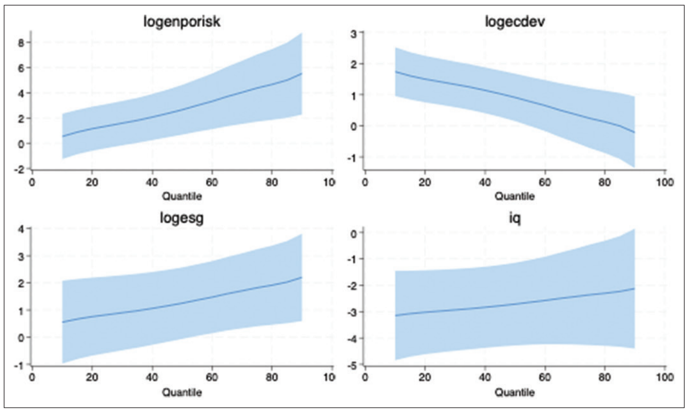
*, **, and *** denote statistical significance at 10%, 5%, and 1% levels, respectively

Table 7: MMQR results of developed economies

Variables	10%	25%	50%	75%	90%
Dependent variable: RENERGY					
LOGENPORISK	17.648***	17.702***	17.783***	17.910***	17.991**
LOGECDEV	12.589***	12.452***	12.247***	11.922***	11.714***
LOGESG	−26.937***	−17.784***	−4.158	17.466*	31.288***
IQ	−6.651***	−7.932***	−9.840***	−12.868***	−14.803***
Constant	−52.414**	−85.672***	−135.183***	−213.760***	−263.984***

** and *** denote statistical significance at 5% and 1% levels, respectively

Figure 1: The marginal effect of LOGENPORISK, LOGECDEV, LOGESG and IQ on RENERGY



Given that greater values of this variable indicate safer results, it is in line with the theoretical relationship. In other words, lower energy policy risk enhances renewable energy supplies. It aligns with Karlilar Pata (2024), who uses the method of cross-quantilogram to present that in the long term, energy policy uncertainty hampers the consumption of renewables in the context of the USA, even though in the short term the opposite is evident. Similarly, Korkut Pata (2024) studies this in the case of the USA, Germany, Japan, and Spain via multivariate quantile-on-quantile regression, revealing that energy policy uncertainty leads to a lowering of RENENERGY. This implies for policymakers that they should take a proactive approach via employing policies targeted to mitigating such risks, regardless of the extent to which renewables are consumed.

Likewise, LOGECDEV also has a positive and significant impact on RENENERGY across all quantiles, though its magnitude slightly decreases at higher quantiles. Stressing that while economic development is the basis for renewable energy incorporation, its relative impact diminishes as renewable energy becomes a more popular source. It aligns with Sadorsky (2009a), Apergis and Payne (2010), Menegaki (2010), Mohamed et al. (2019), Gozgor et al. (2020), and Dogan et al. (2021), whose' research comprises a sample of various advanced economies as well as different methodologies, but all provide growth in the economy positively impacting renewable energy.

In contrast, LOGESG poses a mixed impact, a negative and statistically highly significant influence at lower and a positive at higher quantiles, while at 50% there is no significance identified. In other words, within developed nations that consume lower rates of renewables, higher levels of LOGESG hinder this consumption, while higher rates of consumption are positively influenced by the score. The number of environmental technology patents, which is considered a proxy for the ESG environmental score, can be thought of as an effective mechanism for enhancing renewable energy consumption (Onofrei et al., 2024), which only partially aligns with the finding. Moreover, an investigation of CO_2 emissions, another element of the ESG index, found that the higher the CO_2, the lower the pledges to renewable energy in European countries (Marques et al., 2010).

Lastly, the results of IQ on RENERGY are observed to be negative and highly significant starting from 10% till 90%, with the increasing coefficients in developed nations. However, these findings oppose the outcomes of Sequeira and Santos (2018) and Uzar (2020), who systematically review research articles providing insights that democratic institutions promote renewables, and that in a perspective, the use of renewable energy is positively impacted by institutional quality.

The above-mentioned notion is also supported by the positive marginal effect of LOGENPORISK on RENERGY, as seen in Figure 2. More specifically, renewable energy consumption is also improved by a reduction in the extra unit of energy policy risk in advanced economies. LOGESG has a positive marginal influence on RENERGY as well. Although it is still favorable, LOGECDEV's marginal impact on RENERGY is waning. While the effect is growing, IQ has a marginally negative impact on RENERGY.

In comparison, the context of emerging markets depicts differing results of MMQR presented in Table 8. Overall, significance levels of the studied variables are less pronounced, and coefficients are much lower than in advanced markets. For instance, RENERGY is positively impacted by LOGENPORISK only at the 75th and 90th quantiles with 10% and 5% significance correspondingly. Which highlights that in developing markets, mitigating the risks related to energy policy becomes a strategically pressing challenge only after reaching high levels of renewables' integration. Which does not align with Alsagr and van Hemmen (2021), who find a significant positive impact of geopolitical risk on renewable energy usage in the case of emerging markets.

At all quantiles except the 10th, LOGECDEV has a considerable negative impact on RENERGY in the context of developing nations. It is inconsistent with a number of studies. In particular, Sadorsky (2009b) uses panel cointegration estimations that show per capita consumption of renewable energy is positively and statistically significantly impacted by improvements in real per capita income, and Apergis and Payne (2014) examine seven

Table 8: MMQR results of developing economies

Variables	10%	25%	50%	75%	90%
Dependent variable: RENERGY					
LOGENPORISK	−1.258	−0.413	0.672	2.113*	3.150**
LOGECDEV	−0.546	−0.946**	−1.461***	−2.144***	−2.636***
LOGESG	2.018**	2.070***	2.135***	2.223***	2.285***
IQ	−0.733	−0.314	0.222	0.936	1.449
Constant	34.143***	37.046***	40.775***	45.725***	49.287***

*, **, and ***denote statistical significance at 10%, 5%, and 1% levels, respectively

Figure 2: The marginal effect of LOGENPORISK, LOGECDEV, LOGESG and IQ on RENERGY in developed economies

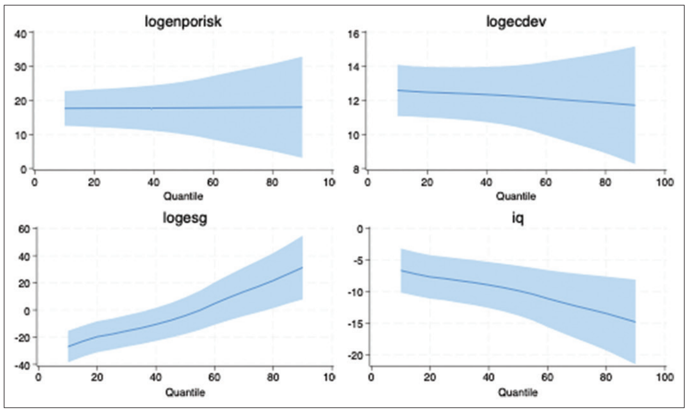
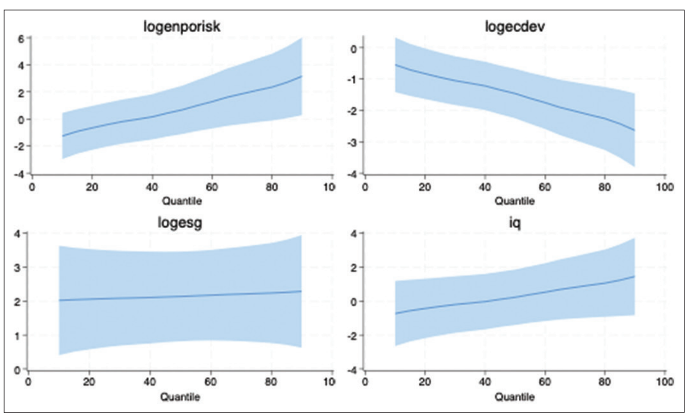


Figure 3: The marginal effect of LOGENPORISK, LOGECDEV, LOGESG and IQ on RENERGY in developing economies



Central American countries and find a similar effect of real per capita GDP on per capita renewable energy consumption based on the FMOLS output.

On the other hand, LOGESG affects RENERGY positively with a high significance level through each regarded quantile in developing nations. This finding is in alignment with Apergis and Payne (2014), Omri and Nguyen (2014), and Mukhtarov et al. (2023), studies considering CO_2 emissions (a component of ESG environmental performance) and renewables showing a positive significant relation.

Despite Wu and Broadstock (2015) and Rahman and Sultana (2022) presenting the impact of IQ on RENERGY as significantly positive in emerging economies, our outputs suggest no significance within this sample.

The above-mentioned notion is also supported by the positive marginal effect of LOGENPORISK on RENERGY, as seen in Figure 3 in emerging economies. More specifically, renewable energy consumption is also improved by a reduction in the extra unit of energy policy risk. LOGESG has a positive marginal influence on RENERGY as well. In contrast, LOGECDEV's marginal impact on RENERGY is negative within this context. IQ has a marginally positive impact on RENERGY.

5. CONCLUSION

For the 1st time, the study evaluates how energy policy risk affects the use of renewable energy. In order to do this, the robust MMQR approach is used. The empirical results provide insight into the literature that is currently available. More precisely, the theoretical relationship is validated by the fact that rising energy policy risk encourages the use of renewable energy. Since the influence is positive and significant between the 50th and 90th quantiles across the whole sample, which includes diverse stages of economic development, the results are solid. The system of the relationship between energy policy risk and renewable energy uses economic development, environmental quality, and institutional quality as control variables. The primary factors influencing the growth of renewable energy are the risks related to energy policy. All hazards are included by the study's composite energy policy risk index, and as high values indicate lower risk, renewable energy benefits from this index.

Since the costs of the low-carbon transition are thought to be substantial, it is true that managing economic risks aids in the promotion of renewable energy. More specifically, increasing investment spending in the field of renewable energy is essential. Effective fiscal and monetary policies are also necessary to persuade companies and consumers to support the production and selection of renewable energy-related projects.

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The use of renewable energy is also impacted by climate change issues. In order to produce power, renewable energy advancement needs the right environmental circumstances. Therefore, any environmental harm will eventually have a negative effect on the development of renewable energy. To maintain the steady growth of renewable energy, climate action should be encouraged.

Reaching a high standard of institutional quality contributes to the growth of renewable energy. Because institutional quality risks lead to more corruption, inefficient governance, and legal violence. All of these therefore have a negative impact on the growth of renewable energy. As a result, policies pertaining to renewable energy should carefully take institutional quality into account.

The study's findings provide policymakers with useful guidance in the area of renewable energy. In particular, decision-making procedures need to emphasize how energy policy risk affects the adaptation to renewable energy. The energy policy risk index's components have a significant impact on how renewable energy is integrated. The study's conclusions can particularly be applied to the attainment of SDGs 7 and 13, as the adoption of renewable energy not only encourages the use of clean, inexpensive energy but also aids in the fight against climate change.

The study has certain limitations even if it covers one of the most important literary topics. More precisely, it would be intriguing to confirm the findings using the extra estimates that the energy policy risk components have included. On the one hand, nevertheless, such elements have been thoroughly examined in the literature in relation to renewable energy. The additional estimations, however, would overwhelm the manuscript's length.

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