International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(5), 730-740.

Does Energy Policy Risk Threaten Energy Sources Diversification?

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Received: 13 May 2025 **Accepted:** 09 August 2025 **DOI:** https://doi.org/10.32479/ijeep.21140

ABSTRACT

Recently, to enhance energy sources diversification is becoming on the main priorities in the world. However, effective diversification of energy sources is affected by risks associated with energy policy. In this context, the study explores the effect of energy policy risk on energy sources diversification of the panel of 64 countries spanning the period from 2000 to 2018, employing Method of Moments Quantile Regression. The findings indicate that energy policy risk negatively influences on energy sources diversification across all the quantiles, 10-90%. Moreover, the impact of Chinese energy investment on energy sources diversification is investigated using Difference-In-Differences method since Chinese energy investment might serve as an additional factor shaping energy policy in the region. The results show that Chinese energy investment also has a negative effect of energy sources diversification. The policymakers should implement effective policies considering those factors in order to achieve productive diversification of energy sources.

Keywords: Energy Policy Risk, Energy Sources Diversification, MMQR, DID Method
JEL Classifications: O44, Q20, Q40, Q57

1. INTRODUCTION

Energy policy is crucial in encouraging environmentally friendly and carbon-free transitions in light of the world's growing climate crisis. The US has announced several energy plans, including the "Net Zero Emissions Strategy 2050" (UNFCCC, 2021), to achieve the goal of a completely sustainable energy system by 2050, which thoroughly addresses important topics such sustainable energy, essential nutrients, carbon reduction, and energy storage. Effective energy policymaking is essential for both advancing the economy and easing the shift to more sustainable energy integration. Problems, commercial disagreements, and political strains are examples of geopolitical hazards that have a significant influence on policy regarding energy determinations because they are able to alter energy prices, undermine the stability of energy supply, and endanger the energy security of a country (Cai and Wu, 2021). In order to ensure long-term viability, energy policies must prioritize resource variety and encourage the discovery and use of new energy resources (Sun et al., 2024).

The concept of comparative advantage of Ricardo states that due to variations in their respective productivity levels, countries with various production sources will have the opportunity to concentrate on a wide range of economic endeavors. One of the key issues in light of the changing climate is attracting investments in sustainable energy sources. However, there is a dearth of study on how risk or uncertainty impacts the deployment of renewable energy, despite the fact that several studies look at the factors that drive renewable energy.

Empirical research makes it abundantly evident that greater ambiguity in economic policy influences financial development, innovation, macroeconomic indicators, business-level capital investment, firm profitability and cash flow, economic growth and tourism (Ashraf and Shen, 2019). The efficiency of energy-saving and green measures in improving the quality of the environment is examined by Charfeddine and Rahman (2025). The results show that environmental quality is improved by exceeding specific threshold levels of energy-saving and green policies, as demonstrated by the load capacity factor's improvements, reductions in ecological footprints and emissions of carbon dioxide. The supply chain has a significant impact in reinforcing the energy efficiency policy cycles of a few developing Asian nations, according to a study by Khan et al. (2025). When countries started depending more and more on fossil fuels to meet their energy demands in the early 20th century, diversification attempts in the energy industry began. Furthermore, the supply of energy is a essential component of nation states' economic stability and security due to the unequal and limited distribution of energy resources worldwide (Radovanović et al., 2017). Different nations require different kinds and amounts of energy resources to suit their energy requirements. A dynamic energy mix is characterized by the different types and quantities of energy sources used in each nation (Rubio-Varas and Muñoz-Delgado, 2019). Energy is an essential aspect of economic progress, but energy production releases carbon dioxide, a major contributor to climate change and environmental degradation. Therefore, a variety of energy sources can help achieve both environmentally sustainable growth and economic expansion (Ahmed et al., 2022). That is required to have secure energy systems evolving due to the increasing effects of climate change, the drive for clean energy transitions, and the characteristics of renewable energy sources (IEA, 2024).

Countries can stimulate economic growth, technological progress, and widespread use of innovation through energy diversification. Studies have shown that energy diversification has created momentum for even more technological development, leading to even more economic growth in the future. Diversification, defined as expanding the product structure, has been designated as one of the main policy priorities of the region (Kireyev, 2021). As a result, the dynamics of energy supply and demand can cause the relationship between diversification of energy sources and economic outcomes to move in many directions, from energy diversity to economic development (Gozgor and Paramati, 2022). Energy diversification and economic policy uncertainty indices are combined in Dagar et al.'s (2024) investigation of energy security. Based on the authors' results, the range of energy sources decreases, and energy security is adversely affected when economic policy uncertainty rises. Energy diversity is helpful for reducing energy risk, according to a study by Cooray et al. (2025), although they point out that its efficacy varies depending on the nation's economic circumstances. Energy diversification's impact on improving company performance is demonstrated by Gozgor et al. (2024), who also discover that energy diversification has a greater beneficial effect on firm performance in companies with higher levels of corporate' social responsibility participation.

Theoretically, energy policy and the diversification of energy sources are related, but this relationship has not been examined in literature. Therefore, to fill in this gap of literature, the current work assesses the impact of energy policy risk on energy sources diversification using the sample of 64 countries due to data availability. To obtain robust results, the research employs Method of Moments Quantile Regression which allows to check the effect of energy policy risk on the energy sources diversification across different quantiles. Moreover, the influence of energy policy caused by Chinese energy investment is also investigated to consider potential endogeneity running Difference-In-Differences method. Every estimate confirms the theoretical connection; hence the study adds to the body of knowledge in two ways.

The remaining of the manuscript is shaped in the following way: Section 2 provides literature review; Section 3 represents the data and methodology; Section 4 includes empirical estimations, and lastly Section 5 concludes and presents policy suggestions.

2. LITERATURE REVIEW

2.1. Theoretical Background

One of the most important strategic approaches in national and international energy planning is energy diversification. To enhance energy security, environmental sustainability and economic stability, it aims to lessen the dependence on one or limited energy sources. The environmental effects of energy diversification can be explained from a variety of theoretical perspectives, and they can be both negative and positive depending on the energy transition`s time frame and the direction of diversification.

The benefits of diversity in energy planning for risk management have been widely explained by portfolio theory, which was first proposed by Markowitz in 1952. This theory states that by distributing investments over a variety of resources, a balanced and diversified energy portfolio may reduce risks, boosting resistance to outside shocks and promoting supply security and price stability (Roques et al., 2008). In support of this, Francés et al. (2013) contend that energy diversity improves the reliability of the energy supply and lowers fuel price volatility. In order to achieve these advantages, resources need to be complementary, meaning that attributes like cost or availability must be negatively associated (Mazo et al., 2020).

Simultaneously, the environmental Kuznets curve theory posits that as economic growth progresses, environmental consciousness rises and leads to changes in production and consumption patterns which promote sustainability. According to Hoang et al. (2025), as businesses struggle to maintain their competitive advantages and adapt to changing customer expectations, this social transformation may act as a catalyst for the adoption of renewable energy.

In recent times, researchers have emphasized how important institutional quality and energy policy risk are in determining the results of energy diversification policies. Long-term expenditures on renewable energy and developing technologies may be discouraged by regulatory volatility, subsidy withdrawals, and uncertain energy transition paths. Yuen and Yuen (2024) show that economic policy uncertainty lowers spending on renewable energy research and development, which hinders innovation in accordance with the theory of policy risk and uncertainty.

In a similar vein, Pata (2024) reveals that policy unpredictability hinders the energy transition process and erodes investor confidence. In addition, the significance of governance quality and regulatory frameworks is emphasised by institutional theory. Lockwood (2022) argues that while weak institutions frequently increase policy risks and perpetuate fossil fuel dependency, strong, transparent institutions may create positive feedback loops leading to diversification. Marra and Colantonio (2022) support this notion by demonstrating that nations with effective and stable regulatory frameworks implement renewable technology more quickly. Furthermore, Lockwood (2013) highlights the significance of political economy dynamics, pointing out that lobbying efforts and special interests might take advantage of institutional flaws to thwart the shift to a more diverse energy mix.

When taken as a whole, these theoretical perspectives and empirical results highlight how crucial it is to build institutional capacity and lessen uncertainty around energy policy in order to promote energy diversity. In conclusion, institutional and political economy theories emphasise the role of governance and vested interests; portfolio theory presents diversification as a reasonable risk management strategy; and the environmental Kuznets curve reveals that as economic growth advances, environmental consciousness rises and leads to favour sustainability. These frameworks, however, might be upset when energy policy risks are high, which may result in fewer investments, delayed innovation, and a failure to diversify. Consequently, attracting investments and guaranteeing a safe, sustainable, and diverse energy future depend heavily on the design of energy policies that are both effective and rational.

2.2. Impact of Energy Policy Risk on Energy Sources Diversification

Today, the relationship between energy policy risks and diversification of energy sources is a very relevant topic, as changes in the energy market and political decisions around the world significantly affect the economy and the environmental situation. Energy policy risk, encompassing factors like geopolitical instability and policy uncertainty, significantly influences energy source diversification, prompting countries to seek more secure and diverse energy portfolios. In academia, the scholars examine the relation between energy policy risk and the variables associated with energy sources. More precisely, Erdogan and Leirvik (2025) examine how energy policy uncertainties drive mineral-dependent renewable energy production. They discover that the generation of renewable energy powered by cobalt, graphite, copper, nickel, and rare earth elements might be seriously jeopardized by energy policy uncertainty. The impact of government effectiveness, energy policy uncertainty, climate policy uncertainty, and economic policy uncertainty on renewable energy in the United States is examined in Karlilar's study (2024). 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. Feng and Zheng (2022) use a panel of 22 nations from 1985 to 2019 to examine how economic policy uncertainty affects innovation in renewable energy. The findings show that uncertainty in economic policy has a favorable impact on innovation in renewable energy for at least 3 years. The impact of geopolitical risk on carbon dioxide emissions is examined by Chen et al. (2024). A significant long-term connection between between the associated variables in the empirical models is demonstrated by the panel cointegration tests. Per capita income, the capital-labor ratio, and geopolitical risk all contribute to the disparity of CO_2 emissions, according to panel data regression estimates. Wang et al. (2023) compare various energy sources' diversification and hedging capabilities in an unpredictable environment. Their findings reveal that the energy policy uncertainty has an asymmetrical and often a positive impact on energy cross-market linkages. According to Dagal et al. (2024), energy security can be estimated by combining energy diversification and economic policy uncertainty indicators. The results show that when economic policy uncertainty increases, the variety of energy sources decreases, significantly harming energy security. Using monthly time series, Lin and Zhang (2025) examine the time-varying relationships between energy metals, renewable energy, and geopolitical risk. various time periods have various impacts on renewable energy from shocks resulting from geopolitical risk. In order to mitigate risk and enhance China's energy security, this study makes specific policy recommendations. For example, it highlights the importance of diversifying the sourcing of energy metals as the country continues its shift to alternate sources. Fan et al. (2024) examined how energy mix diversification affected the risk of energy security in the 22 OECD countries. The results of the Granger non-causality test show a relationship between energy mix diversification and energy security. Tobash et al. (2024) examine the connections between energy use and geopolitical risk. They find that the use of renewable energy is significantly positively impacted by geopolitical risk. This suggests that acceptance and use of renewable energy sources are increasing in tandem with global risk.

2.3. Impact of Economic Development on Energy Sources Diversification

Economic development has a significant impact on energy source diversification. As economies grow, their energy needs evolve, and they become more reliant on a variety of energy sources to ensure reliable, sustainable, and cost-effective energy supply. Shahbaz (2024) examines the connection between the energy diversification of China and globalization of the economy. According to their causality study, energy diversification is positively impacted by economic globalization. According to Yusoff et al. (2024), there seems to be a sustained relationship between the GDP of six ASEAN nations and using sustainable energy. Economic growth appears to be the main factor propelling ASEAN's embrace of renewable energy, as evidenced by the strong correlation between GDP and the utilization of renewable energy. Using a Granger causality test, Esposito (2023) investigates the present relationship between economic growth and the use of renewable energy in Finland for the years 1990-2019. The Granger Causality test demonstrates how renewable energy usage might impact the rate of future growth, and the analysis clearly shows that economic growth and the use of renewable energy have a feedback relationship. Shahbaz et al. (2023) investigate the relationship between financial development and energy diversification in the Australian economy. According to their empirical findings, financial development has a positive effect on energy diversification. Energy diversification is positively connected with natural capital. Liu et al. (2023) argue that energy diversification is critical in terms of economic, political, and environmental sustainability. The goal of this research is to look at how energy diversification contributes to sustainable development in the Asia-Pacific Economic Cooperation. The results suggest that energy diversification has a positive and significant impact on APEC countries' long-term development.

2.4. Impact of Globalization on Energy Sources Diversification

The growth of the digital economy, which currently contributes between 4.5% and 15.5% of the world's GDP and has the potential to sustainably promote social and economic advancement, has coincided with the growth of globalization (Gozgor et al., 2020). Globalization in the economy and diversification of energy are related ideas that support stability, energy security, technological innovation, and protection of the environment (Shahbaz et al., 2023; Zhang et al., 2023). Sustainable energy is encouraged by higher levels of economic integration, and the evidence is consistent across several metrics of globalization. The growth of sustainable energy is essential to ensuring long-term stability in the context of globalization, and the digital economy is a key factor in this process (Zhan et al., 2022). Evidence suggests that digital economies may change the structure of energy consumption, decrease CO_2 emissions, and enhance the efficiency of energy use (Kramers et al., 2014). The consequences of globalization and foreign direct investment on energy diversity in BRICS (Brazil, Russia, India, China, and South Africa) is examined by Qamruzzaman (2022) utilizing a recently developed indicator for energy variety. The long-term coefficients of globalization and foreign direct investment showed a favorable and a significant statistical connection with energy diversification. Research by Sun et al. (2024) examines the trends in energy diversification in six developing Asian countries, determining how globalization, economic growth, innovation, overall investment, and pressure from the worldwide supply chain affect energy diversity. According to the study's findings, worldwide supply chain pressures and total investment have a good effect on energy diversification, and innovation is a key component in boosting it. Zhang et al. (2021) study examine how financial development, foreign direct investment, and economic policy uncertainties affect the use of renewable energy. The results of the study indicate that while financial development and foreign direct investment contribute positively to energy diversification, policy uncertainty has a negative impact on energy diversification, or the integration of renewable energy. According to the report, the process of energy diversification is aided by both foreign ownership participation and domestic capital accumulation in the energy industry.

2.5. Impact of Government Effectiveness on Energy Sources Diversification

Government effectiveness, one of the factors that indicates the ability of governments of countries around the world to implement public policies, provide services, effectively manage resources, and achieve overall development, in turn affects the direction of energy resource diversification. Because the tasks of developing policies and laws aimed at diversifying energy sources, supporting investment and innovation attraction are carried out by the government. The research community has its own scientific views on this matter. The connections between government economic actions in the power industry and energy security indicators are examined by Karpavicius et al. (2025). Their findings suggest that policies that support energy efficiency, diversification, and renewable energy are essential to securing a steady and sustainable supply of power. They also call for more study that integrates data analytics and dynamic models to develop complete energy security plans. A study has been done by (Cooray et al., 2025) claims that government efficacy is a stand-in for institutional quality, which is a potentially significant variable in the link between energy risk and energy diversification. The study found that government effectiveness helps to improve the efficiency of energy diversification. This can help to reduce energy risk, as effective governance and government spending can have an impact on reducing energy risks. Sun et al. (2024) investigate the impact of factors influencing government efficiency on energy diversification, such as global supply chain pressures, innovation, aggregate investment, globalization and economic growth, by examining energy diversification trends in six developing Asian countries from 1998 to 2021. The study's findings suggest that economic growth and more globalization, or integration into the global economy, encourage energy diversification. Dong et al. (2024) study whether the capability of the government to develop and set up rational legislations is able to ensure the association of renewable energy utilization and natural resource rents. This implies that by creating and implementing reasonable laws, the government may lessen and even reverse the curse of natural resources on renewable energy. According to Zhou and Feng (2024), policymakers' top priority in the quickly changing and technologically transformed period is managing natural resources in order to achieve long-term economic growth. Their analysis advises improving government efficiency, diversifying the resource market, and increasing investment in digitization, research and development, and renewable energy.

2.6. Impact of Population on Energy Sources Diversification

With population growth, it is anticipated that energy demand would rise. This leads to the diversification of energy sources, that is, the increase in demand for traditional and renewable energy sources. The long-term effects of human capital development on Ghana's use of nonrenewable energy are investigated by Amoako et al. (2023). Their findings show that urbanization and foreign direct investment have a positive impact on nonrenewable energy use. In a similar vein, Pradhan et al. (2024) focuses on emerging nations, particularly those in South Asia, in order to take a fresh approach to researching the nexus among carbon dioxide emissions, economic growth and energy consumption.

Their findings indicate that population and financial development boost the consumption of energy. Muzayanah et al. (2022) investigate the population density`s influence on the overall energy consumption in Indonesia. Their findings indicate that population density has a favorable effect on total energy usage, which includes both electricity and fuel. According to Sugiharti et al. (2025), the region's rising CO_2 emissions are largely due to economic growth, population growth, and increased energy intensity. This report emphasizes the significance of diversifying the energy mix, increasing energy efficiency, and rethinking economic and demographic development methods to improve ASEAN's environmental standards. According to Sadoughipour et al. (2025), population growth and economic development are the main causes of the daily increase in the world's power demand. Renewable energy is crucial for supplying this growing demand for electricity in order to lower greenhouse gas emissions. The complex links between Vietnam's population trends, carbon dioxide (CO_2) emissions, and utilization of renewable energy are examined by Mai et al. (2024). The results demonstrate a positive trend in the use of renewable energy, with significant contributions from hydropower, wind, and solar power.

3. DATA AND METHODOLOGY

3.1. Data

The current study assesses the impact of energy policy risk (EPOLR) on energy sources diversification (ENDIV) in order to validate the theoretical linkage. To this end, the panel of 64 countries are applied over the period of 2000-2018. The main variables of interest are energy sources diversification index, the dependent variable, and energy policy risk score which is the main independent variable. The high values of both variables mean the high level of diversification and risk, respectively. The control variables of the study are economic development (PGDP), measured as per capita GDP in US dollars, government effectiveness (GEF) index, given as an index ranging from −2.5 to 2.5, number of population (POP), and globalization (KOF), given as a Kof index. The energy sources diversification is obtained from Gozgor and Paramati (2022), whereas energy policy risk score is downloaded from Refinitive[1]. The data of per capita GDP, and population is obtained from World Bank. The data for government effectiveness index is downloaded from Our World in Data. Lastly, Kof globalization index is obtained from KOF Swiss Economic Institute.

Table 1 provides the descriptive statistics of the respective variables. More detailed, ENDIV is 3.098 on average in countries. EPOLR is a bit higher than the average which is 69.801. Per capita gross domestic product is counted as 22201.12 USD. Average population is 82,600,000 people. The effectiveness of government is evaluated as 0.6842 on average, and average globalization level is 72.7302.

All the variables except GEF are transformed into natural logarithm such as LOGENDIV, LOGEPOLR, LOGPGDP, LOGPOP and LOGKOF. GEF is not transformed into logarithm since it contains negative values. Thus, the general specification of regression equation can be prescribed as follows:

$$LOGENDIV_{it} = \alpha_0 + \alpha_1\, LOGEPOLR_{it} + \alpha_2\, LOGPGDP_{it} + \alpha_3\, LOGPOP_{it} + \alpha_4\, GEF_{it} + \alpha_5\, KOF_{it} + \varepsilon_{it} \quad (1)$$

Where α_0 is an intercept, α_1, α_2, α_3, α_4 and α_5 are the impact coefficients of the explanatory variables, ε is an error term, i is a cross-sectional dimension, and t is a time dimension.

In Table 2, the results of heteroscedasticity tests are given. Both White`s and Breusch-Pagan tests indicate the presence of the heteroscedasticity since P-values are significant within 1% and 5% levels. The existence of the heteroscedasticity determines the econometric models to be applied. More specifically, under the presence of the heteroscedasticity OLS based methods lose their effectiveness since the assumptions of OLS are mean value and normal distribution. Therefore, heteroscedasticity and non-linearity consistent methods should be applied when heteroscedasticity is detected.

3.2. Methodology

3.2.1. Method of moments quantile regression (MMQR)

Energy sector is vulnerable to the economic fluctuations such as financial crisis, COVID-19 pandemic, trade wars and etc. Financial crisis might interfere the relationship between government policy and renewable energy adoption (Wang et al., 2022). Moreover, in the Brent market, the COVID-19 effect is more pronounced during the turbulent times (Sharif et al., 2024). Therefore, the study employs quantile regression method in order to empirically examine the influence of energy policy risk on energy sources diversification. Previous works in the literature also show that quantile regression is consistent and effective to explore the energy variables. More precisely, recent studies (Shahbaz et al., 2025; Cooray et al., 2025; Kuziboev et al., 2025a; Kuziboev et al., 2025b) utilize the quantile regression methods when applying energy risk variables, energy source diversification, and other energy-related variables. Following the previous studies, this work runs Method of Moments Quantile

Table 1: Descriptive statistics

Variable	Observations	Mean value	Standard deviation	Minimum values	Maximum values
ENDIV	1216	3.098	0.5824	1.6058	4.5819
EPOLR	1216	69.801	24.3473	1.86	100
PGDP	1216	22201.12	22281.88	394.583	123679
POP	1216	82,600,000	223,000,000	281,205	1400,000,000
GEF	1216	0.6842	0.9082	−1.2097	2.4696
KOF	1216	72.7302	11.7422	37	91

1 Accessed by Prof. A. Nazif Çatık, Department of economics, Ege University, Turkiye. Email: a.nazif.catik@ege.edu.tr

Table 2: Heteroscedasticity test

Test	Chi-square	P-value
White's test	276.22	0.0000
Breusch-Pagan test	5.21	0.0224

***P<0.01, **P<0.05

Regression (MMQR) in order to investigate the impact of energy policy risk on energy sources diversification.

A reliable estimator for determining the importance of the explanatory variables across different ENDIV quantiles is MMQR. Equation 1 is transformed into the MMQR for this purpose in a way described below (Machado and Silva, 2019):

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

β denotes the vector which includes the variables' coefficients. α_i is the individual fixed effect, whereas δ_i is country is quantile-specific fixed effect. Zit is a vector for the explanatory variables's established differentiable transformations, and it satisfies the probability $P\left\{\delta_i + Z_{it}^{'}\gamma > 0\right\} = 1$. U_{it} is an unobservable random variable with no correlation to explanatory variables. In order to meet the following moment criteria, it has been normalised: U_{it}'s expected value is zero, $E(U_{it}) = 0$, while U_{it}'s expected absolute value is one $E(|U_{it}|) = 1$. The first-moment conditions are used to estimate the parameters of Equation 2, i.e. α_i, β', δ_i, γ' and q(τ)', while accounting for the explanatory variables' exogeneity. This estimating technique aligns with the methodology outlined by Machado and Silva (2019). As a consequence, the conditional quantile specification for the model is exactly as follows:

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

This takes a panel of individuals into account seen across a number of time periods and calculates the response variable ($LOGENDIV_{it}$)'s conditional quantiles in respect to the covariates. The scalar parameter $i(\tau) \equiv (\alpha_i + \delta_i\, q(\tau))$ in parentheses is the individual i's quantile-τ fixed effect, or the distributional impact at τ. The model given is estimated using one-step GMM estimator[2] built by Hansen (1982).

3.2.2. Difference-in-differences (DID) method

Chinese energy investment may also influence the diversification of energy sources. More precisely, China has been able to reduce its dependence on fossil energy sources and conduct diversification of its energy portfolio through creating renewables like hydropower, wind, and solar. John Hopkins University`s China-Africa Research Initiative reports that the investment from China to Africa is surged from US$ 75 million in 2003 to US$ 5 billion in 2021 (China Africa Research Initiative, 2023). Wen et al. (2024) investigates the correlation between Chinese investment and energy independence in Africa, positing that the influx of Chinese capital is enhancing indigenous energy production capability. Since the proclamation of the Belt and Road Initiative (BRI) by China in 2015, much attention has been directed towards the environmental repercussions of China's energy investments in the nations participating in the BRI. The driving mechanism and economic and social benefits of China's BRI renewable energy investments provide a foundation for encouraging renewable energy investments in nations like Pakistan, which can then benefit from the global trend of low carbon transition that is driving social and economic growth (Li et al., 2022). It is commonly acknowledged that access to and investment in renewable energy are essential to reaching nations' objectives for economic growth and sustainable development. In the BRI middle corridor nations that border the Black Sea, Tatar et al. (2025) provide an analytical evaluation technique for investment risk variables for renewable energy (RE). The results demonstrate that Türkiye and Romania, two Black Sea coastal nations in the BRI mid-corridor, are the most favorable choices for Chinese companies seeking to invest abroad in renewable energy.

This study uses the DID approach to objectively investigate how Chinese energy investment affects LOGENDIV. After the BRI's inception in 2013, which signaled a sharp rise in China's international energy and infrastructure spending, the experimental period runs from 2014 to 2019 (Massimiliano, et al., 2024). A DID design is based on this time frame and the regional differences between nations that get Chinese energy investment and those that do not. In order to address possible endogeneity issues, the DID technique is used to determine the causal influence of Chinese OFDI on LOGENDIV (Blundell and Dias, 2002; Meyer et al., 1995). DID model used in the study can be specified as:

$$LOGENDIV_{it} = \beta_0 + \beta_1 DY_{it} + \beta_2 LOGPGDP_{it} + \beta_3 LOGPOP_{it} + \beta_4 LOGKOF_{it} + \beta_5 LOGKOF_{it} + \varepsilon_{it} \quad (4)$$

Where, DY_{it} can be expressed as $DY_{it} \times YEAR_{it}$; $YEAR_{it}$ is used to determine if the BRI was put into action during the year *t*. For the years 2000 through 2013, the variable is set to 0; for all other years, it is set to 1. Moreover, DID method is used with one-way fixed effects.

4. EMPIRICAL RESULTS

4.1. The Main Estimations

As a first step, the cross-sectional dependence test is run to assess whether the cross-sectional dependence exists or not among residuals. For this purpose, the Lagrange Multiplier (LM) cross-sectional dependence (CD) test is conducted. The results are shown in Table 3. Non-significant test statistics show no cross-sectional dependence among panel units.

The absence of the cross-sectional dependence leads to the application of the first-generation methods for unit root and cointegration tests. Therefore, Levin et al. (2002) test is applied to check the stationarity of the variables. The unit root test outcomes are given in Table 4, indicating the integrated order of the variables as the first differences.

As a next step, the cointegration test is run in order to examine the long-run relation among the studied variables. Pedroni (2004) cointegration test is utilized to investigate this. The findings are

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

provided in Table 5. The findings presented in Table 5 suggest the presence of long-run relationship among the variables, as evidenced by the significant t-statistics at the one percent level across all tests, including the Modified Phillips-Perron t, Phillips-Perron t, and Augmented Dickey-Fuller t. This supports the long-term equilibrium relationship between LOGENDIV and independent variables.

Since the long-run relationship exists among the employed variables, as a next step, the model estimations are calculated. More precisely, MMQR method is employed to explore the influence of energy policy risk and other explanatory variables on energy sources diversification. The findings are provided in Table 6. According to the estimations, LOGEPOLR has a negative effect on energy sources diversification across all the quantiles. This result is in line with the theory. The finding is similar with the result obtained by Charfeddine and Rahman (2025) who indicate that energy policy efficiency promotes environmental quality (a proxy for renewable energy development). However, Dagar et al. (2024) find a positive correlation between energy policy uncertainty and energy diversification. This means that as energy policy uncertainty increases, the diversity of energy sources tends to decrease.

At all quantiles, LOGPGDP also shows a strong inverse association with energy diversity, indicating that more economic growth does not always translate into energy diversification. The findings of Apergis and Payne (2010), who contended that economic development may increase traditional energy dependency in the absence of focused green initiatives, are consistent with this finding. Meanwhile, Gozgor and Pramati (2022) finds that major economies, including G20 countries, experience positive economic growth in the long run with increased energy diversification. However, in the short term, some countries within the OECD and G20 may face negative economic growth due to energy diversification. Additionally, low-income economies do not benefit from energy diversification in either the short or long term, indicating the need for caution in energy transition strategies.

Moreover, in the quantiles of 25-90%, the variable LOGPOP exhibits a strong negative influence on energy diversification, suggesting that fast population expansion may reinforce existing fossil fuel-based infrastructures and raise energy consumption, hence impeding diversification. This finding is in line with Sadorsky's (2014) research, which emphasizes the difficulties the transition to renewable energy faces due to population expansion. In addition, Seriño (2018) confirms that population growth is a significant factor influencing the need for diversification in energy sources to meet rising energy demands.

However, in quantiles of 75-90%, GEF shows a positive and statistically significant influence on energy diversification, indicating that energy diversification is encouraged by improvements in governance and green economy frameworks, particularly at higher levels of diversification. The findings of Kahia et al. (2017), who highlighted the significance of institutional quality in promoting the adoption of renewable energy, are supported by this result. Finally, LOGKOF continuously shows a negative correlation in the quantiles of 25-90%, suggesting that globalization may increase integration into fossil fuel markets in the absence of robust environmental regulations. This study is in accordance with Sadorsky (2012), who pointed out that unless there is a change in trade and investment patterns towards renewable energy, globalization frequently increases emerging nations' dependency on fossil fuels.

Across quantiles, Figure 1 illustrates the marginal effects of significant variables on energy source diversification (LOGENDIV). The substantial negative impacts of economic development (LOGPGDP) and energy policy risk (LOGEPOLR), particularly at lower quantiles, suggest that economic growth and policy instability may impede diversification in less developed energy systems. Population size (LOGPOP) also shows a consistently negative, though flatter, effect. On the other hand, diversification is favourably impacted by government effectiveness

Table 3: Cross-sectional dependence test

Test name	Statistic	p-value
LM CD*	1.418	0.1561

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

Table 4: Levin-Lin-Chu unit root test

Variable	Level	First difference
LOGENDIV	0.032	0.000
LOGEPOLR	0.000	0.000
LOGPGDP	0.000	0.000
LOGPOP	0.326	0.000
GEF	0.000	0.000
LOGKOF	0.000	0.000

***denote statistical significance at 1% level

Table 5: Cointegration test of Pedroni

Test	Statistic	P-value
Modified Phillips-Perron t	8.9777	0.000
Phillips-Perron t	−11.0800	0.000
Augmented Dickey-Fuller t	−10.5577	0.000

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

Table 6: MMQR results

Quantiles	10%	25%	50%	75%	90%
Dependent variable: LOGENDIV					
LOGEPOLR	−0.0558***	−0.0501***	−0.0424***	−0.0359***	−0.0325**
LOGPGDP	−0.0246***	−0.0294***	−0.0361***	−0.0416***	−0.0445***
LOGPOP	−0.0881*	−0.0877**	−0.0872***	−0.0868***	−0.0866***
GEF	0.0088	0.0119	0.0161*	0.0195**	0.0214**
LOGKOF	−0.1040*	−0.0970**	−0.0874**	−0.0794**	−0.0752**
Constant	3.4401***	3.4503***	3.4643***	3.4760***	3.4821***

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

Figure 1: The marginal effects of energy policy risk (LOGEOPLR), economic development (LOGPGDP), population (LOGPOP), government effectiveness (GEF) and globalization (LOGKOF) on energy sources diversification (LOGENDIV)

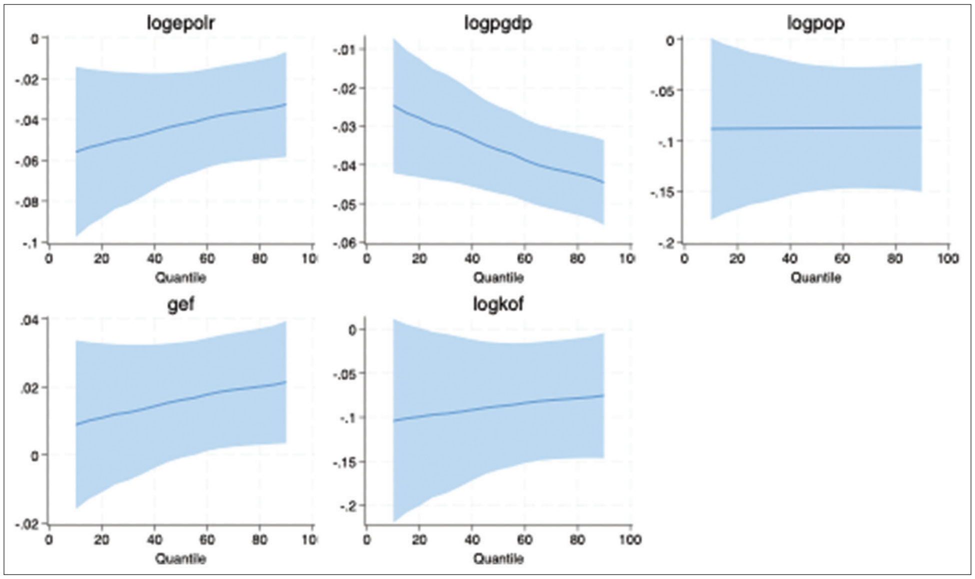

Table 7: Dependent variable: LOGENDIV

Variables	Fixed effects DID regression without control variables	Fixed effects DID regression with control variables
DY	−0.0121**	−0.0128**
TIME	−0.0444***	−0.0323***
TREATED	-	-
LOGPGDP	-	−0.0312***
LOGPOP	-	0.0315
GEF	-	0.0178**
LOGKOF	-	−0.0056
Constant	1.1289***	0.8983*
P-value of F-statistic	0.000	0.000

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

(GEF), especially at higher quantiles, suggesting that strong institutions support broad energy portfolios. Finally, diversification is severely impacted by globalization (LOGKOF), particularly in economies with lower levels of diversity.

4.2. Endogeneity Check

4.2.1. Difference-in-difference method (DID)

The study applies Difference-in-Difference method in order to explore the possible endogeneity caused by Chinese energy investment. The Chinese energy investment is treated as a policy change in countries, affecting on energy sources diversification.

The results obtained by both models in Table 7 express that Chinese energy investment has an adverse effect on energy sources diversification in countries. More specifically, the treatment variable DY has a negative and statistically significant coefficient (−0.0121) in Model 1, which eliminates control factors. This suggests that Chinese energy investment is linked to less diversity. This relationship is reinforced in Model 2, which includes structural control variables; here, the DY coefficient becomes slightly more negative (−0.0128) and remains significant at the 5% level. These results provide robust evidence that Chinese energy investments lead to a narrowing of energy portfolios in host countries.

5. CONCLUSION AND POLICY IMPLICATIONS

The current study examines the effect of energy policy risk on energy sources diversification in the case of 64 countries. The overall estimations show that energy policy risk is a threat to the diversification of energy sources. These findings are in line with the theoretical linkage. Admittedly, risks associated with energy policy discourage energy sources diversification. More precisely, energy policy risks such as disruption in energy supply, weak management can affect on diversifying energy sources. Since energy sources diversification is mostly dependent on good management for renewable energy transition, and increasing other sources of energy, any policy risks negatively impact on the effective diversification. Furthermore, interruption of various energy types' supply leads to a fall in energy diversification.

On the other hand, mediating effect of economic development, demographic changes, globalization and institutional quality also play necessary roles in energy sources diversification. More specifically, effective energy policies require strong economic background for investment spendings, good institutions for effective policy decisions. Moreover, demographic fluctuations and globalization require permanent adjustments of energy policies. Therefore, those factors should be considered in the relation between energy policy risk and energy sources diversification as mediators.

Apart from own energy policy, exogenous energy policies should be also considered. More precisely, the work explores the impact of Chinese energy policy on host countries' energy diversification. The results represent that Chinese energy policy i.e. energy investment also harmful for the energy sources diversification in countries. Admittedly, China is investing on fossil fuels in foreign countries in order to ensure its own energy needs. As a result, Chinese energy investment is adversely impacting on energy sources diversification since Chinese energy investment is ignoring renewable energy sources in foreign countries. In order to cope with the risks caused by Chinese energy investment, the nations should implement rules to enhance foreign investment on renewable energy sector.

The research also has some limitations. More precisely, the data of energy sources diversification is only available for 64 countries. It would be interesting to explore the global sample in order to predict the global energy sources diversification affected by energy policy risk. However, the data availability does not allow to investigate it. Therefore, this drawback might serve as a future research agenda.

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