Pol. J. Environ. Stud. Vol. 34, No. X (2025), 1-19
DOI: *10.15244/pjoes/188189* ONLINE PUBLICATION DATE:

Original Research

Does Geopolitical Risk Endanger Energy Resilience? Empirical Evidence from Cross-Country Data

Lu Chen[1], Tianyi Zhang[2*], Ci Zhang[2], Fangkun Liu[3], Yanchao Feng[2]**

[1]College of Criminal Justice, Henan University of Economics and Law, Zhengzhou 450046, China
[2]Business School, Zhengzhou University, Zhengzhou 450001, China
[3]Business School, Nanning University, Nanning 530200, China

Received: 27 January 2024
Accepted: 1 May 2024

Abstract

With geopolitical tensions rising, energy supply chain shortages emerging, and natural gas prices skyrocketing, dealing with geopolitical risk and ensuring energy security are attracting increasing attention from countries around the world, and the need for energy resilience has never been more urgent. To probe the causality between geopolitical risk and energy resilience, the paper establishes an energy resilience based on the panel data of 20 countries from 2000 to 2019 for empirical analysis. The results indicate that geopolitical risk improves energy resilience, and the conclusions still hold after a series of robustness tests. Moreover, this study also tests the underlying heterogeneity characteristics. To explore the influencing mechanism, this paper proposes that geopolitical risk has an impact on energy resilience through the scale effect, structural effect, and technological effect. Specifically, this paper concludes that geopolitical risk will not endanger energy resilience, which is mainly attributed to the fact that the dependence of countries on fossil energy for energy consumption hinders the negative effect of geopolitical risk on energy resilience. Finally, conclusions and policy implications are provided.

Keywords: geopolitical risk, energy resilience, mediating effects, global case, heterogeneity

Introduction

Energy is the driving source for economic stability, employment creation, and sustainable development [1]. The stability of the energy system is a crucial element for the economic operation of countries and the promotion of sustainable development. Meanwhile, human productive activities, the good functioning of modern society, and the development of the economy all rely on a stable and abundant supply of energy. Under such conditions, policymakers are concerned about how to measure the resilience of energy so as to enhance its ability to deal with risks. Energy resilience means the capacity of an energy system to recover to its original state after experiencing the interference and effect of economic, technological, and social factors [2], and still maintain its recovery and revival, which is an essential precondition for sustainable development. Thus, more and more attention has been paid to the characteristics of energy resilience and adaptive management. Overall,

*e-mail: 15737314116@163.com
**e-mail: fengyanchao@zzu.edu.cn
Tel.: +86 15002182995; Fax: 0371-67780163

measuring energy resilience is critical for understanding the properties of energy resilience, and identifying the determinants of resilience is crucial for countries to develop resilience policy policies to address external risks.

The concept of energy system resilience was developed in conjunction with the engineering category study on the resilience of key infrastructures, despite the lack of agreement on the definitions and components of energy resilience [3]. According to Rehak et al. (2019), infrastructure resilience (such as electrical infrastructure) is a trait that lessens an element's susceptibility, attracts the effects of disruptive events, improves its capacity for response and recovery, and makes it easier for it to adapt to disruptive events that are similar to those it has already experienced. In order to increase the resilience of interconnected infrastructure systems, Zhang and Peeta (2011) allotted restoration resources. The economic loss and the system's immutability were used to gauge the system's resilience. Thus, energy resilience is not only related to external shocks and risks but also closely linked to the level of regional economic development. The panel datasets can be used to analyze cross-country determinants and provide adequate energy resilience policies. A stable and resilient global energy system can effectively guarantee normal production and green research and development activities. Nevertheless, in today's globalized and more unpredictable contexts, energy systems face a variety of disruptive events that could jeopardize their functionality and put energy resilience at risk. At present, geopolitical risk is the most dramatic challenge to energy resilience among many disruptive events. Events like global or local wars, civil wars, military takeovers, nuclear crises, public protests, and terrorist attacks are frequently directly related to geopolitical risk and have a substantial impact on the peace, stability, and development of the world and its regions [4].

Geopolitical risk and energy resilience go hand in hand, and geopolitical risk is substantially to blame for the world's energy resilience issue. For instance, the worldwide oil crisis was directly brought on by the Middle East war that started in the 1970s. Local oil production facilities have been severely destroyed by regional wars like those in Syria, Libya, and Iraq, and oil output and export have dramatically decreased, leading to dramatic changes in the global energy market. Recently, the Russia-Ukraine conflict has increased global geopolitical risk and seriously affected the international energy market [5]. Under the impact of geopolitical risk, the resilience of the energy system has experienced severe disturbance and destruction, its ability to return to its original state is minimal, and its ability to maintain or develop its functions is bound to face an obvious decline. On the contrary, geopolitical risk has increased energy resilience to some extent. In order to fully address the risks to energy security posed by the abrupt change in the geopolitical environment, certain nations, like China, are adamant about understanding the value of energy security. Many nations are aggressively advancing nuclear power, increasing the development of renewable energy, and deploying the solar, wind, and hydrogen industries as they analyze their energy transition processes from a geopolitical perspective [6]. Under the circumstances, the possible detrimental effects of geopolitical risk have increased certain nations' resolve to advance renewable energy and quicken the course of the energy transition. As a result, energy resilience is also enhanced in the process of achieving energy transition.

Given the conflicting and contradictory views, the paper will comprehensively explore the impacts of geopolitical threats on energy resilience in the data of 20 nations from 2000 to 2019. Taken collectively, the findings of this paper do provide useful takeaways for practitioners and academics. First, we take geopolitical risk into account as a possible influence of energy resilience together with other controls. As far as we know, it is the first paper in the field to consider how geopolitical risk, as determined by the new geopolitical risk indicators studied by Caldara and Iacoviello (2022), affects energy resilience [7]. It is also the first time that geopolitical risk and energy resilience are incorporated into a framework in the literature, which enriches the research scope of the energy system and provides a new perspective for further research. Second, the paper tests the potential heterogeneity to determine whether the connection between geopolitical risk and energy resilience changes under different economic levels. The approach and the variables used guarantee the scientific nature of the research while looking at previously undiscovered parts of the subject. Moreover, targeted policy suggestions are put forward for countries with different economic levels, which has profound practical significance for different types of countries to formulate reasonable energy policies and build more resilient energy systems. Finally, we examine the possible pathways on how geopolitical risk influences energy resilience from the perspective of scale, structural, and technological effects, which may help in offering policymakers concepts and strategies to build an independent energy system. Since the majority of the other papers discovered the detrimental influence of geopolitical risk on energy resilience, this originality in the paper offers distinct conclusions from those of the preceding papers.

The subsequent sections of this paper are structured as follows (Fig.1). And Section 2 provides an overview of past empirical research in the literature. Section 3 measures energy resilience and explores its temporal distribution features. Section 4 presents the empirical results. Section 5 concludes and offers policy recommendations.

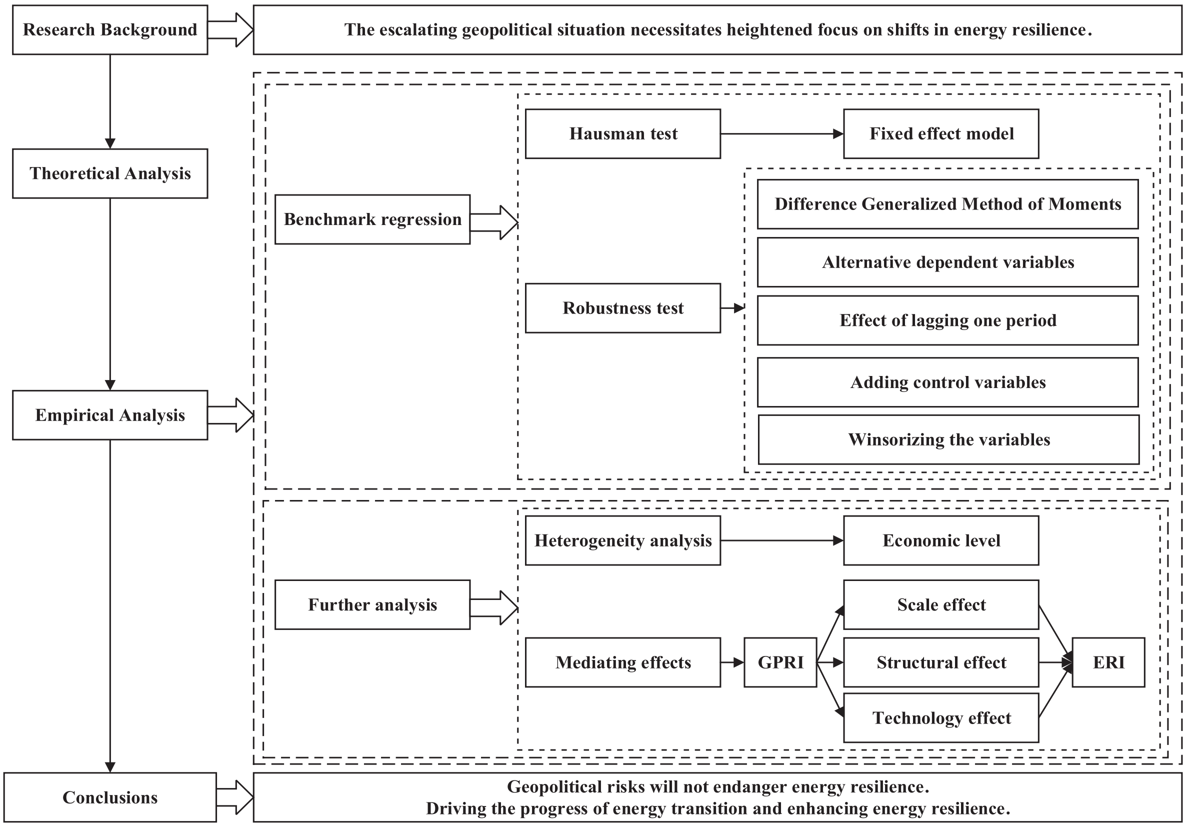

Fig. 1. Structural framework diagram.

Experimental

Literature Review

Research on Geopolitical Risk

In recent years, the world economic landscape and geopolitical situation have stood tremendous challenge [8]. According to Caldara and Iacoviello (2022), geopolitical risk is defined as the risk associated with war, terrorism, and tensions affecting relations between states. It is separated into two categories: risks connected to recent events and risks associated with recent events' escalation. Military wars, ongoing armed conflicts, and political turmoil have increased global geopolitical risks, which are destructive to both national and international economic growth and energy security. In general, areas with abundant oil and other fossil fuels, tend to have higher geopolitical risk, such as the Middle East, North Africa, and Russia. Therefore, geopolitical risk is going to have a negative influence on the growth of the world's energy markets and systems.

The conflict between Russia and Ukraine is another example of how geopolitical issues have had an adverse effect on energy production and consumption. Apart from higher energy prices, the conflict has adversely affected the stock market and energy consumption and production. The Granger causality model was developed by Fernandois and Medel (2020) to investigate the influence of geopolitical conflicts and unforeseen alterations in the price of oil [9]. According to Li et al. (2020), geopolitical risk has a favorable impact on oil prices for the West Texas Intermediate (WTI) and Brent markets but has the reverse effect on the Dubai and Nigerian markets [10]. This illustrates that the results of geopolitical risk vary across diverse areas. There are various ways in which geopolitical factors might have a huge effect on the oil markets.

In addition, the negative influence of geopolitical risk on energy security and renewable energy development is the focus of existing research. Khan et al. (2020) explained that economic and political crises have worsened competition in energy markets [11]. This competition increases the instability of the energy supply. Insecurity and geopolitical risk in resource-rich countries caused oil prices to rise in the short term and oil production to fall sharply. Gong et al. (2022) studied a system to estimate the safety of China's oil fields. Then, explored how geopolitical risk affected security [12]. They pointed out that geopolitical risk endangers the sources of China's oil imports and have a negative impact on the security of China's oil resources. What's more, from 1985 to 2018, the generation of energy from renewable sources was significantly impacted by worldwide geopolitical risk. Floros et al. further confirmed that the relationship between international politics and energy is considered an important element for economic development from multiple perspectives such as economic growth, climate change, and energy security [13]. In further research, geopolitical risk boosted the profitability of clean energy pricing in a brief period, according to research by Sarker et al. using data collected in time series from 2001 to 2021. On the other hand, over time, the impact is detrimental [14].

Research on Energy Resilience

As a significant precondition for driving economic growth, stabilizing employment, and promoting sustainable development, energy is already a key factor in promoting industrialization and urbanization [15]. In recent years, resorting to renewable energy gradually attracted the attention of countries around the world and has become a mainstream trend, partially replacing traditional fossil fuels. Considering the instability and unavailability of renewable energy, and the random and ever-increasing characteristics of energy demands, it is necessary to assess the intrinsic features of district energy systems, especially for energy resilience during periods of exposure to external risks and shocks.

Recently, the study on the issue of energy resilience has gradually increased, yet there isn't an explicit description or way to quantify energy resilience in the research currently available. Energy sustainability, energy vulnerability, and resilience have not been properly distinguished from one another. In the context of the gradual depletion of natural resources and the rapid development of renewable energy, Niu et al. deeply explored the causes and countermeasures of energy poverty, emphasizing the strategic importance of energy resources and the need to enhance energy resilience [16]. In addition, Feng et al. analyzed the influencing factors of energy resilience from the perspective of energy security, and put forward suggestions for optimizing energy issues and ensuring energy security and sustainable development [17]. According to Gatto and Drago (2020), energy resilience in our research might be defined as a system's capacity to react to and recover from external shocks and risk shocks (such as economic, social, environmental, and public health events). In order to understand the characteristics of energy resilience, different scholars use various methods to measure the energy resilience. For instance, Gupta et al. (2019) indicated that the energy resilience of a deprived neighborhood in Oxford by deploying solar PV systems and smart batteries for 82 residential communities [18]. Shen et al. studied the impact of industrial agglomeration on carbon emissions and proposed that changing the way energy is produced and used and investing in renewable energy are important ways to reduce carbon emissions and improve energy resilience [19]. To maintain sustainable development, Guang et al. (2019) used China's multi-regional input-output table in 2012 to propose an input-output linear programming model, which can analyze the energy elasticity of multi-regional economies. The authors found that technical efficiency in energy-intensive industries has a significant impact on energy resilience [20]. On that basis, Gatto and Drago (2020) developed an interval-based composite energy resilience indicator using the three parts and 27 indicators of the Sustainable Energy for All initiative offered by the World Bank (2019). Moreover, Feng et al. explored the impact of low-carbon energy transition on energy intensity, which can effectively reduce energy intensity by improving the use of renewable energy, reduce dependence on traditional energy, and enhance the resilience of the energy system [21].

In short, the papers mentioned above demonstrate that researchers have evaluated energy resilience from several professional angles. However, a thorough and efficient analysis of energy resilience from the standpoint of influencing factors is usually neglected. Meanwhile, geopolitical risk and other factors affecting energy resilience have not attracted extensive focus.

Research Between Geopolitical Risk and Energy

At present, there are almost no papers analyzing the influence of geopolitical risk on energy resilience, and some existing studies mainly focus on the relationship between geopolitical risk and energy safety or the connection between geopolitical risk and renewable energy development. Regarding these studies, for instance, Su et al. analyzed the impact of geopolitical risk on oil supply security, pointing out that oil supply security depends on geopolitical risk [22]. In this context, oil-rich regions are highly vulnerable to geopolitical risk, as reflected in rising energy security indices. The conclusion shows that geopolitical risk contributes to oil supply security. In a further study, Vakulchuk et al. (2020) investigate that geopolitical risk aggravates security risks and international relations [23]. Similar to this, Su et al. believed that geopolitical risk and energy had a mutually reinforcing connection [24]. Zhang et al. studied the global causal relationship between renewable energy consumption, financial development, and public health in the context of changing geopolitical risks, emphasizing the importance of renewable energy, which provides an important reference for accelerating energy transition and enhancing energy resilience [25]. Additionally, Li et al. (2022) concluded that geopolitical risk played a critical role in the insecurity of the energy supply [26]. Feng et al. studied the negative impact of geopolitical risks on environmental changes and concluded that geopolitical risks pose a threat to energy security and supply stability in countries rich in natural resources, which is a great challenge [27].

Furthermore, Sweidan et al. (2021) studied the effect of geopolitical risk on renewable energy development in developing economies with net crude oil imports. The study found the influence of geopolitical risk on the deployment of renewable energy in America between 1973 and 2020. The results showed that geopolitical risk promoted the deployment of renewable energy in America. Sweidan checked the effect of geopolitical threats on renewable energy utilization and uncovered that geopolitical threats would promote the utilization of renewable energy. Shen et al. studied the impact of environmental regulation on energy in the context of geopolitical risks and carbon neutrality goals and concluded that informal environmental regulation can reduce carbon emissions by promoting industrial structural transformation and renewable energy substitution, which provides an effective reference for enhancing energy resilience [28]. Zhao et al. (2023) investigated how geopolitical risk affected the requirement for renewable energy in 20 OECD member nations from 1970 to 2019. Geopolitical risk is proven to decrease consumption of renewable energy and jeopardize the strategies for reducing climate change. Additionally, policymakers in OECD nations should consider regional geopolitical harmony [29].

In brief, a number of studies in the literature concern the influence of geopolitical risk on energy security and renewable energy. These papers mainly start from the aspects of energy supply security or renewable energy demand, so as to deeply explore and analyze the influence of geopolitical risk on the energy system. In this study, we through the analysis from 2000 to 2019, 20 countries geopolitical risk panel data set for the impact of higher energy resilience, contributing to the academia. To our knowledge, this is the first paper in the literature that examines the connection between geopolitical risk and energy from the perspective of energy resilience.

Literature Gaps

Undeniably, the extant literature on geopolitical risk and energy resilience is sufficient and substantial. Nevertheless, the influence of geopolitical risk on energy resilience has received only a small amount of research attention to date. Energy resilience has been defined and evaluated in numerous prior papers, but the academic field has not yet created an official, common standard. The establishment of a fair and efficient index system for evaluating energy resilience is necessary. Additionally, to our knowledge, no research has looked at how geopolitical concerns affect energy resilience. Analyzing the diverse impacts of geopolitical risk on energy resilience is essential to ascribe to the intrinsic differences in economic and natural conditions across countries. Furthermore, it is essential, from the perspective of building an independent and complete energy system, to explore the unique mechanism of geopolitical threats on energy resilience from the perspective of scale effect, structural effect, and technological effect. However, there haven't been any comprehensive analyses on the previously mentioned subjects by researchers.

Methodology and Data

This study analyzes the impact of geopolitical risk by controlling carbon dioxide emissions per capita (PCO2), the gross domestic product per capita (PGDP), natural resources rent (NATRES), energy vulnerability index (EVI), total primary energy supply (TPES), and energy efficiency (EE) on energy resilience. From 2000 to 2019, 20 countries are the subject of empirical analysis. The choice of countries depends on the availability of data for the economies in the sample period.

ERI Measurement

In order to effectively assess energy resilience and further investigate the influence of geopolitical risk on it, the energy resilience calculation index is built into this study. This study further estimates the energy resilience index（ERI）statistics for every country from 2000 to 2019 using the energy vulnerability index（EVI）data. We observe that, in terms of numerical values, the ERI and the EVI show a trend of rising and falling.

The IEM technique is employed in this study, which is based on Dong et al. (2021), to determine an integrated energy vulnerability index by giving each sub-indicator a distinct weight [30]. Then, the energy resilience is further determined. The steps in the computation are as follows.

To get proper weights, each sub-indicator must first undergo standardization in order to remove the impacts brought on by unit discrepancies [31]. The seven positive and nine negative proofs of the indicator system are normalized using Eq. (1) and (2):

$$V_{ij}^{t}=\frac{v_{ij}^{t}-min\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}}{max\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}-min\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}} \quad (1)$$

$$V_{ij}^{t}=\frac{max\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}-v_{ij}^{t}}{max\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}-min\left\{v_{1j}^{t},v_{2j}^{t},\cdots,v_{mj}^{t}\right\}} \quad (2)$$

Second, on the basis of the standardized data of each sub-indicator, the information entropy is calculated as follows:

$$p_{ij}^{t}=\frac{V_{ij}^{t}}{\sum_{i=1}^{m}V_{ij}^{t}} \quad (3)$$

$$E_{j}^{t}=-\frac{\sum_{i=1}^{m}p_{ij}^{t}*ln\left(p_{ij}^{t}\right)}{ln\left(m\right)} \quad (4)$$

Third, the weight of each sub-indicator, i.e., the degree of contribution to the measurement result, is calculated as follows:

$$W_j^t = \frac{1-E_j^t}{\sum_{i=1}^{m}\left(1-E_j^t\right)} \quad (5)$$

Lastly, a composite energy vulnerability index is created by weighting and summing each dimensionless sub-indicator. Then, the energy vulnerability composite index is subtracted from 1 to obtain the energy resilience composite index:

$$EVI_j^t = \sum_{j=1}^{n} W_j^t * V_{ij}^t \quad (6)$$

$$ERI_j^t = 1 - EVI_j^t \quad (7)$$

In conclusion, the energy resilience index (ERI) has a range of 0 to 1. Energy resilience increases with increasing ERI, and vice versa.

Econometric Model

From the angle of the Porter hypothesis, we analyzed the influence of GPRI on the ERI by adopting a fixed effect (FE) regression estimation model. The model can reduce estimation bias from omitted variables. The specific econometric model was expressed as below:

$$lnERI_{it} = \alpha_0 + \alpha_1 lnGPRI_{it} + \beta X_{it} + \mu_i + v_t + \varepsilon_{it} \quad (8)$$

Whereas, ERI_{it} and $GPRI_{it}$ are the explained and core explanatory variables of i country at t period, respectively. X_{it} are the control variables. μ_i and v_t denote the individual and time effect. ε_{it} is the random error.

Variable Selection

(1) Dependent Variable (ln ERI_{it}). The dependent variable is the energy resilience of countries, which is calculated based on the data of the EVI. Following the studies of Gatto and Busato (2020) and Genave et al. (2020), we also consider the impact of energy mix diversity, mainly measured by the Shannon-Wiener index. At the same time, we construct an energy security indicator including energy import, fuel export, and energy structure diversity as the key sub-indicator to measure the energy vulnerability index (EVI), which can be further calculated to obtain the energy resilience index (ERI).

(2) Core independent variable (ln$GPRI_{it}$). The independent variable comes from British Petroleum (2022), and geopolitical risk is the main explanatory factor. Caldara and Iacoviello (2022) provided the geopolitical risk index (GPRI) statistics on their website. In particular, the GPRI's coefficient is predicted to be positive, indicating that lowering geopolitical risk also lowers energy resilience. In addition, the decline of energy resilience means that the energy intensity is reduced, which is the embodiment of the beginning to change the extensive development, so as to further promote the optimization and upgrading of energy structure.

(3) Control variables. To mitigate the influence of the omitted variables on the estimated results, this paper selected the following indicators as control variables. Carbon emissions per capita (ln$PCO2_{it}$) was measured by carbon emissions per capita after taking logarithm. Numerous studies have investigated the connection between carbon emissions and energy, considering that the significance of decreasing carbon emissions to combat global climate change encourages nations to switch from fossil fuel energy to RE. The carbon emissions from consumption of energy were used in this study as a proxy for carbon emissions. The per capita GDP was converted to log form *(*$lnPGDP_{it}$*)* to determine the level of affluence. Geopolitical risks are political and economic trends that are potentially destructive to human well-being. In addition to violent conflicts, the most important manifestations are global or regional economic and financial turbulence and natural energy risks caused by non-human environmental changes. From an economic perspective, the intensification of geopolitical risks will directly cause economic problems and lead to changes in GDP per capita. In terms of energy, generally speaking, as the level of economic development increases, the energy resilience of a region will increase. However, the economic development experience of developed countries shows that with economic development, the trajectory of the energy resilience coefficient changes in an inverted N-shaped shape. Hence, it is theoretically uncertain what relationship energy resilience and economic growth should maintain in different periods of economic development. The value of natural resources (such as petroleum, natural gas, coal, minerals, and forests) to economic output is measured by natural resource rents ($NATRES_{it}$) as a portion of gross domestic product (GDP). Natural resource rents are typically derived from oil and gas rents. According to Sweidan and Elbargathi (2022), globalization and natural resource (oil) rents are important controls for examining the impact of geopolitical risks on economic development. Therefore, we choose natural resource rents as one of the control variables for our empirical analysis. Data on GDP per capita and natural resource rents are taken from the World Bank's World Development Indicators dataset (2023). Following Dong et al., we use the energy vulnerability index to proxy energy system level (lnEVI_{it}) and express it in logarithmic form. The EVI has a range of 0 to 1. Energy system vulnerability increases with increasing EVI values and vice versa. Notably, the energy resilience index and the energy vulnerability index show a trend of rising and falling, correspondingly. Meanwhile, we also choose the log form of total primary energy supply (ln $TPES_{it}$) as a control variable. Fossil fuels account for 82.28%

of the total energy supply globally in 2021. The continued dominance of fossil fuels in the global energy mix means that an increase in the overall amount of energy available will ultimately result in higher energy use and higher CO2 emissions. In addition, we explore how energy resilience, which is determined by the output of the economy (i.e., GDP) corresponding to a unit of energy consumption, is affected by energy efficiency (ln EE_{it}). According to Dong et al. (2020), fossil fuels tend to explain a sizable portion of the world's energy consumption and are a significant contributor to carbon emissions [32]. Therefore, increasing energy efficiency is crucial for reducing carbon emissions globally and affecting energy resilience. Energy efficiency improvements are successful at reducing CO_2 emissions, according to research by Akram et al. (2020), and as a result, have some indirect influence on energy resilience [33]. Additionally, Energy efficiency has been also utilized as a control variable in papers by several researchers [34]. The specific variable construction and sources are shown in Table 1.

Data Source

Based on the data continuity and availability, we employ balanced panel data for 20 countries from 2000 to 2019 for the empirical regression, which is the maximum sample size that can be selected due to data constraints. These countries contain almost all the major countries distributed in all continents of the world and can effectively represent the whole sample. Missing data is the only reason for dropping Spain, Japan, and other countries from the sample. The variables mentioned above were collected from the International Statistics Yearbook. Table 2 displays the descriptive statistics of the explained and explanatory variables. The table contains the fundamental facts, such as observed quantity, minimum, mean, maximum, and standard deviation. This information illustrates the concentration and distribution of data.

Table 1. Variable construction and sources.

Name of variables	Variable symbol and construction	Source
Energy resilience index	ln ERI = ln (ERI)	Calculated
Geopolitical risk index	ln GPRI = ln (GPRI)	Caldara and Iacoviello, 2022
Carbon emissions per capita	ln PCO2 = ln (PCO2)	Our World in Data
GDP per capita	ln PGDP = ln (PGDP)	World Bank, 2023
Natural resource rents	NATRES	World Bank, 2023
The energy vulnerability index	ln EVI = ln (EVI)	Calculated
Total primary energy supply	ln TPES = ln (TPES)	Calculated
Renewable energy consumptions	ln REC = ln (REC)	British Petroleum, 2022
Energy efficiency	ln EE = ln (EE)	Calculated
The evolution of urbanization	ln URB = ln (URB)	World Bank, 2023
Trade openness	ln TRA = ln (TRA)	World Bank, 2023

Table 2. Descriptive analysis of the selected variables.

Variables	Obs	Mean	Std. Dev.	Min	Max
$lnERI_{it}$	400	-0.286	0.474	-2.827	0.064
$lnGPRI_{it}$	400	-2.245	1.465	-5.835	1.543
$lnPCO2_{it}$	400	0.966	1.357	-1.820	3.342
$lPGDP_{it}$	438	8.702	1.312	6.187	11.23
$NATRES_{it}$	400	1.966	2.941	0.0117	12.21
$lnEVI_{it}$	400	-1.662	0.525	-2.567	-0.673
$lnTPES_{it}$	400	13.22	1.416	10.94	16.35
$lnEE_{it}$	400	11.95	0.545	10.64	13.08

Results and Discussion

We examine the data's cross-sectional dependence and stationarity at first. We apply the Pesaran test, which is appropriate for small panels, for the cross-sectional correlation estimation. The findings of the cross-sectional dependence test demonstrate that the Pesaran test mathematically rejects the null hypothesis of cross-sectional dependence at the 1% significance level. The specific test outcomes are shown in Table 3. Thus, cross-sectional correlations are seen in each series.

We introduced second-generation unit root tests, which are robust to cross-sectional dependence, to solve this problem. The logarithms of the geopolitical risk, carbon emissions per person, and energy vulnerability index do not have unit roots, according to the stability findings, which are shown in Table 4. In contrast to spurious regression in a single time series, the issue of erroneous regression in the case of short panel data appears to be minor, even though the test results indicate many variables are non-stationary. Baltagi et al. (2012) found that because the panel estimator averages across people, each value in the independent cross-section data in the panel generates a larger overall sign than in the pure time series case [35].

In order to take into consideration any possible heteroscedasticity and serial correlation issues, this study used a trustworthy Hausman specification test to perform fixed and random effect estimations. The goal was to select the most appropriate econometric assumptions. In accordance with Table 5's data, the fixed panel model behaved better in the situation. According to the empirical results in Table 5, the results are significantly positive under the fixed effect and the random effect. In contrast, energy resilience is more sensitive to the impact of geopolitical risks under fixed effects. In addition, the fixed effect model can also combine the individual heterogeneity and time heterogeneity in the disturbance term, and estimate the errors that may lead to endogeneity problems at the same time, so as to improve the consistency of the estimation results. However, the random effect model only obtains a more effective estimator than the fixed effect under the condition of no endogeneity. Therefore, the fixed effect model is finally selected for the analysis.

Benchmark Estimates

This study used the fixed-effects model to perform regressions for energy resilience based on the results of the aforementioned tests. Table 5 displays the sample's empirical findings.

Table 5 explores the consequences of regressions that took energy resilience as the dependent variable. The geopolitical risk is significant at the 5% level,

Table 3. Pesaran cross-sectional dependence test results.

Dependent variable	Energy Resilience Index of countries
FE model	3.329***
RE model	3.111***

Table 4. Unit root test results.

Variable	PESCADF	CIPS
	Statistic	Statistic
Energy resilience index	-0.539	-0.845
Geopolitical risk index	-1.972	-0.3029***
Carbon emissions per capita	-1.989	-2.323**
Natural resource rents	-1.669	-1.902
The energy vulnerability index	-1.966	-2.304**
Total primary energy supply	-1.862	-2.061
Energy efficiency	-1.994	-2.111*

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5. Fixed and random effect illustration.

	ln ERI	ln ERI
Variables	Fixed	Random
ln GPRI	0.0502***	0.0489***
	(3.8761)	(3.8293)
ln PCO2	-0.0901**	-0.0533
	(-1.9980)	(-1.2707)
ln PGDP	0.0901	0.0953*
	(1.5274)	(1.6820)
NATRES	-0.0103**	-0.0110***
	(-2.4804)	(-2.6716)
ln EVI	-0.0118	-0.0076
	(-0.1557)	(-0.1050)
ln TPES	0.1543***	0.1113***
	(3.3952)	(2.8149)
ln EE	-0.1144**	-0.1178**
	(-2.1918)	(-2.2817)
Constant	-1.5331**	-0.9987
	(-2.1154)	(-1.4782)
Bootstrap Hausman fixed–random	0.70	
Observations	400	400
R-squared	0.131	
Number of countries	20	20

Note: Robust t-statistics in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

showing apparent driving effects on energy resilience. The total primary energy supply is significant at a 5% level, indicating significant facilitating impacts on energy resilience. The conclusion demonstrates that the expansion of geopolitical risk will lead to the improvement of energy resilience, that is, geopolitical risk and energy resilience show a certain positive relationship. Furthermore, the coefficients of the geopolitical risk are smaller than the total primary energy supply on the energy resilience, indicating that energy resilience is more sensitive to geopolitical risk than the total primary energy supply. This result was expected because the geopolitical risk is uncertain and unstable, which will affect energy resilience in many ways. Assuming that the dependent variable is in logarithmic form, we can conclude that the effect of geopolitical risk on the energy resilience of each country is about 5.02% based on the regression.

It is worthwhile to discuss the control variables. Carbon emission per capita has a negative obvious impact on energy resilience. The connection between energy resilience and carbon emissions is constantly disputed [36]. The majority of high carbon emission countries have a reversely high degree of economic growth and a considerable route reliance on fossil fuel energy, despite the fact that these nations are more driven to cut carbon emissions and promote renewable energy. Strong energy resilience may be able to ensure energy supply in time to handle external shocks, which could be one explanation for the rise in short-term CO2 emissions. Nevertheless, over time, with the progress of science and technology, energy efficiency is greatly improved, and the energy consumption structure is upgraded, so as to curb carbon dioxide emissions and create a "win-win" outcome. In particular, high carbon emissions per person reveal a society's relative indifference to environmental concerns. Thus, carbon emissions per capita evidently negatively affect energy resilience.

On the contrary, the GDP per capita has an evidently positive impact on energy resilience. The coefficient of GDP per capita is obviously positive for energy resilience, indicating that economic development improves energy resilience. Various pieces of literature have reported similar conclusions. Salim and Rafiq, for example, made the case that rising incomes lead to more commercial activity, which can raise energy consumption and energy resilience. Furthermore, as income levels rise, residents' concerns about the environment and support for energy resilience grow. Additional funding is also available for investment in the creation of RE technologies, which may support energy recycling and boost energy resilience in nations that are experiencing economic expansion.

Regarding the NATRES factor, we found that the natural resources rent negatively influences energy resilience. The statistically significant findings reveal that a 0.9% reduction in the energy resilience demand occurs for every percentage rise in the natural resource rent. This finding has a sound economic foundation. The increase in natural resource rents is indicative of economic activities, such as the extraction of fossil fuels like coal and oil. Due to their availability and cost, the nation is more dependent on these traditional energy sources. This problem, in turn, substitutes the use of renewable energy as an alternative for production and consumption activities. It follows that it makes sense that a country's ability to meet its energy needs will decline as natural resource availability increases.

The energy vulnerability index has a negative but insignificant effect on energy resilience. The energy vulnerability index does not promote energy resilience. However, the coefficient of EE is significantly negative at the 10% level, implying that increased energy efficiency will obviously curb energy resilience, a truth many studies have confirmed.

Robustness Tests

Thus far, we discovered that geopolitical risk can give energy resilience an improvement. Further, we carried out several robustness tests to improve the results' validity.

Differential-Generalized Method of Moments (Diff-GMM)

The following supports the selection of Diff-GMM as the benchmark model: First, in contrast to the static model, the dynamic model considers the impact of the lagged energy resilience features. The dynamic model may resolve the endogeneity issue because of two-way causality. However, the inclusion of the dependent variable's lag term results in the development of a fresh endogeneity issue. Arellano and Bond (1991) suggested utilizing a Diff-GMM strategy to overcome this endogeneity problem, in which all potential lagged variables are used as instrumental factors. In their Sys-GMM proposal from 1998, the research of Arellano and Bover (1995) was extended by Blundell and Bond by analyzing distinctions and level equations as a set of equations. Diff-GMM has a greater estimation efficiency than Sys-GMM and is better able to deal with a possible poor instrumental variable difficulty.

The Arellano-Bond (A-B) estimation and the Hansen test must also be used on the assessment findings in order to confirm their accuracy. The differences of the random disturbance terms must have first-order autocorrelation and no second-order autocorrelation in order for the A-B test to be valid, meaning that the p-values for AR (1) and AR (2) should, respectively, be less than 0.1 and larger than 0.1. The Hansen test is used to test for over-identification of the instrumental variables, and a p-value of more than 0.1 ensures that all the instrumental variables are valid.

Assessments from Table 6 indicate a substantial positive relationship between GPRI and ERI, suggesting that lowering the geopolitical risk may simultaneously decrease energy resilience. This new information supports the demand for actions to increase the energy system's capacity to handle geopolitical risk. It turns out that each 1% drop in GPRI can result in a 0.17% drop in energy resilience, which is in line with our estimate. A possible reason is that the decline in geopolitical risk discourages energy resilience by reducing non-essential energy rivalry and raising energy efficiency [37]. Nevertheless, Dong et al. (2021) reached the opposite finding in a related investigation. Strong energy resilience may be able to ensure energy supply in time to withstand extrinsic risks, which could explain why the geopolitical risk has decreased. However, with the growth of science and technology, energy efficiency is gradually improved, and the transformation process of energy structure is accelerated, which enhances the ability to deal with geopolitical risk and decreases energy resilience in the long run, achieving a "win-win" condition.

Alternative Dependent Variables

Although researchers usually apply energy resilience to analyze the energy resilience of an area, many researchers consider renewable energy consumption (REC), measured in exajoules. They believe that renewable energy consumption is very appropriate to explore the energy resilience of a region because it considers the factors of energy demand. Therefore, REC is used as a new dependent variable in this section's regression analysis, and the results are shown in column (1) of Table 7. The predicted GBP coefficient is strongly positive, which is in line with the results of the benchmark regression.

Table 6. Estimation result of Diff-GMM.

Variables	ln ERI
	Diff-GMM estimation
L. ln ERI	0.1265***
	(7.6538)
ln GPRI	0.2581***
	(11.1955)
ln PCO2	0.0714
	(1.3241)
ln PGDP	0.7469***
	(7.2943)
NATRES	-0.0116***
	(-6.3344)
ln EVI	0.5188***
	(8.3987)
ln TPES	-0.2956***
	(-3.7133)
ln EE	-0.5303***
	(-5.8074)
Observations	360
AR (1)	0.034
AR (2)	0.650
Hansen	1.000

Effect of Lagging One Period

Geopolitical risks typically take time to materialize before creating an effect on social production and economic activities. The pertinent findings are therefore in column (2) of Table 7 when using ERI(t+1) as the dependent variable to reevaluate the impact of geopolitical concerns. The positive predicted GPRI coefficients suggest that geopolitical risk is advantageous for boosting energy resilience. The aforementioned findings demonstrate the main conclusion is robust.

Adding Control Variables

By including control variables, this section reduces the bias in the results brought on by the omission of certain variables. We discover the influence of the evolution of urbanization (URB) as measured by the urban population's share of the total population. Meanwhile, we assess the influence of trade openness (TRA) on energy resilience, as measured by the ratio of total imports and exports to GDP. The relevant data are shown in column (3) of Table 7 after considering the two controls for URB and TRA. The coefficient of geopolitical risk is positive, which is in accordance with the main result of the study.

Winsorizing the Variables

Outliers can cause alters in the main trend, which could lead to erroneous conclusions. Hence, this section uses the winsorizing 1% quantile method for data smoothing in accordance with convention and the number of samples. The pertinent regression results are shown in column (4) of Table 7. The underlying conclusion is more robust because the GPRI coefficients are still positive.

Elimination of Time Periods

To exclude the impact of the 2008-2009 financial crisis on the sample data, we adopt the elimination method of time period, so as to better analyze the impact of geopolitical risks on energy resilience. The relevant regression results are shown in Column (5) of Table 7. Since the coefficient of GPRI is still positive, the basic conclusion is consistent with the previous one.

Table 7. Other robustness tests.

	Alternative dependent variable	Lag effect	Add control variable	Winsorize 1%	Time period of elimination
	ln REC	ln $ERI_{(t+1)}$	ln ERI	ln ERI	ln ERI
Variables	(1)	(2)	(3)	(4)	(5)
ln GPRI	0.0696*	0.0052	0.0496	0.0456	0.0437
	(1.7405)	(0.4231)	(1.1459)	(1.1339)	(1.1027)
ln PCO2	-0.2925	-0.1402	-0.0778	-0.0815	-0.0438
	(-0.7790)	(-1.6099)	(-1.4674)	(-1.5791)	(-1.3850)
ln PGDP	0.2429	0.1533	0.0850	0.0869	0.0630
	(0.4950)	(1.3176)	(1.0141)	(1.0920)	(0.9256)
NATRES	-0.0021	-0.0109	-0.0100	-0.0131	-0.0130
	(-0.1583)	(-1.0962)	(-0.8734)	(-0.9865)	(-0.9842)
ln EVI	-0.0138	0.0210	-0.0544	-0.0028	-0.0637
	(-0.0286)	(0.3199)	(-0.6962)	(-0.0425)	(-0.8249)
ln TPES	-0.7113*	0.1487**	0.1752***	0.1442**	0.1468***
	(-1.8070)	(2.8556)	(3.0585)	(2.5532)	(2.8909)
ln EE	0.3164	-0.1663	-0.1071	-0.1109	-0.0981
	(0.7668)	(-1.4665)	(-1.4833)	(-1.4758)	(-1.7239)
ln URB			-0.1929		-0.2091
			(-1.1989)		(-1.3640)
ln TRA			-0.0086		0.0056
			(-0.2784)		(0.1958)
Constant	6.5728	-1.3724*	-1.1128	-1.4115*	-0.7031
	(1.1310)	(-1.9665)	(-1.2661)	(-1.8219)	(-0.7781)
Observations	369	380	400	400	360
R-squared	0.318	0.099	0.135	0.143	0.143
Number of countries	19	20	20	20	20

Notes: The values in parentheses are robust standard errors, clustered at the city level. ***, **, and * denote the 1%, 5%, and 10% significance levels, respectively.

Heterogeneity Analysis

Regression using the entire sample frequently entails the risk of obfuscating crucial data. In order to do sub-sample regression, the sample is split into two or three nearly equal halves depending on the economic level criterion.

The findings of the heterogeneity study are presented in Table 8. One main outcome emerges based on the importance and the amount of significance. First of all, despite the modest variation in effect, the geopolitical risk does influence the energy resilience of nations with varying economic sizes. This shows that geopolitical concerns have a broad and pervasive impact on energy resilience. It is believed that this phenomenon is the result of current geopolitical developments, and it affects practically all nations in the world. Second, whereas the effects of geopolitical threats on energy resilience are negligible in high-level cities, they are significant in countries with medium- and low-level economies. A common indication to evaluate a region's overall strength and stage of development is its economic size. In general, a region's ability to respond to geopolitical concerns and its demands for energy increase as a region becomes more developed. However, the economic development experience of developed countries shows that with economic development, the trajectory of the energy resilience coefficient changes in an inverted N-shaped shape. This phenomenon indicates that when the economic level of a region is medium, the ability to deal with geopolitical risks is weak and the energy resilience is poor. At this time, geopolitical risk has a negative but insignificant impact on energy elasticity. On the contrary, energy in high-income and low-income countries shows better energy resilience in the face of shocks from geopolitical risks. The impact of geopolitical risk on energy resilience is all significantly positive. In general, regions with more developed economies have a stronger ability to control geopolitical risks and demonstrate greater energy resilience. Regions with low economic levels have a relatively low ability to deal with geopolitical risks and cannot well deal with energy problems brought by geopolitical risks [38]. As a result, the coefficient on energy resilience is lower in low-income countries than in high-income countries.

Table 8. Heterogeneity analysis - different levels of the economy.

Economy	High-level	Medium-level	Low-level
Variables	ln ERI	ln ERI	ln ERI
	(1)	(2)	(3)
ln GPRI	0.0629***	-0.0019	0.0386***
	(2.8362)	(-0.1904)	(3.6071)
ln PCO2	-0.1328*	0.1723***	0.1937
	(-1.7711)	(3.2018)	(1.1229)
ln PGDP	0.2540**	-0.1976***	-0.5261*
	(2.1232)	(-3.6883)	(-2.1373)
NATRES	-0.0162**	0.0074**	0.0024
	(-1.9925)	(2.3077)	(0.5536)
ln EVI	-0.0673	0.0696	-0.0851
	(-0.6286)	(1.5124)	(-0.7270)
ln TPES	0.1863*	-0.0924**	0.3356
	(1.6794)	(-2.1565)	(1.6446)
ln EE	-0.1646*	0.0377	0.0352
	(-1.6540)	(1.5522)	(0.1876)
Constant	-2.7759*	2.1771**	-1.1208
	(-1.6923)	(2.6254)	(-0.2376)
Observations	260	100	40
R-squared	0.966	0.936	0.997
Country FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: The values in parentheses are robust standard errors, clustered at the country level. ***, **, and * denote the 1%, 5%, and 10% significance levels, respectively. Based on the average GDP of all the countries in the sample year, the total sample is divided into three groups, namely, “High-level”, “Medium-level”, and “Low-level”.

In addition, we also group the samples according to the degree of country resource dependence and trade dependence. The results of heterogeneity analysis are shown in Table 9. The results show that the impact of geopolitical risk on energy resilience is more significant in countries with higher resource dependence, while the relationship between energy resilience and geopolitical risk is not obvious in countries with lower resource dependence. Moreover, for countries with high trade dependence, the greater the geopolitical risk index is, the smaller their energy resilience is. Shocks to geopolitical risks in countries with low trade dependence will increase their energy resilience. The possible reason is that countries with higher import and export trade are more dependent on import and export trade, and cannot restore energy supply in time when they are hit by external shocks, so their energy resilience is low. On the contrary, countries that are less dependent on import and export trade tend to have better energy reserves, a stronger ability to deal with geopolitical risks and higher energy resilience.

Mediating Effects

Model Construction

Nevertheless, the precise internal influence mechanism is unknown, which attracts our curiosity in this field of study. The study hypothesizes that geopolitical risks have a direct positive effect on energy resilience and that the total primary energy supply (TPES), the proportion of renewable energy consumption in the overall energy supply (REC), and energy efficiency (EE) mediate this relationship through geopolitical risks. We employ the mediation analysis using a stepwise regression approach to examine this hypothesis and utilize the Sobel test to assess the significance of the mediating effect. As a result, we create the theoretical model below to investigate the impact processes, referencing the research of Baron and Kenny (1986).

$$lnM_{it} = \eta_0 + \eta_1 lnM_{it-1} + \eta_2 lnGPRI_{it} + \eta_3 lnTPES_{it} + \eta_4 lnREC_{it} + \eta_5 lnEE_{it} + \eta_6 lnPGDP_{it} + \eta_7 NATRES_{it} + \delta_{it} \tag{9}$$

$$lnERI_{it} = \gamma_0 + \gamma_1 lnERI_{it-1} + \gamma_2 lnGPRI_{it} + \gamma_3 lnM_{it} + \gamma_4 lnTPES_{it} + \gamma_5 lnREC_{it} + \gamma_6 lnEE_{it} + \gamma_7 lnPGDP_{it} + \gamma_8 NATRES_{it} + \delta_{it} \tag{10}$$

In the above formula, η_0 and γ_0 represent the constant terms; η_1 – η_7 and γ_1 – γ_8 stand for the estimated coefficients respectively; ε_{it} stands for the random disturbance term; and M_{it} for the mediating variables.

According to earlier research, the shape effect, structural effect, and technological effect can all be used to explain energy resilience. Thus, we empirically

Table 9. Heterogeneity analysis - different levels of resource and trade dependence.

Interdependency	High resource dependence	Low resource dependence	High trade dependence	Low trade dependence
Variables	ln ERI	ln ERI	ln ERI	ln ERI
	(1)	(2)	(1)	(2)
ln GPRI	0.0842***	0.0241	-0.0174***	0.0895***
	(2.9293)	(1.1025)	(-3.1391)	(3.1778)
ln PCO2	-0.1598	0.1702***	0.0016	-0.2283*
	(-1.6309)	(3.3909)	(0.1264)	(-1.7725)
ln PGDP	0.2831	-0.2414***	-0.0325	0.0998
	(1.4646)	(-4.1097)	(-1.4834)	(0.6210)
NATRES	-0.0361	-0.0088	-0.0020	-0.0074
	(-1.1755)	(-1.5441)	(-0.2555)	(-0.9913)
ln EVI	-0.0863	-0.0863	0.1414***	-0.1739
	(-0.5966)	(-0.9353)	(5.7252)	(-1.0062)
ln TPES	0.3599**	0.1937**	0.0773***	0.3893*
	(2.1703)	(2.0980)	(4.2331)	(1.9218)
ln EE	-0.1081	0.1953***	-0.0014	-0.0994
	(-1.3332)	(3.8322)	(-0.0646)	(-0.7077)
Constant	-5.7273*	-3.3541**	-0.6712**	-5.2567*
	(-1.8102)	(-2.3010)	(-2.2325)	(-1.6921)
Observations	159	241	187	212
R-squared	0.977	0.841	0.948	0.967
Country FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Notes: The values in parentheses are robust standard errors, clustered at the country level. ***, **, and * denote the 1%, 5%, and 10% significance levels, respectively. Based on the average GDP of all the countries in the sample year, the total sample is divided into three groups, namely, "High-level", "Medium-level", and "Low-level".

investigate how the three effects affect the link between geopolitical risk and energy resilience. In order to depict the scale effect, we first select the total primary energy supply (TPES) as a mediating variable. According to Roupas et al. (2011), 82.28% of the world's primary energy will come from fossil fuels in 2021. Since fossil fuels still account for the majority of the world's energy mix, an increase in the total amount of available energy will inevitably lead to higher energy consumption and thus higher carbon dioxide emissions. Secondly, in order to capture the structural influence, we select the proportion of renewable energy consumption in the overall energy supply (REC) as a mediating variable. According to Dong et al. (2020), renewable energy plays a crucial part in the mitigation of the greenhouse impact. The share of primary energy coming from renewable sources has increased significantly in recent years, from 7.82% in 2000 to 13.47% in 2021. Third, for the sake of capturing the technological effect, we select energy efficiency (EE) as a mediating variable. Global energy intensity has dramatically lowered as a result of technological advancements, falling from 1.84 kWh/USD in 2000 to 1.42 kWh/USD in 2018. Energy resilience is impacted even more by increases in energy efficiency since they not only lower the expense of power generation but also motivate enterprises to upgrade their present technology through competition [39]. We decided to apply energy efficiency as a stand-in for the technological effect because Wang et al. 's (2022) found that it can be a reliable predictor of technological advancement. The UN statistics and Worldwide Development Indicators databases provide the pertinent information for the mediating variables.

Additionally, if γ_2 in Eq. (10) is obvious, it points out that GPRI directly and significantly influences energy resilience; if γ_3 in Eq. (10) and η_2 in Eq. (9) are both significant, it shows that geopolitical risk also indirectly and significantly influences energy resilience.

Table 10. Estimation results of the mediating effects.

Variables	Scale effect		Structural effect		Technological effect	
	ln TPES	ln ERI	ln REC	ln ERI	ln EE	ln ERI
	(1)	(2)	(3)	(4)	(5)	(6)
ln GPRI	0.0067	0.0307**	0.0635	0.0486***	0.0062	0.0331**
	(0.5642)	(2.2399)	(1.6278)	(3.2462)	(0.3995)	(2.3979)
ln TPES		0.2322***				
		(3.8072)				
ln REC				-0.0524**		
				(-2.4702)		
ln EE						-0.1383***
						(-2.9344)
ln PCO2	0.5599***	-0.0621	-0.6773***	-0.0062	-0.4028***	0.0122
	(19.2710)	(-1.3018)	(-7.0994)	(-0.1574)	(-10.6258)	(0.3156)
ln PGDP	-0.2682***	0.0352	0.2497*	0.0368	0.6775***	0.0666
	(-6.3193)	(0.6859)	(1.7656)	(0.6789)	(12.2354)	(1.1380)
NATRES	-0.0043	-0.0101**	0.0028	-0.0127**	-0.0053	-0.0118*
	(-0.9711)	(-2.0115)	(0.2029)	(-2.4114)	(-0.9314)	(-2.3353)
ln EVI	0.0582	-0.0219	-0.2885	-0.0826	-0.2987***	-0.0497
	(0.8737)	(-0.2863)	(-1.3516)	(-1.0106)	(-3.4381)	(-0.6346)
ln URB	-0.0935	-0.2301	-1.6608***	-0.2751*	0.2540	-0.2167
	(-0.7170)	(-1.5376)	(-4.0200)	(-1.7028)	(1.4933)	(-1.4328)
ln TRA	-0.0617*	-0.0010	0.3196***	0.0256	-0.0686	-0.0228
	(-1.8679)	(-0.0264)	(3.0271)	(0.6256)	(-1.5921)	(-0.5948)
Constant	15.5237***	-2.6267**	5.9583***	0.5003	5.3063***	1.7121**
	(24.0495)	(-2.1848)	(2.8003)	(0.6087)	(6.3000)	(2.1739)
Sobel Z		3.4860***		2.6990***		-2.0050***
Observations	400	400	369	369	400	400
R-squared	0.845	0.186	0.311	0.172	0.627	0.173
Number of countries	20	20	19	19	20	20

Note: ***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively.

Results and Discussions

The results of mediating effects are shown in Table 10. Columns (1) and (2) represent the scale effect. The findings indicate that GPRI and TPES have a positive association and that a 1% increase in TPES causes a 0.25% increase in energy resilience. This suggests that GPRI can indirectly enhance energy resilience by increasing the entire primary energy supply. Although it is an inevitable trend for new energy sources, mainly wind, electricity, and light energy, to replace fossil energy, the dependence of the energy market on high-carbon fossil energy is difficult to be shaken in the short term. The energy consumption of various countries mainly depends on fossil energy, mainly coal, automobiles, and steel, and the continuous burning of fossil energy promotes the expansion of the energy scale [40]. However, due to the stationarity of fossil energy supply, the dependence of the energy market on fossil energy acts as a stabilizer, which ensures that the energy system has stable and sufficient energy reserves, thus indirectly enhancing energy resilience.

The structural effect is outlined in columns (3) and (4). We discover a substantial positive relationship between GPRI and REC, and that for every 1% rise in REC, the energy resilience decreases by 0.057%. This suggests that GPRI indirectly reduces energy resilience under an increase in renewable energy use. In the face of geopolitical risk and other external shocks, some countries tend to use new energy to replace traditional fossil energy. However, there is great uncertainty in the acquisition of new energy, mainly wind and light energy, which makes energy supply and demand also fluctuate to some extent. Therefore, the process of energy structure reconstruction is not smooth. Geopolitical risk impacts the transformation of energy structure, destroys the process of energy system reconstruction, and reduces energy resilience. On the other hand, under the general trend of energy structure transformation, countries are optimizing and upgrading their energy structure by replacing old energy such as coal and fossil energy with new energy [41]. However, at the same time, the labor and cost of energy structure adjustment are also huge, and in the face of the impact of external geopolitical risk, there is great instability in energy supply and demand, which makes it inevitable to reduce energy resilience. Hence, we demonstrate that a key mediating factor in the relationship between GPRI and energy resilience is renewable energy.

Columns (5) and (6) represent the technical effect. Based on the analysis of the relationship between GPRI and EE, it is concluded that there is a positive correlation between geopolitical risk and energy efficiency, and every 1% increase in energy efficiency will decrease energy resilience by 0.141%. This suggests that by increasing energy use efficiency, GPRI can indirectly reduce energy resiliency. This discovery strengthens the argument that energy efficiency plays a crucial role in ensuring energy resilience, which has been widely acknowledged by academics. Many governments have recognized that increasing energy efficiency is a good energy policy in order to alleviate the effects of energy issues. For instance, China has made enhancing energy efficiency a top priority in order to achieve its goals of carbon peaking and carbon neutrality; the European Commission has also made enhancing energy efficiency a top priority in order to achieve its goals of the European Green Deal. However, in terms of economic costs, improving energy efficiency will not happen overnight. In the process of improving energy efficiency, countries are constantly trying to replace old energy with new energy and promote the adjustment of energy structure. Due to the long investment cycle, energy supply and demand are unstable, which indirectly impacts the energy system and reduces energy resilience. Subsequently, we conduct the Sobel test to examine the significance of the mediating effect. The results of the Sobel test show that the Sobel statistics of the scale effect, the structure effect, and the technology effect all exceed the critical value of 1.96 ($\alpha = 0.05$), which indicates that the mediating effect is statistically significant.

Last but not least, when we compare the GPRI coefficients in columns (2), (4), and (6) to those in the benchmark regression, the paper discovers that not only are they all less significant than the coefficients in the benchmark regression, but they are also all smaller. This indicates that scale effect, structure effect, and technology effect all play a mediating role to a certain extent, and geopolitical risk has a significant impact on energy resilience but does not have a significant impact on the mediating variable. In other words, the scale effect, the structure effect, and the technology effect all indirectly affect energy resilience, while the significance is weak and different [42]. The main reason is that in the process of energy structure reconstruction, the dependence of the energy market on fossil energy makes the scale effect strong and plays a role in enhancing energy resilience. Nevertheless, due to the uncertain characteristics of new energy, such as the supply of light energy, wind energy, and electric energy will be disturbed by many factors, and the supply will be unstable [43]. Therefore, in the process of promoting energy structure adjustment, both the structural effect and the technical effect play a negative role, which hinders the promoting effect of geopolitical risk on improving energy resilience.

In summary, in the context of increasing geopolitical risk, increasing total primary energy supply can indirectly enhance energy resilience, which is mainly attributed to the dependence of the energy market on high-carbon fossil energy. Conversely, increasing the use of renewable energy and improving energy efficiency indirectly reduce energy resilience, and the possible reason is the uncertainty of new energy supply and high investment cost during the restructuring of the energy structure. It reflects the challenges encountered in the process of adjusting the energy system, which aligns with empirical evidence and underscores the scientific and rational nature of this study.

Conclusions

This study intends to examine the causal connection between energy resilience and geopolitical risk. Thus, to quantify a composite index of energy resilience, we first build a system with 16 sub-indicators. Moreover, we use a balanced panel dataset of 20 countries from 2000 to 2019 and investigate the relationship between geopolitical risk and energy resilience. Then, we examine potential heterogeneity. In order to explore the influencing mechanism, the research explores the mediating channels from three sub-effects, namely the scale effect, the structural effect, and the technological effect. This research reveals the three results listed below.

First, the study confirms that geopolitical risk is positively associated with energy resilience. The elevated geopolitical risk significantly increases energy resilience. Unexpectedly, we discovered a positive impact of geopolitical risk on energy resilience for the first time, this conclusion was anticipated but not made prior to our study. In order to solve the energy security risk caused by the abrupt challenge of geopolitical threats, some countries have gradually realized the value of energy safety. Many nations began to evaluate their own energy transition process and vigorously promoted the energy transition. Meanwhile, in the process of energy transition, countries have improved energy resilience and accelerated the construction of independent energy systems. Second, obvious heterogeneity lies in the connection between geopolitical risk and energy resilience. The study specifically identifies an inverted N-shaped nexus between geopolitical risk and energy resilience in the consideration of economic level. The outcomes of the heterogeneity analysis demonstrate that the local energy system will be at risk in both high-income and low-income countries due to the influence of geopolitical risk. Low-income countries have lower economic strength and are less able to resist external risk, so it is obvious that an increase in geopolitical risk will reduce energy resilience. However, although high-income countries have strong economies, geopolitical turmoil is often significantly concentrated in the stock market, and the country is more focused on the improvement of the trade market, while the energy resilience is relatively low. Thus, the ability to cope with geopolitical risk and energy resilience will be optimal only when the economic level of a region reaches moderate stability [44]. Finally, the results of the mediating effect show that geopolitical risk affects energy resilience both directly and indirectly. In other words, in the face of geopolitical risk shocks, dependence on fossil energy can stabilize the energy system and further enhance energy resilience, while in the energy structure adjustment where the new energy replaces the traditional energy, the use of renewable energy and the improvement of energy efficiency will hinder the improvement of energy resilience under the influence of high cost and the unstable supply of new energy.

These findings suggest that, in the current context of highly fossil-dependent energy markets, geopolitical risks do not endanger energy resilience, but rather enhance it to some extent. Therefore, policymakers of various countries should not only pay attention to the geopolitical alignment among economic players, groups, and regions but also vigorously support the adjustment of energy structure and promote the construction of a more autonomous and perfect energy system.

In light of these findings, this research provides several policy recommendations for enhancing energy resilience and building an autonomous energy system. First of all, as geopolitical instability hinders the evolution of energy systems, the global community, including the 20 countries studied, should focus on geopolitical harmony among economies, blocs, and regions. Geopolitical concerns should be understood to be a potential pressure on nations to develop their own independent energy systems, in addition to having an adverse effect on global economic growth, employment, and energy markets. Therefore, a peaceful and friendly geopolitical arena is very necessary to build an independent and perfect energy system. Moreover, to solve the unpredictability of geopolitical risk and guarantee the integrity of the energy system, policymakers must increase their risk management and contingency planning, and prepare for possible obstructs. Especially, when geopolitical tensions are high, governments and other relevant authorities, especially in the energy sector, should design and develop strategic plans, regulations, and processes to help energy systems demonstrate strong resilience in times of high global geopolitical risk. Specifically, on the one hand, we should support the development of diversified energy supply sources, including renewable energy, natural gas, nuclear energy, etc., and reduce dependence on a single energy source. Energy-importing countries are encouraged to establish long-term cooperative relations and energy security agreements with multiple suppliers to ensure the stability of the energy supply. Formulate policies to encourage local energy production and storage and reduce dependence on imported energy. On the other hand, international cooperation and multilateral mechanisms should be strengthened. Participating in international energy cooperation mechanisms, such as the International Energy Agency and the Energy Security Initiative, to jointly address the impact of geopolitical risks on global energy supply. We will strengthen regional energy cooperation and energy connectivity, and promote energy resource sharing and supply chain connectivity. At the same time, it invested in the security transformation and upgrading of energy infrastructure to improve its anti-interference capability and ability to cope with geopolitical risks.

Second, countries should adjust policy measures to local conditions given the impact of heterogeneity. For regions with different geopolitical environments, it is usually easier for regions with geopolitical stability to implement transnational energy cooperation and multilateral mechanisms to promote diversification and security of energy supply. Conversely, regions with geopolitical tensions may face challenges of difficult cooperation between states, and high energy security risks, and may require more sophisticated and prudent policies and mechanisms to ensure energy resilience. For countries with different economic conditions, high-income countries usually have more financial and technological resources and can more easily implement energy infrastructure transformation and diversify energy supply. Low-income countries, where economic conditions may be more limited, may need to rely on international aid or foreign investment to support the implementation of energy resilience policies. In addition, we advise that the governments of low-income nations create long-term objectives and strategies for sustainable development, steer clear of unsustainable behaviors, diversify their energy sources, and lessen their reliance on one kind of energy or supplier. Authorities should also invest in energy infrastructure to ensure it can withstand and mitigate the impact of geopolitical risk on energy resilience [45]. On the other hand, the worldwide community, particularly high-income nations, should take advantage of the escalating geopolitical threats throughout the world and aggressively take steps to strengthen the energy system and increase energy resilience. In particular, high-income countries ought to help low-income nations with finance and advanced technology, which is also conducive to building a good and harmonious geopolitical relationship [46]. For regions with different degrees of trade dependence, especially countries with different degrees of dependence on energy imports, targeted measures should also be taken to deal with energy challenges. In countries that are highly dependent on energy imports, geopolitical risks may have a greater impact on their energy supply. For example, for oil-exporting countries in the Middle East and some energy-importing countries in Europe and Asia, geopolitical tensions may lead to energy supply disruptions or price fluctuations, which in turn affect national economic and energy security. These countries need to take more proactive measures to deal with geopolitical risks, such as diversifying energy supply sources and strengthening international cooperation to ensure the stability of energy supply. However, some countries have abundant local energy resources and are able to achieve energy self-sufficiency or almost self-sufficiency. To some extent, these countries can reduce their dependence on international trade and thus reduce the impact of geopolitical risks on energy supply. However, these countries may also face challenges in terms of resource extraction costs and environmental protection and need to strike a balance between energy development and environmental protection to ensure the sustainability of energy supply.

At last, the findings of the mediating effect show that geopolitical risk can indirectly and weakly enhance energy resilience by increasing the total supply of primary energy, reducing the consumption of renewable energy, and reducing energy efficiency. However, in practice, it is not always appropriate to reduce renewable energy consumption and lower energy efficiency, especially when facing global warming pressure. This strategy's viability for actual execution is debatable. The world economy is currently experiencing fast growth, and guaranteeing an abundant energy supply is a critical assurance for economic progress. Therefore, countries should properly deal with the consumption of primary energy, the optimization of the energy structure, and the promotion of high-quality economic development. For example, on the supply side, governments should accelerate the development of wind power and solar power, develop hydropower and biomass power according to local conditions, actively develop nuclear power in a safe and orderly manner, and provide financial subsidies and tax incentives to corresponding sectors [47]. Furthermore, the government should set scientific and reasonable energy intensity targets based on national conditions and support the creation of platforms for industry-university-research collaboration to ensure energy supply. Of course, promoting energy transformation, improving the robustness and resilience of energy systems, learning from foreign sophisticated technologies, and boosting international exchanges and cooperation should also be paid attention.

Finally, policymakers in these countries need to develop flexible and targeted policy measures tailored to the specific circumstances of each country, taking full account of local needs and challenges, and promoting common development through international cooperation and consultation. However, this study also has some limitations. Our evidence is limited to a panel data set of 20 countries from 2000 to 2019, and future research could remedy this limitation by collecting more comprehensive and accurate data. Moreover, geopolitical risks and energy resilience are affected by many factors, such as geopolitical events, economic factors, and technological developments. Future research could explore the interactions between these factors in greater depth to more fully understand the complexity of energy markets. In addition, future research could explore the mediating effect in depth. Further explore the mediating mechanisms such as scale effect, structure effect, and technology effect to determine their mechanism of action between geopolitical risk and energy resilience, and explore other mediating effects that may exist. The influence of other factors can also be considered comprehensively. In addition to geopolitical risk and energy resilience, other factors that may affect the relationship between the two, such as government policies and market demand, can be considered to more fully understand the complexity of the energy system. Interdisciplinary research can also be conducted, intersecting the study of geopolitical risk and energy resilience with other disciplinary fields, such as international relations, economics, geography, *etc.*, to explore the topic from multiple perspectives.

Acknowledgments

We acknowledge the financial support from the Key Research and Special Popularization (Soft Science Research) Projects of Henan Province (222400410135) and the Postdoctoral Science Foundation of China (2022M720131).

Conflict of Interest

The authors declare no conflict of interest.

References

1. REN X., TONG Z., SUN X., YAN C. Dynamic impacts of energy consumption on economic growth in China: Evidence from a non-parametric panel data model. Energy Economics, **107**, 105855, **2022**.

2. GATTO A., DRAGO C. Measuring and modeling energy resilience. Ecological Economics, **172**, 106527, **2020**.
3. REHAK D., SENOVSKY P., HROMADA M., LOVECEK T. Complex approach to assessing resilience of critical infrastructure elements. International Journal of Critical Infrastructure Protection, **25**, 125, **2019**.
4. SWEIDAN O.D. Is the geopolitical risk an incentive or obstacle to renewable energy deployment? Evidence from a panel analysis. Renewable Energy, **178**, 377, **2021**.
5. SHAHZAD U., MOHAMMED K.S., TIWARI S., NAKONIECZNY J., NESTEROWICZ R. Connectedness between geopolitical risk, financial instability indices and precious metals markets: Novel findings from Russia Ukraine conflict perspective. Resources Policy, **80**, 103190, **2023**.
6. JOHANNESSON J., CLOWES D. Energy Resources and Markets - Perspectives on the Russia-Ukraine War. European Respiratory Review, **30** (1), 4, **2022**.
7. CALDARA D., IACOVIELLO M. Measuring Geopolitical Risk. American Economic Review, **112** (4), 1194, **2022**.
8. NITOIU C., SUS M. Introduction: The Rise of Geopolitics in the EU's Approach in its Eastern Neighbourhood. Geopolitics, **24** (1), 1, **2019**.
9. FERNANDOIS A., MEDEL C.A. Geopolitical tensions, opec news, and the oil price: A Granger causality analysis. Review of Austrian Economics, **35** (2), 57, **2020**.
10. LI J., ZHANG X., ALI S., KHAN Z. Eco-innovation and energy productivity: New determinants of renewable energy consumption. Journal of Environmental Management, **271**, 111028, **2020**.
11. KHAN M.K., KHAN M.I., REHAN M. The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. Financial Innovation, **6** (1), 1, **2020**.
12. GONG X., SUN Y., DU Z. Geopolitical risk and China's oil security. Energy Policy, **163**, 112856, **2022**.
13. FLOUROS F., PISTIKOU V., PLAKANDARAS V. Geopolitical Risk as a Determinant of Renewable Energy Investments. Energies (Basel), **15** (4), 1498, **2022**.
14. SARKER P.K., BOURI E., MARCO C.K.L. Asymmetric effects of climate policy uncertainty, geopolitical risk, and crude oil prices on clean energy prices. Environmental Science and Pollution Research, **30** (6), 15797, **2023**.
15. ZHAO W., ZHONG R., SOHAIL S., MAJEED M.T., ULLAH S. Geopolitical risks, energy consumption, and CO_2 emissions in BRICS: an asymmetric analysis. Environmental Science and Pollution Research, **28** (29), 33759102, **2021**.
16. NIU S., CHEN Y., ZHANG R., LUO R., FENG Y. Identifying and assessing the global causality among energy poverty, educational development, and public health from a novel perspective of natural resource policy optimization. Resources Policy, **83**, 103770, **2023**.
17. FENG Y., SHOAIB M., AKRAM R., ALNAFRAH I., AI F., IRFAN M. Assessing and prioritizing biogas energy barriers: A sustainable roadmap for energy security. Renewable Energy, **223**, 120053, **2024**.
18. GUPTA R., GOZGOR G., KAYA H., DEMIR E. Effects of geopolitical risks on trade flows: evidence from the gravity model. Eurasian Economic Review, **9** (4), 515, **2019**.
19. SHEN Q., PAN Y., FENG Y. Identifying impacts of industrial co-agglomeration on carbon emissions: Evidence from China. Frontiers in Public Health, **11**, 1154729, **2023**.
20. GUANG F., HE Y., WEN L., SHARP B. Energy intensity and its differences across China's regions: Combining econometric and decomposition analysis. Energy (Oxford), **180**, 989, **2019**.
21. FENG Y., ZHANG J., GENG Y., JIN S., ZHU Z., LIANG Z. Explaining and modeling the reduction effect of low-carbon energy transition on energy intensity: Empirical evidence from global data. Energy (Oxford), **281**, 128276, **2023**.
22. SU C.-W., KHAN K., TAO R., NICOLETA-CLAUDIA M. Does geopolitical risk strengthen or depress oil prices and financial liquidity? Evidence from Saudi Arabia. Energy (Oxford), **187**, 116003, **2019**.
23. VAKULCHUK R., OVERLAND I., SCHOLTEN D. Renewable energy and geopolitics: A review. Renewable & Sustainable Energy Reviews, **122**, 109547, **2020**.
24. SU C.-W., KHAN K., UMAR M., ZHANG W. Does renewable energy redefine geopolitical risks? Energy Policy, **158**, 112566, **2021**.
25. ZHANG Z., ZHANG Y., ZHAO M., MUTTARAK R., FENG Y. What is the global causality among renewable energy consumption, financial development, and public health? New perspective of mineral energy substitution. Resources Policy, **85**, 104036, **2023**.
26. LI M., LI Y., PAN J., WU H. Potential of renewable energy development and its geopolitical risk implications for China s energy security. China Population Resources and Environment, **32** (11), 1, **2022**.
27. FENG Y., SABIR S.A., QUDDUS A., WANG J., ABBAS S. Do the grey clouds of geopolitical risk and political globalization exacerbate environmental degradation? Evidence from resource-rich countries. Resources Policy, **89**, 104533, **2024**.
28. SHEN Q., PAN Y., FENG Y. Identifying and assessing the multiple effects of informal environmental regulation on carbon emissions in China. Environmental Research, **237**, 116931, **2023**.
29. 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 Economics, **122**, 106700, **2023**.
30. DONG K., DONG X., JIANG Q., ZHAO J. Assessing energy resilience and its greenhouse effect: A global perspective. Energy Economics, **104**, 105659, **2021**.
31. MENG F., LIANG X., XIAO C., WANG G. Integration of GIS, improved entropy and improved catastrophe methods for evaluating suitable locations for well drilling in arid and semi-arid plains. Ecological Indicators, **131**, 108124, **2021**.
32. DONG K., DONG X., JIANG Q. How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels. World Economy, **43** (6), 1665, **2020**.
33. AKRAM R., MAJEED M.T., FAREED Z., KHALID F., YE C. Asymmetric effects of energy efficiency and renewable energy on carbon emissions of BRICS economies: evidence from nonlinear panel autoregressive distributed lag model. Environmental Science and Pollution Research, **27** (15), 18254, **2020**.
34. WANG B., ZHAO J., DONG K., JIANG Q. High-quality energy development in China: Comprehensive assessment and its impact on CO2 emissions. Energy Economics, **110**, 106027, **2022**.
35. BALTAGI B.H., FENG Q., KAO C. A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. Journal of Econometrics, **170** (1), 164, **2012**.
36. NGUYEN K.H., KAKINAKA M. Renewable energy consumption, carbon emissions, and development stages:

Some evidence from panel cointegration analysis. Renewable Energy, **132**, 1049, **2019**.
37. LIDDLE B., SADORSKY P. How much do asymmetric changes in income and energy prices affect energy demand? Journal of economic asymmetries, **21**, e00141, **2020**.
38. SMITH D.C. Geopolitical realities of the energy transition supply chain: energy security risks and opportunities. Journal of Energy & Natural Resources Law, **41** (3), 233, **2023**.
39. LIN B., XU B. How does fossil energy abundance affect China's economic growth and CO2 emissions? Science of the Total Environment, **719**, 137503, **2020**.
40. LIU Y., DONG K., JIANG Q. Assessing energy vulnerability and its impact on carbon emissions: A global case. Energy Economics, **119**, 106557, **2023**.
41. LIU Y., FENG C. Promoting renewable energy through national energy legislation. Energy Economics, **118**, 106504, **2023**.
42. OWJIMEHR S., EMAMI MEYBODI M., JAMSHIDI N. Can geopolitical risk improve energy efficiency in European countries? Energy strategy reviews, **49**, 101145, **2023**.
43. LEE C.-C., WANG F., CHANG Y.-F. Towards net-zero emissions: Can green bond policy promote green innovation and green space? Energy Economics, **121**, 106675, **2023**.
44. AHMADI S., SABOOHI Y., VAKILI A. Frameworks, quantitative indicators, characters, and modeling approaches to analysis of energy system resilience: A review. Renewable & Sustainable Energy Reviews, **144**, 110988, **2021**.
45. ZHOU Y. Climate change adaptation with energy resilience in energy districts – A state-of-the-art review. Energy and Buildings, **279**, 112649, **2023**.
46. WANG Q., ZHANG C., LI R. Impact of different geopolitical factors on the energy transition: The role of geopolitical threats, geopolitical acts, and geopolitical risks. Journal of Environmental Management, **352**, 119962, **2024**.
47. DING S., WANG K., CUI T., DU M. The time-varying impact of geopolitical risk on natural resource prices: The post-COVID era evidence. Resources Policy, **86**, 104161, **2023**.