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## Article

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## Full Length Article

# The spillover effects of political risk, financial risk, and economic freedom on ecological footprint: Empirical evidence from Belt and Road Initiative countries

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## Abstract

Determining the relationships between economic freedom, political and financial risk, and ecological footprint has important implications for all nations and surrounding countries' environmental sustainability. Nevertheless, the regional influence of these variables has largely been ignored, particularly in countries that are part of China's Belt and Road Initiative (BRI), with only a few studies examining institutions' participation in reducing environmental degradation. This article expands previous research regarding whether the economic freedom and political and financial risks of surrounding countries can also impact domestic ecological footprints. We apply a spatial dynamic econometric model to a panel of 86 BRI countries from 1995 to 2020 to investigate these influences. Our results demonstrate the presence of regional dependency in countries' ecological footprint, also revealing evident spillover effects of indirect political and financial risks and economic freedom.

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**Keywords:** Ecological footprint; Economic freedom; Political risk; Financial risk; Spatial econometric

## 1. Introduction

Rising environmental degradation (ED) and climate change are among the most serious challenges facing the world today. With the accelerated development of contemporary industrial civilization across the globe in recent decades, fossil fuel energy use (e.g., natural gas, oil, and coal) has steadily increased, leading to rising ED (Danish, Baloch, Mahmood, & Zhang, 2019; Dong et al., 2018; Wang et al., 2017; Zhao, Jiang, et al., 2021). British Petroleum data, presenting statistical analyses of worldwide energy use (BPSTATS, 2019) in recent decades, demonstrate a substantial increase of 0.85 °C in global temperature from 1980 to 2012. Indeed, global carbon dioxide (CO<sub>2</sub>) emissions rose from 25,716.4 million tons (Mt) of CO<sub>2</sub> in 2003 to 33,891.7 Mt of CO<sub>2</sub> in 2018, representing a 32.49%

increase. As a primary constituent of greenhouse gases, CO<sub>2</sub> emissions significantly affect global warming. The continuous escalation of greenhouse gases has generated a multitude of environmental and social issues, such as melting glaciers, rising sea levels, and expanding deserts, which could have disastrous effects on the global environment and the flourishing of human civilization (Liobikienė & Butkus, 2019; Yang et al., 2017). Notably, primary fossil fuel consumption in developing nations is projected to rise by 3.2% annually by 2025 (Saidi & Omri, 2020). Given that energy is essential for economic progress and is also a major cause of ED, the link between energy, gross domestic product (GDP), and environmental quality (EQ) is among the most debated and contentious issues of the 21<sup>st</sup> century.

In recent decades numerous studies have investigated the relationships between GDP growth, EQ, and energy use (Danish, Baloch, Mahmood, & Zhang, 2019; Dong et al., 2018; Khan et al., 2021; Saidi & Omri, 2020). However, the spillover effects of economic freedom (EFD), political risk (PR), and

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financial risk (*FR*) on *EQ* have largely been ignored. This study fills this vacuum in the academic literature. We posit that a stable economic and political climate stimulates investment and development and stabilizes environmental regulation.

Institutional factors such as *EFD* are important determinants of *EQ*. The correlations of *EFD* and the environment can be classified into categories of scale, market failure, efficiency, trade regulation, moderating, and stability effects (Carlsson and Lundström, 2001, 2003; Joshi & Beck, 2018). From the efficiency perspective, *EFD* could improve external internalization, relative pricing, energy efficiency, and ecological laws, increase the focus on lowering  $CO_2$  emissions as a worldwide public benefit, and mitigate free-riding (Shahnazi & Dehghan Shabani, 2021). From the stability perspective, *EFD* could impact *EQ* through long-term investments in energy-efficient companies and clean renewables. From the moderating perspective, increased competitiveness due to rising *EFD* increases consumers' ability to select environmentally friendly goods (Arrow et al., 2004). Scale effects indicate that rising *EFD* via higher output evokes increased *ED* (Carlsson & Lundström, 2001). Based on trade regulation effects, trade impacts the environment through five mechanisms of size, technological and competitiveness impacts, international norms, and pollution havens, and *EFD* could both positively and negatively impact the environment (Grossman & Krueger, 1991; Sheikh, 2017).

*PR* and *EQ* are also the subject of intense examination among academics and economists since political institutions can directly and indirectly affect ecosystems. Political institutions must actively participate in ecological transformation, and such research also supports the premise that a more robust political environment reduces the costs of rapid *GDP* expansion, improving *EQ* (Ashraf, Luo, & Anser, 2022; Hussain & Dogan, 2021). In terms of *PR*, good governance, political stability, and decreased violence and disputes significantly influence ecological regulation and *ED* mitigation (Al-Mulali & Ozturk, 2015; Ashraf, 2022). Political institutions can also impact *EQ* by affecting the development, enforcement, and oversight of effective environmental laws and regulations. A superior political environment leads to less pollution and improved ecological quality (Ahmad et al., 2021). Wen et al. (2016) demonstrate that an effective ecological strategy interacts strongly with a country's national atmosphere (i.e., politics and institutional systems), particularly with major political parties. Dasgupta and de Cian (2018) also determine that the impacts of ecological intervention rely on the political context leading to policy decisions. Su et al. (2021) argue that lowering *PR* improves the political environment and lowers  $CO_2$  emissions.

Financial stability is critical for economic development (Lee et al., 2013) and significantly affects the ecosystem. First, a financially stable environment and effective financial institutions may encourage higher foreign direct investment (*FDI*), boost economic development, and increase energy consumption (Shahbaz et al., 2018), thus increasing *ED*. Second, the growth of financial markets may raise *ED* by lowering credit restrictions for companies with investment initiatives that

do not benefit the environment and for consumers purchasing energy-intensive products (Zhao, Shahbaz, et al., 2021). Third, financial stability may promote financial assistance for green technology research and development, increasing energy efficiency and substantially decreasing *ED* (Shahbaz et al., 2018; Zhao, Shahbaz, et al., 2021).

*PR*, *FR*, and *EFD* ratings could be considered an integrated representation of political stability, economic strength, and the ability and desire to provide services in exchange for financial commitments (Hoti & McAleer, 2002). Nevertheless, little is known regarding the impact of *PR*, *FR*, and *EFD* on ecological footprint (*EF*); thus, to the author's knowledge, this research adds to the literature on the risk rating environmental Kuznets curve (*EKC*) hypothesis using these variables.

This study concentrates on Belt and Road Initiative (*BRI*) countries due to their accelerated development and increasing economic and environmental significance. In 2013, China proposed the *BRI* to encourage collaborative growth, and has since aggressively pursued its ongoing development. The *BRI* was established to exchange development opportunities and attain collaborative and mutually beneficial growth and development with participating countries. Ashraf, Luo, and Khan (2022) argue that *BRI* policy has a significant spatial impact on host nations' as well as neighboring regions' economic progress. Figures released by the International Monetary Fund in October 2018 demonstrate an average annual growth rate of *BRI* countries between 2013 and 2017 of 5.1%, which is much higher than other aggregate rates, such as the European Union, at 2.2%; the world, at 3.5%; and developed economies, at 2.1%. In addition, investment is advancing in *BRI* countries (Wang, Ma, et al., 2020), and with over 3 billion people, *BRI* nations represent 42% of the global population (United Nations, 2019). This huge population has considerable development potential and also exerts significant environmental strain (Apergis & Ozturk, 2015). Apart from the gains cited above, it is crucial to note that *BRI* countries confront a number of challenges (Wang et al., 2018). The most visible of these issues are poor rule of law, political instability, rising corruption as a result of increased social disparities, and ecological stress caused by the intensive use of energy (i.e., oil and fossil fuel consumption) and conventional technologies (Danish, Baloch, & Wang, 2019). Consequently, *BRI* countries are accountable for almost 40% of global  $CO_2$  emissions (He et al., 2020). Based on this premise, *BRI* nations are suitable for examining the regional impact of *EFD*, *PR*, and *FR* in the context of *ED*.

The environmental sustainability of neighboring nations is affected by key countries' development, risk, and climate. A well-functioning country will have an impact on neighboring nations and regions. Traditional econometric panel methods can lead to skewed results because they overlook spatial relationships and fail to capture spillover effects. Spatial panel models (*SPMs*) are found to be more efficient and productive (Khezri et al., 2021). Spatial impacts are crucial considerations when evaluating the connections of the environment–growth–energy nexus (Zou & Zhang, 2020). According to Hosseini and Kaneko (2013), political institutions affect a

country's own *EQ* and this effect spreads to adjacent countries through institutional spillover channels.

This study's contributions are three-fold. First, this research represents an initial foray considering the regional influence of *EFD*, *PR*, and *FR* on *ED* in *BRI* nations from 1995 to 2020 using *GDP* growth and energy consumption as control variables. Examining the relationships between *EFD*, *PR*, *FR*, and *ED* is critical since the nations engaged in these megaprojects also seek to reach “sustainable development objectives” by 2030. This study addresses this gap in the literature. Second, the majority of previous research on the risk–environment nexus examines the impact of cumulative Country Risk (*CR*) on the environment, and few studies have thoroughly examined the effect of *CR* on the environment. To address this gap, this study investigates the connection between *EFD*, *PR*, *FR*, and *ED* based on a comprehensively constructed index, and this research on the interdependence of these variables will be helpful for the strategic development of appropriate government policies. Third, we use the *SPM*, a spatial technique that is selected because of the considerable variability among *BRI* nations, wherein different regions have vastly differing characteristics in areas such as risk, energy consumption, *GDP* growth, and *ED* due to gravitational effects. There are spatial relationships between countries, and modern research models often disregard such spatial features, contributing to the failure of conventional models to consider the critical aspect of spatial dependence. This research provides a novel perspective regarding the relationships between *GDP*, energy consumption, *EFD*, *PR*, *FR*, and *ED*.

## 2. Literature review

In recent decades, some studies have concentrated on the impact of *CR* on *EQ*, but a consensus has not yet been reached. For example, [Zhang and Chiu \(2020\)](#) used a panel dataset from 1985 to 2014 to examine the nonlinear effect of a *CR* index including *PR*, *FR*, and economic risks on the environment based on the smooth transition regression model, determining that *CR* has a monopoly rising effect on *ED*, and [Abbasi and Riaz \(2016\)](#), [Shahbaz et al. \(2018\)](#), and [Zaidi et al. \(2019\)](#) confirm this view. In contrast, [Zhang \(2011\)](#) claims that *FR* is a major driver of *EQ* in China, which is confirmed by [Shahbaz et al. \(2016\)](#). In terms of the negative and positive links between *FR* and the environment, according to [Ozturk and Acaravci \(2013\)](#), the long-run effect of *FR* has not significantly affected Turkey's environment.

[Guo et al. \(2020\)](#) conduct a systematic investigation into the effects of *CR* and income inequality on *CO<sub>2</sub>* emissions, demonstrating that the marginal impact of income inequality on *CO<sub>2</sub>* continuously decreases with a decreasing *CR* index, even exhibiting negative results. In both low- and high-income nations, *CR* index significantly negatively impacts the relationship between inequality and the environment. Some research has also evaluated the effect of sovereign risk on *CO<sub>2</sub>* emissions using annual data from G7 advanced nations from 1996 to 2014, indicating that sovereign risks significantly negatively impacts *CO<sub>2</sub>* emissions ([Chaudhry et al., 2020](#)). Similarly,

[Zhao, Shahbaz, et al. \(2021\)](#) demonstrate the mediating effect of *FR* on *CO<sub>2</sub>* emissions, determining that high *FR* hurts *CO<sub>2</sub>* emissions not only directly but also indirectly.

[Lee and Chen \(2021\)](#) conduct panel quantile regression to examine the effect of *CR* index on *EF*, demonstrating that *PR* ratings have a more positive impact than economic and *FR* ratings on *EF*, indicating the correlation of countries' political ratings with environmental deterioration. Some research has identified aspects of *PR* that may enhance *EQ*, such as control, corruption, and democracy ([Tamazian & Bhaskara Rao, 2010](#)). [Ashraf \(2022\)](#) finds that lowering *PR*, such as by decreasing conflict and corruption, improves *EQ*, while others observe that similar traits may impair the environment ([Yamineva & Liu, 2019](#)). [Abid \(2016\)](#) argues that political instability, corruption, democracy, government efficiency, and socioeconomic circumstances have a mediating impact on *CO<sub>2</sub>* emissions in Sub-Saharan Africa.

Some studies consider the impact of institutions on the environment (e.g., [Immergut & Orlowski, 2013](#); [Lægrend & Povitkina, 2018](#)), identifying *EFD* as a factor that may influence the environment indirectly and directly. In this regard, one notable investigation is [Shahnazi and Dehghan Shabani \(2021\)](#). According to [Carlsson and Lundström \(2001\)](#), *EFD* positively impacts *ED* in developed nations but negatively affects *ED* in developing nations. [Carlsson and Lundström \(2003\)](#) examine the connection between *EFD* and *CO<sub>2</sub>* emissions, examining indicators of “structure and usage of markets,” “freedom to trade with foreigners,” and “legal security and price stability.” The authors determine that legal security and price stability has a substantial negative connection on *CO<sub>2</sub>* emissions, but no other variables exhibited significant correlations. [Joshi and Beck \(2018\)](#) find that *EFD* positively impacts *CO<sub>2</sub>* emissions in *OECD* nations but negatively impacts *non-OECD* nations.

A review of previous research indicates that research on the relationship between national risk and the environment is limited and primarily covers specific circumstances. Furthermore, the impact of *EFD*, *PR*, and *FR* on *ED* remains unexplored. *CO<sub>2</sub>* emissions are extensively used to measure *ED* in the previous studies. In addition, research on the risk–environment nexus relies on the traditional panel methods and other econometrics techniques that disregard the critical matter of spatial dependence, which could potentially generate inaccurate estimates. We presumed that no country isolates; therefore, in circumstances of geographical dependence between regions, *SPMs* must be considered to avoid skewed empirical results. Traditional techniques, such as the generalized method of moments and (*GMM*) ordinary least squares (*OLS*) do not comprehensively address the issues created by spatial dependence between attributes by monitoring the fixed outcomes ([Anselin et al., 2008](#)). *SPMs* are also applied nationally or worldwide to investigate the causes of *ED*, and are robust in detecting the spatial connections between the environment and other variables ([Khezri et al., 2021](#)). This study applies a more robust indicator of *ED* and investigates the impact of *EFD*, *PR*, and *FR* using spatial econometric techniques.

### 3. Data description and theoretical framework

A panel sample dataset for 86 countries between 1995 and 2020 (other countries are excluded due to data unavailability) is used to examine the spatial effect of the risk–environment nexus across *BRI* countries. Figure 1 presents a map of each nation's location, and Appendix A presents a list of the countries included. Table 1 defines the data sources and variables. In particular, this study aims to thoroughly address concerns regarding the spatial impact of *PR*, *FR*, and *EFD* on *ED*. The dependent variable in this research is *EF*, which is used as a proxy for *ED*. *EF* is measured by summing components of carbon, built-up land, fishing grounds, forest land, cropland, and grazing land. *EF* has also received attention as a broader indicator of *ED* (Danish & wang, 2019; Dogan et al., 2020). Other independent variables are presented below.

The main independent variable is *PR*. Political institutions have an important influence on *EQ* via ecological policy initiatives. Political stability implies low corruption and allows for rigorous environmental rules to be enacted, implemented, and effectively enforced to improve *EQ* (Dasgupta & de Cian, 2018). Stable political institutions support the implementation of environmental laws, preserve property rights, improve the quality of contract execution, and improve the efficacy of policy initiatives via the level of institutional independence from political influence (Phuc Canh et al., 2019). Weak

institutions exacerbate corruption, whereas ineffective bureaucratic processes disregard strong policy efforts. The institutional function is critical not only for a country's progress, but it may also substantially enhance or reduce *ED* (Danish & Ulucak, 2020). *PR* is measured using 12 indicators of political risk and institutions, and the data are sourced from the International Country Risk Guide (*ICRG*) rating published by the Political Risk Services (*PRS*) Group.

As with *PR*, most studies do not address *EFD* as an ecological element. While many studies examine the ecological effect of trade openness or proprietary rights, few include a comprehensive measure of *EFD* for more comprehensive insight into the interplay between *EFD* and *EQ*. We use *EFD* to measure economic freedom in its entirety, with the knowledge that the effects on the environment may prove contradictory and complicated. More *EFD* may damage the environment by increasing the number of companies and industries that create more products and generate more pollutants (Carlsson & Lundström, 2001). In contrast, countries with excellent *EFD* may also exert moderating competitive impact on polluting activities, as consumers are increasingly able to choose more ecologically friendly goods (Arrow et al., 2004). When demand for a better environment rises, companies typically react by creating more customer-friendly products. This variable assesses the extent to which national policies and institutions promote *EFD*, and the data are sourced from the Fraser Institute.

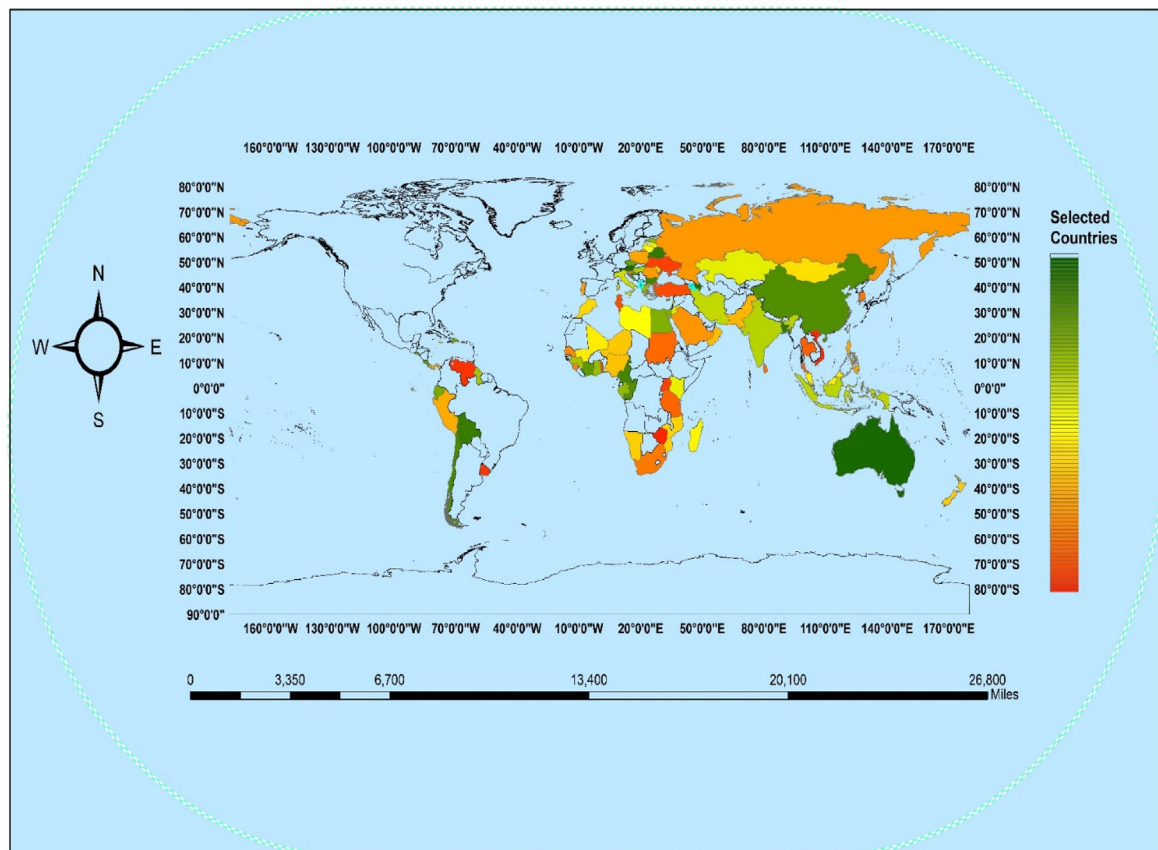


Fig. 1. Geographical locations of the selected countries.

Table 1  
Variable explanation.

| Variable                  | identifier | Measurement                                                                                                                                                                                                                                                                                       | Source           |
|---------------------------|------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Environmental degradation | ED         | This is proxied by ecological footprint of Consumption (Global hectares per capita).                                                                                                                                                                                                              | GFN              |
| Economic growth           | GDP        | it is measured by <i>GD P</i> per capita (constant 2010 US \$)                                                                                                                                                                                                                                    | WDI              |
| Energy consumption        | ENC        | Energy use (kg of oil equivalent per capita)                                                                                                                                                                                                                                                      | WDI              |
| Political risk            | PR         | It is an index covering corruption, internal conflicts, government stability, external conflicts, socio-economic conditions, demographic accountability, law & order, ethnic tensions, military in politics, investment profile, religious tension, internal conflicts, and bureaucratic quality. | PRS Group        |
| Financial risk            | FR         | It is an index covering the debt service, current account as a share of total <i>EGS</i> , international liquidity, exchange rate stability, and external debt                                                                                                                                    | PRS Group        |
| Economic freedom          | EFD        | An index measures the degree to which policies and institutions of countries are supportive of <i>EFD</i> . A higher score indicates higher <i>EFD</i> .                                                                                                                                          | Fraser Institute |
| <b>BRI</b> Policy         | BRI        | The <i>BRI</i> dummy variables test <i>BRI</i> policy's effect on environment. It equals 0 if the year is before 2013 and 1 if the year is after 2013                                                                                                                                             | Made by author   |

As a key independent variable, *FR* measures financial risk to date, which is a significant issue as no consistent measurement standard has been developed; therefore, this research constructs a complete index to evaluate *FR* in a novel way. According to the *ICRG* rating published by the *PRS*, five indicators of international liquidity, exchange rate stability, the proportion of current accounts representing exports of goods and services (*EGS*), debt service as a percentage of *EGS*, and foreign debt as a percentage of *GDP* to evaluate comprehensively *FR*.

Economic growth is denoted as *GDP*. Grossman and Krueger's (1991) *EKC* hypothesis places significant focus on the dynamic relationship of *GDP* and *EQ*. In particular, accelerated *GDP* growth raises *ED* in the early stage and supports improved *EQ* once a threshold inflection point is crossed (Khezri et al., 2021; Saidi & Omri, 2020; Zhao, Shahbaz, et al., 2021). Therefore, we provide the level and square term of *GDP* growth in this research to investigate the *EKC* hypothesis that is assessed by the *GDP* per capita. The economic growth data are sourced from the World Development Indicators (World Bank, 2020).

Energy consumption is denoted as *ENC*. Coal and oil-dominated energy consumption structures worldwide generate significant *CO<sub>2</sub>* emissions, and many researchers have verified the positive effect of *ENC* on *ED* (e.g., Khan et al., 2021; Shahnazi & Dehghan Shabani, 2021). Energy consumption is the primary driver of *ED* and climate change (Destek & Sinha, 2020). *ENC* data are sourced from the World Bank (2020).

#### 4. Estimation methods

##### 4.1. Spatial dependency

*ED* could exhibit characteristics of spatial dependence. Determining this requires spatial econometric analysis instead of the conventional econometric analyses. Spatial dependency analysis can be separated into local spatial autocorrelation (*LSA*) and global spatial autocorrelation (*GSA*) analyses (Anselin & Tam Cho, 2002). Moran's Global *I* is a key indicator of *GSA* and can be calculated as follows.

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (1)$$

where  $x_i$  and  $x_j$  indicate the observed value of area  $i$  and area  $j$ , respectively and  $\bar{x}$  indicates the average of the observed value.  $S^2$  represents the standard deviation (*SD*) of the sample.  $W_{ij}$  is the elements of the  $i_{th}$  and  $j_{th}$  column of the spatial matrix. The spatial matrix is constructed using a spatial distance reciprocal; the matrix values of components are as follows:

$$W_{ij} = \begin{cases} 1/k_{ij}, & i \neq j \\ 0, & i = j \end{cases} \quad (2)$$

$i = 1, 2, \dots, n$   
 $j = 1, 2, \dots, n$

where  $k_{ij}$  represents the spatial distance between the  $i_{th}$  and  $j_{th}$  area. The total number of columns and rows of  $W_{ij}$  equals the number of sample areas ( $n = 86$ ).

*LSA* analyzes statistics and measures the indicators of local indications spatial association (*LISA*). The fundamental index is local Moran's *I*, and the analytical instruments include *LISA* cluster maps and Moran's *I* scatterplots (Anselin, 1995). The local Moran's *I* of the  $i_{th}$  sample area can be determined using the following formula:

$$I_i = \frac{(x_i - \bar{x}) \sum_{j=1}^n W_{ij}(x_j - \bar{x})}{\left[ \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \right]} \quad (3)$$

##### 4.2. Spatial dynamic models

The dynamic spatial model may minimize the potential estimate bias caused by missing data and unobservable variables (LeSage, 2008; Elhorst, 2010, 2012). The dynamic spatial autoregression model (*SAR*) and dynamic spatial Durbin model (*SDM*) are used as the basic models in this research. The dynamic *SAR* model considers the geographic impact of the dependent variable; therefore, its formula

contains the dependent variable's spatial lag term can be stated as follows:

$$Y_{it} = \alpha + \tau Y_{it-1} + \eta \sum_{j=1}^n W_{ij} Y_{it-1} + \rho \sum_{j=1}^n W_{ij} Y_{it} + \beta X_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

where  $Y$  represents the dependent variable,  $i$  denotes the country (area), and  $t$  is the time (year).  $\tau$  indicates the lag of the coefficient variable  $Y_{it-1}$  to reflect temporal dependency, and  $\alpha$  represents the intercept.  $W_{ij}$  denotes the matrix of spatial weight.  $\eta$  represents the coefficient of spatial endogenous interaction lag term explaining the explanatory variable's time and geographical dependency, reflecting the spatial interplay of exogenous factors over time (Debarsy et al., 2012).  $\rho$  indicates the spatial autoregression coefficient, wherein, when  $\rho$  has statistical significance, it indicates a significant geographical dependency between dependent variables, implying that  $EQ$  in a location relies on adjacent areas. The value of  $\rho$  indicates the degree of geographical dependence (Gelfand et al., 2010).  $X_{it}$  is the  $k \times 1$  vector of independent variables, and  $\beta$  represents the coefficient of the independent variables.  $\mu_i$  is a specific effect that cannot be directly captured and measured, and  $\varepsilon_{it}$  indicates the disturbance term.

The dynamic  $SDM$  includes the spatial lags of the dependent variable and independent variables. It uses the marginal effects of independent factors from the neighboring area/country based on the  $SAR$  model. The following is a general description of  $SDM$ .

$$Y_{it} = \alpha + \tau Y_{it-1} + \eta \sum_{j=1}^n W_{ij} Y_{it-1} + \rho \sum_{j=1}^n W_{ij} Y_{it} + \beta X_{it} + \delta \sum_{j=1}^n W_{ij} X_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

where  $W_{ij} X_{it} \delta$  indicates the spatial lag of the independent variables,  $X_{it}$  denotes the  $n \times (k-1)$  matrix of an independent variable, and  $\delta$  represents the  $(k-1) \times 1$  parameter vector that computes the independent factors' marginal effects on the dependent variable based on adjacent data.

The effect of a variable in spatial measurements is not directly obtainable from the regression coefficient, which is included in the marginal effect calculation's recursive process; hence, the estimated model's direct and indirect impacts must be calculated. These effects can be obtained at two distinct time scales of the short-run impact of short-run variable changes and the long-term effect of continuous variability changes. The computation can be conducted using the following equations:

Short-run ( $SR$ ) direct effect:

$$[(I - \rho W)^{-1}(\beta_k I + \theta_k W)]^{\bar{d}} \quad (6)$$

Short-run ( $SR$ ) indirect effect:

$$[(I - \rho W)^{-1}(\beta_k I + \theta_k W)]^{\bar{d}} \quad (7)$$

Long-run ( $LR$ ) direct effect:

$$[((1 - \tau)I - (\rho + \eta)W)^{-1}(\beta_k I + \theta_k W)]^{\bar{d}} \quad (8)$$

Long-run ( $LR$ ) indirect effect:

$$[((1 - \tau)I - (\rho + \eta)W)^{-1}(\beta_k I + \theta_k W)]^{\bar{d}} \quad (9)$$

where the  $d$  superscript indicates the average diagonal factor of the matrix, and  $T$  represents the average row amount of non-diagonal elements. When  $\tau = 0$ , the long-run impact estimate is as follows:

Long-run ( $LR$ ) direct effect:

$$[((1 - \tau)[I - \rho W)^{-1}(\beta_k I + \theta_k W)]^{\bar{d}} \quad (10)$$

Long-run ( $LR$ ) indirect effect:

$$[((1 - \tau)I - \rho W)^{-1}(\beta_k I_N + \theta_k W)]^T \quad (11)$$

Elhorst (2003) suggests evaluating the static spatial panel model using the maximum likelihood ( $ML$ ) technique; however, Yu et al. (2008) conclude that the  $ML$  estimator contribution cannot be adequately centered, and the  $ML$  estimator is inconsistent. Lee and Yu (2010) offer the quasi-maximum probability ( $QML$ ) method, which provides consistent estimators with correct centered distributions to address the limitations of the  $ML$  approach; hence, we apply the  $QML$  technique for estimating the model.

## 5. Results and discussion

The research applies an appropriate methodological path to assess the empirical results for the implications of the policy outcomes of  $BRI$  targets.

### 5.1. Descriptive statistics

Table 2 presents a summary of data for each variable, which includes 86 cross-sections and 26 time periods. The variation for  $GDP$  and  $ENC$  has a mean value of \$9175.23 and \$1405.30, respectively. The  $EF$  appears miniscule throughout the periods of global per capita hectares in  $BRI$  nations, indicating that the use of fossil fuels is highly variable across areas. This research examines the study's hypothesis in the  $BRI$  area to navigate this volatility.

### 5.2. Spatial dependency analysis

In spatial analysis, we first investigate whether the  $EQ$  in  $BRI$  nations is spatially autocorrelated ( $SA$ ) applying the Moran's  $I$  test to investigate the depth of  $SA$ . A significant

Table 2  
Summary of statistics.

| Variables | Obs. | Mean     | Std. Dev. | Min.     | Max.     |
|-----------|------|----------|-----------|----------|----------|
| ED        | 2236 | 4.31219  | 4.495221  | .0336    | 25.2731  |
| GDP       | 2236 | 9175.233 | 11385.06  | 215.547  | 59374.44 |
| ENC       | 2236 | 1405.309 | 1830.521  | 69.9597  | 12406.81 |
| PR        | 2236 | 5.301165 | 1.168903  | 2.2639   | 7.5764   |
| FR        | 2236 | 7.073488 | 1.473631  | 0.9      | 10       |
| EFD       | 2236 | 6.612188 | .9385117  | 2.773333 | 8.68     |
| BRI       | 2236 | .3076923 | .4616417  | 0        | 1        |

positive number from Moran's  $I$  indicates geographical clustering, whereas a negatively significant figure suggests spatial dispersion among the nations (Sun et al., 2021). We calculated the annual Moran's  $I$  based on the projected environmental index for the 86 BRI nations between 1995 and 2020. Table 3 demonstrates that Moran's  $I$  values are higher than zero, indicating a positive SA in  $EQ$ . The Moran's  $I$  value is positively significant at the 1% level. This result indicates countries with high  $EQ$  surround high  $EQ$  countries, and countries with low  $EQ$  surround low  $EQ$  areas. Fig. 2 presents LISA maps in 1995 and 2020 based on the local weight matrix  $K2$ , demonstrating a significant geographical dependency in BRI  $EQ$ .

### 5.3. Comparing dynamic spatial panel models

To minimize the effects of heteroskedasticity,  $GDP$  and  $ENC$  variables were created in the form of logarithms. We estimate the spatial weight matrix using models based on the spatial weight matrix  $K2$ . Moran's  $I$  values are also estimated based on the  $K2$  spatial weight matrix.

Table 4 presents the spatial dynamic SAR model and  $SDM$  with individual, time, and combined effects. The likelihood ratio (LR) test is insignificant in the SAR model; thus, we eliminate the SAR model. We also eliminate the individual fixed  $SDM$  and both fixed  $SDMs$  because the spatial effect is not statistically significant at the 5% level. Accordingly, we choose the time-fixed  $SDM$ . In general, the dynamic time-fixed  $SDM$  goodness-of-fit test and LR test values are greater than other spatial dynamic models. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) are lower than other models. As a result, subsequent discussion is based on dynamic time-fixed  $SDM$ .

The findings are noteworthy for the coefficient of the spatially lagged dependent variable  $\rho$ , which demonstrates that  $EF$  in neighboring BRI countries positively impacts the  $EF$  in a given country. You et al. (2020) show positively significant spatial spillover effects among BRI countries' environmental activities. The coefficient  $ED(-1)$  has a significant positive

effect, indicating that the findings corroborate the self-strengthening hypothesis of  $EQ$  in that previous levels of  $EQ$ , owing to strategic complementarity, are a significant predictor of present  $EQ$ . This result corresponds with previous literature (Gök & Sodhi, 2021). The coefficient  $W.ED(-1)$  is positive and statistically significant, indicating that the time-lapse interpreted variable may also produce geographical spillover effects in the present era, allowing for an elongated duration of spatial dependency between cities. These findings explain why positive SA may be long-lasting in many countries. This result is congruent with previous literature (Wang, Zhao, et al., 2020). We interpret the factors of implication primarily based on the results of dynamic time-fixed  $SDM$  estimates.

### 5.4. Analysis of long- and short-run spatial effects

Table 5 presents the average total, indirect, and direct impacts based on various short- (SR) and long-run (LR) explanatory factors. The average direct effect indicates the marginal impact of a 1% change in the independent variable on the dependent variable in the same area. The average indirect effect shows the marginal impact of a 1% change in the independent variable on the dependent variable in all neighboring regions. The sum of direct and indirect effects is the total average effect.

The average direct effects of the  $GDP$  coefficient have a positively significant impact on  $ED$  in the SR and LR. This effect reveals that a 1% rise in  $GDP$  raises  $ED$  in the same region by 0.38% and 0.36% in the SR and LR, respectively. The average indirect effects of the  $GDP$  coefficient on  $ED$  have a positively significant impact in the SR and LR. This effect reveals that a 1% rise in  $GDP$  raises  $ED$  in all neighboring regions by 0.28% and 0.041% in the SR and LR, respectively. These results correspond with previous literature (Hosseini & Kaneko, 2013; Shahnazi & Dehghan Shabani, 2021; You et al., 2020), indicating that the magnitude of impact outweighed the composition and technical effect in BRI countries. This suggests that economic growth promotes  $ED$ , as more energy is used generating increased pollution; thus, increasing

Table 3  
Global Moran  $I$  test.

| Year | Value                         | Year | Value                         | Year | Value                         | Year | Value                         |
|------|-------------------------------|------|-------------------------------|------|-------------------------------|------|-------------------------------|
| 1995 | 0.258 <sup>a</sup><br>(0.005) | 2002 | 0.353 <sup>a</sup><br>(0.002) | 2009 | 0.336 <sup>a</sup><br>(0.003) | 2016 | 0.355 <sup>a</sup><br>(0.003) |
| 1996 | 0.254 <sup>a</sup><br>(0.005) | 2003 | 0.359 <sup>a</sup><br>(0.002) | 2010 | 0.330 <sup>a</sup><br>(0.003) | 2017 | 0.369 <sup>a</sup><br>(0.003) |
| 1997 | 0.263 <sup>a</sup><br>(0.003) | 2004 | 0.358 <sup>a</sup><br>(0.002) | 2011 | 0.354 <sup>a</sup><br>(0.003) | 2018 | 0.371 <sup>a</sup><br>(0.002) |
| 1998 | 0.252 <sup>a</sup><br>(0.008) | 2005 | 0.351 <sup>a</sup><br>(0.002) | 2012 | 0.346 <sup>a</sup><br>(0.002) | 2019 | 0.359 <sup>a</sup><br>(0.001) |
| 1999 | 0.248 <sup>a</sup><br>(0.008) | 2006 | 0.357 <sup>a</sup><br>(0.002) | 2013 | 0.337 <sup>a</sup><br>(0.003) | 2020 | 0.358 <sup>a</sup><br>(0.001) |
| 2000 | 0.277 <sup>a</sup><br>(0.008) | 2007 | 0.362 <sup>a</sup><br>(0.002) | 2014 | 0.341 <sup>a</sup><br>(0.003) |      |                               |
| 2001 | 0.270 <sup>a</sup><br>(0.008) | 2008 | 0.355 <sup>a</sup><br>(0.002) | 2015 | 0.350 <sup>a</sup><br>(0.003) |      |                               |

<sup>a</sup> Indicate that 1% level of significance.

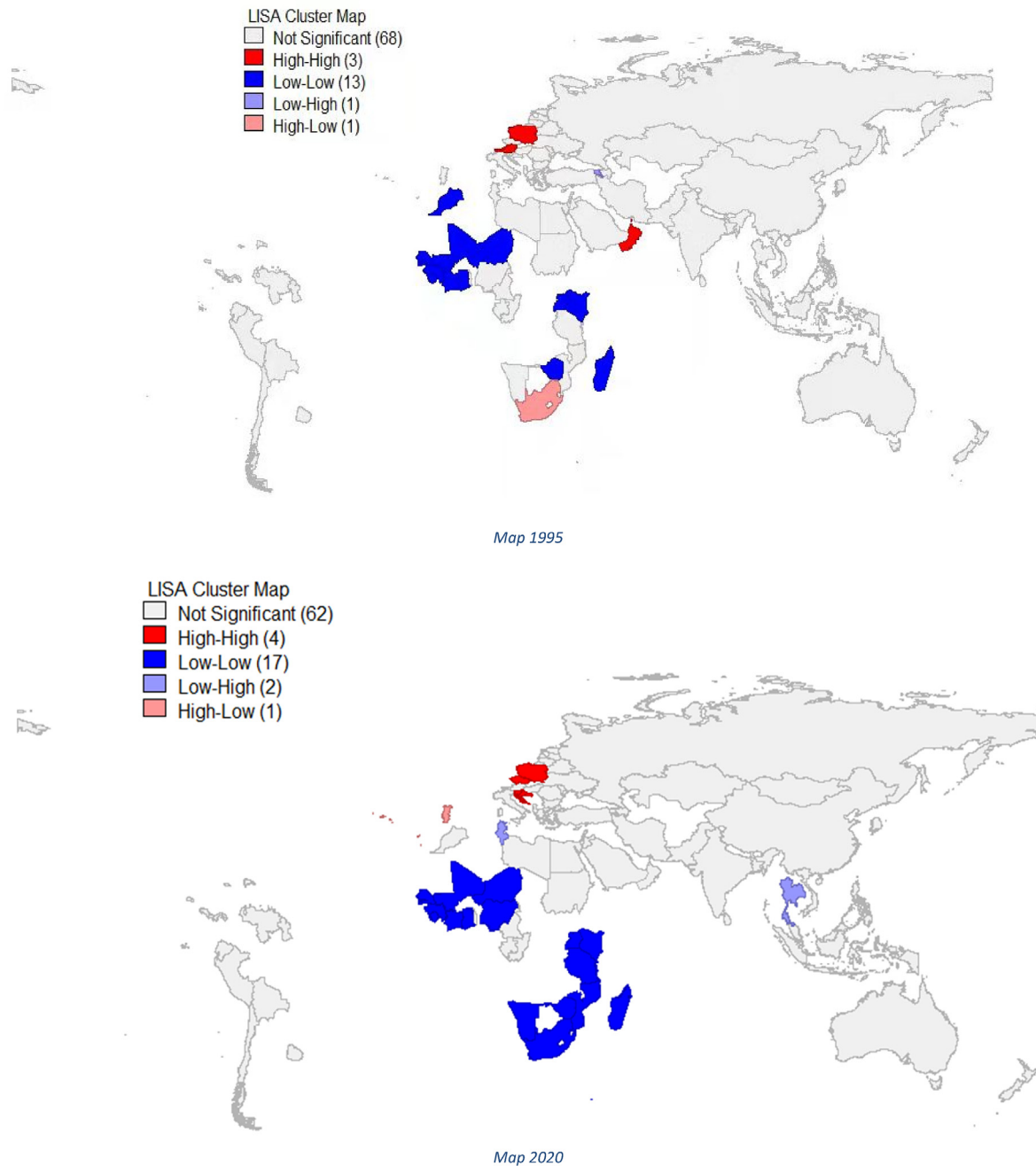


Fig. 2. LISA map environmental quality BRI region in 1995 and 2020.

neighboring countries' *ED*. For example, one country's economy may affect the environment of neighboring countries since neighboring countries may emulate a country's economic structure (You & Lv, 2018) or construct a supplementary economic framework (Dornbusch et al., 1977). The positive impact of *GDP* on *ED* is logical, as *BRI* countries drive worldwide economic growth.

The average direct effects of the  $GDP^2$  coefficient on *ED* are negative and significant in the *SR* and *LR*. This effect reveals that a 1% rise in  $GDP^2$  reduces *ED* in the same region by 0.034% and 0.39% in the *SR* and *LR*, respectively. The average indirect effects of the  $GDP^2$  coefficient on *ED* are

negatively significant in the *SR* and *LR*. This effect reveals that a 1% rise in  $GDP^2$  reduces *ED* in all neighboring regions by 0.025% and 0.007% in the *SR* and *LR*, respectively, indicating an inverted *U*-shaped link between *GDP* and *ED*. This finding demonstrates that once a certain income level is achieved, improved ecological laws, technical advances, sustainable manufacturing, and consumption patterns may decrease environmental problems in *BRI* countries. It also suggests that existing policies in *BRI* countries are moving progressively from highly polluting sectors and technologies to cleaner, low-carbon industries and green technologies as economies grow.

Table 4  
Estimation result from spatial dynamic panel models.

| Variables                 | SAR                  |                      |                       | SDM                    |                      |                      |
|---------------------------|----------------------|----------------------|-----------------------|------------------------|----------------------|----------------------|
|                           | Individual           | Time                 | Both                  | Individual             | Time                 | Both                 |
| <i>ED</i> (− 1)           | 0.8896*<br>(0.000)   | 1.0752*<br>(0.000)   | 0.8933*<br>(0.000)    | −0.2039**<br>(0.035)   | 1.0873*<br>(0.000)   | 0.8910*<br>(0.000)   |
| <i>W.ED</i> (− 1)         | 0.1371*<br>(0.000)   | 0.1731*<br>(0.000)   | 0.1009*<br>(0.000)    | 0.0216**<br>(0.042)    | 0.1651*<br>(0.000)   | 0.1086*<br>(0.000)   |
| <i>GDP</i>                | −0.2375**<br>(0.011) | 0.1859*<br>(0.000)   | −0.2975<br>(0.003)    | 0.0054<br>(0.583)      | 0.3610*<br>(0.000)   | −0.2485**<br>(0.020) |
| <i>GDP</i> <sup>2</sup>   | 0.0250*<br>(0.007)   | −0.0184*<br>(0.000)  | 0.0316<br>(0.002)     | −0.1003*<br>(0.005)    | −0.0325*<br>(0.000)  | 0.0268**<br>(0.013)  |
| <i>ENC</i>                | 0.0086<br>(0.114)    | 0.0072<br>(0.278)    | 0.0173***<br>(0.059)  | −0.1733*<br>(0.009)    | 0.2656*<br>(0.000)   | 0.0124<br>(0.229)    |
| <i>PR</i>                 | −0.0872*<br>(0.007)  | −0.0834*<br>(0.002)  | −0.0685**<br>(0.017)  | −0.0272***<br>(0.0717) | −0.1407*<br>(0.000)  | 0.0822<br>(0.113)    |
| <i>PR</i> <sup>2</sup>    | −0.1221*<br>(0.002)  | −0.1567**<br>(0.039) | −0.0108**<br>(0.027)  | 0.0057<br>(0.307)      | −0.3488*<br>(0.000)  | −0.1559<br>(0.138)   |
| <i>FR</i>                 | −0.0372**<br>(0.016) | −0.0349*<br>(0.000)  | −0.0155***<br>(0.082) | 0.2737<br>(0.130)      | −0.3826*<br>(0.000)  | −0.0223<br>(0.765)   |
| <i>FR</i> <sup>2</sup>    | −0.0682**<br>(0.019) | −0.0313*<br>(0.000)  | −0.0049**<br>(0.035)  | −0.0240***<br>(0.099)  | −0.3575*<br>(0.000)  | 0.0055<br>(0.326)    |
| <i>EFD</i>                | 0.2727**<br>(0.011)  | 3.6450*<br>(0.000)   | 0.2279**<br>(0.020)   | −0.2039**<br>(0.035)   | −0.1371*<br>(0.000)  | 0.25739<br>(0.159)   |
| <i>EFD</i> <sup>2</sup>   | −0.0242*<br>(0.081)  | −0.2808<br>(0.000)   | −0.0199**<br>(0.016)  | 0.0216**<br>(0.042)    | 0.3201*<br>(0.000)   | −0.0219<br>(0.136)   |
| <i>BRI</i>                | —                    | 0.0627*<br>(0.009)   | —                     | —                      | 0.0487*<br>(0.000)   | —                    |
| <i>W.GDP</i>              |                      |                      |                       | −0.0692<br>(0.651)     | 0.1697**<br>(0.025)  | −0.2013<br>(0.219)   |
| <i>W.GDP</i> <sup>2</sup> |                      |                      |                       | 0.0082<br>(0.558)      | −0.0148*<br>(0.003)  | 0.0225<br>(0.143)    |
| <i>W.ENC</i>              |                      |                      |                       | 0.0051<br>(0.637)      | 0.0229**<br>(0.018)  | 0.0241**<br>(0.078)  |
| <i>W.PR</i>               |                      |                      |                       | 0.0646<br>(0.328)      | −0.1049**<br>(0.013) | 0.0324<br>(0.647)    |
| <i>W.PR</i> <sup>2</sup>  |                      |                      |                       | −0.04751<br>(0.736)    | −0.1974**<br>(0.010) | −0.0318<br>(0.829)   |
| <i>W.FR</i>               |                      |                      |                       | −0.0239<br>(0.819)     | −0.0279*<br>(0.005)  | 0.0105<br>(0.921)    |
| <i>W.FR</i> <sup>2</sup>  |                      |                      |                       | 0.0031<br>(0.069)      | −0.0404*<br>(0.000)  | 0.0055<br>(0.943)    |
| <i>W.EFD</i>              |                      |                      |                       | 0.0338<br>(0.150)      | −0.3182*<br>(0.000)  | −0.0380<br>(0.872)   |
| <i>W.EFD</i> <sup>2</sup> |                      |                      |                       | −0.0045<br>(0.800)     | 0.6512*<br>(0.000)   | 0.0031<br>(0.872)    |
| <i>W.BRI</i>              |                      |                      |                       |                        | 0.0025**<br>(0.031)  | —                    |
| $\rho$                    | 0.1364*<br>(0.000)   | 0.1704*<br>(0.000)   | 0.1070*<br>(0.000)    | 0.1296*<br>(0.000)     | 0.2043*<br>(0.000)   | 0.0986*<br>(0.000)   |
| <i>R</i> <sup>2</sup>     | 0.9810               | 0.9861               | 0.9848                | 0.9852                 | 0.9882               | 0.9823               |
| AIC                       | 2909.011             | 3062.114             | 3075.181              | 2918.811               | 2849.104             | 2855.533             |
| BIC                       | 2988.436             | 3135.866             | 3199.992              | 3049.295               | 2922.856             | 2980.344             |
| LR stat                   | 2.67<br>(0.102)      | 2.39<br>(0.304)      | 2.31<br>(0.315)       | 13.90***<br>(0.072)    | 32.39*<br>(0.000)    | 23.19*<br>(0.002)    |

\*, \*\*, \*\*\* indicate that 1%, 5%, 10% level of significance, respectively.

The average direct effects of the *ENC* coefficient on *ED* are positively significant in the *SR* and *LR*. This effect reveals that a 1% rise in *ENC* raises *ED* in the same region by 0.025% and 0.39% in the *SR* and *LR*, respectively. The average indirect effects of the *ENC* coefficient on *ED* are positively significant in the *SR* and *LR*. This effect reveals that a 1% rise in *ENC* raises *ED* in all neighboring regions by 0.019% and 0.35% in the *SR* and

*LR*, respectively, indicating that *ENC* enhancement lowers *EQ*. The positive effects suggest that a rise in *ENC* from neighboring and local countries may increase local *ED*. This finding corresponds with [Khezri et al. \(2021\)](#), [Ren et al. \(2021\)](#), and [Shahnazi and Dehghan Shabani \(2021\)](#). Based on these findings, in both the *SR* and *LR*, local nations should remain vigilant regarding their own and neighboring countries' natural gas use.

Table 5  
Estimation results spatial long-run and short-run.

| variables              | Short-run           |                      |                     | Long-run             |                       |                      |
|------------------------|---------------------|----------------------|---------------------|----------------------|-----------------------|----------------------|
|                        | direct              | indirect             | total               | direct               | indirect              | total                |
| <b>GDP</b>             | 0.3833*<br>(0.000)  | 0.2840*<br>(0.000)   | 0.6674*<br>(0.000)  | 0.3681*<br>(0.000)   | 0.0416**<br>(0.030)   | 0.4097*<br>(0.002)   |
| <b>GDP<sup>2</sup></b> | −0.0344*<br>(0.000) | −0.0251*<br>(0.000)  | −0.0595*<br>(0.000) | −0.3930*<br>(0.000)  | −0.0071***<br>(0.054) | −0.4001*<br>(0.001)  |
| <b>ENC</b>             | 0.0252*<br>(0.000)  | 0.0199***<br>(0.063) | 0.0452**<br>(0.047) | 0.3927**<br>(0.029)  | 0.3585*<br>(0.006)    | 0.7512**<br>(0.049)  |
| <b>PR</b>              | −0.1525*<br>(0.000) | −0.1586*<br>(0.002)  | −0.3112*<br>(0.001) | −1.6273*<br>(0.001)  | −0.3872**<br>(0.045)  | −2.0145*<br>(0.001)  |
| <b>PR<sup>2</sup></b>  | −0.3433*<br>(0.000) | −0.1576*<br>(0.004)  | −0.5009*<br>(0.003) | −0.0341**<br>(0.022) | −3.8448**<br>(0.010)  | −3.8748**<br>(0.021) |
| <b>FR</b>              | −0.4084*<br>(0.000) | −0.4134*<br>(0.001)  | −0.8218*<br>(0.001) | −1.3712*<br>(0.000)  | −0.9348***<br>(0.058) | −2.306*<br>(0.001)   |
| <b>FR<sup>2</sup></b>  | −0.0391*<br>(0.000) | −0.5593*<br>(0.001)  | −0.5984*<br>(0.000) | −0.3749*<br>(0.000)  | −0.2396***<br>(0.075) | −0.6145*<br>(0.000)  |
| <b>EFD</b>             | −0.8093*<br>(0.000) | −0.8805<br>(0.000)   | −1.6898*<br>(0.000) | −3.3864*<br>(0.000)  | −6.2464*<br>(0.000)   | −9.6328*<br>(0.000)  |
| <b>EFD<sup>2</sup></b> | 0.3727*<br>(0.000)  | 0.8509<br>(0.000)    | 1.2236*<br>(0.001)  | 2.7223*<br>(0.001)   | 5.2046*<br>(0.000)    | 7.9269*<br>(0.000)   |
| <b>BRI</b>             | 0.0221**<br>(0.049) | 0.0057**<br>(0.048)  | 0.0278**<br>(0.049) | 0.0359**<br>(0.049)  | 0.0223*<br>(0.006)    | 0.0582**<br>(0.048)  |

\*, \*\*, \*\*\* indicate that 1%, 5%, 10% level of significance, respectively.

Finally, our primary concern variable, *PR*, elicits some surprising illustrations of the direct and indirect influence of increased political institution quality on *EF*. For instance, rules for lower *PR* greatly reduce *EF* by enhancing the quality of political institutions. The average direct effects of the *PR* coefficient on *ED* have a negatively significant impact in the *SR* and *LR*. This effect reveals that a 1% rise in political stability decreases *ED* in the same region by 0.152% and 1.6% in the *SR* and *LR*, respectively. The average indirect effect of the *PR* coefficient on *ED* has a negatively significant impact in the *SR* and *LR*. This effect reveals that a 1% rise in political stability decreases *ED* in all neighboring regions by 0.158% and 0.38% in the *SR* and *LR*, respectively. These results follow Hosseini and Kaneko's (2013) assumption that a country's institutional quality may affect the quality of neighborhood institutions and consequent *EQ*. The authors argue that institutional spillovers have a significant influence on the severity of neighboring pollution (see also Keleşian et al., 2013).

The average direct and indirect effects of the square term *PR<sup>2</sup>* coefficient have a negatively significant effect on *ED* in the *SR* and *LR*, revealing a significant U-shaped link between *PR* and *ED* among local and neighboring countries, and the diversion has been exceeded. Ashraf (2022) argues that lowering *PR* reduces countries' *EF*, which would improve *EQ*.

The average direct effects of the *FR* coefficient on *ED* are negatively significant in the *SR* and *LR*. This effect reveals that a 1% rise in *FR* decreases *ED* in the same region by 0.40% and 1.3% in the *SR* and *LR*, respectively. The average indirect effects of the *FR* coefficient on *ED* are negatively significant in the *SR* and *LR*. This effect reveals that a 1% rise in *FR* decreases *ED* in all neighboring regions by 0.41% and 0.93% in the *SR* and *LR*, respectively. In particular, a progressive rise in *FR* (for example, financial institution, market, or product risks) will negatively

affect the regular functioning of financial trade and may even threaten financial institutions' normal functioning and survival. In addition, rising *FR* may undermine the healthy operation of the financial system as a whole. When a financial system collapses, social and economic instability will undoubtedly impact a nation's economic growth. Rising *FR* will also impact regular capital operations and generate investors' uncertainty. Consequently, greater *FR* may decrease *ED*.

The average direct and indirect effects of the square term *FR<sup>2</sup>* coefficient on *ED* are negatively significant in the *SR* and *LR*. These results show a significant U-shaped link between *FR* and *ED* among local and neighboring countries, and the diversion has been exceeded. In particular, when the *FR* is low, market activity is high, and accelerated economic development requires a large quantity of energy, significantly advancing *ED*. With progressive growth of *FR*, cash shortages can limit companies' production and commercial operations, reducing energy consumption and lowering *ED*.

The average direct effects of the *EFD* coefficient and its square term on *ED* are negatively and positively significant in the *SR* and *LR*, respectively. The average indirect effects of the *EFD* coefficient and its square term negatively and positively significant effect on *ED* in the *SR* and *LR*, respectively. This connection demonstrates that *EFD* initially decreased *ED* via improved stability and efficiency, but subsequently increased it through scale impacts and market failure. These findings reveal a U-shaped link between *EFD* and *ED*.

The average direct effects of the *BRI* coefficient on *ED* are significant and positive in the *SR* and *LR*. The average indirect effects of the *BRI* coefficient on *ED* are significant and positive on *ED* in the *SR* and *LR*. The *BRI* policy in affiliated countries is expected to have a positive impact on economic development, whereas this achievement may be realized as a result of enormous energy consumption for power production and mass

communication, urbanization, transportation, industrial growth, and forest clearance to advance and accommodate rapid development. Ashraf (2022) argues that BRI participation boosts economic growth, increasing both energy consumption and *ED*.

## 6. Conclusions and policy recommendations

Studies have been conducted to investigate the *EF* effects of *EFD*, *PR*, and *FR*; however, particularly in this age of increasing globalization, when nations are more closely and frequently in contact with one another, to provide additional insights into the impacts of these variables on *EF*, we investigate spillover effects using geographical panel models.

Our findings indicate that the *EF* has *SA* in the 89 BRI nations under consideration. More importantly, the research provides empirical evidence for risk–environment nexus spatial dependency. In particular, the *LR*, *SR*, direct, and indirect impacts of *EFD*, *PR*, and *FR* on *EF* are revealed to be statistically significant, indicating that these institutions within a country contribute to environmental sustainability, with positive spillover effects on neighbors' environments.

Based on the findings of this research, three primary important policy implications are drawn. First, increased *EQ* is not only driven by improvement in a country's internal institutions but also by improved institutions in neighboring countries or regions. Consequently, policymakers should focus on improving domestic institutions' functionality and efficiency to advance the achievement of a sustainable global environment. This is only feasible if institutions are given the authority to make key legislative and administrative choices to promote environmental sustainability.

Second, the findings reveal a U-shaped link between *EFD* and *ED*. Minimizing *ED* requires focus on strategies to prevent market failure; however, governments that extend *EFD*

predominantly elevate national economic circumstances by encouraging the establishment and growth of more companies, resulting in increased *ED*. Subsequently, while promoting industrial development, government regulation must also be enacted, implemented and effectively enforced to moderate *EFD* for ecological protection.

Third, policymakers must support economic growth while maintaining a stable economic environment to achieve a specific risk threshold to reduce *ED*. Even as governments support political and financial stability, green technology investment must also be strongly supported and encouraged to increase energy efficiency and encourage the adoption and use of energy-saving products. Moreover, the impacts and potential growth of national hazards on the connection between *ED* and its determinants should also be addressed prior to governments' adopting any ecological or energy policy.

## Data availability statement

Data are accessible from the corresponding author upon request.

## Funding information

There is no funding source regarding the publication of this article.

## Declaration of competing interest

There is no conflict of interest.

## Appendix A. BRI Country sample

| S.No. | Country Name   | S.No. | Country Name       | S.No. | Country Name | S.No. | Country Name | S.No. | Country Name |
|-------|----------------|-------|--------------------|-------|--------------|-------|--------------|-------|--------------|
| 1.    | Albania        | 21.   | Dominican Republic | 41.   | Latvia       | 61.   | Philippines  | 81.   | Uganda       |
| 2.    | Armenia        | 22.   | Ecuador            | 42.   | Lebanon      | 62.   | Poland       | 82.   | Ukraine      |
| 3.    | Australia      | 23.   | Egypt              | 43.   | Libya        | 63.   | Portugal     | 83.   | Uruguay      |
| 4.    | Austria        | 24.   | El Salvador        | 44.   | Lithuania    | 64.   | Romania      | 84.   | Venezuela    |
| 5.    | Azerbaijan     | 25.   | Estonia            | 45.   | Madagascar   | 65.   | Russia       | 85.   | Vietnam      |
| 6.    | Bahrain        | 26.   | Gabon              | 46.   | Malaysia     | 66.   | Saudi Arabia | 86.   | Zimbabwe     |
| 7.    | Bangladesh     | 27.   | Ghana              | 47.   | Mali         | 67.   | Senegal      |       |              |
| 8.    | Belarus        | 28.   | Greece             | 48.   | Malta        | 68.   | Sierra Leone |       |              |
| 9.    | Bolivia        | 29.   | Guinea             | 49.   | Moldova      | 69.   | Singapore    |       |              |
| 10.   | Brunei         | 30.   | Guyana             | 50.   | Mongolia     | 70.   | Slovenia     |       |              |
| 11.   | Bulgaria       | 31.   | Hungary            | 51.   | Morocco      | 71.   | South Africa |       |              |
| 12.   | Cameroon       | 32.   | India              | 52.   | Mozambique   | 72.   | South Korea  |       |              |
| 13.   | Chile          | 33.   | Indonesia          | 53.   | Namibia      | 73.   | Sri Lanka    |       |              |
| 14.   | China          | 34.   | Iran               | 54.   | New Zealand  | 74.   | Sudan        |       |              |
| 15.   | Congo          | 35.   | Israel             | 55.   | Niger        | 75.   | Tanzania     |       |              |
| 16.   | Costa Rica     | 36.   | Italy              | 56.   | Nigeria      | 76.   | Thailand     |       |              |
| 17.   | Cote d'Ivoire  | 37.   | Jamaica            | 57.   | Oman         | 77.   | The Gambia   |       |              |
| 18.   | Croatia        | 38.   | Jordan             | 58.   | Pakistan     | 78.   | Togo         |       |              |
| 19.   | Cyprus         | 39.   | Kazakhstan         | 59.   | Panama       | 79.   | Tunisia      |       |              |
| 20.   | Czech Republic | 40.   | Kenya              | 60.   | Peru         | 80.   | Turkey       |       |              |

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