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ORIGINAL PAPER

The implications of forest resources depletion, agricultural expansion, and financial development on energy demand and ecological footprint in BRI countries

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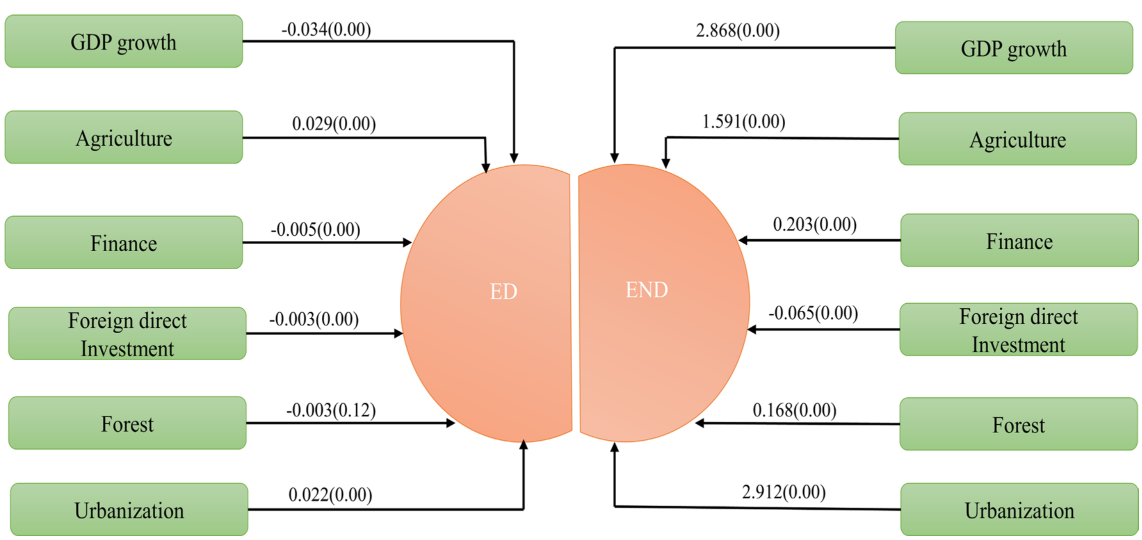
Abstract

The Belt and Road initiative is a comprehensive strategic initiative initiated by the Chinese government; it encompasses a significant segment of geo-territory, interaction of economy, investment, environment and ecology worldwide. In recent years, much has been said and written about the Belt and Road initiative's economic and investment prospectus; however, relatively little attention has been paid to the comprehensive quest of its emergent ecological and sustainable environmental spares. This paper aims to investigate the association of forest resources, agricultural expansion, and financial development with energy demand and environment; based on ecological footprints among selected ninety-seven nations of Belt and Road initiative from 1995 to 2018 by employing a Generalized Method of Moments and Driscoll and Kraay approaches. Empirical outcomes of the study have revealed that GDP growth reduces the environmental burden, and agricultural expansion deteriorates the environment. Contrarily, finance, foreign direct investment, and forest resources are providing solutions for environmental improvement in the study area. Similarly, the role of forests, agriculture, and finance remain positive determinants of energy demand in the study area. From the causal test, we found that the indicators of environment, energy, forest, agriculture, and finance all have bidirectional linkages. Based on our research results, we have concluded some policy implications for policymakers within the Belt and Road initiative framework.

Graphical abstract



An overview of research results

Keywords Ecological footprints · Agricultural expansion · Forest resources · Financial development · Belt and Road initiative

Extended author information available on the last page of the article

Abbreviations

BRI	Belt and Road initiative
CD	Crossectional dependence
COP	Conference of the parties
ED	Environmental degradation
EKC	Environmental kuznets curve
END	Energy demand
GHG	Greenhouse gas
GMM	Generalized method of moments
IPCC	International panel on climate change
OPEC	Organization of petroleum exporting countries
PSH	Panel slope homogeneity
QARDL	Quantile autoregressive distributed lags
SAARC	South Asia association for regional cooperation
URB	Urbanization
WDI	World development indicators
WWF	World wide fund

Introduction

Global rise in temperature is the result of human activities, including burning fossil fuels and deforestation (Raihan 2023). In previous centuries, technological advancements have further deteriorated the environmental condition accelerating the combustion of fossil-related fuels in various fields, including agricultural production, transportation, and electricity power production generating enormous environmental waste (Waheed et al. 2018). The International Panel on Climate Change (IPCC) report claimed that agriculture, forestry and other land use contribute 20–24% of global GHG emissions (Smith et al. 2014). The continuous combustion of fossil fuels is responsible for damage to environmental and ecological balances creating dominant issues for human life and other creatures of society. Therefore, handling environmental damage by making societies resilient towards global carbon neutrality, mitigating climate issues and ensuring the path towards sustainable development is the focus of the COP 26 agenda.

Briefly, forest resources are crucial for carbon sequestration, through which they absorb CO_2 emissions from the atmosphere by storing CO_2 in tree biomass (Raihan et al. 2019). Aziz et al. (2020) cited that about 300 billion tonnes of CO_2 emissions yearly are absorbed by forest resources, and almost the same amount of CO_2 is emitted to the atmosphere as a result of deforestation. Thereby, deforestation causes environmental troubles by accelerating climate issues attributing to soil erosion, floods, and loss of natural species (Raihan and Tuspekova 2022a). To bring back the global rise in the temperature to pre-industrial 1.5 °C (IPCC 2018), forest resources would play a significant role in absorbing the GHG emissions by improving the environmental quality. In addition to the forest ecosystems, the role of agricultural expansion is also elementary in global environmental quality and used to be a major element contributing to global CO_2 emissions and considered ultrasensitive towards climate change (Naseem et al. 2020). Therefore, probing into the role of forestry and agricultural expansion in the environment and energy demand is a new dimension and will help to make thorough policy guidelines.

The Belt and Road initiative (BRI) is a historical initiative forwarded by Chinese President Xi Jinping in 2013, claimed to be the most ambitious and vigorous investment and infrastructure proposal in modern history. It connects people worldwide and facilitates various opportunities for global connectivity, infrastructural development, ultimate global harmony, and sustainable development (Afraz and Khawar 2019). This project occupies 30% of the global GDP, comprising 4.4 billion individuals (Qian and Madni 2022) and expected that this project will raise the global income by 0.7% by 2030 (Anwar et al. 2020, 2021). This initative injected an approximate investment of six trillion USD; since the inception of BRI in 213 till 2019, China has invested around 760 billion US$, of which 39% in energy, 26 in transport, and 7% in metal, sharing 35% of global trade (Madni 2023). In recent years, much has been said and written about the BRI, especially its economic and investment issues; however, haven't paid significant attention to the comprehensive economic, financial, ecological, and environmental quests from the Belt and Road initiatives countries as the BRI encompasses a considerable portion of diverse ecological, environmental, and natural resources. Arguably, the BRI's fast-growing energy demand, urbanization, forest resource depletion, and agricultural expansion have given massive environmental challenges; this increasing depletion of natural resources causes severe environmental and ecological concerns. Therefore, it is essential to address and estimate the consequence of forest resource depletion, agricultural expansion, and financial development on energy demand and ecological footprint towards Belt and Road initiative's participatory countries.

On exploiting the role of agriculture and forest, most of the previous studies have tested the data of individual countries (Waheed et al. 2018; Raihan and Tuspekova 2022a; Raihan 2023; Shabbir Alam et al. 2023) or specific panels (Jiang et al. 2021). At the same time, others have consumed the agricultural expansion and forest data separately (Pata 2021; Balogh 2022). However, the role of current research is significant, and it utilizes the panel data of Belt and Road initiative countries (BRI) over 195–2018 in order to bring consensus on the role of agriculture expansion, forest resources, and financial development in energy demand and environmental degradation based on ecological footprints. Not same as CO_2 emissions, ecological footprints capture more comprehensively the degradation of the environment (Destek and Sarkodie

2019). More broadly, ecological footprints introduced by Rees et al. (1996) are more comprehensive indicators of environmental degradation because it indicates the environment's assimilative capacity in response to production and consumption (Baloch et al. 2019). Ecological footprints are a composite index of six indicators of footprints, including built-up land, which refers to the land used for infrastructure, including roads, buildings, bridges, and other electricity infrastructure. Fishing grounds indicate the sustainable yearly use of marine products. Grazing land indicates the use of land for pastures and grassland as fodder for livestock. Crop land is the land required for crop production. Forest products refer to the annual land needed for the harvest of forests, for example, for paper products and fuel requirements. Finally, the carbon footprints indicate the land required for the sequestration of carbon by the forest resources (Khan et al. 2021b). Therefore, utilizing this indicator as proxy for environmental degradation in the BRI countries makes much sense.

Against this backdrop, the study contributes and extends the literature by bridging the gap in the following way: (1) It brings the agriculture and forest resources in the context of ecological footprint and energy demand, which is new to the literature, specifically to the BRI context. (2) Using the STIRPAT model, this research constructs two structural equations separately for energy demand and ecological footprint. As per our knowledge, this nexus has never been explicitly explained for the BRI countries, which will give important policy proposals to policymakers. (3) Similarly, it includes FDI, urbanization, and GDP are framed as the STIRPAT's major components, which will produce relevant long-run impacts on environmental and energy demand. (4) We utilized the possible long-time series and employed GMM and Driscoll and Kraay, panel Dumitrescu and Hurlin Granger causality, which will disclose the run causal linkages between the variables for the study area; therefore, we are confident that the results obtained from the given study have strong policy proposals for a better environment by achieving sustainable development goals in BRI countries.

The rest of the study is designed as follows: After the literature review in the second section, the study models the data by highlighting the data sources and estimation strategies. In the next section, the study portrays the results and concludes by highlighting the major policies obtained from the study.

Literature review

The literature review on the topic is fragmented into three sub-parts, and available literature is detailed in the subsequent sections.

Forest resources, energy demand, and environment

Forest has been a fundamental resource of economic provisions and the foundation for maintaining ecosystems. The dependence on forest resources is more intense for rural and indigenous populations of the world. Likewise, many households of BRI-associated developing countries largely rely on natural sources from forests for their subsistence and energy security. However, excessive reliance on forests has led to forest degradation and deforestation (Ntiyakunze and Stage 2022), also significantly contributing to the emission of GHGs. Global climate change triggered by greenhouse gases (GHGs), in particular carbon dioxide (CO_2) emissions, poses unparalleled threats to environmental sustainability (Raihan and Tuspekova 2022b). The demand for energy in the world is growing rapidly due to the rapid population growth and economic development activities, whereas energy is important input to meet domestic needs and enable industry and trade. Thus, growing energy demand can be replaced by forest resources; such as biofuels (Battuvshin et al. 2020); which can be obtained through the use of wood and forest biomass resources, in addition to promoting renewable energy sources and proper forest management, which could assist achieve environmental sustainability through reduction of emission (Titus et al. 2021). Further, emphasizing the vitality of renewal energy Liu et al. (2021) suggested that forest-based biomass energy is an excellent choice among the available renewal energy sources. Where; the forest resource reserve is affluent in reserves and comparatively less harmful towards the local environment after consumption(Peluso 1992). Paradoxically, Pang et al. (2019) argued that "demand size for bioenergy feedstocks is expected to increase in many countries; however, sustainable use of forest biomass resources can only be ensured if local and landscape conditions are taken in to account, and energy use is linked to its resource base".

One of the studies by Dasgupta et al. (2022) on the pattern of forest biomass use in the Himalayan region and its consequences within the rural community; suggested that biomass harvesting is closely related towards forest degradation and carbon emission, the dependency on biomass energy correlated on an altitude of settlement, family size, education and occupation of household members, and retention of cattle unit ownership by household. Further, their study also suggested that improving environmental quality thru reducing emissions is the central discussion not only for the alternative exchange of energy sources but also immensely critical for mitigating adverse effects of climate change and enhancing the vitality of forest resources, renewal energy, and environment study by Waheed et al. (2018), who employed the ARDL estimator in Pakistan from 1990 to 2014. Their findings reported the "significance of renewable energy use and forested area on

CO_2 emissions reduction", i.e. increment of 1% forested area resulted in a 3.86% reduction in CO_2 emission. Likewise, a notable empirical study results from the "dynamic panel data method" by Parajuli et al. (2019) suggested that "forests are an important determinant in reducing CO_2 emissions worldwide, but the impacts vary regionally, i.e. a 1% increment in forest cover resulting the decrement of 0.11% of CO_2 emissions globally". Extendedly, Raihan and Tuspekova's (2022b) study on Malaysia, their empirical results also confirmed that increased use of renewable energy and forested area could help achieve environmental sustainability.

Despite great concern and various efforts by international environmental agencies and organizations over the past three decades, the world has been confronted with the phenomenon of gross ecological deficit, and ecological footprint indices are steadily increasing due to the continued decline in per capita biocapacity consumption (Wenlong et al. 2022). Thereof, the multilateral efforts of various countries and organizations to ensure environmental sustainability and energy demand are essential in a global framework; this stand study by Lei et al. (2022) on multilateral international cooperation and renewable energy at the regional level has shown that the countries with strong international ties have a higher ability to adopt environmental policies that can help promote renewable forest-based biomass energy. As the geographical areas of the countries participating are highly diverse and unique in terms of ecological endowments, some of the focused areas of belt and road initiatives, such as Southeast Asia, where firewood accounts for 72% of all harvested wood, similarly the South Asia where firewood accounts 93%, despite of utterly use of firewood energy by Asia Pacific region; it occupied only 17% of global forests(WWF and ADB 2012). As a result, many BRI member states have a deficit in forest biocapacity and overexploitation of biologically productive land and sea to support their consumption of food, fibre, and energy (Du et al. 2022). This deficit can only be filled by importing natural resources or further depleting the limited natural capital with significant economic and environmental consequences (Du et al. 2022). This deficit can only be met by importing natural resources or further depleting limited natural capital, bearing significant economic and environmental consequences(Mancini et al. 2018). Therefore, broader policies are needed to ensure adequate support for a sustainable BRI region; we need to address the complex sustainability issues at multiple levels of the BRI framework enhancing support for transnational conservation programmes that reflect the fact that large ecosystems are "public goods" that transcend national borders and require coordinated multi-stake regional framework and initiatives within BRI.

Agricultural expansion, energy demand, and environment

Agriculture is one of the world's most prominent and most promising industries. "It employs more than a billion people and generates trillions of dollars' worth of food and fibre annually; when the agricultural process is managed sustainably, they can maintain and restore critical habitats, protect watersheds, improve soil health and water quality, but unsustainable practices and expansion have serious impacts on people and the environment"(World Wildlife Fund 2022); the demand for agricultural products is increasing as the world's population is growing rapidly, economic activities are gradually shifting the new dimension, which prolonging the expansion of agriculture and increasing energy needs (FAO 2017). As reported by Leng et al. (2020), the study of agricultural expansion is a crucial part of understanding human–land interface systems in ecosystems. These include clearing the primary forests reserve to plantations and the expansion of agricultural land (Sattar et al. 2022), while; the phenomenon of human-induced land use and land cover change is crucial for assessing and scientific response trade-off between development and environmental health (Johnson et al. 2021). Further deepening the literature on agricultural expansion's methodological underpinning, Leng et al. (2020) argued that "two main research fields analyzed the driving forces of agricultural expansion, which mainly depends on the analysis of economic models and the direction of research related to the impact of management systems and policy rely deeply on statistical models to show the relationship between different drivers and land-use change". In this respect study by Ridzuan et al. (2020) on the "effects of agriculture expansion, renewable energy and environment in Malaysian agriculture" based on the EKC hypothesis suggested that despite economic contribution to national GDP, agricultural expansion contributes to environmental degradation. It also leads to severe impacts on deforestation and semi-arid land, including crops grown for both human and animal consumption (Laurance et al. 2014). Agricultural expansion might favour the countries for export success, create employment opportunities and alleviate poverty but has substantial spatial spillover effects (Li et al. 2021).

Moreover, leading researchers agreed that improving the quality of the environment by reducing agricultural emissions is the point of departure for mitigating climate change and achieving sustainable development goals(Raihan and Tuspekova 2022a). According to the study by Bidogeza et al. (2014); Malla (2009), agriculture is one of the most widely identified sources of greenhouse gas (GHG) emissions worldwide; in addition, the amount of emissions released per unit of energy consumption positively linked to the amount of energy consume(Chontanawat 2020). Reduction of greenhouse gas emissions is possible through the endorsement of renewable energy sources. For example, the use of renewable energy in overall agricultural systems could reduce the dependence on fossil fuels, benefiting not only environmental sustainability but also farmers (Zhang et al. 2022). Constantly, an empirical study of "changes in energy consumption in agriculture in the European Union (EU) countries" by Rokicki et al. (2021) argued that agricultural mechanization resulting the replacement of manual agricultural tasks with machinery, where the energy is an inseparable input in overall mechanized agriculture activities. Nevertheless, the excessive deployments of agricultural mechanization could lead towards a high volume of energy demand. Still, at the same time, the demand and consumption of non-renewal energy outpace the growth of renewable energy alternatives (IEA 2021).

In contrast, one of the recent research by Duong and Ngo, (2022) to examine the impact of energy consumption and agricultural expansion on environmental degradation in ASEAN countries using Phillips–Perron (PP), Augmented Dickey–Fuller (ADF), QARDL approach their results show that energy use and emissions are inversely related. Based on the results of analysis of time series data, a study by Raihan et al., (2022) on the relationship between energy use, agricultural land expansion, deforestation, and emissions in Malaysia also shows that the energy consumption coefficient in CO_2 emissions is positive and significant, indicating that a 1% increase in energy consumption is associated with a 0.91% increase in CO_2 emissions, while a 1% increase in agricultural land emissions led to the rise of 0.84% CO_2 in the long term. Further, regarding the assessment of China's future food needs and their impact on trade and the environment, by suggested that without agricultural expansion and agricultural import very challenging to meet China's rising agricultural products demand in days ahead, to limit the environmental pressure of its growing food consumption, China must take responsibility in developing sustainable agricultural trade and international cooperation. Likewise study by Zhao et al., (2021) in relation to assessing China's future food needs and their impact on trade and the environment, suggested that "without agricultural expansion and agricultural imports, it would be very difficult to meet increasing demand for agricultural products in the coming days to limit its growing food consumption; China must take responsibility to develop sustainable agricultural trade and setup comprehensive international cooperation in this end".

Hence, agriculture's far-reaching links to the world's gross economy, societies, the environment and biodiversity make it one of the most important frontiers for global conservation and cooperation(Ortiz et al. 2021); in this respect, agricultural expansion comes with increased energy demand, which ultimately quantifies the higher volume of emissions, this unfortunate trend is expected to exacerbate further the global environmental problem (Vuuren et al. 2017); thus, reducing agricultural emissions, especially CO_2 is a critical issue. This issue is significant because emissions mitigation in agriculture is one of the major solutions for climate change and global warming (Ridzuan et al. 2020). However, without proper substitutes, alternatives of large dependency on agriculture of developing and least developed countries remain the most crucial challenge ahead to embrace sustainable agriculture practices, sustainable agricultural production growth, and controlling the agricultural land expansion; (Hayami and Ruttan 1971); hence, reducing agricultural production without proper alternatives is not a sustainable strategy towards Belt and Road Initiatives associated countries in a short run. Agriculture expansion, energy demand, and environmental nexus trilateral critical relationship should be addressed by policymakers to achieve sustainable development goals. Therefore, implementing integrated policies to promote renewable energy, climate-friendly agriculture, and sustainable management of forest ecosystems could help reduce environmental degradation in the Belt and Road initiatives region.

Financial development, energy demand, and environment

Numerous studies have attempted to examine the relationship between environmental degradation, energy needs, and economic development, but relatively little research has been conducted on the triple relationship between financial development, energy needs, and the environment across different sample sizes and large numbers of countries(Tariq et al. 2022). The increment of economic growth gradually leads to increases in energy demand which consequently accelerates the emission, thus endangering the ecosystem and biodiversity (Khan et al. 2019a, b). Previous studies by Shahbaz and Lean (2012); Imamoglu (2019) argued that "energy is a key element of economic growth which is closely correlated with financial activities and highly associated". Similarly, researchers Sattar et al. (2022); Baloch et al. (2019); Alam et al. (2015); Imamoglu (2019) have examined the positive relationship between energy and economic growth in different countries and the results of energy growth nexus show a significant positive correlation. In contrast, researchers Kotzé and Adelman (2022) claimed that: despite the adequate intentions behind the emergence of sustainable development, it enables considerable exploitative economic development activities that exacerbate systemic inequalities and injustices without significantly protecting all forms of life in the Anthropocene. However, the empirical study by Shobande and Ogbeifun (2022) revealed that financial development and clean energy positively impact energy consumption. Apparently, the empirical findings of Yang et al. (2022) indicated that green technological innovations and financial development play a crucial role in environmental protection, especially in long-term endeavours. Analysing the data of 63 developed and emerging countries (Saqib 2022) also concluded that financial development is a positive determinant of environmental quality. Conducting the research using third-generation econometric approaches (Sharif et al. 2022), green finance is the source of improving environmental quality in G7 countries. Further, Wang et al. (2022) suggested that "the transition to renewable energy is likely to be delayed and increasingly costly without timely and necessary financial support as there is a bidirectional causality between financial development and renewable energy; renewable energies and CO_2 emissions". According to (Saqib et al. 2022a), financial deepening is a must source to improve the environmental quality in the six GCC countries. However, (Fakher et al. 2021a) found a negative impact of financial development on environmental quality for a selected group of OPEC countries. Likewise, using ecological footprints as the factor of environmental degradation (Fakher et al. 2021b) discovered that financial development alone, and through the moderating role with economic growth, in both cases enhances the environmental degradation of OPEC countries. Recently, (Fakher and Murshed 2023) have started a new discussion that financial development at initial stages decreases the environmental quality, while at later stages, it improves identifying an inverted U hypothesis for financial development environmental nexus. The study by Oskenbayev and Issabayev (2018) concluded that "financial development has become one of the most significant factors influencing energy consumption; the net overall effect of financial development on energy demand suggests that an increase in financial depth by one standard deviation unit results in a decrease in energy use of 0.09 kg oil equivalent per capita".While attending the data of selected OPEC countries between 1994 to 2919 (Fakher et al. 2023) explored mixed results for six environmental quality indicators.

In this respect, notable studies by Kirikkaleli and Adebayo (2021) and Sun et al. (2023) also discovered that "while the economic expansion is increasing carbon flaring around the world; conversely the global financial development and renewable energy consumption have a major long-term positive impact on environmental sustainability". Contextual research by Alam et al. (2015) on "South Asian" countries the study concluded that there is a trade-off between the energy and growth variables in the SAARC region; it also further noted that financial development indicators, followed by GDP per capita and foreign direct investment, have a more significant impact on increasing energy demand. Likewise, studies by Jalil and Feridun (2011) on China's financial development, energy and environmental nexus outcomes showed a negative sign for the coefficient of financial development, implying that financial development in China has not taken place at the expense of pollution. Some researchers argue that financial development reduces CO_2 by encouraging and funding technical adoption and innovation at lower costs, as the study of Ehigiamusoe et al. (2022) and Tamazian et al. (2009), who consider financial development to be a key determinant of environmental performance, further arguing that higher financial development can allocate more significant financial resources to environmental projects at lower financing costs. Whereas; Shahbaz et al. (2013) study, which examined the relationship between energy consumption and economic growth by incorporating financial development, international trade and capital in China over the period 1971–2011 through ARDL-bound testing approach, found that the rapid growth of both financial development and economic growth boosts energy demand, which has a significant negative impact on environmental degradation.

Literature gap

Concluding from a detailed analysis of the available literature on agricultural expansion, forest resources, and financial development. We find that some existing studies have explored the role of agriculture in CO_2 emissions in a time series framework (Waheed et al. 2018; Raihan and Tuspekova 2022a; Raihan 2023; Shabbir Alam et al. 2023) or used specific panels (Jiang et al. 2021). At the same time, some other studies have been conducted that employed forest or agriculture as their variable of interest (Pata 2021; Balogh 2022). Different from those studies, we find not a single significant study which has addressed the role of forest resources, agricultural expansion, and financial development on ecological footprints and energy demand, specifically for BRI countries, which is still unattended. As the role of forest resources and agriculture in environment and energy consumption is imperative, neglecting such relationships in the empirical literature may mislead policymakers. Therefore, this study designs to discover the empirical linkages between all these variables for BRI countries.

Modelling the economic relationship

The association between human activities on the environment was explained through an IPAT model. This initiated a new discussion among environmental economists that environmental impact (I) is the product of population, affluence, and technology (PAT) (Khan et al. 2021c). However, this was only a mathematical identity and could not add other central element responsible for environmental degradation. Therefore, (Dietz and Rosa 1994) redesigned the standard IPAT model by adding the stochastic part by updating it to the Stochastic Impact of Regression on Population, Affluence, and Technology (STIRPAT) model, which become very famous as a methodological approach in the studies identifying the interactions between human social systems and non-human environments (McGee et al. 2015). This model (STIRPAT) performs on the assumption that environmental impact is the product of population, affluence and technologies. As an alternative to population, we frame urbanization in the model, while the technological aspects in the study are captured with foreign direct investment, and to demonstrate affluence, we used GDP in the model. The standard form of the STIRPAT becomes; $I_i = \alpha P_i^p A_i^a T_i^t$, where I is environmental impact, PAT is population (urbanization), affluence (GDP), and technology (FDI), while p, a, t are the elasticities to be estimated. The major advantage of STIRPAT is that it can be updated by adding more environmental impact factors. Therefore, we initially added multiple indicators and transformed the multiplicative model into a standard additive econometric. However, before explaining the econometric models, the following section describes the theoretical relevance of the variables in detail.

Environmental degradation (ED)

For the modelling purpose of the variables, we considered ecological footprints as the dependent variable and took agricultural land area for production, forest rents and financial development as leading indicators of the concern. We adopted the dependent variable "Ecological footprints" from the previous studies (Fakher 2019; Khan et al. 2019a) as a significant indicator of environmental degradation. In most of the previous research, researchers have used CO_2 emissions as the primary indicator of the environment by neglecting the ecological footprints (Nathaniel et al. 2023), which combines six different indicators of footprints, including grazing lands, forest resources, fishing grounds, built-up land, croplands, and carbon footprints. Therefore, we used these indicators as a proxy to gauge the intensity of environmental degradation, which is also supported by the study of Yasmeen et al. (2022). This study constructed another equation for energy demand as a major indicator of environmental degradation. Simultaneously, the second dependent variable for the energy demand model (END) has been adopted from the study of Hussain and Zhou (2022). This indicator ensures the intensity of energy use in the countries which the previous studies have not widely used; we hope this will significantly provide the basis for theoretical studies in future on similar areas.

Independent variables

Further developing the econometric models, we considered some variables as main independent variables in the study, which include agricultural land use for the production of agricultural commodities, forest depletion proxies with the rents paid for the footprints of the forest resources, and for financial development, we adopted domestic credit to the private sector by banks. All these significant environmental and energy demand indicators have been supplemented with the previous literature.

Other variables

In addition to major independent variables, this study has captured the affluence in the models with GDP (per capita in 2015$), and technology is proxied in the study with FDI (inflows of FDI as a percentage of GDP), while the population in the models is determined with urbanization (Urban population as a percentage of the total population). The data sources, definitions, and descriptive statistics are provided in Table 2 for a clearer understanding of the chosen variables.

By incorporating all these variables into the ED and END equations. The linear econometric form we found is;

$$\begin{aligned}(\mathrm{LnED})i,t =& \gamma 0 + \gamma 1(\mathrm{LnGDP})i,t + \gamma 2(\mathrm{LnAGR})i,t \\ &+ \gamma 3(\mathrm{LnFD})i,t \ + \gamma 4(\mathrm{LnFOREST})i,t \\ &+ \gamma 5(\mathrm{LnFDI})i,t + \gamma 6(\mathrm{LnURB})i,t + \eta i + \xi i,t\end{aligned} \tag{1}$$

After having the theoretical background on the variables chosen, we further constructed the energy demand model. So, after including the variables, the structure of the energy demand model becomes;

$$\begin{aligned}(\mathrm{LnEND})i,t =& \gamma 0 + \gamma 1(\mathrm{LnGDP})i,t + \gamma 2(\mathrm{LnAGR})i,t \\ &+ \gamma 3(\mathrm{LnFD})i,t \ + \gamma 4(\mathrm{LnFOREST})i,t \\ &+ \gamma 5(\mathrm{LnFDI})i,t + \gamma 6(\mathrm{LnURB})i,t + \eta i + \xi i,t\end{aligned} \tag{2}$$

Here, ED indicates the environmental degradation measured with ecological footprints, GDP is a gross domestic product, AGR indicates agricultural land, FD is financial development, FDI is foreign direct investment, and URB stands for urbanization in their logarithmic forms (for details, see Table 2). Additionally, $\gamma 0$ is the slope coefficient of the models, $\gamma 1$, …., $\gamma 6$ are the coefficients of the modelled variables to be estimated, ξ is the error term of the equations and t, and i are used to indicating the time, and cross sections of the study. After defining the econometric models, we introduce the data and develop estimation steps in the coming sections.

Data resources and estimation

Data availability

This study extracted the data from the World Banks online database (WDI) and the database of Global Footprints Network (Global Footprints Network 2022). The data on time series are balanced for all the countries; therefore, we have adopted to analyse the balanced panel for 1995–2018 for a list of 97 BRI countries given in Table 1. There we some missing values observed in the data set, and they have been filled by using the methods of forward and backward interpolation similar to the studies of Bhuiyan et al. (2018) and Zaman et al. (2016). To bring clarity into the discussion, we have given the description, definition, and some summary statistics of the variables in Table 2. The descriptive statics indicates the variations in means, and standard deviations, between the variables, indicating the disparity of the modelled variables in the study.

Econometric techniques used

Our study aims to investigate the impact of the forest, agricultural, and financial development on the environment and energy demand for selected 97 BRI countries from 1995 to 2018. Since the data have long "N" and short "T", we may not overlook the standard approach for this data quality. Usually, when there are small time series (short T) and long cross sections (long N), then simple pooled OLS cannot provide consistent estimators of regressions. Thus, to avoid this problem, we have adopted the instrumental variable Generalized Method of Moments in this study (GMM) by

Table 1 List of countries source: (Belt and Road initiative portal China;2022)

Albania	Cyprus	Lebanon	Senegal
Algeria	Czech Republic	Libya	Slovak Republic
Angola	Dominican Republic	Luxembourg	Slovenia
Argentina	Ecuador	Malaysia	South Africa
Armenia	Egypt, Arab Rep	Malta	Sri Lanka
Austria	El Salvador	Moldova	Sudan
Azerbaijan	Eritrea	Mongolia	Suriname
Bahrain	Estonia	Mozambique	Syrian Arab Republic
Bangladesh	Ethiopia	Myanmar	Tanzania
Belarus	Gabon	Namibia	Thailand
Benin	Georgia	Nepal	Togo
Bolivia	Ghana	New Zealand	Trinidad and Tobago
Bosnia and Herzegovina	Greece	Niger	Tunisia
Botswana	Hungary	Nigeria	Turkey
Brazil	Indonesia	Oman	Ukraine
Brunei Darussalam	Iran, Islamic Rep	Pakistan	United Arab Emirates
Bulgaria	Iraq	Panama	Uruguay
Cambodia	Italy	Peru	Vietnam
Cameroon	Jamaica	Philippines	Yemen, Rep
Chile	Kazakhstan	Poland	Zambia
China	Kenya	Portugal	Zimbabwe
Congo, Dem. Rep	Korea, Rep	Qatar	
Costa Rica	Kuwait	Romania	
Cote d'Ivoire	Kyrgyz Republic	Russian Federation	
Croatia	Latv-zia	Saudi Arabia	

Table 2 Variables, definition and descriptive statistics

Symbols	Definition	Mean	Std. Dev	Maximum
ED	Ecological footprints per capita	5.02	6.29	47.70
END	Energy imports net of energy use	−31.43	158.98	100.00
GDP	GDP per capita constant 2015 US$	9885.60	14,617.76	112,417.90
AGR	Agricultural land as % of total land area	39.50	21.72	85.49
FDI	Foreign direct investment net inflow	5.14	19.03	449.08
FOREST	Forest rents of GDP	1.53	3.57	36.06
URB	Urban population % of the total population	57.64	21.25	100.00
FIN	Domestic credit to the private sector by Banks	38.34	35.87	255.19

following the study of Judson and Owen (1999). This was proposed by Holtz-Eakin et al. (1988) for small "T" data.

We followed the instruments procedures forwarded by Judson and Owen (1999), who used the lags of endogenous variables as instruments. In addition, we also applied the other exogenous, strict variables as instruments suggested by Judson and Owen (1999). When used the lags of variables in the model, it produces the problem of autocorrelation. We have employed the AR (II) test of Arellano and Bond (1991) to check for autocorrelation, and the instrument's reliability is tested with the Hansen test. Hansen's test uses the null hypothesis that all the instruments are not correlated with residuals. However, to the robustness of results obtained from this estimator, we again estimated the models with the Driscoll and Kraay (1998) estimator, which can obtain good results in cross-sectional dependence data sets; it's equally beneficial in balanced and unbalanced data sets with missing observations (Sicen et al. 2022). There are some prerequisites for applying this estimator in the study, therefore, we tested the variables here for the cross-sectional dependence, panel homogeneity, unit roots, and panel cointegration one by one. Finally, the study extended its circle to estimate the causal linkages between the variables. Therefore, it applied Dumitrescu and Hurlin's (2012) panel causality test. The long-run parameter analysis cannot support the direction of causal linkages, and in that case, using Dumitrescu and Hurlin (2012) test is advantageous, and this has a strong significance in policy orientations(Zafar et al. 2019; Sicen et al. 2022). Its importance in panel data sets, including accounting for the cross-sectional dependence, and its usefulness in small samples Destek and Sarkodie (2019) makes this test suitable for the current study. For a detailed view, a diagrammatic explanation of the methodology is given in Fig. 1.

Results and discussion

After looking at the descriptive statics, we further moved towards the statistical analysis of the data. In doing so, we first tested the variables for cross-sectional dependence (CD) and panel homogeneity (PSH). The results in Table 3 for CD and PSH indicate that the variables have cross-sectional dependence over the cross sections, and their slopes are heterogeneous. Therefore, rejecting the null hypothesis of both tests (No CD and Slope homogeneity).

Unit-root analysis of the chosen variables has been conducted, and results are given in Table 4. From the results, we conclude that the variables show non-stationary properties at

Table 3 Panel cross-sectional dependence and homogeneity test

Pesaran CD test	Statistics	*P*-values
END	26.87	0.000
ED	37.29	0.000
GDP	182.2	0.000
FIN	103.39	0.000
AGR	2.88	0.000
FDI	30.57	0.000
FOREST	3.756	0.000
URB	7.453	0.000
Slope homogeneity		
ED-model		
Δ	29.563	0.000
Δ-adjusted	36.208	0.000
END-model		
Δ	28.949	0.000
Δ-adjusted	35.455	0.000

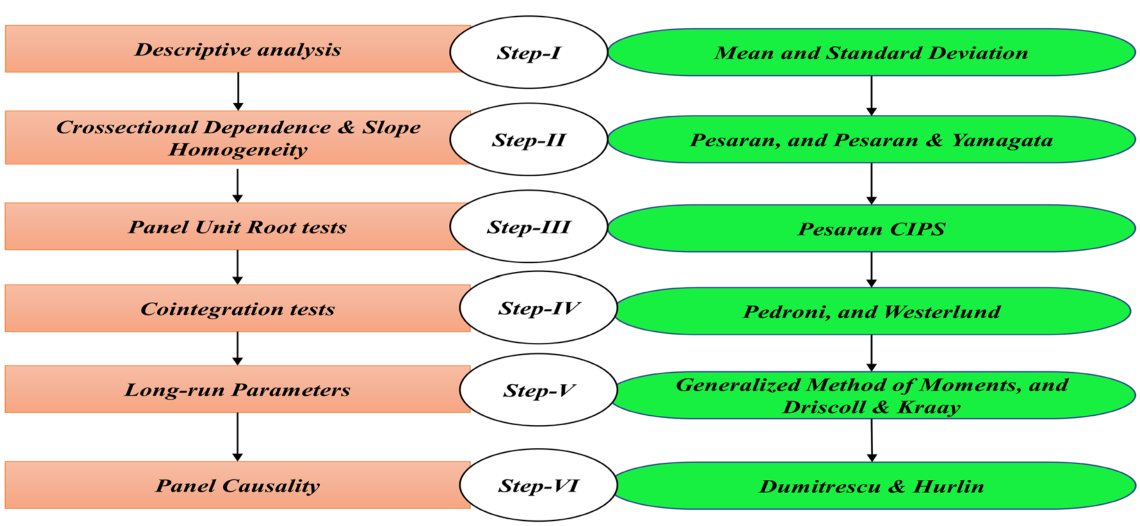


Fig. 1 Diagramtic explanation of estimation steps

Table 4 Unit-root tests

Variables	Statistics	Stationary at level	Statistics	Stationary at 1st diff
Pesaran CIPS unit-root test				
END	−0.881	No	−4.217	Yes
ED	−1.485	No	−4.174	Yes
GDP	−1.254	No	−2.867	Yes
AGR	−1.778	No	−4.231	Yes
FIN	−1.907	No	−3.59	Yes
FDI	−1.33	No	−5.342	Yes
FOREST	−1.228	No	−4.675	Yes
URB	−1.871	No	−3.041	Yes

Critical values at 10, 5, and 1% are −2.01, −2.07, and −2.17

Table 6 Long-run estimates of the ED-model

	Coefficients	Std.Err	*Z* tests	*P*>|*Z*|
GMM estimates				
EFP_{L1}	0.872	0.001	627.110	0.000
GDP	−0.034	0.001	−39.660	0.000
AGR	0.029	0.001	28.350	0.000
FIN	−0.005	0.000	−23.170	0.000
FDI	−0.003	0.000	−37.260	0.000
FOREST	−0.003	0.002	−1.520	0.129
URB	0.022	0.002	10.660	0.000
Hansen (*p*)	0.71			
AR-II (*p*)	0.22			
DK estimates				
GDP	−0.236	0.326	−0.720	0.477
AGR	0.057	0.003	19.500	0.000
FIN	−0.010	0.002	−4.540	0.000
FDI	−0.017	0.002	−7.030	0.000
FOREST	−0.089	0.031	−2.840	0.009
URB	0.146	0.016	8.980	0.000

the level and stationary properties at the first difference level with both the tests of unit roots. Therefore, providing us with the opportunity to analyse the data for long-run parameters.

The results for cointegration tests in Table 5 for both “Pedroni” and “Westerlund” supports the existence of a long-run equilibrium relationship between the models at a 5% significance level or below. This relationship quality between the models (ED and END) permits us to test them for the long-run parameters and determine the magnitude of individual variables and their response towards the dependent variable in the long run.

Discussion of the empirics

Panel results of “GMM” and “DK” have been produced in Table 6; to address the problem of second-order autocorrelation, we have adopted the AR(II) test of the null hypothesis of no autocorrelation against the alternative of correlation; results also have proved that there is no autocorrelation among the variables. To validify the instruments used in the model, this study further used the Hansen test, which uses the null of instruments that are not correlated with residuals. Results have provided that the instruments used are valid by rejecting that the instruments applied have a correlation with the residual terms. For the results of the BRI panel, we have seen that the coefficient of the first lag of ED is positive and significant, indicating the existence of a long-run relationship. Similarly, the role of GDP is negative with significant explanatory power, which implies that a one per cent rise in economic activities is improving the environment with −0.034% in the long run. These results are also supported by the study of Pettinger (2021) and Osuntuyi and Lean (2022a, b), who believes that with rising incomes, people have a greater ability to conserve natural resources, therefore protecting the environment from harmful emissions. Similarly, a recent panel data study by Osuntuyi and Lean (2022a, b) also indicated that economic growth and a rise in real income are the long-run solutions to environmental degradation. In contrast, this notion is refuted by the study of (Saqib et al. 2022b) for MINT countries that at initial stages, the economic growth improves on the exchange of environmental deterioration. Similar conclusions were also drawn by the previous studies of Fakher et al. (2018), Can et al. (2022), and Fakher and Inglesi-Lotz (2022), who resembles that at initial stages of economic growth enhances environmental

Table 5 Cointegration results of ED-model

Null hypothesis: no cointegration	ED-model		END-model	
Pedroni cointegration	Statistics	*P*-values	Statistics	*P*-values
Phillips–Perron	−4.690	0.000	−3.418	0.000
Modified Phillips–Perron	9.608	0.000	10.143	0.000
Augmented Dickey–Fuller	−6252.000	0.000	−3.358	0.000
Westerlund cointegration				
Some panels are cointegrated	−2.045	0.020	−8.027	0.000
All panels are cointegrated	2.904	0.002	−1.998	0.023

degradation supporting the EKC phenomenon. Further, the role of agriculture in ecological footprints is positive, indicating that a one per cent agriculture expansion tends to raise the ecological footprints of the BRI countries with 0.029% in the long run. This result supplies that; agricultural land expansion requires huge and energy-intensive machinery, and for the rise in production, further use of fertilisers which are also the primary sources of environmental deterioration in the long run. Likewise, the increase in farming erodes the soil, raises environmental pollution, desertification, deforestation and many more in the long run (Nunes et al. 2020; Chowdhury et al. 2022). The results are further supported by a recent study by (Shabbir Alam et al. 2023). Therefore, in line with the study of (Saqib et al. 2023), new policy ideas on targeting sustainable goals are essential in the study area. Our findings differ from (Raihan 2023), who find that agricultural productivity reduces CO_2 emissions in the Philippines.

Further, the impact of finance, FDI, and forest are negative, which indicates that a one per cent rise in finance tends to reduce environmental degradation with 0.005%, where this explanatory power in the case of FDI is 0.003%, which indicates the import of clean technology to these countries. In the case of forest rents, it's 0.003% in the long run. The positive role of finance in curbing environmental degradation is supported by the studies of (Saqib et al. 2022a). While disagreeing with this (Fakher and Murshed 2023) revealed that financial development at initial stages enhances environmental degradation while, after a certain threshold, it starts improving the environmental quality. Financial development is a significant source of economic growth (Fakher et al. 2022), and economic growth raises environmental degradation. Similar to the study of (Raihan 2023), our results also explored that forest resources are positive indicators of environmental quality. At the same time, urbanization is found to be detrimental and increases the ecological footprints of these countries.

Results for the energy demand model are separately analysed, and their results are portrayed in Table 7. To sort out the econometric issues of autocorrelations and the use of instruments are tested, and results of second-order AR(II) and Hansen's probability values are provided in the respective tables, which signals there is no autocorrelation, and the instruments applied are valid. Further, the first lag of the dependent variable is significant with a positive sign, which implies the variables have long-run bonding. The empirical results further disclose that GDP, AGR, and finance have positive coefficients with 2.868, 1.591, and 0.202 explanatory powers. The positive role of GDP in enhancing environmental degradation is supported by (Khan et al. 2021a), who revealed that with the rise in income, people tend to demand more goods (buying machines, vehicles, and other household items) which are energy intensive. Similarly, for an expansion of agricultural land, heavy machinery is involved; for the operating and reforming of the land, they consume an enormous amount of energy. Therefore, their relationship evolves to be positive. While refuting the positive role of finance in environmental degradation revealed that finance plays an essential role in reducing fossil energy demand (Muhammad et al. 2021) in a panel of Muslim countries. In contrast, various previous studies have explored that finance and agriculture are positive drivers of energy consumption, and our findings support this notion (Shahbaz and Lean 2012; Ma and Fu 2020; Paris et al. 2022). Similarly, the role of FOREST and urbanization also positively impact the energy demand of the BRI countries. However, the role of FDI is negative with a −0.065 coefficient, which implies that the FDI coming to these countries is efficient, and due to various environmental protocols, they have started importing environmentally friendly technology, which is efficiently utilizing energy.

Table 7 Long-run estimates of the END-model

	Coefficients	Std.Err	*Z* tests	*P*>|*Z*|
GMM estimates				
END_{L1}	0.936	0.000	4876.530	0.000
GDP	2.868	0.048	59.200	0.000
AGR	1.591	0.043	37.360	0.000
FIN	0.203	0.002	97.270	0.000
FDI	−0.065	0.002	−32.600	0.000
FOREST	0.168	0.033	5.010	0.000
URB	2.912	0.022	130.740	0.000
Hansen (*p*)	0.36			
AR-II (*p*)	0.75			
DK estimates				
GDP	4.548	2.499	1.820	0.082
AGR	2.146	0.290	7.390	0.000
FIN	1.059	0.174	6.080	0.000
FDI	−0.385	0.145	−2.650	0.014
FOREST	2.297	0.763	3.010	0.006
URB	1.559	0.236	6.600	0.000

Finally, to the causal nexus between the chosen dimension of variables, we have applied the Dumitrescu and Hurlin (2012) causality method, and the results are portrayed in Table 8. The causal results imply no causality from FDI and FOREST to energy demand; similarly, there are no causal linkages from END and GDP towards FDI, END to FOREST. Similarly, there is another no linkage observed from FDI to FOREST in the short run; all of the no causal links are written boldly in the table. Contrarily, from the results, we conclude that all the remaining variables support bidirectional causal linkages. Thus, giving significance to the results can be widely used for policy implications.

Table 8 DH causality results

Variables	ED	END	GDP	AGR	FIN	FDI	FOREST	URB
ED	–	2.95[1%]	3.05[1%]	2.97[1%]	2.85[1%]	2.06[1%]	2.15[1%]	10.64[1%]
END	1.87[1%]	–	2.99[1%]	3.41[1%]	2.26[1%]	**1.33**	**1.15**	9.92[1%]
GDP	3.63[1%]	2.98[1%]	–	4.26[1%]	4.22[1%]	**1.35**	2.26[1%]	23.6[1%]
AGR	3.12[1%]	2.93[1%]	3.12[1%]	–	3.71[1%]	1.48[5%]	1.95[1%]	17.59[1%]
FIN	3.29[1%]	2.67[1%]	3.64[1%]	2.52[1%]	–	2.19[1%]	1.52[5%]	14.34[1%]
FDI	1.76[1%]	**1.23**	2.24[1%]	1.75[1%]	2.11[1%]	–	**1.29**	4.19[1%]
FOREST	1.42[10%]	**1.32**	2.12[1%]	3.36[1%]	2.96[1%]	1.49[5%]	–	7.92[1%]
URB	3.83[1%]	3.34[1%]	3.83[1%]	6.55[1%]	3.35[1%]	1.73[1%]	2.51[1%]	–

The superscripts [1, 5], and [10%] indicate the level of significance

Conclusion and policy implications

This study investigated the relationship between forest resource depletion, agricultural expansion, and financial development for a panel of 97 BRI (Belt and Road initiatives) countries from 1995 to 2018. The study estimated by accounting for the dynamic influences and endogeneity issues with instrumental variable GMM. Further applied Driscoll and Kraay estimator as a benchmark for the results obtained for ecological footprints and energy generation in the BRI countries. Form the results, it is noted that economic growth, financial development, and forest resources improve environmental quality. On the other hand, agricultural expansions are raising the ecological footprints in the long run. In addition, FDI through these countries is clean, thereby reducing fossil-based energy consumption, whereas forests, agricultural expansion, GDP, urbanization, and finance are positive factors contributing to fossil-based energy consumption. Supporting the previous outcomes, the results from the causal dimension give feedback effects between environmental degradation, energy demand, forest resources, GDP, finance, and agricultural expansion.

Based on the aforementioned research results, discussion, and conclusion, some of the remarkable empirical policy recommendations are drawn for the large scale of stakeholders and concerned population. Firstly, the role of agricultural expansion in environmental quality and energy consumption indicates the requirement of green mechanization in agricultural production, land levelling, and other agricultural machinery to be energy efficient; thus, that will help economic growth, food security, and environmental quality by environmental quality. Therefore, mechanization in agriculture should be improved by green technologies application. Further, encourage clean FDI in the agriculture sector, the inflows of clean and green FDI to these countries will enhance the environmental quality significantly. Similarly, reliance on the consumption of fossil energy in agriculture should be promptly encountered, which may be possible by using organic and low-carbon agriculture. It can reduce emissions as well as store carbon. The government's administration, alongside BRI, may encourage wind, solar, and biofuel use to increase agricultural productivity and fight global warming and climate change. Cutting-edge equipment in agriculture may also reduce the negative burden on the ecosystem. Finally, international cooperation on efficient agriculture production may also help remove environmental toxicants. Further, the role of forest resources improves the environmental quality, the governments, alongside BRI countries at various levels, should strongly encourage the protection of forest resources and afforestation initiatives; similarly, forest protection should be largely prioritized, boosting plantation at various levels. Add projects in BRI with response to forest conservation and allocate reasonable finance for these projects by the respective governments that may initiate new awareness on improving the environmental quality. Thus, better forest management policies should be introduced, which may help greening the BRI countries. Based on the research results, it also suggested that the BRI member countries should prioritize the formation of sovereign environmental protection forums within the framework of BRI and collaborated pragmatic action plans for environmental and ecology preservation should be highlighted.

Due to the paucity of the available literature on the given research quest in the BRI region may generate certain limitations. The foremost is data availability. Due to the limitation of the data, this study adopted time series data between 1995 and 2018. Similarly, the data constraint also limits the countries chosen for the investigation to 97. On methodological constraints, this study conducted a symmetrical analysis of the selected variables. Based on these limitations, this study is expected to open multiple avenues for future research work for more in-depth analysis. For example, the time period chosen should be expanded by future research. The number of countries should be increased by comparing the symmetrical and asymmetrical analysis of the chosen variables. Further, this study could be expanded to other regions, including BRICS, G7, and OECD countries for clearer picture.

Appendix

Belt and road initative countries official list

https://www.yidaiyilu.gov.cn/xwzx/roll/77298.htm

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Authors contributions LKB conceived the study and was responsible for the design and development of this paper. KR, WW, and AR were responsible for data collection and analysis. JQ was responsible for data interpretation and supervision; LKB wrote the final draft of the manuscript. All authors read the final draft of the manuscript and approved to submission.

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Data availability Relevant data available from the first author upon request.

Declarations

Conflicts of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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