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Technological innovation, natural resources, financial inclusion, and environmental degradation in BRI economies

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Abstract

This research aimed to examine the relationship between financial inclusion (FNI), technological innovation (TIN), and natural resources (NRS) and their impact on environmental degradation in the 45-belt and road initiative (BRI) region from 2001 to 2018. The study utilized advanced econometric techniques, including the generalized method of moments–panel vector autoregressive, as well as traditional methods such as ordinary least squares and dynamic ordinary least squares, to examine the relationship between these factors and environmental degradation, measured by carbon footprint (CFP) and ecological footprint (EFP). The long-run estimate confirms that NRS and FNI appear to have led to higher regional CFPs and EFP pressure. Meanwhile, the relationship with TIN, economic governance institutions (government effectiveness and regularity quality), and human capital contribute to overcoming environmental degradation and increasing environmental sustainability. The findings of this study have important implications for policymakers and central authorities in the BRI region to address environmental degradation and promote sustainable development.

Recommendations for Resource Managers

- Natural resources (NRS) and financial inclusion increase the regional carbon footprint (CFP) and ecological footprint.
- Human capital and technological innovation positively contribute to environmental sustainability.
- Belt and road initiative (BRI) economies should retain innovative access to financial services, sustainable forest, and biocapacity development to meet environmental disasters.
- Moreover, BRI economies should not increase NRS used extensively to minimize the regional CFP.

KEYWORDS

environmental deterioration, financial inclusion, natural resource rent, technological innovation

1 | INTRODUCTION

Sustainable development is a strategic objective globally, and advanced and emerging economies have difficulties balancing economic development and environmental protection. The biggest obstacle to sustainable development is environmental deterioration driven by a high carbon footprint (CFP) and ecological pressure. The CFP measures the human impact on the environment with the quantity of greenhouse gases (such as GHGs in the unit of CO_2, consumption of electricity, and burning fossil fuels) (Ali et al., 2021; Jianguo et al., 2022; Luo et al., 2021). The United Nations Framework Convention on Climate Change reveals that CO_2 emissions are the primary cause of 75% of GHGs and significantly contribute to environmental degradation and global warming. In this context, British Petroleum observed a rise in CO_2 emissions from 2009 to 2017 of 29,714.2–33,444.0 million tons. If present trends in GHG emissions continue, global temperatures will climb by 1.5°C between 2030 and 2050. The amount of CO_2 emissions in the atmosphere is growing alarming, requiring "immediate action" to mitigate environmental deterioration. Thus, several recent studies have urged the adoption and implementation of pertinent policies and regulations to maintain global environmental sustainability (Fareed et al., 2022; Khan et al., 2022; Qin et al., 2021).

However, CFP is not always a relevant factor in environmental degradation. Therefore, the ecological footprint (EFP) is also responsible for environmental deterioration. EFP measures the human demand on earth's ecological capacity (such as land and water area). Ecological deterioration is caused by a variety of factors across the world, such as (i) biodiversity; the earth's biodiversity is quickly vanishing at "mass extinction" rates, with species populations declining by about 60% since 1970. (ii) Deforestation; by 2050, the Amazon Basin's current deforestation rates may cause a regional rainfall decline of 8%, resulting in a transition to a "savannah state," which would have broader effects on the planet's atmospheric circulation networks. (iii) Oceans, fishing ground; nitrogen and phosphate pollution from fertilizers has washed into seas, potentially having the most extraordinary and fastest influence on the nitrogen cycle in the last 2.5 billion years. This has influenced fish stocks and resulted in "dead zones" in 10% of the world's oceans. (iv) Clean air; around 91% of the world's population lives in areas that do not satisfy the air quality standards established by the WHO. (v) Water scarcity; the global water cycle is suffering from comparable severe consequences due to overabstraction and unchecked pollution, with related research indicating that the globe may face a 40% deficit in freshwater required to maintain the global economy by 2030. The current study used the CFP–EFP concept (Figure 1) to depict environmental degradation in selected belt and road initiative (BRI) nations, along with drivers, such as natural resources (NRS), financial inclusion (FNI), technological innovation (TIN), and other macroeconomic variables.

Life on earth depends on the flow of products and services provided by the earth's natural processes (Ali, Jianguo, et al., 2022). They provide the food we eat, the resources we use for housing and fuel, and the air for breath and water we drink. The CFP–EFP depends on biological resources and NRS and amenities that the area of biological production may quantify. NRS rent is determined by the total resources rent as a proportion of GDP and includes gas, oil, coal, minerals, and forest. NRS are rare and deteriorate daily, causing environmental degradation over time (Hussain et al., 2020). The relationship between NRS and environmental deterioration is a polarizing issue. On the one hand, some NRS, such as coal and oil, pollute the environment (Ahmadov & van der Borg, 2019). Conversely, the availability of NRS might discourage the utilization of fossil fuels by lowering their importation (Balsalobre-Lorente et al., 2018). Similar to these arguments, there is still no consent on the effect of NRS extraction on the CFP–EFP and this subject is still debatable. Accordingly, in our study, we use CFP–EFP environmental proxies in this study. Additional research is required to develop toward environmental sustainability and utilize the comprehensive proxies for measuring environmental degradation (CFP–EFP), which was ignored in the previous study.

In recent years, there has been a rapid global economy transition, raising concerns about environmental and financial problems. The importance of environmental stability has increased, and several economies have devoted to investing to meet these goals (Jianguo et al., 2022). FNI is an integral part of financial development (FND), which fosters economic

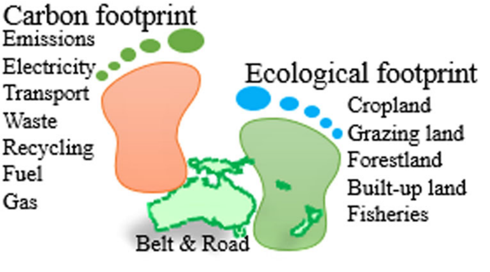

FIGURE 1 Carbon footprint and ecological footprint. *Source*: Author's completion.

growth and financial sector development (Le et al., 2020). The environmental effects of FND have been the subject of several studies conducted worldwide (Dada et al., 2022; Khan & Ali, 2020; Kirikkaleli & Adebayo, 2021). However, very few studies look at the importance of FNI in preventing climate change. Only a few research have looked into the effects of a sustainable environment (such as Ahmad, Ahmed, Gavurova, et al., 2022; Chaudhry et al., 2022; Dong et al., 2022; Huang et al., 2021; Le et al., 2020). FNI refers to the accessibility of various financial services and products to all organizations and people to meet their requirements in an easily manageable, dependable, and sustainable way. According to the Alliance for FNI, inclusive green finance (IGF) is an FIN policy that intends to support a low-carbon economy. Focusing on social well-being, environmental health, and FIN, IGF is the primary mechanism promoting FND. The BRI nations were selected as our case study due to the region's importance (regarding FNI and environmental degradation). In BRI economies, the growth rate of finance declined between 1980 and 2016. To enhance sustainable and economic development in the region, these economies need funding in the form of financial improvements and green investment. Therefore, this study examines FNI as a factor in climate change in the BRI context.

Furthermore, scholars believe that TIN may play an essential role in protecting FND and NRS while minimizing the impact of their use on the environment (Jianguo et al., 2022; Luo et al., 2021). Numerous factors throughout the world are contributing to environmental deterioration, including increased energy consumption, GHG emissions, toxins, water contamination, and EFP (Nathaniel, 2021a; Uzar, 2021). Scholars are relating several elements to the CFP–EFP to reveal mitigation solutions that might contribute to achieving sustainable development and boosting environmental quality. Therefore, it is usually recognized that TIN plays a vital role in both FND and the quantity of sustainable growth generated by industrial activities (Ali et al., 2021). It has been determined via research on the environmental quality that using highly effective technology during production improves environmental sustainability. Fareed et al. (2022) have asserted that TIN mitigates the usage of energy and CO_2 emissions. In light of the fact that TIN has a vital role in decreasing GHGs, Ahmad et al. (2020), Gupta et al. (2022), Khan et al. (2020), Luo et al. (2021), and Zuo et al. (2022) have attempted to study the connections between TIN and CO_2 reduction, and their studies focus only on GHGs–CO_2 emissions. However, our study used two proxies for measuring environmental sustainability, employing CFP–EFP as indicators to measure environmental degradation. Therefore, to satisfy the pledges set at a global climate change summit, TIN in the country is more important than ever. As we discussed earlier, we used both comprehensive assessments in our study. The complete assessment proxy, CFP–EFP, should be utilized to evaluate environmental degradation that has been neglected in prior BRI research.

To accomplish the stated objectives, this paper uses "BRIs" as a case study. Why BRI economies? The "BRI" was proposed by China. China is investing billions of dollars in infrastructure projects in 146 countries along the historic Silk Road, which connects China to Asia, Europe, Africa, and the Middle East, and by the end of January 2021, BRI signed 205 cooperation agreements worldwide. In recent decades, BRI nations have displayed remarkable economic performance and maintained faster growth in the economy than the rest of the globe. The project's estimated costs 21.1 trillion dollars and BRI nations represent 80% of the global population and contribute 5% of international trade and 31% of the global gross domestic product (GDP) (Bakhsh et al., 2022). Mainly, BRI has a higher proportion of the world's NRS, such as 55.17% of oil supply (per day thousand barrels), 74.69% of coal production (thousand tons), 58.54% of crude oil reserves (billion barrels), and 53.85% natural gas production (billion cubic feet) (Ozturk & Ullah, 2022).

In addition, these BRI nations' advancements significantly impact world CO_2 emissions, which has become a significant issue; almost 9816.77 tons of global carbon emissions are produced in BRI. As a result, their carbon emissions are 50% greater than the global average. The ecological system is also being progressively degraded by expanding economic activity in all sectors, which results in the heavy use of NRS. Since its launch, the BRI has received considerable interest, with the international community and academics particularly concerned about the BRI's environmental quality (Coenen et al., 2021; Li et al., 2021; Saud et al., 2020; Zuo et al., 2022). Some studies revealed that the BRI would provide additional possibilities for nations along the route to share experiences with low-carbon technologies, green finance, and green governance and strengthen their capacity to combat global warming, which contributes to environmental sustainability (Zuo et al., 2022).

Meanwhile, the Chinese government has announced a policy statement,[1] such as the "Guidance on Promoting Green Belt and Road" and taken numerous constructive steps, for example, encouraging the International Coalition for Green Development on the BRIs) to increase environmental support and reduce emissions and ecological hazards in BRI collaboration.

This study stands out among other investigations due to its unique focus on the impact of various factors on CFP and EFP in BRI economies. By examining the effects of TIN, NRS, FNI, human capital (HCT), and economic governance institutions, this study provides a comprehensive understanding of the relationship between these factors and the CFP–EFP in BRI nations. To the best of our knowledge, there has been no prior research that has examined these relationships in the context of BRI nations. The findings will have important implications for policymakers in BRI nations looking to achieve a balance between economic development and environmental sustainability.

This work contributes to the body of knowledge in several ways. First, to the best of the authors' knowledge, this is the first study to examine how these factors interact within the context of BRI. Second, as TIN[2] has been a prominent field of study in recent years, several scholars have studied the nexus between TIN and environmental degradation (Adebayo, Kartal, et al., 2023; Fareed et al., 2022; Liu et al., 2020). According to our knowledge, this study is the first to examine how technological advancement affects the CFP–EFP. In fact, revealing how TIN interacts with NRS and FNI to influence environmental sustainability. This is an important contribution because scholars use R&D expenditure as a measure of patent and input innovation as a proxy for output innovation (Jianguo et al., 2022; Luo et al., 2021). We employ a more significant measurement for innovation (researchers' participation in R&D). We anticipate that more "R&D professionals will turn R&D expenditures (input innovation) into patents or trademarks (output innovation)" effectively and efficiently. This investigation reveals the critical results of each of these parameters for environmental protection, which helps develop successful green technologies to attain net zero emissions in BRIs economies in the future decades. This successful input-to-output innovation uses clean technology and inventive techniques. Thereby providing information to aid evidence-based better, sustainable, environmentally friendly green innovation regulations/policies on the continent. The model incorporates TIN as the most constructive aspect for reducing the EFP.

Third, unlike other research, this study uses FNI to provide a complete picture of the FNI and CFP–EFP nexus and explores FNI's holistic implications on environmental quality. We employ the IMF's most comprehensive FNI index. The FNI index consists of four variables: (a) the number of bank branches per 100 thousand people, (b) automated teller machines per 100 thousand people, (c) the number of depositors in commercial banks per thousand persons, and (d) the total borrowers from the commercial banks per thousand persons. Therefore, in the financial context, few works have studied the effect of FIN on environmental degradation, and we could not identify any in the BRI context. On the contrary, most prior research concentrated on FND. Consequently, our study is a crucial step toward filling this gap.

Fourthly, it is connected to the unique circumstances of the BRI. To our knowledge, no study focuses directly on BRIs nations' NRS, financial sector, HCT, economic governance institutions, TIN, and other control factors on the sustainable environment. Earlier research in the context of sample nations has not been determined. In this context, the study's findings will be an essential guide for regulators and policymakers in achieving the CFP–EFP mitigation objectives.

Finally, the study used modern econometric techniques, and all suggested relationships will be empirically investigated using the most recent data set from 2001 to 2018 in the 45-BRI economies context. The cross-sectional dependence (CSD) is taken into account using the second-generation panel data technique. We use a unique strategy known as the method of generalized method of moments–panel vector autoregressive (GMM–PVAR). This study also produces conventional outcomes by employing different approaches, such as fully modified ordinary least square (FM-OLS), fixed effects ordinary least square (FE-OLS), and dynamic ordinary least square (D-OLS).

The study is expected to contribute to the development of policies and strategies that promote sustainable development in the BRI economies while taking into account the relationship between TIN, NRS, FNI, and environmental degradation. By providing a better understanding of these complex interrelationships, the study aims to support the development of effective and sustainable solutions that will help promote the sustainable development of BRI economies.

2 | LITERATURE REVIEW

2.1 | FNI and environmental degradation

The study of the relationship between FNI and environmental deterioration has recently received much attention in environmental economics. Therefore, to develop a connection between FNI and environmental deterioration, the empirical details of FND are also involved in the analysis of prior works. There are two primary strands of study regarding the link between FND and environmental sustainability. Some researchers examined that FND can lead to environmentally friendly technological advancements that manufacture environmentally friendly products and aim to keep the environment as clean as possible, increasing the level of developmental sustainability at the global, national, and regional levels (Ali et al., 2021; Khan & Ali, 2020; Zuo et al., 2022). The second line of the study suggests that because FND encourages production activities, it may be responsible for the rise in CO_2 emissions (Ali et al., 2023; Atif Khan et al., 2020; Jianguo et al., 2022). Research has shown how FND affects environmental degradation (Ahmad, Ahmed, Gavurova, et al., 2022; Dada et al., 2022; Jianguo et al., 2022; Khan et al., 2020; Kirikkaleli & Adebayo, 2021; Zaidi et al., 2019). However, there are very few works that establish the role of FIN in environmental deterioration (Ahmad, Ahmed, Gavurova, et al., 2022; Dong et al., 2022; Fareed et al., 2022; Huang et al., 2021; Le et al., 2020; Qin et al., 2021; Shahbaz et al., 2022; Zaidi et al., 2021). Earlier studies found that the relationship between FNI and environmental proxies (CFP–EFP) is scant, complex, and debatable in BRI economies. Developing a green financial system might be a way forward in this environment, and it is now a hot issue among researchers and policymakers worldwide. Green finance aims to provide financial products, including funding and investment for environmentally sustainable activities. As a result, establishing a green finance system might be an effective strategy for BRI and the entire world to continue development while decreasing environmental devastation.

2.2 | Natural resources and environmental degradation

Environmental deterioration and NRS have recently received significant attention from regulators and academicians. The study of Ahmed et al. (2020) revealed that NRS mitigates environmental degradation and increases the EFP in China. Similarly Ibrahim et al. (2022) adopted cross-sectional-autoregressive-distributed lag (CS-ARDL), augmented mean group, and common correlated effect mean group techniques for top-10 NRS countries between 1995 and 2019 and found that NRS boosts CO_2 emissions. Several other papers studied the role of NRS in the environment and other variables for other regions, such as Gupta et al. (2022) for emerging economies, Ali, Jianguo et al. (2022), Halliru et al. (2020), and Langnel et al. (2021) for Economic Community of West African States (ECOWAS) member countries, and Nathaniel et al. (2021) in the Middle East and North African region. Ahmed, Ahmad et al. (2022) for Pakistan economy, Nathaniel et al. (2021) for African economies, Hussain et al. (2020) and Li et al. (2021) for BRI economies, Awosusi et al. (2022) and Danish, Ulucak, and Khan (2020) for Brazil, Russia, India, China, and South Africa (BRICS), Ahmad et al. (2020) analyzed for 22 emerging countries, Ahmadov and van der Borg (2019) for the European Union, and Balsalobre-Lorente et al. (2018) for 5-EU economies. Considering the literature above, the earlier study was ineffective in critically and in-depth analyzing the link between environmental quality and the use of NRS.

To summarize the discussion on the relationship between NRS and environmental quality, the prior study findings are ambiguous and contradictory. Furthermore, no previous research has focused on the BRI, which covers 85% of the world's population and contributes 35% of global trade and 31% of global GDP, with an estimated cost of $21.1 trillion (Bakhsh et al., 2022). To validate the nexus between NRS and environmental sustainability in BRI, it is necessary to collect new evidence, which is the purpose of this study. The examination of the current literature indicates contradictory results, and there is no particular study on BRI; hence, new research is vital to evaluate fresh outcomes in BRI. This work focuses on providing new insights to overcome the constraints of the previous study and to give insights for policy design to minimize the CFPs and EFP pressure in BRI.

2.3 | Technological innovation and environmental degradation

As environmental challenges are crucial, more researchers are studying innovation's impact on environmental degradation. Previous findings have revealed that TIN has a significant impact on environmental sustainability. TIN has received little attention in previous studies, and researchers have identified both its negative and positive effects of TIN. In this regard, Jianguo et al. (2022) revealed the impact of TIN on environmental sustainability in the case of 35-Organisation for Economic Cooperation and Development (OECD) and showed that TIN significantly declines environmental quality (Luo et al., 2021). The analysis indicates that TIN positively influences reducing environmental damage in some Asian economies (Gupta et al., 2022). The results reveal that TIN improved environmental sustainability in Bangladesh. Similarly (Ahmed, Caglar, et al., 2022), the findings of the study revealed that TIN promotes environmental sustainability in the G7 economies. Fareed et al. (2022) demonstrated that TIN reduces CFP and EFP in the Eurozone. Ahmad, Ahmed, Bai, et al. (2022) examine the empirical impact and reveals a persistent and long-run link between TIN and environmental degradation. The recently published study of Adebayo, Ullah et al. (2023) adopted CS-ARDL approach from 1990 to 2019 for the BRICS region. The outcome shows that TIN improves environmental sustainability in the region. Most academics feel that TIN helps increase environmental quality (Ahmed et al., 2021; Khan et al., 2020; Luo et al., 2021; Tao et al., 2022). They contend that TIN facilitates the rapid development of new techniques. Consequently, it increases energy efficiency and decreases the requirement for fossil fuel energy consumption.

The literature on the effects of TIN on environmental sustainability is contradictory. However, most of their findings are inconsistent with TIN's favorable and unfavorable environmental impacts. Therefore, there is no consensus in the prior research about whether TIN intensifies or mitigates environmental degradation.

In summary, the body of existing literature demonstrates that the impact of TIN on environmental sustainability can be classified as either positive or negative. Although many academics have attempted to investigate this relationship, there are still many flaws in the academic work that highlight the need for new research and evidence based on a sample of countries and periods. As we have discussed, earlier research has produced contradictory results; thus, such results cannot be used for policymaking without a new study. Therefore, the significance of the new study that performs a preliminary analysis and gives further information for policy recommendations appears to be of the utmost importance. Keeping in mind these inconsistencies in findings and the uninvestigated connection between TIN and CFP–EFP, this article studies the environmental effects of FNI, NRS, and TIN to focus on policy recommendations for BRI economies.

3 | RESEARCH DESIGN

3.1 | Theoretical framework and description of data

Motivated by study objectives, this research investigated the effect of FNI,[3] NRS rent, TIN, economic governance institutions, and HCT on environmental deterioration using panel data of 45-BRI[4] economies from 2001 to 2018.[5] In this regard, following the studies of Fareed et al. (2022) and Ullah et al. (2022), Table 1 reports the description, measurement, and sources of the variables.

The impact of FNI on environmental degradation is a complex issue that is still being studied. The findings from recent studies are conflicting and provide a mixed picture. On the one hand, a study by Ibrahim et al. (2022), Kirikkaleli et al. (2022), and Kirikkaleli and Adebayo (2021) found that FNI has a negative impact on environmental quality and mitigates environmental degradation. On the other hand, the study of Ali, Kirikkaleli et al. (2022) and

TABLE 1 Indicators description, measurement, and sources.

Symbol	Description	Unit of measurement	Data source
CFP	Carbon footprint	Metric tons per capita	WDI
EFP	Ecological footprint	Global hectares (gha)	GFPN
FNI	Financial inclusion	Index	IMF
NRS	Natural resources	% of GNI	WDI
TIN	Technological innovation	Researchers in R&D (per million people)	WDI
GEF	Government effectiveness	Economic governance institutions, GEF from (−2.5 to 2.5)	WGI
RQL	Regularity quality	Economic governance institutions RQL from (−2.5 to 2.5)	WGI
HCT	Human capital	Index	Penn world

Abbreviations: GFPN, global footprint network; GNI, gross national income; IMF, international monetary fund; WDI, world development indicators; WGI, world governance indicators.

Source: Author's estimation.

Ullah et al. (2022) suggests that FNI has a positive impact on CFP–EFP. Hence the nexus of FNI-CFP and EFP could be ambiguous; it could be (−) impact on environmental degradation in the BRI or could be (+) on CFP–EFP; $\beta_1 = \frac{\delta \text{CFP}_{,it}, \delta \text{EFP}_{,it,}}{\delta \text{FNI}_{it}} < 0$ or $\beta_1 = \frac{\delta \text{CFP}_{,it}, \delta \text{EFP}_{,it,}}{\delta \text{FNI}_{it}} > 0$. The recent studies by Adebayo, Kartal, et al. (2023), Ahmed et al. (2020), and Ibrahim et al. (2022) have emphasized the positive impact of the NRS on CFP and EFP. The studies suggest that the NRS can effectively increase the issue of environmental degradation. However, these findings also suggest that an increase in the NRS may negatively affect environmental sustainability. On the basis of these studies, it can be deduced that the energy transition may have a detrimental effect on CFP and EFP; $\beta_2 = \frac{\delta \text{CFP}_{,it}, \delta \text{EFP}_{,it,}}{\delta \text{NRS}_{it}} < 0$. Additionally, the role of TIN in shaping the environment is complex. First, TIN stimulates the development of renewable energy sources by fostering green innovation (Ahmed et al., 2021; Ahmed, Can, et al., 2022; Kirikkaleli et al., 2023). On the other hand, TIN also promotes rapid industrialization, which may not necessarily align with the goals of transitioning to sustainable energy (Jianguo et al., 2022). As a result, the impact of TIN on the environment in economies participating in the BRI is uncertain. It is unclear whether TIN will have a positive or negative effect on the environment in these economies. $\beta_3 = \frac{\delta \text{CFP}_{,it}, \delta \text{EFP}_{,it}}{\delta \text{TIN}_{it}} > 0$ or $\beta_3 = \frac{\delta \text{CFP}_{,it}, \delta \text{EFP}_{,it}}{\delta \text{TIN}_{it}} < 0$.

3.2 | Specification of model

The primary function of the model is studying the panel analysis. The basic functional form of the model is in Equation (1):

$$\text{CFP} - \text{EFP} = f\,[\text{FNI} + \text{NRS} + \text{TIN} + \text{GEF} + \text{RQT} + \text{HCT}]. \tag{1}$$

In Equation (2), the log-linear data are more efficient and consistent than linear data (Jianguo et al., 2022; Luo et al., 2021). Below is a log-linear representation of the function,

$$\ln \text{CFP} - \text{EFP}_{i,t} = \alpha_i + \Lambda_t + \beta_1 \ln \text{FNI}_{it} + \beta_2 \ln \text{NRS}_{it} + \beta_3 \ln \text{TIN}_{it} + \beta_4 \ln \text{GEF}_{it} + \beta_5 \ln \text{RQT}_{it} + \beta_6 \ln \text{HCT}_{it} + \varepsilon_{it}. \quad (2)$$

3.3 | Methodology

The six-step econometric technique is used to conduct the econometric assessment in Figure 2. The details of each section are presented in the subsequent subsections.

3.3.1 | CSD test

3.3.2 | Slope homogeneity (SLH) test

Following the assessment of the CSD, the slope homogeneity (SLH) between the cross-sections is examined. The problem of heterogeneity is crucial because of disparities in the demographic and economic frameworks of the BRI nations. Variations in slope parameters may impact the consistency of panel estimators. As a result, the SLH technique was used in this research (Hashem Pesaran & Yamagata, 2008): we employ the $\tilde{\Delta}$ test of Hashem Pesaran and Yamagata (2008), which is based on the modified Swamy's (1970) statistic $\tilde{S}$, which is suitable in the case of $N, T \to \infty$:

$$\tilde{\Delta} = (N)^{\frac{1}{2}}(2K)^{-\frac{1}{2}}\left(\frac{1}{N}S - k\right), \quad (3)$$

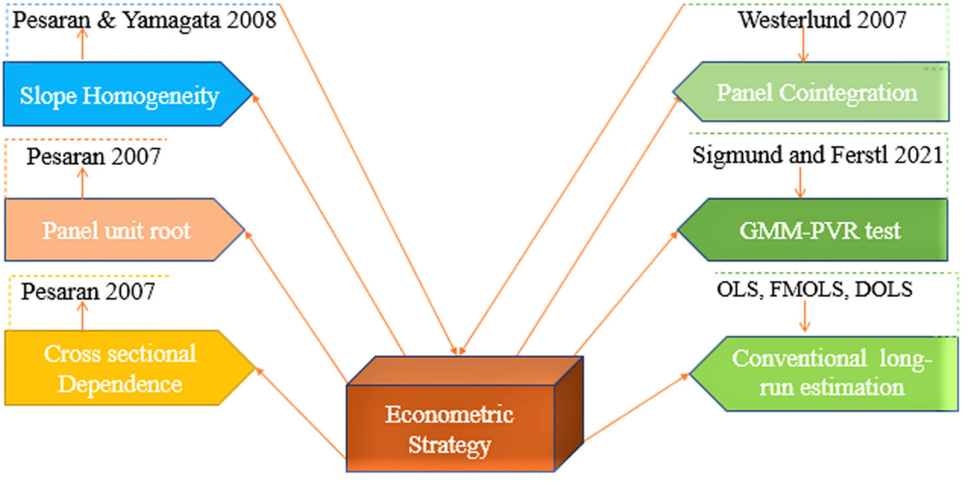

FIGURE 2 Econometric strategy. *Source*: Author's completion. D-OLS, dynamic ordinary least square; FE-OLS, fixed effects ordinary least square; FM-OLS, fully modified ordinary least square; GMM, generalized method of moments; PVAR, panel vector autoregressive.

$$\tilde{\Delta}_{adj} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}S-k\right). \tag{4}$$

In Equations (3) and (4) $\tilde{\Delta}$ the test consists asymptotically normal and standard distribution, where $\tilde{S}$ is the Swamy statistic, k the explanatory indicators, $\tilde{\Delta}_{adj}$ represents the bias-adjusted from the slope homogeneity test.

3.3.3 | Panel stationarity test

In the presence of SLH and CSD, the conventional unit root tests, such as the Choi test, Pesaran and Shin, Fisher-ADF, Levin–Lin–Chu, and Im do not perform well. To address this issue, this paper utilizes the second-generation unit root test of cross-sectionally augmented Dickey–Fuller (CADF)–cross-section Im–Pesaran (CIPS) (Pesaran, 2007), observing the stationary qualities of the variables under study. The test equation is given as

$$\Delta \text{CA}_{it} = \varphi_i + \varphi_i Z_{it-1} + \varphi_i \overline{\text{CA}}_{t-1} + \sum_{I=0}^{P} \varphi_{iI}\, \Delta\overline{\text{CA}_{t-1}} + \sum_{I=0}^{P} \varphi_{iI}\, \Delta \text{CA}_{i,t-1} + \varepsilon_{it}, \tag{5}$$

where in Equation (5) $\overline{\text{CA}}_{t-1}$ and $\Delta\overline{\text{CA}_{t-1}}$ are the averages of the cross-sections. The study incorporates CIPS statistics in Equation (6):

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{n} \text{CDF}_i, \tag{6}$$

where χ_{it} is the regressors, σ_{it} the intercept, T the time, Δ shows the different operative, and ε_{it} the error term.

3.3.4 | Second-generation cointegration test

Third, an advanced cointegration test (Westerlund, 2007) investigates the long-run relationship between the modeled structures.

(1) Westerlund cointegration test (Westerlund, 2007):

$$\Delta Y_{it} = \alpha_i d_t + \rho_i y_{it-1} + \gamma_1 \chi_{it-1} + \sum_{j=1}^{\tau i} \rho_{ij}\, \Delta Y_{it-j} + \sum_{j=-\alpha i}^{\tau i} Y_{ij}\, \Delta\chi_{it-j} + \epsilon_{it}, \tag{7}$$

where, in Equation (7), d is the model residuals, i is the CS in the data (panel), and t is the period. The absence of cointegration among indicators is accepted as a priori of the null hypothesis in this test.

3.3.5 | GMM–PVAR technique

After checking the CSD, SLH, level of stationarity, and cointegration, the GMM–PVAR model was implemented. Sigmund and Ferstl (2021) expanded the PVAR model and introduced a PVAR approach with fixed effects, which was adopted by Dogan et al. (2022). Our study's proposed PVAR model is as follows:

$$y_{i,t} = \left(Z_n - \sum_{i=1}^{p} W_i\right) n_i + \sum_{i=1}^{p} W_i\, y_{i,t-1} + Sy_{i,t} + Gv_{i,t} + \mu_{i,t}. \tag{8}$$

In Equation (8), $y_{i,t}$ is the endogenous factor with time t, $y_{i,t-1}$ specifies the lagged value of the endogenous factor, Z_n is an $(n * n)$ identity matrix, and W, S, and G are the homogeneity parameters. The term $v_{i,t}$ shows a vector of completely exogenous covariates, where $v = 1, ..., T$. Lastly, $\mu_{i,t}$ represents the individual error hypothesized to be independent and well-behaved. There are two ways to curtail fixed effects. The first difference, the forward orthogonal conversion, enables us to circumvent the issue of the fixed effect. By employing the GMM approach, though, we may avoid these steps. Specifically, if we retained the conversion matrix between modified variables and lagged covariates, we could use the parameters as instrumental variables (lagged regressors) in the GMM estimation. Dogan et al. (2022), following Sigmund and Ferstl 2021, recognized the first difference in the GMM estimation as

$$\Delta y_{i,t} = \sum_{i=1}^{p} W_i\, \Delta y_{i,t-1} + S\Delta y_{i,t} + G\Delta v_{i,t} + \Delta\mu_{i,t}. \tag{9}$$

In Equation (9), the term Δ signifies the forward orthogonal conversion or first difference. Our model's lagged endogenous factor y encompasses TIN, NRS, FNI, HCT, economic governance institutions (regularity quality [RQL] and government effectiveness [GEF]), and CFP–EFP. In addition, we applied the forward orthogonal conversion method advised by Hayakawa (2009). Finally, lag choice criteria are based on the Andrews and Lu (2001) process. In precise, the study proposed three different measures based on the moment selection criteria (MMSC), that is, the Hannan–Quinn information criterion, and the Bayesian information criterion (MMSC-BIC). We rely on MMSC-BIC in our study lag length determination (Dogan et al., 2022; Ozcan et al., 2020) where the lag length $p = 1$ was set for all frameworks.

In general, the conventional panel techniques like pooled OLS, random and fixed effect models seem insufficient and incapable of effectively evaluating outcomes due to multiple concerns, including lagged dependent variables, country-specific impacts, endogeneity of explanatory variables, and autocorrelation (Sigmund & Ferstl, 2021). Endogeneity is a traditional issue for panel data modeling that discloses erroneous and inconsistent estimators, and to avoid this concern, several studies adopt the GMM approach (e.g., Ali et al., 2021; Jianguo et al., 2022; Luo et al., 2021). Nevertheless, the GMM approach still cannot thoroughly establish the relationships. The GMM–PVAR method develops a framework of equations where all factors are considered as endogenous. Therefore, this strategy can adequately address the issue. Additionally, it may preserve the impact of one exogenous shock by using the orthogonalized response and making the remaining factors invincible to the external shock (Sigmund & Ferstl, 2021). Several researchers also utilized a GMM–PVAR approach (Dogan et al., 2022; Ozcan et al., 2020; Zhang & Zhang, 2021).

4 | DISCUSSION OF RESULTS

4.1 | Pre-estimation assessment

We began our empirical analysis by looking at descriptive statistics for the parameters under consideration. The carbon footprint (log CFP) and ecological footprint (log EFP) are significantly correlated with all the regressors (i.e., log NRS, log FNI, log TIN, log HCT, log RQL, and log GEF). Panel-A of Table 2 demonstrates significant differences between the minimum and maximum values of the variables indicating the various levels of environmental sustainability and other explanatory variables. Similarly, Table 2, Panel-B, shows the variable correlation matrix.

The correlation matrix shows a negative correlation between TIN, GEF, RQL, and HCT to environmental sustainability indicators CFP–EFP. In contrast, we also found that NRS and FNI are positively correlated with CFP–EFP. Even if the correlation coefficients (in absolute terms) are not very high ($r = 0.7$), the VIF test is used to determine multicollinearity. In the literature Jianguo et al. (2022) and Luo et al. (2021) multicollinearity is defined as detrimental to the regression findings when the value of VIF is greater than 10 for given indicators. The study in Table 2 found that VIF values are less than 10 for all the indicators. Consequently, we can conclude that our regressions will not encounter a multicollinearity issue (Table 2).

In sum, it has been discovered that TIN, HCT, RQL, and GEF are negatively related to environmental sustainability (CFP–EFP). In contrast, NRS and FNI are positively linked to both.

TABLE 2 Descriptive statistics, correlation matrix, and multicollinearity test.

Variable	CFP	EFP	TIN	NRS	FNI	HCT	RQL	GEF	VIF
Panel-A: Descriptive stats									
Mean	7.124	5.097	3.854	7.674	0.897	0.897	1.687	1.946	
Std. Div.	7.657	3.619	1.452	11.398	0.096	0.175	0.214	0.442	
Maximum	70.523	42.145	8.214	13.017	1.849	8.014	2.417	2.446	
Minimum	0.970	0.427	0.089	0.001	0.429	0.324	−2.157	−1.214	
Panel-B: Correlation matrix and VIF									
CFP	1								
EFP	0.647	1							
TIN	−0.546	−0.451	1						2.22
NRS	0.727	0.621	0.211	1					2.36
FNI	0.516	0.463	0.453	−0.356	1				3.334
HCT	−0.482	−0.546	0.356	0.467	0.342	1			2.36
RQL	−0.374	−0.453	−0.114	0.382	−0.322	0.192	1		1.96
GEF	−0.546	−0.367	0.261	0.112	−0.421	0.089	0.356	1	1.89

Abbreviations: CFP, carbon footprint; EFP, ecological footprint; FNI, financial inclusion; GEF, government effectiveness; HCT, human capital; NRS, natural resources; RQL, regularity quality; TIN, technological innovation; VIF, variance inflation factor.
Source: Author's estimation.

4.2 | CSD and SLH test

Table 3 Panel-A and Panel-B, the CSD and SLH are severe problems in panel data estimation and lead to inconsistent and unreliable results. We generally can expect CSD when we use macroeconomic indicators. CSD is usually due to the macroeconomic relationship between countries. Therefore, the measures taken in one country also affect nearby countries' economies. Panel-B gives the results of the SLH test, the presence of heterogeneity in the panel data, and infers that the model's coefficients are heterogeneous and the slope varies across economies. It also shows that one country's social and economic structure cannot affect both countries similarly Jianguo et al. (2022).

We use CSD test (Pesaran, 2007) and SLH test (Hashem Pesaran & Yamagata, 2008) to identify the CSD and SLH in our panel. The findings in Panel-A of Table 3 confirm the presence of CSD in our model; we note that all the *p* values are less than 0.001 for all the parameters, as the *p* values of the statistics suggest rejecting the null hypothesis of no CSD. It indicates that the economic shock in any variable in any panel country may also affect the other countries in the panel. Panel-B of Table 3 reveals the presence of heterogeneity in the panel data. SLH test confirms the rejection of the null hypothesis that the slope is homogeneous and concludes that the slope of both models by taking CFP–EFP as dependent variables are heterogeneous. Applying the second-generation unit root and second-generation cointegration (Westerlund, 2007) techniques to the panel data is necessary due to the presence of CSD and heterogeneity.

TABLE 3 CSD and SLH results.

Variable		Test statistics (*p* values)
Panel-A: CSD results		
CFP		19.238*** (0.000)
EFP		21.637*** (0.000)
TIN		26.373*** (0.000)
NRS		22.472*** (0.000)
FNI		31.363*** (0.000)
HCT		26.636*** (0.000)
RQL		19.373*** (0.000)
GEF		21.167*** (0.000)
Panel-B: SLH results		
Statistics	DV = CFP	DV = EFP
Delta tilde	23.546 (0.000)	28.748*** (0.000)
Delta tilde adjusted	24.238 (0.000)	29.647*** (0.000)

Abbreviations: CFP, carbon footprint; CSD, cross-sectional dependence; DV, dependent variable; EFP, ecological footprint; FNI, financial inclusion; GEF, government effectiveness; HCT, human capital; NRS, natural resources; RQL, regularity quality; SLH, slope homogeneity; TIN, technological innovation.

***Explains the significance level at 1%, whereas the values in parentheses contain *p* values.

4.3 | Second-generation panel unit root and cointegration tests

CSD and SLH suggest adopting second-generation tests to investigate the stationarity level and long-run association among variables. Consequently, we employed CIPS–CADF (Pesaran, 2007) tests to determine the stationary and cointegration (Westerlund, 2007) to validate the existence of a long-run correlation among parameters. In the presence of CD and heterogeneity factors, the CIPS analysis results are more essential and reliable than the CADF. The results of unit root and cointegration tests are, respectively, presented in Panel-A and Panel-B of Table 4, showing the CIPS and CADF results at the level and the first difference. Indicating that all of the selected variables are stationary at the first difference and the existence of a long-run nexus among the indicators since *p* values suggest rejecting the null hypothesis of no cointegration. The report contains the results of the Westerlund (2007) test (Panel-B Table 4). This cointegration outcome is produced using the data and panel groups (*Gt*, *Ga*) (*Pt*, *Pa*). The null hypothesis was found suitable to reject due to substantial test statistics.

4.4 | GMM–PVAR result

After validating the presence of a CSD, nonstationary, and SLH in the panel of economies, we may proceed to estimate the long-run and short-run correlations, which are the primary focus

TABLE 4 Unit root and cointegration test results.

Panel-A: Unit root test results			
Variable	**CIPS**	**CADF**	**Integration order**
CFP	−3.574***	−3.372***	*I*(1)
EFP	−3.728***	−3.193***	*I*(1)
TIN	−4.348***	−3.478***	*I*(1)
NRS	−4.716***	−3.893***	*I*(1)
FNI	−2.485**	−2.311**	*I*(1)
HCT	−3.283***	−2.849**	*I*(1)
RQL	−4.819***	−3.456***	*I*(1)
GEF	−4.271***	−3.233***	*I*(1)

Panel-B: Westerlund cointegration results						
	DV = CFP			**DV = EFP**		
Statistics	**Value**	***Z* value**	***p* Value**	**Value**	***Z* value**	***p* Value**
Gt	−9.384	−10.79	(0.000)	−8.463	−8.938	(0.000)
Ga	−11.72	−5.53	(0.000)	−11.473	−7.374	(0.000)
Pt	−21.47	−17.42	(0.000)	−18.374	−13.817	(0.000)
Pa	−19.83	−12.63	(0.000)	−14.718	−9.655	(0.000)

Abbreviations: CADF, cross-sectionally augmented Dickey–Fuller; CFP, carbon footprint; CIPS, cross-section Im–Pesaran; DV, dependent variable; EFP, ecological footprint; FNI, financial inclusion; GEF, government effectiveness; HCT, human capital; NRS, natural resources; RQL, regularity quality; TIN, technological innovation.

*** and ** explain the significance level at 1% and 5%, respectively, whereas the values in parentheses contain *p* values.

of the empirical approach. For this purpose, the GMM–PVAR method adopted. The study results regarding the long-run impact of TIN, NRS, FNI, HCT, RQL, and GEF on environmental sustainability through the GMM–PVAR strategy are provided in Table 5. The outcomes are estimated comprehensive proxy for variables of environmental sustainability, that is, CFP–EFP, respectively, given in Panel-A and Panel-B in Table 5 and for graphical interpretation, see Figure 3.

In the scenario of TIN, the negative and significant coefficient demonstrates the supporting effect of TIN in reducing CEP–EFP and increasing environmental quality in BRI. It is shown in Table 5 that there is a negative and significant impact of TIN on CFP–EFP, implying TIN is a promoter of environmental quality. A 1% increase in TIN reduces the CFP and EFP by 0.42% and 0.21%, respectively, in the long run in BRI economies. The relationship between TIN and environmental sustainability is justified because TIN is a significant issue to be studied and incorporated into environmental degradation in the BRI region. In addition, TINs aid in encouraging low-carbon emissions and improving energy efficiency. Furthermore, because BRI nations have increased their output of products significantly over the previous two decades, and strong development is expected, this outcome attracts even more highly productive TIN investments. Thus, BRI's aim of creating environmental degradation may be achieved through increasing investments, notably in the innovation of manufacturing and distribution of products. Technology's mitigating effects are consistent with those (Fareed et al., 2022; Jianguo et al., 2022; Luo et al., 2021).

In contrast, NRS has a positive and significant effect on both CFP–EFP, as indicated by the coefficient value of NRS. Showing a stimulating effect on the CFP–EFP of NRS. A 1% increase in NRS decreases the environmental quality by increasing 0.11% CFP and 0.18% EFP in the long run. Rising NRS and usage puts more emissions and ecological pressure on BRI countries. The favorable influence of the NRS is confirmed by the fact that, for example, the economies of the BRIs are among the most abundant producers of oil, coal, and other natural minerals. To meet their need for energy and other resources, BRI economies are exerting immense strain on their NRS reserves, causing a rise in environmental stress. The results specify that the unsustainable use of NRS is prevalent in BRI countries; consequently, regulators and policymakers should design energy policies that decrease reliance on conventional energy approaches, as fossil fuel exerts more significant distortion and damage to environmental sustainability (Khan et al., 2020). The results demonstrating the positive relationship between NRS and environmental sustainability are consistent with the research of Khan and Ali (2020), Khan et al. (2020), Langnel et al. (2021), and Nathaniel (2021b).

The impact of FNI on the environment is a subject of intense debate. Similarly, the relationship between FNI and CFP–EFP is statistically significant and positive. More specifically, a 1% influence on FNI will increase the environmental quality of (CFP–EFP by 0.35% and 0.32%) in the long run. This indicates that FNI in BRI countries is not favorable to environmental quality. According to Khan et al. (2020), a country's emissions depend on its income level and FND. This outcome implies that FNI increases the pollution level and EFP pressure for BRI economies. The results are consistent with those of Le et al. (2020) and Luo et al. (2021), who suggest that improved access to financial services facilitates and improves industrial and commercial activity, which can lead to high pollution levels. The financial support for the long-term BRI initiative developments (i.e., from rail, road, and sea) may raise demands on NRS, combined with rapid development in industrialization and transportation activity. Financial dealings

TABLE 5 GMM–PVAR results.

Panel-A	Dependent variables						
Explaining variables	**ln CFP**	**ln TIN**	**ln NRS**	**ln FNI**	**ln HCT**	**ln RQL**	**ln GEF**
ln $CFP_{(-1)}$	0.052** (0.023)	−0.116 (0.211)	−0.201** (0.089)	0.246 (0.387)	−0.133 (0.328)	−0.316 (0.278)	0.273** (0.127)
ln $TIN_{(-1)}$	−0.421*** (0.051)	0.017 (0.023)	−0.181 (0.131)	0.291*** (0.031)	0.258** (0.117)	0.103 (0.093)	0.238 (0.387)
ln $NRS_{(-1)}$	0.119*** (0.004)	−0.225 (0.211)	0.051 (0.084)	0.168 (0.431)	0.219 (0.387)	−0.334 (0.245)	−0.261 (0.654)
ln $FNI_{(-1)}$	0.356** (0.159)	0.411*** (0.019)	−0.213** (0.091)	0.143 (0.113)	0.348** (0.144)	0.317 (0.676)	0.289 (0.434)
ln $HCT_{(-1)}$	−0.182** (0.079)	0.372** (0.161)	−0.117 (0.099)	0.415** (0.179)	0.062 (0.076)	0.437** (0.202)	0.345*** (0.054)
ln $RQL_{(-1)}$	−0.217*** (0.006)	0.091** (0.038)	−0.432** (0.193)	−0.263*** (0.045)	0.354** (0.155)	0.012* (0.007)	0.142*** (0.023)
ln $GEF_{(-1)}$	−0.389*** (0.003)	0.115** (0.049)	−0.273* (0.143)	0.225** (0.096)	0.267*** (0.007)	0.126** (0.051)	0.014 (0.245)
Panel-B	**ln EFP**	**ln TIN**	**ln NRS**	**ln FNI**	**ln HCT**	**ln RQL**	**ln GEF**
ln $EFP_{(-1)}$	0.072** (0.028)	0.263 (0.474)	−0.311** (0.137)	0.234 (0.188)	0.171 (0.301)	−0.231 (0.463)	−0.119 (0.372)
ln $TIN_{(-1)}$	−0.218*** (0.026)	0.127 (0.198)	−0.179 (0.322)	0.275** (0.129)	0.343* (0.536)	0.098 (0.074)	0.241 (0.211)
ln $NRS_{(-1)}$	0.187** (0.069)	−0.245 (0.389)	0.056 (0.122)	0.159 (0.283)	0.211 (0.382)	−0.301 (0.646)	−0.272 (0.327)
ln $FNI_{(-1)}$	0.326*** (0.145)	0.398** (0.159)	0.221** (0.104)	0.137 (0.381)	0.381*** (0.011)	0.295 (0.453)	0.234* (0.121)
ln $HCT_{(-1)}$	−0.244*** (0.036)	0.226** (0.095)	−0.131* (0.068)	0.201*** (0.002)	0.076 (0.074)	0.246** (0.121)	0.156** (0.066)
ln $RQL_{(-1)}$	−0.111** (0.043)	0.089** (0.038)	−0.108*** (0.002)	−0.256** (0.103)	0.334** (0.147)	0.005 (0.021)	0.141** (0.061)
ln $GEF_{(-1)}$	−0.276** (0.103)	0.121*** (0.008)	−0.254** (0.113)	0.121*** (0.029)	0.271* (0.139)	0.131* (0.063)	0.023 (0.118)

Abbreviations: CFP, carbon footprint; EFP, ecological footprint; FNI, financial inclusion; GEF, government effectiveness; GMM, generalized method of moments; HCT, human capital; NRS, natural resources; PVAR, panel vector autoregressive; RQL, regularity quality; TIN, technological innovation.

***, **, and * explain the significance level at 1%, 5%, and 10%, respectively, whereas the values in parentheses contain robust standard errors.

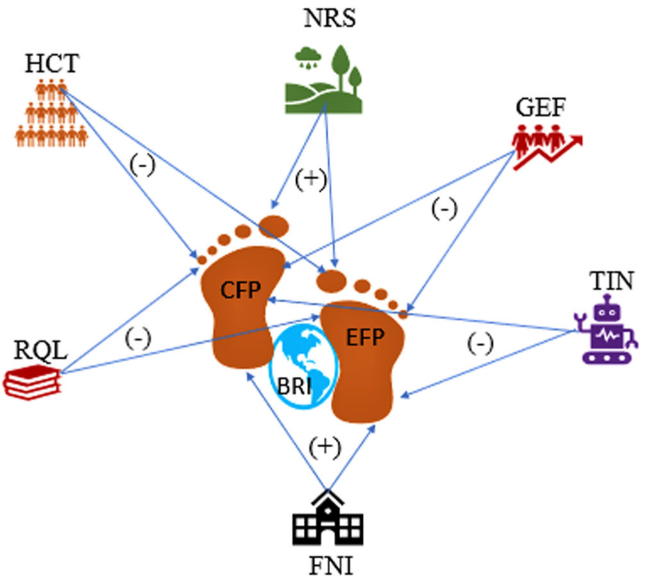

FIGURE 3 Summary result of GMM–PVAR. BRI, belt and road initiative; CFP, carbon footprint; EFP, ecological footprint; FNI, financial inclusion; GEF, government effectiveness; GMM, generalized method of moments; HCT, human capital; NRS, natural resources; PVAR, panel vector autoregressive; RQL, regularity quality; TIN, technological innovation.

encourage changes in economic growth, resulting in increased resource exploitation, waste creation, and environmental degradation. It attracts FDI inflows, which promote R&D, promote the financial sector, and, as a result, induce environmental deterioration. Boosting environmental sustainability and addressing global warming and climate change has received considerable attention.

Table 5, Panel-A and Panel-B, HCT is seen as a favorable indicator of environmental quality as it has an adverse impact on both indicators. A 1% increase in HCT reduces the CFP and EPF by 0.18% and 0.24% in BRI economies. The findings unveil the potential to reduce the CFP and EFP by developing HCT.

The economic governance institutions measure we used in our study, RQL and GEF, adversely affect CFP and EFP. A 1% increase in RQL decreases the CFP and EFP by 0.21% and 0.11%, while CFP and EFP are reduced by 0.38% and 0.27% by 1% in GEF. Effective governance and better regulations encourage environmentally sustainable policies and enhance the environment's quality (Ahmed, Can, et al., 2022; Salman et al., 2019). A strong institutional structure encourages environmental policy initiatives that reduce CFP–EFP and enhance environmental sustainability in the region. The governments should also introduce effective regulations to motivate green investment and renewable energy use with minimal environmental implications.

4.5 | Results of conventional long-run estimation methods

We also applied conventional approaches to compare the results obtained through the GMM–PVAR method. The estimated outcomes by employing OLS, FM-OLS, D-OLS, and random effect methods are presented in Appendix Table A1.

To summarize, the conventional methodologies provide conflicting outcomes. We discovered that the conventional estimation methods contrast with the outcomes of GMM–PVAR when examining the connection between TIN, NRS, FNI, HCL, RQL, GEF, CFP, and EFP. The primary cause of providing the findings of conventional methods is to highlight the noticeable distinction among results of both approaches, that is, advanced and conventional econometric methods. The conventional methodologies cannot address the problem of endogeneity. Similarly, these methods also cannot solve the issue of cross-sectional dependency. Therefore, the conclusions drawn by conventional methodologies might be inaccurate, ambiguous, and biased; thus, these conclusions cannot be accurate to draw policy recommendations.

5 | CONCLUSION AND POLICY IMPLICATIONS

Economic and social policies must be fundamentally altered to safeguard the environment. China started the BRIs initiative to strengthen links among host countries in the trade and energy industries. Aside from several advantages, transportation and industrialization significantly influence the environment. The exploitation and consumption of NRS in today's BRI economies have been accelerated due to tremendous economic expansion and modernization. However, technological advancements are seen as one of the approaches that may be utilized to combat the growing CFP–EFP. To fill the gap in the literature, this study examines the effect of NRS, FNI, and TIN on the CFP–EFP, the comprehensive environmental indicators in 45-BRI countries. Moreover, HCT and economic governance institutions (GEF and regularity quality) are included in the model as control indicators for the period spanning from 2001 to 2018. The long-term effects of TIN, FNI, NRS, and other control variables on environmental sustainability are obtained with the GMM-PRV. The findings indicate that TIN, HCT, RQL, and GEF are essential factors in mitigating the CFP–EFP in BRI economies to increase environmental sustainability. Conversely, FNI and NRS increase CFP–EFP and reduce environmental quality.

The policy implications based on empirical outcomes are that BRI countries are required to improve green financial systems, environmental, technological advancement, and economic governance institutions quality in BRI economies to decline environmental degradation due to carbon emissions and ecological pressure. Governments must improve accessibility to and diversity of environmental financing to assist vulnerable and economically marginalized elements of society in dealing with boosting CFP–EFP. Small and medium-sized businesses should access financial products and services to reduce CO_2 emissions locally. In addition, it is necessary to strengthen and improve economic governance institutions and let them function efficiently to preserve the natural environment. Moreover, economies in the BRI may focus on proper environmental policies and regulations to encourage the usage of green energy, green finance, and green technologies with minor environmental problems.

Although the current study's findings are impressive to increase environmental sustainability in the BRI region, such factors were ignored in the investigation undertaken in this study, and we recommend a future research path in this area; this study used carbon and EFP as a proxy for environmental degradation; thus, future studies should use different measurements for environmental deterioration, such as load capacity factor, transportation emissions, consumption, and production-based CO_2 emissions.

Furthermore, apart from the BRI countries other region blocs can be performed for various economies, such as ECOWAS, E7, G-20, OECD, BRICS, and so forth, that could benefit from this research when formulating their sustainable development objectives. Additionally, in the context of the BRI countries, the effects of digital FNI, patent on environmental technology, energy transition, and other potential indicators on other environmental quality indicators could also be evaluated.

The limitations to a study on TIN, NRS, FNI, and environmental degradation in the economies involved in the BRI. Some of these limitations include: Data on TIN, NRS, FNI, and environmental degradation may not be readily available in some of the BRI economies. Furthermore, The BRI is a long-term initiative, and it may take several years or even decades to fully understand the impact of TIN, NRS, FNI, and environmental degradation on BRI economies. The study may also be limited by political economy considerations, such as government policies and regulations, trade and investment agreements, and access to capital and technology.

AUTHOR CONTRIBUTIONS

Kishwar Ali: Conceptualization; data curation; investigation; resources; validation; visualization; writing—original draft. **Du Jianguo**: Conceptualization; formal analysis; funding acquisition; methodology; project administration; resources; software; writing—review and editing. **Dervis Kirikkaleli**: Conceptualization; investigation; supervision; validation; writing—review and editing. **Zoltán Bács**: Supervision; validation; writing—review and editing. **Judit Oláh**: Project administration; supervision; writing—review and editing.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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ENDNOTES

[1] www.yidaiyilu.gov.cn

[2] Researchers produce operational models, techniques, instruments, theories, ideas, and software for operational approaches. We follow the study of Fareed et al. (2022).

[3] FNI is calculated using four features developed by IMF. In our study we used the Principal Component Analysis approach.

[4] So far, 146 countries have joined the BRI, includes China. However, owing to data availability and the need to balance the data set's horizontal and vertical axes, only 45 nations are included in this study.

[5] The analysis timeframe 2001–2018 is determined by the availability of CFP–EFP data. Some countries were excluded from the analysis owing to a lack of data.

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APPENDIX

See Table A1.

TABLE A1 Conventional tests results.

	OLS		FM-OLS		D-OLS		Random effect	
Explanatory variables	**DV = CFP**	**DV = EFP**	**DV = CFP**	**DV = EFP**	**DV = CFP**	**DV = EFP**	**DV = CFP**	**DV = EFP**
ln TIN	−0.263*	−0.374**	−0.118**	−0.247***	−0.187	−0.260**	−0.323	−0.242**
	(0.137)	(0.173)	(0.046)	(0.009)	(0.234)	(0.097)	(0.545)	(0.116)
ln NRS	−0.373**	0.561	−0.322*	−0.237	−0.284**	−0.353	−0.167**	−0.296*
	(0.151)	(0.463)	(0.141)	(0.411)	(0.128)	(0.455)	(0.068)	(0.151)
ln FNI	0.118**	0.363	0.238**	0.362	0.463**	0.269	0.327	0.362
	(0.053)	(0.327)	(0.107)	(0.526)	(0.221)	(0.284)	(0.318)	(0.434)
ln HCT	−0.089	−0.211	−0.313	−0.127**	−0.229	−0.314**	−0.248	−0.285**
	(0.078)	(0.501)	(0.425)	(0.048)	(0.331)	(0.145)	(0.493)	(0.128)
ln RQL	−0.372***	−0.127**	−0.443**	−0.489**	−0.374**	−0.279***	−0.337	−0.238
	(0.019)	(0.059)	(0.204)	(0.221)	(0.171)	(0.072)	(0.549)	(0.475)
ln GEF	−0.219***	−0.266	−0.322**	−0.364	−0.289	−0.149	−0.271	−0.333
	(0.041)	(0.327)	(0.149)	(0.526)	(0.464)	(0.211)	(0.485)	(0.363)
Constant	0.367***	0.463***	–	–	–	–	0.439***	0.574***
	(0.003)	(0.008)	–	–	–	–	(0.003)	(0.003)
Hausman test	–	–	–	–	–	–	7.364	6.849
R^2	0.893	0.912	–	–	–	–	0.952	0.911

Abbreviations: CFP, carbon footprint; D-OLS, dynamic ordinary least square; DV, dependent variable; EFP, ecological footprint; FE-OLS, fixed effects ordinary least square; FM-OLS, fully modified ordinary least square; FNI, financial inclusion; GEF, government effectiveness; HCT, human capital; NRS, natural resources; RQL, regularity quality; TIN, technological innovation.

***, **, and * explain the significance level at 1%, 5%, and 10%, whereas the values in parentheses contain robust standard errors.