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Nexus between green investment and technological innovation in BRI nations: What is the role of environmental sustainability and domestic investment?

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The critical role of technological innovation has been extensively investigated by considering various aspects of macro-fundamentals across the world. Although the determents of technological innovation have been investigated predominantly from the perspective of firms, the role of macro-fundamentals is yet to be extensively explored. The aim of the study is to investigate the effects of green investment, measured by renewable energy; domestic investment measured by gross capital formation; and environmental sustainability measured by carbon emission on technological innovation in BRI nations for the period 2000–2021. The study used a cross-sectional dependency test, a unit root test following CADF and CIPS, an error correction-based panel cointegration test, ARDL, CS-ARDL, and a nonlinear ARDL. Furthermore, the directional causalities were documented by performing the heterogeneous causality test. Taking into account the findings of the study, it is revealed that green investment and domestic investment are positively connected with technological innovation in BRI nations, while environmental sustainability is correlated negatively and statistically significant to technological innovation. Furthermore, the asymmetric investigation established asymmetric effects from green investment, environmental sustainability, and domestic investment to technological innovation. According to the asymmetric coefficients, the positive and negative shocks of green and domestic investment disclosed positive and statistically significant links with technological innovation, whereas the asymmetric shocks in environmental sustainability revealed adverse ties to technological innovation in BRI nations. The study documented the unidirectional causal effects from green investment to technological innovation [GI→TI] and technological innovation to environmental sustainability [TI→ES]. Furthermore, the study documented bidirectional casualties between domestic investment, foreign direct investment, financial development, and technological innovation [TI←→DI; TI←→FDI; TI←→FD]. The study suggested that domestic capital formation and environmental protection in BRI nations should be actively promoted to accelerate technological innovation. Furthermore, the study postulated that investment in research and development should be encouraged with incentives for technological innovation.

KEYWORDS

green investment, environmental sustainability, domestic investment, ARDL (autoregressive distributed lag), CS-ARDL, NARDL asymmetric

1 Background of the study

From time immemorial, scholars and policymakers have found the significance of technical innovation, as well as its role in explaining domestic production, developing job possibilities, and enhancing social welfare, to be an incredibly intriguing issue (Solow, 1957; Romer, 1986; Aghion and Howitt, 1990). It is interesting to note that innovative possibilities are available to leading and trailing nations. Researchers have paid significant attention to technological innovation over time, particularly since the beginning of the fourth industrial revolution, characterized by technological transformations, artificial intelligence, and digital revolution. Based on theoretical contributions, it has been recognized for a long time that innovation is the driving force behind economic development (e.g., (Aghion and Howitt, (1990); Romer, (1990)). In a similar line, empirical evidence suggests that the main drivers of economic growth are technological improvement, national creative capabilities, and productivity advantages associated with innovation (for example, (Geroski, 1995; Fagerberg et al., 2012)). Furthermore, recent decades have shown an increase in technical capabilities. The development of new technology, especially information technology (IT), has rapidly progressed. It is commonly accepted that financial investment in this technology is a crucial component of a solid infrastructure for managing knowledge (Youndt et al., 2004). Despite the widespread belief that technological innovation positively affects business performance, empirical evidence on the link between technical innovation and enhanced firm success remains inconsistent.

Acknowledging the importance of technological innovation, existing literature has produced two lines of evidence: the role of technological innovation and the determinants of technological innovation. Referring to the first line of the assessment, the existing literature postulated that technological innovation accelerated economic growth (Nosheen et al., 2021), foreign trade (Márquez-Ramos and Martínez-Zarzoso, 2010), FDI (Qamruzzaman, 2014; Qamruzzaman and Ferdaous, 2014; Qamruzzaman, 2015; Razzaq et al., 2021; Zhuo and Qamruzzaman, 2021), ecological efficiency (He et al., 2021), climate change (Lin and Zhu, 2019; Huang et al., 2021), environmental sustainability (Sinha et al., 2020), energy efficiency (Pan et al., 2019), among others. The study of Bong and Premaratne (2019) established the importance of technological innovation in enhancing both environmental protection and the economic performance of businesses. They argued that not only does it help cut down on the price tag for keeping pollution at bay but also boosts output, productivity, and profits by introducing novel products and refining existing ones. This is accomplished through the introduction of novel products and refinement of existing ones. Furthermore, a group of researchers have investigated the impact of technological innovation with specific assessments of firms (Wachira, 2013; Ince et al., 2016; Ferdousi and Qamruzzaman, 2017; Jianguo and Qamruzzaman, 2017; Qamruzzaman, 2017).

The present study considered green investment measured by renewable energy, environmental sustainability measured by carbon emission, and domestic investments measured by gross capita formation in the assessment of technological innovation. Green development, also known as environmentally adjusted multifactor productivity growth, depends on cleaner and more sustainable energy sources. Countries worldwide are trying to restructure their industrial and economic systems to promote green development with cleaner and more sustainable energy sources (Işık, 2013; Wang et al., 2021). Because of the emergence of the Fourth Industrial Revolution, environmentally friendly technologies have significantly improved the environment's condition in modern economies. These technologies have also helped repair environmental damage. Eco-innovation is gaining recognition across governments and businesses as an effective strategy in combating climate change and support green development (GG), most importantly for sustainable, equitable development. Equitable development demands substantial support from the economy through the channels of environmental sustainability, climate protection, quality of life, and economic growth. Technological advancement assists the economy in ensuring climate protection with environmentally friendly technological integration, energy efficiency, and efficient natural resource allocation. An innovation-led economic development strategy accelerated economic growth through environmental protection by lowering carbon emissions (Andriamahery and Qamruzzaman, 2022).

The aim of the study is to investigate the effects of green investment, environmental sustainability, and domestic investment on technological innovation in BRI nations for the period 2005–2020 with the implementation of both symmetric and asymmetric frameworks. As a sample, the study considered a panel of 56 (fifty-six) BRI nations, and the following facts induced their selection.

The novelty of this study lies in the following facts. First, to our best knowledge, this is the first-ever empirical study that has initiated exploring the role of green investment, measured by renewable energy consumption, environmental sustainability, and domestic investment, in technological innovation in BRI nations. It is assumed that the study findings will extend the existing literature by offering a development avenue for technological innovation in the economy with the understating of the key macro determinants. Second, referring to the existing literature survey dealing with the determinants of technological innovation, it is apparent that very less literature is available focusing on the nexus between technological innovation and macro-fundamentals, whereas an increasing number of studies have been performed dealing with firms' specific determinants. This study's findings will be considered an informative way to mitigate the existing literature gap dealing with technological innovation and macro-fundamentals. Furthermore, the study considered both symmetric and asymmetric frameworks in investigating the empirical relation and firmly believes that asymmetric assessment will open an avenue in effective policy formulation. Third, technological innovation focusing on BRI nations is yet to be investigated in empirical studies, and a few studies have been initiated to discover the role of technological innovation in environmental sustainability (Khan et al., 2021), environmental quality (Zuo et al., 2021), employment (Van Reenen, 1997), and green development (Xu et al., 2022). However, dealing with the key determinants of technological innovation in BRI is completely ignored in the empirical assessment.

Taking into account the study findings, it is revealed that green investment and domestic investment are positively connected with technological innovation in BRI nations, while environmental sustainability is correlated negatively and statistically significant to technological innovation. Furthermore, the asymmetric investigation established asymmetric effects from green investment, environmental sustainability, and domestic investment to technological innovation. According to the asymmetric coefficients, the positive and negative shocks of green and domestic investment disclosed positive and statistically significant links with technological innovation, whereas the asymmetric shocks in environmental sustainability revealed adverse ties to technological innovation in BRI nations. The study documented the unidirectional causal effects from green investment to technological innovation [GI→TI] and technological innovation to environmental sustainability [TI→ES]. Furthermore, the study documented bidirectional casualties between domestic investment, foreign direct investment, financial development, and technological innovation [TI←→DI; TI←→FDI; TI←→FD].

The remaining structure of the study is as follows: Section II deals with the related literature, focusing on the nexus between green investment, environmental sustainability, domestic investment, and technological innovation. Model specification, variable definition, and estimation strategies are displayed in Section III. Empirical model estimation and its interpretation are available in Section VI. Section V contains the discussion of the study. Finally, the conclusion and policy suggestions are explained in Section VI.

2 Literature review and hypothesis development

To maintain national economic competitiveness in the face of growing global awareness of the effects of economic activity on resource consumption and the environment, new production and consumption patterns are becoming increasingly popular as a means of spurring innovation in business sector activities, particularly technology (Galende, 2006; Li and Qamruzzaman, 2022). The innovation process depends on external variables; the development of new technologies results from interactions with consumers, suppliers, rivals, and numerous other public and private organizations. This helps explain why clusters, competitions, and other business connections are vital for technological advancement (Wang and Yan, 2022). In this context, innovation, understood as a system in terms of spatial parameters at the regional or national level, allows for the study and analysis of these interactions which influence the innovation propensity and performance of innovation activity (Qamruzzaman et al., 2021; Liu et al., 2022).

In the last few decades, greater human well-being and worldwide economic development have been accompanied by a rapid depletion of natural resources and an increase in environmental sustainability, resulting in a heightened focus on environmental issues. The Environmental Kuznets Curve (EKC) theory demonstrates economic expansion and environmental protection trade-offs. This concept suggests that as economic development develops, environmental conditions will degrade and then improve (Grossman and Krueger, 1991; Abdo et al., 2022). According to the endogenous economic growth hypothesis, an increase in expenditure on research and development (R&D) may enhance economic output efficiency and resource usage efficiency. Despite this, it is uncertain as to how much technical innovation can contribute to advances in environmental quality, especially in CO_2 emissions (Howitt, 2000; Pablo-Romero and Sánchez-Braza, 2015; Li and Qamruzzaman, 2022; Xia et al., 2022). Technology advancement is expected to boost productivity and efficiency during the Fourth Industrial Revolution as a supply-side miracle. The digital revolution is also expected to usher in cost-effective transportation and communication solutions. These factors, taken together, are expected to generate a new market and hasten its growth. Acknowledging the importance of technological innovation, existing literature has produced two lines of evidence: the role of technological innovation and the determinants of technological innovation. Referring to the first line of the assessment, existing literature postulated that technological innovation accelerated economic growth (Nosheen et al., 2021), foreign trade (Márquez-Ramos and Martínez-Zarzoso, 2010), FDI (Razzaq et al., 2021; Zhuo and Qamruzzaman, 2021), ecological efficiency (He et al., 2021), climate change (Lin and Zhu, 2019; Huang et al., 2021), environmental sustainability (Sinha et al., 2020), energy efficiency (Pan et al., 2019), among others. The study of Guntur et al. (2021) established the importance of technological innovation in enhancing both environmental protection and the economic performance of businesses. They argued that not only does it help cut down on the expenses for keeping pollution at bay but also boosts output, productivity, and profits by introducing novel products and refining existing ones. This is accomplished through the introduction of novel products and the refinement of existing ones. Furthermore, a group of researchers have investigated the impact of technological innovation with specific assessments of firms (Wachira, 2013; Ince et al., 2016).

In the case of China, Shi et al. (2022) investigated the effect of technological innovation and application on development considering provincial data. The study postulated that the efficiency value of China's technological innovation and technological application has to be developed and there is positive and effective inventive activity between technological innovation and technological application. In order to foster an environment that is conducive to the healthy development of technological innovation and application, as well as to boost the vitality of the technological market, important policy proposals have been made. For Pakistan, Abbasi et al. (2022) revealed technological innovation support in carbon mitigation.

The findings of the academic study provide unequivocal evidence in favor of the premise that technological innovation plays a significant role in both the competitiveness of industries and the development of nations (Tidd and Bessant, 2020; JinRu and Qamruzzaman, 2022; Zhao and Qamruzzaman, 2022). Some businesses are more innovative in their use of technology than others, and the factors that influence their inventiveness are of interest to management academics, managers in practice, innovation consultants, and policymakers in the technology field. According to Popp et al. (2011), increasing technology does lead to greater investment, but it is a small effect. Hydropower and nuclear power can be substituted for renewable energy sources as they are carbon-free. A study based on Brazil by Pao and Fu (2013) indicates that Brazil is an energy-independent economy and that economic growth is vital to sustainable development in renewable and non-renewable energy. By utilizing renewable energy, Brazil will not only enhance its economic growth and curb the degradation of its environment but will also achieve a leadership role in the international system and improve its competitiveness against more advanced nations. More evidence can be found in the study of Apergis and Payne (2010), where the authors mentioned a positive and significant relationship between renewable energy and economic growth. The authors also mentioned that economic growth is imperative for renewable energy to be developed and used in the future. Foxon et al. (2005) argued that sustained investment is needed for technologies to achieve their potential and a stable and consistent policy framework is needed to facilitate it. The study by Akella et al. (2009) shows that emission reduction in different years is exponentially increasing after installing renewable energy systems. Again, renewable electricity generation sources such as wind and water are very well-suited to sustainable development (Varun et al., 2009). The study also mentioned that as new technologies and mass production of these systems become more common, the cost of generation of these systems and the emission of GHGs will decrease significantly in the near future. Lund (2007) conducted a study on Denmark and found that there are sufficient renewable energy sources on hand, and if technology can be improved on the energy system, a renewable energy system can be achieved. A study by Kaygusuz (2007) stated that at the micro-to-medium scale, renewable energy could provide homes, schools, and hospitals with clean, flexible power and create jobs simultaneously.

The study by Croezen and Korteland (2010) suggests that several promising technologies will be available by 2020 and 2030 that will help reduce emissions from steel, paper, and cement manufacturing, which will collectively account for 41% of the European industrial CO_2 emissions by 2050. According to Zhang and Cheng (2009), China can pursue a conservative energy policy and reduce carbon emissions without slowing economic growth in the long run. Chen and Lee (2020) disclosed that introducing new technologies does not significantly contribute to reducing global CO_2 emissions. However, group-based studies have shown that technological innovation in countries with high incomes, high levels of technology, and high levels of CO_2 emissions can significantly reduce CO_2 emissions in neighboring countries, whereas the level of R&D intensity in other countries can increase CO_2 emissions. Soytas et al. (2007) mentioned that carbon emissions in the US are not caused by growth in income in the long run but by energy use. As such, income growth alone might not be sufficient to protect the environment. Further evidence can be found in Apergis and Payne (2009), where a study revealed that energy consumption and emissions are positively correlated in long-run equilibrium, while the Environmental Kuznets Curve (EKC) hypothesis predicts a U-shaped pattern. Similar findings can be found in the study by Pao and Tsai (2010), where the authors noted that energy-dependent BRIC countries could reduce emissions by increasing both energy supply investments and energy efficiency and stepping up energy conservation policies to reduce unneeded energy waste. Akella et al. (2009) found that the tendency to reduce emissions has doubled after installing renewable energy systems. Varun et al. (2009) noted that new technologies and mass production of these systems are predicted to reduce the cost of generation and emissions of greenhouse gases as the cost of new technologies and mass production become more widely available. On the other hand, based on the study by Acaravci and Ozturk (2010), the overall results show that energy conservation policies, such as rationing energy consumption and reducing carbon dioxide emissions, are unlikely to harm the real output growth of most countries studied, and the EKC hypothesis is unlikely to hold.

In terms of economic development, global competitiveness, financial systems, quality of life, and trade openness, the many effects of innovations on the economy are readily apparent. When corporations are important contributors to the innovation process, the government's role in enhancing the private sector's ability to absorb, improve, and develop new technologies is evident (Baig et al., 2022). The government provides the required infrastructure and a platform for commerce that institutions supply to enhance enterprises' capabilities. Governments, industries, and academics have emphasized the importance of scientific research and development to economic progress from time immemorial. Research and development operations provide knowledge and technology, both of which boost productivity at the business, industrial, and national levels. As a consequence, the chain effect of productivity will result in improved returns on investment, which represent higher income levels and, therefore, enhanced economic growth. Tang et al. (2008) revealed that China's FDI has contributed to overcoming capital shortages and complemented domestic investment to stimulate economic growth. In the case of Pakistan, Ghazali (2010) conducted a study revealing that FDI inflow in Pakistan supplements domestic investment and stimulates economic growth.

Further evidence can be found in the study of Faeth (2006), where the FDI was found to directly increase domestic investment growth, GDP growth, and FDI itself but decrease export growth. However, according to the findings of Agosin and Machado (2005), FDI effects on domestic investment are not always positive, simplistic policies toward FDI are unlikely to be optimal, and, above all, economic policies that encourage domestic investment need to be given more scrutiny. More evidence can be found in the study by Adams (2009), where the author initially mentioned a negative effect of FDI on DI but later found a positive one. Again, based on the study's results, the country requires a targeted approach to FDI, higher absorption capacity for local firms, and greater collaboration between governments and MNEs for mutual benefit. An industry-level analysis by Arndt et al. (2010) of the German economy found evidence that FDI positively impacts the domestic capital stock over the long run. Another study based on U.S. multinationals by Desai et al. (2009) stated that the domestic activity of U.S. multinationals increases as they go for more investment in foreign countries. Similarly, Herzer and Schrooten (2008) studied both countries and found that outward FDI positively impacts long-term domestic investment in the US. These complementary relationships only exist in Germany for a short period.

In the case of Saudi Arabia, Kahouli et al. (2022) investigated how green energy supports achieving environmental sustainability. The study documented that in the long run, the negative association between technological innovation, green energy, and environmental sustainability implies that green energy inclusion and technological advancement prompt environmental sustainability, which leads to economic progress. Wang et al. (2020) assessed technological innovation's effects on environmental protection in N-11 from 1990 to 2017. The study revealed that technological innovation prompts environmental sustainability through carbon reduction. Further evidence is available in the study of Su et al. (2022). According to the study's findings, improving technological innovation and clean energy inclusion support achieving carbon neutrality. The study further suggested that industries should increase environmental awareness and provide TI-related incentives to encourage structural energy adjustment and reduce carbon footprint REC. The government should develop appropriate policies and procedures to emphasize and expand the use of renewable energy, particularly in regions with high emission levels.

3 Limitations in the literature

1. First, referring to the existing literature survey dealing with the determinants of technological innovation, it is apparent that very few literature are available focusing on the nexus between technological innovation and macro-fundamentals, whereas an increasing number of studies have been performed dealing with firms' specific determinants.
2. Second, technological innovation focusing on BRI nations is yet to be investigated in empirical studies, and a few studies have been initiated to discover the role of technological innovation in environmental sustainability (Khan et al., 2021), environmental quality (Zuo et al., 2021), employment (Van Reenen, 1997), and green development (Xu et al., 2022). However, dealing with the key determinants of technological innovation in BRI is completely ignored in the empirical assessment.
3. Third, referring to the methodological aspect, the existing literature extensively relies on the symmetric framework in assessing the key determinants of technological innovation. The present study has extended the empirical assessment by incorporating the asymmetric framework in empirical relation investigation. Including an asymmetric framework will support effective policy formulation with an in-depth understanding of innovation.

Author	Country	Period	Explanatory variable	INV	TI	EG	PO	ES	Job	ORG	ES	SD
Pao and Fu (2013)	Brazil	1980–2010	EG			+						
Popp et al. (2011)	26 OECD nations	1991–2004	INV	+								
Apergis and Payne (2010)	20 OECD nations	1985–2005	EG			+						
Varun et al. (2009)	10 countries	1995–2006	TI and SD		+							+
Akella et al. (2009)	India	n/a	ES								+	
Kaygusuz (2007)	International	2001	Job and ORG						+	+		
Lund (2007)	Denmark	n/a	TI		+							
Foxon et al. (2005)	The United Kingdom	n/a	INV and GP	+			+					

Author	Country	Period	Explanatory variable	TI	INV	PO	EG	IN	EC	ES	SD
Acaravci and Ozturk (2010)	17 EU countries	1960–2005	EG				+/-				
Pao and Tsai (2010)	BRIC countries	1971–2005	INV and EC		-		+		+		
Croezen and Korteland (2010)	EU	1994–2004	IT	-							
Varun et al. (2009)	Countries	1995–2006	TI and SD	-							-
Akella et al. (2009)	India	n/a	ES							-	
Zhang and Cheng (2009)	China	1960–2007	GP and EG			-	+				
Apergis and Payne (2009)	Central America	1971–2004	EC						+		
Soytas et al. (2007)	The US	1960–2004	IN and EC					None	+		

Author	Country	Period	Explanatory variable	EG	FDI	PO	EXP	IMP
Ghazali (2010)	Pakistan	1981–2008	FDI and EG	+	+			
Arndt et al. (2010)	Germany	1991–2004	FDI		+			
Adams (2009)	42 sub-Saharan countries	1990–2003	FDI		−/+			
Desai et al. (2009)	U.S. multinational companies	1982–2004	FDI		+			
Tang et al. (2008)	China	1988–2003	EG and FDI	+	+			
Herzer and Schrooten (2008)	Germany and US	1970–2004	FDI		+			
Faeth (2006)	Australia	1985–2002	EG, FDI, EXP, and IMP	+	+		- (depends on FDI)	+ (depends on FDI)
Agosin and Machado (2005)	12 developing countries	1971–2000	FDI and PO		Unchanged	+		

EXP, export; IMP, import; SD, sustainable development; ORG, organization; IN, income; PO, policy; ES, environmental sustainability; EG, economic growth; FDI, foreign direct investment; EC, energy consumption; TO, trade openness; INV, investment.

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Summary of the literature survey focusing on the nexus between green investment, environmental sustainability, domestic investment, and technological innovation.

3.1 Hypothesis development

Considering the empirical association between green investment, environmental sustainability, domestic investment, and technological innovation, the following conceptual model (see Figure 1.) has proposed the possible causalities among them. The heterogeneous causality model has been implemented for assessing the proposed causal association.

The following hypothesis is to be tested:

$H_1^{A,B}$: Technological innovation Granger causes green investment and vice versa.

$H_2^{A,B}$: Technological innovation Granger causes domestic investment and vice versa.

$H_3^{A,B}$: Domestic investment Granger causes environmental sustainability and vice versa.

$H_4^{A,B}$: Environmental sustainability Granger causes green investment and vice versa.

$H_5^{A,B}$: Technological innovation Granger causes environmental sustainability and vice versa.

$H_6^{A,B}$: Green investment Granger causes domestic investment and vice versa.

4 Data and methodology of the study

4.1 Model specification

The purpose of the study is to investigate the effects of green investment, environmental sustainability, and domestic investment on technological innovation in the BRI nations for the period 1995–2020. The selection of the study period completely relies on data availability, and it is notable that due to missing variables, we purposively omitted the study period 2021.

Referring to research variable selection, especially for the explanatory variables, the study considered green investment measured by the development of renewable energy consumption, assuming that reducing destructive environmental nature due to carbon emissions could be mitigated with clean energy. Furthermore, renewable energy inclusion is a sign of technological innovation in energy production. Thus, green investment possibility is anticipated to prompt technological innovation in the economy. Environmental sustainability refers to managing environmental adversity by effectively including energy efficiency and operational efficiency. It indicates that environmental concern creates urgency in the economy for innovation in managing the environmental consequences; therefore, the study believes technological innovation has accelerated environmental sustainability as a control mechanism. Capital adequacy in the economy requires investment in R&D, positively suggesting a national innovation act with the promotion of technological innovation. Considering the explanatory and dependent variables, the basic functional model for empirical assessment is as follows:

$$TI_{it} = \int GI_{it} ES_{it} DI_{it} FDI_{it} FD_{it}, \quad (1)$$

where TI denotes technological innovation, GI stands for green investment, DI explains domestic investment, ES stands for environmental sustainability, FDI stands for foreign direct investment, and FD stands for financial development. The abovementioned Eq. 1 is transformed into an econometric form with variable coefficients as follows:

$$TI_{it} = \beta_1 GI_{it} + \beta_2 ES_{it} + \beta_3 DI_{it} + \beta_4 FDI_{it} + \beta_5 FD_{it}, \quad (2)$$

where “it” explained the cross-sectional unit and time. The coefficients $\beta_1 \beta_5$ deal with the explanatory variable magnitudes on technological innovation.

It is anticipated that every nation has been seeking eco-friendly investment for sustainable economic growth with environmental protection, that is, clean energy inclusion instead of fossil fuel, with a motivation of energy transition from conventional to renewable energy sources. The evolution of renewable energy sources in the economy has ensured operation and energy efficiency while controlling environmental adversity. The energy efficiency with renewable energy inclusion in the economy has augmented technological development. Thus, it is anticipated that the magnitudes of green investment, which are measured by renewable energy, have a positive impact on technological innovation; in other words, $\beta_1 = \frac{TI}{GI} > 0$. Environmental protection is the key to sustainable economic development, and controlling environmental degradation with carbon intensity reduction is possible. The continuous emission of greenhouse gases has openly challenged the prospect of equitable development, especially for developing nations. The controlled carbon emission adversely affects their aggregated output level; therefore, they have shown disinclination in managing the carbon emission. Thus, it is assumed that carbon emission has a negative association with technological innovation; in other words, $\beta_2 = \frac{TI}{es} < 0$. Capital adequacy in the economy prompts sustainable development, characterized by technological advancement, which predominately encourages the economy to adapt to technological upgradation in every aspect. Domestic capital formation intensifies the aggregated economic activities, operational efficiency, and demand for improved technological inclusion. Therefore, it is expected to have boosting effects of domestic investment on technological innovation; in other words, $\beta_3 = \frac{TI}{DI} > 0$.

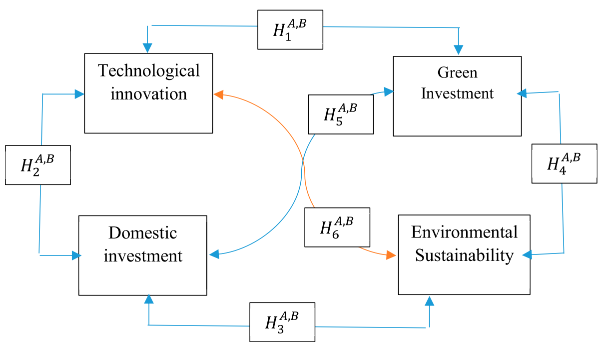

FIGURE 1
Conceptual model for the study of hypothesis testing.

4.2 Estimation strategy

4.2.1 Correctional dependency

Because of globalization and increased collaboration in the economic sphere, variables' effects on one nation may affect other countries. Because of the interconnection of the countries, there is a possibility that cross-sectional dependency problems may appear in the panel data. Previous analysis techniques were flawed because they assumed the cross sections were independent of one another. The findings of the research that was carried out using these approaches may be skewed if it is impossible to consider the cross-sectional dependency in the panel data (Qamruzzaman and Jianguo, 2020; Li and Qamruzzaman, 2022; Mehta et al., 2022; Xia et al., 2022). We successfully overcame this obstacle by first carrying out tests of cross-sectional dependency. To determine whether or not there is cross-sectional dependency, the LM test established by Breusch and Pagan (1980) and the CD test developed by Pesaran (2004) and Pesaran et al. (2008) presented the bias-adjusted LM test, which is the method of choice in instances in which the cross section (N) is much less than the amount of time (T). We can create LM test statistics using the following equation as our guide:

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \text{ i} = 1\ldots\text{N, t} = 1\ldots\text{T}, \tag{3}$$

where y-it denotes a dependent variable, x-it represents an independent variable, and the subscripts t and I stand for cross-section and period, respectively. The iteration number is denoted by the iteration symbol. The coefficients I and I are used in the equation to indicate a nation's specific intercept and slope, respectively. These coefficients are denoted by the symbols I and I, respectively. The alternative hypothesis of cross-sectional dependence is tested using the LM cross-sectional dependency test. This test compares the null hypothesis of cross-sectional independence with the alternative hypothesis of cross-sectional dependence by comparing H-O. = COV, u-it,u-jt = 0 for all t and tj, with the alternative hypothesis of cross-sectional dependence.

In addition to this, the statistics of the LM test may be determined by utilizing the equation that is shown here:

$$: LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{IJ\rightarrow d}X^2 N(N+1)2, \tag{4}$$

where $\hat{\rho}_{ij}$ represents the pairwise correlation of the residuals.

The Lagrange multiplier (CD_{lm}) is the scaled version of the LM test:

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(T\hat{\rho}_{ij} - 1\right). \tag{5}$$

The following CD test is suitable in a situation when N is larger than T:

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\hat{\rho}_{ij}\right). \tag{6}$$

The bias-adjusted LM statistics can be computed with the following equation:

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\frac{(T-K)\hat{\rho}_{ij}^2 - u_{Tij}}{v_{Tij}^2}\right)\vec{d}(N,0), \tag{7}$$

where k refers to the number of regresses and u_{Tij} and v_{Tij}^2 specify the mean and variance of $(T-K)\hat{\rho}_{ij}^2$, respectively.

4.2.2 Panel unit root test

In empirical estimation, identifying the properties of the variables that are the subject of the estimation has historically been seen as an important stage. This is especially true in the case of panel data analysis. Research determining the stationarity of variables used three distinct first-generation unit root tests, including the Levin et al. (2002), the Im et al. (2003), and the ADF-Fisher Chi-square test. These tests were utilized to detect variables' stationarity (Maddala and Wu, 1999). The issue of cross-sectional dependency (CSD) required the utilization of second-generation unit root tests, such as the cross-sectional augmented Dickey–Fuller (CADF) and the cross-sectional augmented Im, Pesaran, and Shin (CIPS) models, both of which were well-known to Pesaran, who was also familiar with both of these models. Despite this, the investigation made use of these tests. The following forms the framework for the unit root test when utilizing CADF, in line with Pesaran's (2007) recommendations:

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \vartheta_i \bar{y}_t + \tau_{it}. \tag{8}$$

Substituting long-term coefficients in Eq. 9 results in the subsequent Eq. 10:

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{k=1}^{p}\gamma_{ik}\Delta y_{i,k-1} + \sum_{k=0}^{p}\gamma_{ik}\overline{\Delta y}_{i,k-0} + \tau_{it}, \tag{9}$$

where $Y_{it}-1$ and $\bar{y}_{t-1}$ represent lagged level average and first difference operator for each cross-section, respectively, and the CIPS unit root test is displayed in Eq. 11.

$$CIPS = N^{-1}\sum_{i-1}^{N}\partial_i(N,T), \tag{10}$$

where the parameter $\partial_i(N,T)$ explains the test statistics of CADF, which can be replaced in the following manner:

$$CIPS = N^{-1}\sum_{i-1}^{N}CADF. \tag{11a}$$

4.2.3 Westerlund cointegration test

Once stationarity in the research variables has been confirmed, the next stage in panel data analysis is to test for the long-run cointegration of the investigated series. Given issues with CSD and heterogeneity, it was important to conduct second-generation panel cointegration tests to learn more about the nature of the long-run cointegration relationship between variables. In order to address the issue mentioned earlier, this study used Westerlund's (2007) error-correction–based cointegration. Error-correcting cointegration tests provide two kinds of data: test statistics for two groups (Gt and Ga) and two panels (Pt and Pa). Assuming that there is no long-run relationship between FDI, FDI, GLO, and EC in BRI countries is a good starting point for a Westerlund cointegration test.

The error correction techniques for long-run cointegration assessment are as follows:

$$\Delta Z_{it} = \partial_i' d_i + \varnothing_i\left(Z_{i,t-1} - \delta_i' W_{i,t-1}\right) + \sum_{r=1}^{p}\varnothing_{i,r}\Delta Z_{i,t-r} + \sum_{r=0}^{p}\gamma_{i,j}\Delta W_{i,t-r} + \epsilon_{i,t}. \tag{12a}$$

The results of group test statistics can be derived with Eqs 14, 15.

$$G_T = \frac{1}{N}\sum_{i-1}^{N}\frac{\varphi_i}{SE\varphi_i} \tag{13a}$$

;

$$G_a = \frac{1}{N}\sum_{i-1}^{N}\frac{T\varphi_i}{\varphi_i(1)}. \tag{14}$$

The test statistics for panel cointegration can be extracted by implementing the following Eqs 16, 15:

$$P_T = \frac{\varphi_i}{SE\varphi_i} \tag{15}$$

;

$$P_a = T\varphi_i. \tag{16}$$

4.2.4 Panel autoregressive distributed lag

Pooled grouped mean, hereafter PGM, can estimate both long-run and short-run magnitude by addressing heterogeneity issues. The following ARDL (p, q. . .. n) as an empirical structure:

$$TI_{it} = \epsilon_{it} + \sum_{j=1}^{p}\beta_{ij}TI_{i,t-j} + \sum_{j=0}^{q}\gamma_{ij}GI_{i,t-j} + \sum_{j=0}^{q}\rho_{ij}DI_{i,t-j} + \sum_{j=0}^{q}\pi_{ij}ES_{i,t-j} + \epsilon_{it}, \tag{17a}$$

where

$$\epsilon_{it} = \omega_t' G_t + \epsilon_{it}, \tag{18a}$$

$$Q_{i,t-j} = \alpha_i + \beta_{ij}TI_{\,i,t-j} + \omega_t' G_t + \mu_{it}, \tag{19}$$

where TI_{it} denotes the dependent variable for sample I, Q_{ij} denotes explanatory variable for group I, and γ_{ij} embodies the factors of explanatory variables. The sample is denoted by i = 1,2,. . ..N, and time by t = 1,2 . . . .T, whereas, μ_i. The generalized empirical ARDL model is as follows:

$$\Delta TI_{it} = \alpha_i + \xi_i\left(TI_{it-1} - \omega_t' Q_{it-1}\right) + \sum_{J=1}^{M-1}\gamma_{iJ}\Delta TI_{it-J} + \sum_{J=0}^{N-1}\beta_{ij}\Delta Q_{it-J} + \mu_{it}, \tag{20}$$

where $\xi_i = -1\left(1-\sum_{j-1}^{M}\gamma_{iJ}\right)$, $\omega_t' = \xi_i^{-1}\sum_{j=0}^{N}\beta_{ij}$, $\gamma_{i,j}^{*} = -\sum_{I=J+1}^{M}\gamma_{il}$ for J = 1, 2, ..M-l, and $\beta_{i,j}^{*} = -\sum_{I=J+1}^{N}\beta_{il}$ for J = 1, 2... .. N-l. $(Q_{it-1} - \omega_t' X_{it-1})$. The short-run dynamics is represented by $\gamma_{i,j}^{*}$, β_{ij}.

4.2.5 CS-ARDL

In analyzing long- and short-run coefficients, we estimated a cross-sectionally augmented autoregressive distributed lag (CS-ARDL) model developed by Chudik and Pesaran (2015). This method offers advantages not displayed by other methods. First, it may produce precise estimates even when the variables are provided in alternative orders, such as I (0) or if I is absent (1). Second, it can offer exact data on the prevalence of both short-term and long-term CSD (Chudik and Pesaran, 2015). Third, it is a group mean estimate with variable slope coefficients for each group member. The CS-ARDL model, based on the mean group, is an upgraded form of the ARDL model that depends on cross-sectional estimates with averages. This model additionally uses the unobserved common components and their delays (Chudik et al., 2017). As a consequence of the lagged dependent variable in the model, this method is useful in instances when there is a low level of homogeneity. In addition, the authors claim that the endogeneity problem will be overcome when the lagged cross-sectional averages are included in the model (Yang et al., 2021; Zhuo and Qamruzzaman, 2021).

The mean group variant of the CS-ARDL model is based on the addition of cross-sectional averages as proxies for unobserved common components and their lags to the ARDL estimates of each cross-section. The Canadian Society for Applied Research in Development and Learning (CS-ARDL) created this model (Chudik et al., 2017). This approach also works well when the lagged dependent variable is included in the model and weak homogeneity is present. Specifically, the issue arises during the addition of the lagged dependent variable. The authors argued that the endogeneity problem might be largely circumvented by including lagged cross-sectional averages in the model.

$$\overline{TI}_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p}\bar{\beta}_{ij}\overline{TI}_{i,t-j} + \sum_{j=0}^{q}\bar{\gamma}_{ij}\bar{Q}_{i,t-j} + \bar{\omega}_t^{'}G_t + \bar{e}_{it}, \quad (21)$$

where $\bar{\alpha}_{it} = \frac{\sum_{i=1}^{N}\alpha_i}{N}$.

$$\overline{TI}_{t-j} = \frac{\sum_i^N TI_{i,,\,t-j}}{N},\quad \bar{\beta}_j = \frac{\sum_i^N \beta_{i,\,j}}{N} \quad j = 0, 1, 2 \quad p$$

$$\bar{Q}_{t-j} = \frac{\sum_i^N Q_{i,,\,t-j}}{N},\quad ,\bar{\gamma}_j = \frac{\sum_i^N ,\gamma_{i,\,j}}{N},\quad J = 0, 1, 2 \quad q$$

$$\bar{\omega}_j = \frac{\sum_{i=1}^N \omega_i}{N},\ \bar{\epsilon}_t = \frac{\sum_i^N \epsilon_{i,\,t}}{N}$$

$$\downarrow$$

$$TI = \bar{\alpha}_{it} + \sum_{j=1}^{p}\bar{\beta}_{ij}\overline{TI}_{i,t-j} + \sum_{j=0}^{q}\bar{\gamma}_{ij}\bar{Q}_{i,t-j} + \bar{\omega}_t^{'}G_t \qquad \bar{\omega}_t^{'}G_t = \overline{ES}_{it}$$

$$-\bar{\alpha}_{it} + \sum_{j=1}^{p}\bar{\beta}_{ij}\overline{TI}_{i,t-j} + \sum_{j=0}^{q}\bar{\gamma}_{ij}\bar{Q}_{i,t-j}\downarrow G_t$$
$$= \overline{TI}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p}\bar{\beta}_{ij}\overline{TI}_{i,t-j} + \sum_{j=0}^{q}\bar{\gamma}_{ij}\bar{Q}_{i,t-j}\Big/\bar{\omega}_t^{'}. \quad (22)$$

The general form of the CS-ARDL framework is as follows:

$$\overline{TI}_{it} = \epsilon_{it} + \sum_{j=1}^{p}\beta_{ij}\overline{TI}_{i,t-j} + \sum_{j=0}^{q}\gamma_{ij}\bar{Q}_{i,t-j} + \sum_{j=0}^{p}\bar{\partial}'_t\bar{Z}_{i,t-j} + \epsilon_{it}, \quad (23)$$

where $\bar{Z} = (\overline{GI}, \overline{ES}, \overline{DI},)$ and $S_{\bar{Z}}$ is the number of lagged cross-sectional average. Finally, the error correction from CS-ARDL is as follows:

$$TI_{it} = \alpha_i + \xi_i\left(TI_{it-1} - \omega_t^{'}Q_{it-1}\right) + \sum_{J=1}^{M-1}\gamma_{iJ}\Delta TI_{it-J} + \sum_{J=0}^{N-1}\beta_{ij}\Delta Q_{it-J}$$
$$+ \sum_{j=1}^{p}\lambda_j\overline{\Delta TI}_{i,t-j} + \sum_{j=0}^{q}\delta_j\overline{\Delta Q}_{i,t-j} + \sum_{j=0}^{S_{\bar{Z}}}\bar{\partial}'_t\bar{Z}_{i,t-j} + \mu_{it}, \quad (24)$$

where $\overline{\Delta TI}_{t-j} = \frac{\sum_i^N \Delta ES_{i,,\,t-j}}{N}$ and $\overline{\Delta Q}_{t-j} = \frac{\sum_i^N \Delta Q_{i,,\,t-j}}{N}$.

4.3 The asymmetric panel ARDL

This kind is usually referred to as an asymmetric panel investigation, and it incorporates both positive and negative shocks of the equation's explanatory variables. A symmetric investigation is the more traditional form of research. In other words, the sign of the coefficients of positive and negative shocks may not be the same when they are produced by shocks of a positive or negative sign depending on the kind of shock. Following the steps in the following equation, Eq. 7 may be rewritten as the nonlinear Eq. 12 (Shin et al., 2014).

$$\begin{aligned}\Delta TI_{it} = {} & \beta_{0i} + \beta_{1i}TI_{it-1} + \beta_{2i}^{+}GI_{t-1}^{+} + \beta_{2i}^{-}GI_{t-1}^{-} + \beta_{3t}^{+}ES_{t-1}^{+} \\ & +\beta_{3t}^{-}ES_{t-1}^{-} + \beta_{4t}^{+}DI_{t-1}^{+} + \beta_{4t}^{-}DI_{t-1}^{-}, \\ & + \sum_{J=1}^{M-1}\gamma_{iJ}\Delta TI_{i,t-J} + \sum_{J=0}^{N-1}\left(\gamma_{ij}^{+}\Delta GI_{i,t-j}^{+} + \gamma_{ij}^{-}\Delta GI_{i,t-j}^{-}\right) + \\ & \sum_{J=0}^{O-1}\left(\left(\delta_{ij}^{+}\Delta DI_{i,t-j}^{+} + \delta_{ij}^{-}\Delta DI_{i,t-j}^{-}\right)\right), \\ & + \sum_{J=0}^{P-1}\left(\mu_{ij}^{+}\Delta ES_{i,t-j}^{+} + \mu_{ij}^{-}\Delta ES_{i,t-j}^{-}\right) + \epsilon_{it},\end{aligned} \quad (11b)$$

where $GI^{+}$and GI^{-} stand for the positive and negative shock of green investment, $DI^{+}$and DI^{-} represent positive and negative shock of domestic investment, and $ES^{+}$and ES^{-} denote positive and negative shocks of environmental sustainability, respectively. The long-run coefficients are computed as $GI^{+} = \frac{-\beta_{2i}^{+}}{\beta_{1i}}$, $GI^{-} = \frac{-\beta_{2i}^{-}}{\beta_{1i}}$, $DI^{+} = \frac{-\beta_{3i}^{+}}{\beta_{1i}}$, $DI^{-} = \frac{-\beta_{3i}^{-}}{\beta_{1i}}$, $ES^{+} = \frac{-\beta_{4i}^{+}}{\beta_{1i}}$, and $ES^{-} = \frac{-\beta_{4i}^{-}}{\beta_{1i}}$. These shocks are computed as positive and negative partial sum decomposition of financial development, trade openness, and capital flows in the following ways:

$$\begin{cases} GI_i^{+} = \sum_{k=1}^{t}\Delta GI_{ik}^{+} = \sum_{K=1}^{T}MAX\left(\Delta GI_{ik}, 0\right) \\ GI_i^{-} = \sum_{k=1}^{t}\Delta GI_{ik}^{-} = \sum_{K=1}^{T}MIN\left(\Delta GI_{ik}, 0\right)\end{cases}. \quad (12b)$$

$$\begin{cases} DI_i^{+} = \sum_{k=1}^{t}\Delta DI_{ik}^{+} = \sum_{K=1}^{T}MAX\left(\Delta DI_{ik}, 0\right) \\ DI_i^{-} = \sum_{k=1}^{t}\Delta DI_{ik}^{-} = \sum_{K=1}^{T}MIN\left(\Delta DII_{ik}, 0\right)\end{cases}. \quad (13b)$$

$$\begin{cases} ES_t^{+} = \sum_{k=1}^{t}\Delta CF_{ik}^{+} = \sum_{K=1}^{T}MAX\left(\Delta ES_{ik}, 0\right) \\ ES_t^{-} = \sum_{k=1}^{t}\Delta CF_{ik}^{-} = \sum_{K=1}^{T}MIN\left(\Delta ES_{ik}, 0\right)\end{cases}. \quad (17b)$$

The error correction version of Eq. 12 is as follows:

$$\Delta TI_{it} = \tau_{1i}\xi_{it-1} + \sum_{J=1}^{M-1}\gamma_{ij}\Delta TI_{i,t-J} + \sum_{J=0}^{N-1}\left(\gamma_{ij}^{+}\Delta GI_{i,t-j}^{+} + \gamma_{ij}^{-}\Delta GI_{i,t-j}^{-}\right)$$
$$+ \sum_{J=0}^{O-1}\left(\left(\delta_{ij}^{+}\Delta DI_{i,t-j}^{+} + \delta_{ij}^{-}\Delta DI_{i,t-j}^{-}\right)\right). + \sum_{J=0}^{P-1}\left(\mu_{ij}^{+}\Delta ES_{i,t-j}^{+} + \mu_{ij}^{-}\Delta ES_{i,t-j}^{-}\right)$$
$$+ \epsilon_{it} \quad (18b)$$

4.4 Dumitrescu–Hurlin panel causality test

The study implements the Granger causality test following the procedure initiated by Dumitrescu and Hurlin (2012); the test statistics are to be derived with the following equation:

$$Y_{it} = \alpha_i + \sum_{K-1}^{P} \gamma_{ik} Y_{i,t-k} + \sum_{K-1}^{P} \beta_{ik} X_{i,t-k} + \mu_{it}. \quad (25)$$

The test forms the average statistic linked with the homogeneous null non-causality (HNC) hypothesis as follows:

$$W_{NT}^{Hnc} = N^{-1} \sum_{i-1}^{N} W_{i,t}. \quad (26)$$

This test reveals the harmonized Z-test statistic is as follows:

$$Z = \sqrt{\frac{N}{2P} \times \frac{T-2P-5}{T-P-3}} \times \left[\frac{T-2P-3}{T-2P-1} \bar{W} - P \right]. \quad (27)$$

5 Model estimation and interpretation

5.1 Cross-sectional dependency, slope of homogeneity, and unit root test

In the initial assessment, the study implemented the cross-sectional dependency test following the studies by Breusch and Pagan (1980), Pesaran (2004), Pesaran (2006), and Pesaran et al. (2008) and the slope of homogeneity following the study by Pesaran and Yamagata (2008). Table 1 reports the results of the test mentioned earlier. According to the test statistics from the cross-sectional dependency test, all the test statistics are statistically significant at a 1% significance level, indicating the rejection of the null hypothesis of cross-sectional independent test. Alternatively, the test-established research units share common dynamics among them. Furthermore, the test statistic from homogeneity, that is, Δ and Adj.Δ is statistically significant and reveals heterogeneous properties among the research variables in the study.

In this step, the study executed the unit root test for documenting the variable's stationarity properties, which are critical in selecting the appropriate econometrical models for coefficient investigation. Referring to the results of the cross-sectional dependency test and test of homogeneity, we implemented the second-generation unit root tests introduced by Pesaran (2007), commonly known as CIPS and CADF. The results of second-generation panel unit root tests are displayed in Table 2. According to the test statistics, all the variables are exposed non-stationary at a level, but all the variables become stationary in the estimation with the first differences.

5.2 Panel cointegration test

The study's long-run association between technological innovation and explanatory variables has been assessed by implementing the panel cointegration test following Pedroni (2004). The results of the cointegration test are displayed in Table 3. According to the test statistics, the rejection of the null hypothesis of no-cointegration is established. Alternatively, we reveal the presence of long-run association in the empirical equation.

Furthermore, the study implemented a cointegration test with an error correction term familiarized with the study by Westerlund (2007), and the test results are displayed in Table 4. All the test statistics are statistically significant at a 1% level, suggesting rejecting the null hypothesis. This is the presence of a long-run association between technological innovation and other explanatory variables.

5.3 Baseline assessment

This section deals with a preliminary assessment of empirical equations with the implementation of pooled OLS, random effects, and fixed-effects models. The baseline estimation results are given in Table 5, and the H-test statistics confirmed that fixed-effects models are robust in elementary assessment. Referring to estimated model coefficients, the study documents green investment, which is measured by renewable energy consumption, positively influencing technological innovation (a coefficient of 0.0841). The similar line of association was revealed for domestic investment (a coefficient of 0.0367), foreign direct investment (a coefficient of 0.0749), and financial development (a coefficient of 0.1232), while environmental sustainability, measured by carbon emission, showed a negative connection to technological innovation (a coefficient of −0.0467).

5.4 Panel ARDL and CS-ARDL

The following section deals with empirical model estimation following the framework offered by Pesaran and Chu. The result of panel ARDL and CS-ARDL displayed in Table 6 includes Panel A for long-run coefficients and Panel B for short-run coefficients.

In the long run, according to empirical model estimation with ARDL (CSARDL), the study documented a positive and statistically significant linkage between green investments measured by renewable energy consumption and technological innovation in BRI nations with a coefficient of 0.0878 (0.1223). More specifically, a 10% further development in green investment focusing on renewable energy development will accelerate technological innovation by 0.878% (1.223%) in BRI nations. For the short run, green investment has revealed a similar line of association that is positive and statistically significant with a coefficient of 0.0182 (0.0759).

The study documented adverse effects from environmental sustainability to technological innovation in BRI nations with a coefficient of 0.179 (−0.1802) in the long-run assessment. Study findings suggest that excessive carbon emission due to inefficiency in environmental protection discourages countries from investing in technological innovation. In particular, a 10% excess carbon emission results in the degradation of technological innovation in the BRI nations by 1.79% (1.802%). Alternatively, effective environmental policies and protection are boosting factors in technological advancement with environmental sustainability. In the short run, environmental sustainability produces the same line of association as in the long run.

Domestic investment, measured by gross capital formation, revealed a positive and statistically significant linkage to technological innovation in BRI nations with a coefficient of 0.0992 (0.1522). Specifically, a 10% growth in domestic capital formation in the economy will result in technological innovation inclusion and progress by 0.992% (1.522%). For the short-run assessment, the study documented a similar line of association that is positive and significant.

Referring to control variables' effects on technological innovation in BRI nations, for the long-run assessment, the study documented that foreign direct investment (financial development) is positively connected to technological innovation. The study findings suggest that foreign direct investment and financial development prompt technological innovation.

5.5 Asymmetric assessment of long-run and short-run coefficients

In the following section, the study implemented the nonlinear framework following the study by Shin et al. (2014) to document the asymmetric effect of green investment, domestic investment, and environmental sustainability on technological innovation both in the long and short run. The study executed two empirical models focusing on panel composition, that is, with China [1] and without China [2]. The results displayed in Table 7.

Referring to the asymmetric nexus between green investment and technological innovation, the study documented that positive (negative) shocks have a positive and statistically significant connection with technological innovation in both model estimations. According to model [1] coefficients, a 10% positive (negative) shock in green investment will result in increasing (decreasing) technological innovation by 1.403% (1.814%) in BRI nations. Furthermore, in empirical model [2] excluding China, a 10% positive (negative) innovation results in technological innovation augmentation (degradation) by 0.734% (1.745%) in BRI nations. In particular, the negative shock of green investment has revealed more significance in technological innovation than the positive innovation of green investment. Taking into account the long-run asymmetric coefficients, the study advocated that degradation of green investment and investment in renewable energies will result in adversity in developing technological progress in the economy.

The asymmetric shocks of environmental sustainability that are positive (negative) variations in carbon emission established a negative and statistically significant linkage to technological innovation with a coefficient of −0.1037 (−0.0984). The study advocated controlled environmental protection, that is, the reduction of carbon emissions accelerated the technological integration of the BRI nations. In particular, a 10% positive (negative) variation in carbon emission will result in degradation (growth) in technological advancement, especially in the energy efficiency and efficient production process by −1.037% (−0.984%). Furthermore, the short-run asymmetric assessment revealed that a 10% acceleration (degradation) in carbon emission results in increase in technological innovation by −0.198% (−0.227%).

Domestic investment, measured by the economy's gross capital formation, is a motivating factor in promoting technological innovation. In the long run, the asymmetric coefficients of domestic investment that are positive (negative) shocks establish a positive and statistically significant linkage with technological innovation with a coefficient of 0.1605 (0.1124). Study findings suggest that a 10% growth (decline) in domestic capital formation can boost (restrict) technological innovation in BRI countries by 1.605% (1.124%), while in the short-run, a 1% positive (negative) innovation in domestic investment results in technological innovation acceleration (degradation) by 0.0798% (0.0437%).

Referring to the symmetry test, the result of the standard wild test revealed that all the test statistics for the long run and short run are statistically significant at a 1% level, suggesting the rejection of the null hypothesis of the symmetric association. Alternatively, an asymmetric association between green investment, environmental sustainability, domestic investment, and technological innovation has been established.

5.6 Country-wise assessment with DOLS estimation

The results of country-wise investigation displayed in Table 8. Referring to the nexus between green investment and technological innovation, according to country-specific assessment, a group of 44 (forty-four) BRI nations has shown a positive and statistically significant linkage in Romania, Saudi Arabia, Israel, Panama, Albania, Slovenia, Myanmar, Oman, Estonia, UAE, South Africa, Singapore, Tajikistan, Ukraine, Russia, Georgia, Kuwait, Poland,

TABLE 1 Results of cross-sectional dependency and homogeneity test.

	LM_{BP}	LM_{PS}	LM_{adj}	CD_{PS}	Δ	Adj.Δ
TI	415.394***	28.787***	130.571***	15.678***	31.969***	113.679***
GI	206.638***	31.35***	100.593***	49.074***	84.464***	116.315***
ES	435.769***	42.752***	167.6***	33.368***	50.026***	122.95***
DI	428.615***	18.079***	127.538***	35.621***	75.757***	59.046***
FDI	378.181***	42.189***	170.433***	25.798***	63.765***	57.386***
FD	243.672***	18.273***	240.243***	18.108***	28.08***	136.448***

Note: the superscript *** denotes a 1% level of significance.

TABLE 2 Results of the second-generation unit root test.

	CIPS		CADF	
	At a level	After first difference	At a level	After first difference
TI	−1.367	−5.761***	−1.213	−7.169***
GI	−1.787	−2.613***	−1.525	−2.611***
ES	−2.911**	−5.803***	−1.986	−7.719***
DI	−1.887	−3.889***	−2.109	−4.595***
FDI	−1.684	−5.11***	−1.389	−7.541***
FD		−6.625***	−2.525	−5.933***

Note: the superscript *** denotes a 1% level of significance.

TABLE 3 Results of Padrones' panel cointegration test.

Panel v-statistic	2.295**	Panel v-statistic	−1.262*
Panel rho-statistic	−6.487***	Panel rho-statistic	−6.127***
Panel PP-statistic	−10.464***	Panel PP-statistic	−10.468***
Panel ADF-statistic	−5.823***	Panel ADF-statistic	−9.422***
Group rho-statistic	−6.399***		
Group PP-statistic	−10.707***		
Group ADF-statistic	−3.159***		

TABLE 4 Results of panel cointegration test-error correction term.

Model	Gt	Ga	Pt	Pa
TI|GI, DI, ES, FDI, and FD	−15.946***	−13.476***	−15.312***	−13.594***

Kyrgyz Republic, Croatia, Turkey, Bosnia, New Zealand, Macedonia, Colombia, Azerbaijan, Indonesia, Qatar, China, Kazakhstan, Hungary, India, Bulgaria, Pakistan, the Republic of Korea, Lebanon, Brunei Darussalam, Morocco, Slovak Republic, and Ethiopia. However, the adverse connection between green investment and technological innovation is negative in 14 BRI nations: Bangladesh, Belarus, Malaysia, Nepal, Moldova, Armenia, Czech Republic, Iraq, Cambodia, Egypt, Iran, Vietnam, Bahrain, and Mongolia.

The study documented that environmental protection prompts technological innovation in 23 (twenty-three) BRI nations, and those are Moldova, Qatar, Macedonia, Cambodia, Bulgaria, Kazakhstan, Malaysia, Mongolia, New Zealand, Israel, Thailand, Colombia, Estonia, Jordan, Pakistan, Iran, Sri Lanka, Belarus, Bahrain, Hungary, Poland, Albania, China, Armenia, and Tajikistan. On the other hand, the adverse association that excess carbon emission degrades technological innovation is found in 34 (thirty-four) nations: India, Egypt, Philippines, Brunei Darussalam, the Republic of Yemen, South Africa, Russia, Nepal, Turkey, Bangladesh, Croatia, Azerbaijan, Romania, Slovenia, Czech Rep,

TABLE 5 Results of baseline estimation.

	Pooled OLS			RE			FE		
	Coefficient	Std. error	t-stat	Coefficient	Std. error	t-stat	Coefficient	Std. error	t-stat
GI	0.1505***	0.0133	11.3157	0.0312***	0.0145	2.1517	0.0841***	0.0099	8.4848
ES	0.1686***	0.0114	14.7894	0.1636***	0.0105	15.5809	−0.0462**	0.0165	−2.801
DI	0.131***	0.0109	12.0183	−0.0047	0.0117	−0.4017	0.0367**	0.0182	2.01648
FDI	0.1253***	0.0128	9.7890	0.066***	0.0126	5.2381	0.0749***	0.015	4.9933
FD	0.1595***	0.0132	12.0833	0.0929***	0.0131	7.0916	0.0348**	0.0161	2.1614
C	0.1669***	0.016	10.4312	0.0088	0.0147	0.5986	0.1232***	0.0166	7.4216

TABLE 6 Results of ARDL and CS-ARDL.

Variables	ARDL			CS-ARDL		
	Coefficient	Std. error	t-stat	Coefficient	Std. error	t-stat
Panel A: long-run coefficient						
GI	0.0878***	0.0328	2.6768	0.1223**	0.0662	1.8474
ES	−0.179***	0.0465	−3.8494	−0.1802***	0.0736	−2.4483
DI	0.0992**	0.0626	1.5846	0.1522***	0.037	4.1135
FDI	0.1208***	0.0258	5.8062	0.025***	0.0048	5.2083
FD	0.1565***	0.0722	2.1675	0.038***	0.0155	2.4516
	0.0306	0.0859	0.3562	0.0604	0.0561	1.0766
C	4.68759	0.0163	287.5822	−2.541	0.049	−51.8571
Panel B: short-run coefficient						
GI	0.0182***	0.0081	2.2347	0.0759**	0.053	1.432
ES	−0.0185	0.0030	−6.0423	−0.01658	0.0984	−1.6849
DI	0.0248	0.042	0.5904	0.0359	0.0637	0.5635
FDI	0.0314	0.0713	0.4403	0.0413	0.0543	0.7605
FD	0.0557	0.0584	0.9537	0.0543	0.0882	0.6156
CointEq (-1)	−0.270381	0.0264	−10.2417	−0.2274	0.0719	−3.1627
CD test	11.911			15.5124		
H-Test	0.175			0.511		

Lebanon, the Republic of Korea, Panama, Indonesia, Kuwait, Oman, Morocco, Singapore, Vietnam, Iraq, Ukraine, Kyrgyz Republic, Slovak Republic, UAE, Georgia, Bosnia & Herzegovina, Ethiopia, Saudi Arabia, and Myanmar.

The study focuses on domestic investment in technological innovation, and it is revealed that domestic capital adequacy accelerates the technological advancement in 40 (forty) BRI nations, namely, Slovenia, Albania, Georgia, Bahrain, Jordan, Qatar, Myanmar, Hungary, Bosnia & Herzegovina, Malaysia, Colombia, Thailand, Macedonia, Armenia, Moldova, Egypt, Panama, China, Cambodia, Kyrgyz Republic, Bangladesh, Mongolia, Bulgaria, Azerbaijan, Sri Lanka, Romania, Iran, the Philippines, the UAE, Turkey, the Republic of Yemen, Iraq, Croatia, Singapore, the Republic of Korea, Russia, Czech Republic, Morocco, Vietnam, and New Zealand.

5.7 Dumitrescu–Hurlin panel causality

The study implemented a heterogeneous panel causality test following Dumitrescu and Hurlin (2012), and the results are displayed in Table 9. The study documented several directional associations between technological innovation and explanatory variables. The study documented the unidirectional causal effects from green investment to technological innovation [GI→TI] and technological innovation to environmental sustainability [TI→ES]. Furthermore, the study documented bidirectional casualties between domestic investment, foreign direct investment, financial development, and technological innovation [TI←→DI; TI←→FDI; TI←→FD].

6 Discussion

Innovation in energy technologies is essential for cleaner manufacturing (Lin and Zhu, 2019). Technology innovation may increase the energy efficiency of fossil fuels, hence reducing production energy consumption (Sohag et al., 2017). Technology innovation may strengthen renewable energy technologies, increasing the production of environmentally friendly renewable energy as a future energy source. Furthermore, innovations in renewable energy may increase the ability to meet energy demands and alter energy portfolios (Tilt, 2019). RETI and air pollution have not received sufficient attention. We know no empirical studies or just a few indirect ones (Álvarez-Herránz et al., 2017; Miao and Qamruzzaman, 2021; Zhuo and Qamruzzaman, 2021). The study documented that the coefficient of green investment is positive and statistically significant with the symmetric assessment. Furthermore, the asymmetric assessment established that positive and negative innovation in green investment is positive and statistically tied with technological innovation both in the long-run and short-run assessment. Our study findings are supported by the existing literature, such as Johnstone et al., (2010), Geng and Ji, (2016), Qamruzzaman, (2021), Mehta et al., (2022), and Serfraz et al., (2022).

Investing money in renewable energy sources such as wind, solar, geothermal, ocean, biomass, and waste might significantly contribute to realizing public environmental objectives. In addition, it is frequently suggested that increasing proportions of renewable energy contribute to other public policy goals, such as better energy security in the face of uncertain markets for fossil fuels. Considering the importance of energy to sustainable development, making investments in environmentally friendly energy forms is very important to fulfill the prerequisites for attaining economic, social, and environmental sustainability (Danish and Ulucak, 2021). As a result, renewable energy sources have become essential in promoting economic growth, reducing pollution, and moving toward social progress. The utilization of green energy technology, which is required for consumption of renewable energy, is an environmentally preferable alternative to the burning of carbon-intensive fossil fuels. Every industry has to adopt cleaner technologies to maximize renewable energy sources and reduce overall energy consumption (Mensah et al., 2019). There is no controversy about the need to expedite the development, dissemination, and deployment of renewable energy technologies (RETs) (JinRu and Qamruzzaman, 2022; Karim et al., 2022). RETs are the most efficient means of mitigating existing energy systems' wasteful and dangerous effects. In addition to its environmental advantages, the renewable energy industry delivers a compelling economic potential (Amankwah-Amoah, 2019; Tabrizian, 2019). Nations that realize the need to strengthen their renewable infrastructures will enjoy global competitive advantages. To do so, however, one needs knowledge of the variables that restrict the development and spread of renewable energy (Brodny et al., 2021; Andriamahery and Qamruzzaman, 2022).

Environmental sustainability, measured by carbon emission, revealed negative and statistically significant associations both in the long run and short run according to ADRL and CS-ARDL estimation. Furthermore, the asymmetric assessment disclosed negative and statistically significant effects from asymmetric shock on environmental sustainability and technological innovation, indicating that environmental control and protection induce the economy to adopt technological innovativeness in energy and production processes for energy efficiency. Our study findings are supported by the existing literature (Karmaker et al., 2021). To solve the environmental problems that the world's countries are experiencing, it is crucial to use the best possible technology and scientific understanding for cleanup, yet this may be prohibitively expensive. Taxes on polluting activities are one tool that might be used to fund the research and development of new, cleaner technologies and help meet other environmental objectives. If new approaches and technology for decreasing pollution are developed, environmental interventions may be made possible with much lower costs (Li and Masui, 2019). Zhang et al. (2017) identified the impact of innovation on environmental deterioration. The authors used data from thirty Chinese provinces from 2000 to 2013. Using the empirical approach of SGMM methodology, the research investigated the impact of technological innovation on decreasing environmental degradation in China's regions. The investigation's findings indicated that innovation is significant in reducing the negative impacts of carbon emissions on the environment; hence, it is recommended that policymakers see innovation as the most effective method for limiting environmental deterioration.

In order to address problems associated with global warming and other environmental threats, a synergistic approach to control excessive CO_2 emissions is essential. Investing in innovation and technology may prove to be an advantageous strategy. This is because the development of environmentally friendly innovation and technology is required for the reduction of carbon emissions and the promotion of the growth of green economies (Ganda, 2019; Ulucak et al., 2020).

The study documented that domestic capital adequacy fosters technological innovation both in the long-run and short-run assessment. Furthermore, the asymmetric

TABLE 7 Result of nonlinear long-run and short-run assessment.

Variables	[1] With China			[2] Without China		
	Coefficient	Std. error	t-stat			
Panel A: long-run asymmetric coefficient						
GI_NEG	0.1403	0.04375	3.2068	0.0734	0.0068	10.7407
GI_POS	0.1814	0.01041	17.4255	0.1745	0.0161	10.7748
ES_POS	−0.1037	0.01566	−6.62196	−0.1057	0.01849	−5.7303
ES_NEG	−0.0984	0.0452	−2.1769	−0.0481	0.0056	−8.5340
DI_POS	0.1605	0.03864	4.15372	0.1477	0.0410	3.5961
DI_NEG	0.1124	0.04142	2.7136	0.0673	0.0143	4.6754
FDI	0.1167	0.03994	2.9218	0.0739	0.0287	2.5661
FD	0.1838	0.03979	4.6192	0.1752	0.0458	3.8243
W_{SR}^{RE}						
W_{SR}^{FDI}		8.951			11.02	
W_{SR}^{CO}		8.796			9.647	
Panel B: short-run asymmetric coefficient						
C	10.5105	0.01814	1.9201	−0.3819	0.016	−23.8734
GI_NEG	0.01247	0.0021	4.3915	0.23081	0.02616	8.82301
GI_POS	0.01782	0.0018	2.3424	−0.145	0.01192	−12.1644
ES_POS	−0.0198	0.0032	−6.1875	−0.0811	0.0426	−1.9037
ES_NEG	−0.0227	0.0066	−3.4394	−0.0268	0.0351	−0.76494
DI_POS	0.0798	0.0131	6.1385	−0.0659	0.0367	−1.79363
DI_NEG	0.0437	0.0089	4.9102	−0.0391	0.0486	−0.8053
FDI	0.1696	0.0439	−2.3496	0.0245	0.0405	0.60467
FD	−0.172	0.0121	3.7929	−0.0476	0.0220	−2.1575
CointEq (−1)*	−0.14178	0.0444	−6.9344	−0.3308	0.0365	−9.0533
W_{SR}^{RE}		11.05			9.678	
W_{SR}^{FDI}		9.479			6.709	
W_{SR}^{CO}		12.584			11.041	
H-test		0.576			0.6589	
Likelihood		231.41			191.32	‘

investigation revealed positive and negative shocks of domestic investments positively linked to technological innovation in the long and short run, suggesting that the domestic capital formation induces technological innovation in BRI nations with the motivation to achieve operational and energy efficiency. Our study findings are supported by the existing literature studies (Massell, 1960; Howitt and Aghion, 1998; Satrovic et al., 2021). The multiple effects of technical innovation on the economy are readily apparent in terms such as economic growth, global competitiveness, financial systems, quality of life, and trade openness (Satrovic et al., 2021). Regarding innovation, businesses are considered crucial factors, and the government is viewed as enhancing their ability to absorb, improve, and develop new technologies. The government offers the required infrastructure and a platform for engagement that institutions supply to enhance enterprises' capabilities. Governments, industries, and academics have emphasized the significance of scientific research and development to economic growth from time immemorial (Rani and Kumar, 2019). Research and development operations provide knowledge and technology, both of which boost productivity at the business, industrial, and national levels. Consequently, the productivity chain effect will result in better returns on investment, reflecting higher income levels and, therefore, stronger economic growth (Dhrifi, 2015; Bernier and Plouffe, 2019).

6.1 Conclusion and policy suggestions

Economists believe that technological innovation is a primary factor contributing to economic expansion. Improvements in the technological frontier are linked to resource reallocation and subsequent economic development

TABLE 8 Results of country-wise DOLS estimation.

	GI	ES	GI	FDI	FD
Albania	0.045***	−0.006**	0.009**	0.035***	0.038***
Armenia	−0.042	−0.002	0.093	0.112	−0.001
Azerbaijan	0.199	0.11	0.159	−0.164	0.039
Bahrain	−0.028	−0.058	0.021	0.177	−0.048
Bangladesh	−0.073	0.095	0.131	−0.071	0.132
Belarus	−0.052	−0.061	−0.054	0.092	0.049
Bosnia & Herzegovina	0.175	0.236	0.055	0.164	0.214
Brunei Darussalam	0.256	0.049	−0.039	−0.114	−0.059
Bulgaria	0.245	−0.135	0.157	0.102	0.267
China	0.241	−0.004	0.115	0.186	−0.001
Colombia	0.192	−0.105	0.061	−0.174	0.242
Cambodia	−0.036	−0.141	0.121	0.05	0.097
Croatia	0.144	0.11	0.22	−0.019	0.216
Czech Republic	−0.042	0.13	0.241	0.079	0.177
Egypt	−0.036	0.012	0.112	−0.042	−0.042
Estonia	0.084	−0.102	−0.091	−0.038	0.178
Ethiopia	0.274	0.242	−0.056	0.255	0.237
Georgia	0.13	0.234	0.016	0.149	0.129
Hungary	0.244	−0.046	0.051	−0.115	0.093
India	0.244	0.003	−0.016	−0.11	0.237
Indonesia	0.202	0.149	−0.084	0.205	0.151
Iran	−0.033	−0.083	0.177	−0.072	0.166
Iraq	−0.041	0.177	0.216	−0.061	−0.002
Israel	0.033	−0.111	−0.032	0.238	0.146
Jordan	−0.005	−0.097	0.036	0.225	0.175
Kazakhstan	0.241	−0.129	0	−0.033	0.047
The Republic of Korea	0.249	0.14	0.222	−0.166	0.048
Kuwait	0.135	0.153	−0.024	0.136	0.122
Kyrgyz Republic	0.141	0.181	0.13	0.101	−0.031
Lebanon	0.254	0.136	−0.11	−0.095	0.198
Macedonia	0.182	−0.155	0.08	−0.064	0.055
Malaysia	−0.051	−0.12	0.056	0.176	0.003
Moldova	−0.05	−0.158	0.094	0.215	0.272
Mongolia	−0.018	−0.112	0.147	0.131	0.241
Morocco	0.258	0.164	0.25	0.213	0.058
Myanmar	0.081	0.262	0.044	−0.073	0.231
Nepal	−0.051	0.078	−0.077	−0.109	0.163
New Zealand	0.178	−0.112	0.255	−0.158	0.185
Oman	0.083	0.162	−0.092	0.06	−0.042
Pakistan	0.245	−0.085	−0.055	−0.04	0.111
Panama	0.044	0.147	0.113	−0.101	0.155
The Philippines	−0.004	0.024	0.196	−0.114	0.038
Poland	0.137	−0.038	−0.035	0.026	−0.026
Qatar	0.214	−0.158	0.044	0.172	0.215
Romania	0	0.124	0.167	0.206	0.201
Russia	0.124	0.073	0.223	−0.039	−0.001
Saudi Arabia	0.02	0.246	−0.018	0.238	−0.061
Singapore	0.109	0.165	0.221	0.178	0.165
Slovak Republic	0.27	0.192	−0.047	0.215	0.025
Slovenia	0.061	0.127	0.004	−0.084	0.155
South Africa	0.093	0.066	−0.081	−0.011	0.049
Sri Lanka	−0.01	−0.067	0.162	0.119	0.179
Tajikistan	0.109	−0.002	−0.049	−0.022	0.266
Thailand	−0.015	−0.11	0.067	0.038	0.082
Turkey	0.149	0.078	0.204	−0.052	0.035
Ukraine	0.11	0.178	−0.084	0.031	−0.069
The UAE	0.086	0.2	0.203	−0.126	−0.069
Vietnam	−0.032	0.168	0.253	−0.146	0.053
Republic of Yemen	−0.013	0.051	0.216	−0.077	0.268

(Continued in next column)

via endogenous growth models, which offer extensive testable predictions regarding aggregate quantities and the cross-section of enterprises. The motivation of the study is to assess the role of green investment measured by renewable energy consumption, environmental sustainability proxied by carbon emission, and domestic investment explained by gross capital formation on technological innovation in BRI nations for the period 2000–2020. The study used several econometrical tools such as a cross-sectional dependency test, panel unit root test with CADF and CIPS, panel cointegration test with error correction term, panel ARDL, CS-ARDL, NARDL, and causality test.

Taking into account the study's findings (see Figure 2), it is revealed that green investment and domestic investment are positively connected with technological innovation in BRI nations, while environmental sustainability is exposed negatively and statistically significant to technological innovation. Furthermore, the asymmetric investigation established asymmetric effects from green investment, environmental sustainability, and domestic investment to technological innovation. According to the asymmetric coefficients, the positive and negative shocks of green and domestic investment disclosed positive and statistically significant links with technological innovation, whereas the asymmetric shocks in environmental sustainability revealed adverse ties to technological innovation in BRI nations. The study documented the unidirectional causal effects from green investment to technological innovation [GI→TI] and technological innovation to environmental sustainability [TI→ES]. Furthermore, the study documented bidirectional casualties between domestic investment, foreign direct investment, financial development, and technological innovation [TI←→DI; TI←→FDI; TI←→FD].

Considering the study findings, the following policy suggestions regarding the policy implications have been proposed.

1. According to a study, green investment accelerated technological innovation, implying that including clean energy instead of fossil fuel in industrial production will open an avenue for

TABLE 9 Results of Dumitrescu and Hurlin's (2012) panel causality test.

	TI	GI	ES	DI	FDI	FD
TI		(5.8533)*** [6.1694]	1.1955 [1.26]	(5.6992)*** [6.007]	(4.5069)** [4.7502]	(3.1987)** [3.3714]
GI	0.9936 [1.0472]		1.5696 [1.6543]	(1.9479) [2.0531]	(4.2592)** [4.4893]	(5.6567)*** [5.9622]
ES	(5.7151)*** [6.0238]	(6.2529)*** [6.5905]		(3.3719) [3.554]	(2.2964) [2.4205]	(4.6865)** [4.9395]
DI	(5.4346)*** [5.7281]	(5.119)*** [5.3954]	(3.0201)** [3.1832]		(4.8299)*** [5.0907]	(5.1232)*** [5.3999]
FDI	(4.0425)** [4.2608]	(2.9776) [3.1384]	(3.4442) [3.6301]	(5.9734)*** [6.2959]		(3.1083) [3.2762]
FD	(5.3443)*** [5.6329]	0.9192 [0.9688]	(2.001) [2.1091]	(5.6216)*** [5.9252]	1.2858 [1.3553]	

Note: the values in [] and () explain the test statistics of W-Stat and Zbar-Stat.

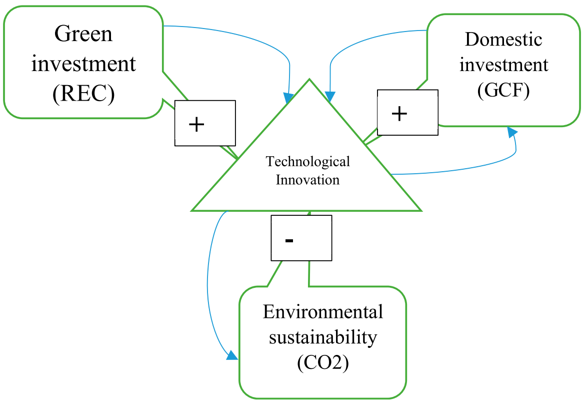

FIGURE 2
Empirical association and causal association.

technological advancement. Therefore, the study advocated that the inclusion of green energy should be promoted in BRI nations as a fostering factor for technological innovation.

2. Environmental sustainability has been revealed to be a catalyst factor in thriving technological innovation in BRI nations, indicating that controlled and restrictive carbon emissions in the economy will boost technological innovation. Thus, it is suggested that BRI nations formulate and ensure effective implementation of environmental regulation, which eventually prompts technological innovation. Furthermore, to foster technological innovation, BRI nations have come up with solid environmental protection policies, which eventually lead to adaptation of technological efficiency in aggregated output levels.
3. Efficient financial intermediation in the financial system leads to reallocation of domestic investment into productive areas, especially in innovation. The study advocates that domestic capital accumulation and reallocation into research and development must be ensured to promote technological innovation.

In concluding note, the present study is not devoid of certain limitations. The study pointed out that the data homogeneity might reveal diverse results for further insight development. In addition, the outcomes of this research indicate that green investment and domestic capital accumulation should be incorporated into technological innovation assessment models as independent variables in addition to the conventional variables connected to economic considerations. Today's complicated and unstable global economy makes this concern more important than ever. There may be a need for further empirical investigations using other methodology and data sets, including various nations such as the target economy can be sub-grouped according to income distribution.

Data availability statement

Publicly available datasets were analyzed in this study. These data can be found here: World Development Indicator and International Financial Statistics.

Author contributions

ZX: introduction, empirical estimation, and final version. MQ: literature survey, methodology, empirical estimation, first draft, and final version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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