Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

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ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 3, 2150670
https://doi.org/10.1080/1331677X.2022.2150670

Drivers of green innovation in BRICS countries: exploring tripple bottom line theory

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ABSTRACT

Green technology adoption is indispensable for sustainable growth. Therefore, this study examines the determinants of green innovation in BRICS countries considering the Triple Bottom Line Theory (social, environmental, and economic). A cross-sectional autoregressive distributed lag (CS-ARDL) model is applied for empirical analysis from 1990 to 2019. The findings show that social, economic, and environmental factors significantly derive green innovation in the long run. However, their marginal contribution is substantially varied. A 1% increase in economic factors increases green innovation by 0.290%, while environmental concerns induce innovation by 0.438% in the long run. In contrast, social factors possess a relatively lower influence on green innovation, with a coefficient magnitude of 0.175%. Lastly, globalization stimulates green innovation by 0.310%. Similar results are observed in the short run; however, the magnitude of variables is significantly lower than long-run. These results are also validated using alternative estimators and recommend TBL factors as core drivers of green innovation in BRICS countries.

ARTICLE HISTORY
Received 30 July 2022
Accepted 17 November 2022

KEYWORDS
Tripple bottom line; green innovation; sustainability; BRICS countries

JEL CODES
O10; O3; Q44

1. Introduction

Many countries have experienced exponential economic expansion and industrialization over the last few decades; however, rampant resource depletion leads to environmental hazards and climate change. These issues compel policymakers to devise long-term, constructive answers on a war footing. In this wake, green technologies are considered a dominant tool in reducing carbon emissions by up to 60% (Du et al., 2019; Ozturk et al., 2022). Controlling deterioration, dilapidation management, and clean-up high tech are examples of green technologies (Chen & Lee, 2020). Green innovation (GI) is the process of new ideas, goods, and environmentally friendly services (An et al., 2021; Sharif et al., 2022). Likewise, GI is contingent on social, environmental, and economic aspects pronounced triple bottom line (TBL).

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GI has recently emerged as a critical tool for lowering dangerous emissions worldwide (Maasoumi et al., 2021). Previous research has suggested the negative influence of technological advancement on carbon emissions (Du et al., 2019; Skare et al., 2021). Ecological deterioration is enhancing a worldwide menace, resulting in socio-economic issues like health problems, which are 90 percent linked to weather change (UNDP). Human capital, financial development, and sequestered R&D are the main determinants of a sustainable environment (Razzaq et al., 2022). Existing research has emphasized the necessity of education and environmental awareness to decrease environmental degradation (Shahzad et al., 2020b). Industrialized economies are increasingly working to address the dangers of CO_2 emissions and environmental degradation caused by hazardous chemicals (Maasoumi et al., 2021). Environmental protection methods that are more stringent, environmental taxes, and lower CO_2 emissions benefit GI (Sharif et al., 2019). Furthermore, Globalization also has a considerable role in increasing CO_2 emissions and energy usage.

Globalization (Glob) has improved innovation, technological access, and communication (Xia et al., 2022). It has boosted economic growth and unlocked many new development opportunities that played a critical role in bringing people from various cultural backgrounds together. Glob has created several issues, with its greatest environmental impact (Song et al., 2020). Green growth agendas are challenging to execute without effective laws and implementation. Reduced production costs are an essential driver of GI (Saunila et al., 2018). Technological innovation has a favorable impact on GDP. Prior research has shown that combining these long-term tactics aids endurance operations in a rapidly irresolute corporate atmosphere (Yu et al., 2020). Using the GI approach in industries can lower operational costs and improve research in developing economies, which can help us understand how numerous factors influence environmental degradation and how to reform ecologically friendly surroundings, Awan et al. (2021). Extant literature used survey data to investigate the correlation between GI and TBL. Due to subjectivity bias, they produced inconclusive results, Hu (2021). Nonetheless, empirical research does not consider these key elements when considering TBL assimilation in a comprehensive framework (Zhao et al., 2022). Despite the abundance of material on GI, the impact of the TBL strategy is still little understood (Zhu et al., 2019). Moreover, recent studies on economic, environmental, and social factors and Glob have been confined to traditional methods, which produce conflicting results.

Against the above backdrop, this study investigates the drivers of GI in BRICS countries. In doing so, we explore the influence of TBL factors framework (economic, environmental, and social factors) along with Glob on long-term innovation transition. In doing so, this study uses a cross-sectional autoregressive distribution lag (CS-ARDL) model to address cross-sectional dependency and slope heterogeneity. The long-run results revealed that TBL factors and Glob substantially contributed to GI transition; however, ecological factors are the most substantial factors in this process.

The rest of the study's structure is divided into four parts. The second chapter serves as a literature review and theoretical background. Material and methods explain the process used for sophisticated panel estimations in the third chapter.

Results and discussions are provided in chapter 4. The final chapter summarizes the conclusion, suggestions, and policy implications.

2. Theoretical background

Technological innovation is an endogenous and fundamental factor in defining economic quality that promotes continuous economic growth (Ghisetti & Quatraro, 2017). Technology innovation is a 'double-edged sword' that is viewed as a major cause of problems like climate change, ecological imbalances, and growing pollution, as well as an efficient way to address these concerns and promote sustainable development. The link between ecological building and economic development is made possible by 'green innovation', which combines environmental conservation and technical advancement (Sun, 2022). It is the cornerstone of green development and social transformation and the key to bringing about change in the energy sector, meeting the double carbon standard, and other areas (Huang & Zhang, 2021). However, comprehensive research and development (R&D) cycles, a high risk of failure, and low returns are frequently characterized by green innovation, which results in a low level of green innovation and insufficient incentives for green R&D in China. The subjects of green innovation in the contemporary market economy are businesses and research institutions whose innovation practices are inextricably linked to financial support (Zhang et al., 2021; Zhang & Vigne, 2021; Zhang & Jin, 2021).

Technology innovation that prioritizes environmental friendliness, clean energy, ecological protection, and addressing climate change is known as 'green innovation' (Sun & Razzaq, 2022). The term 'green innovation' was first used by Braun and Wield (1994) to describe innovations that reduce environmental pollution, material inputs, and energy use, as well as process or product improvements. These innovations are broadly categorized as environmentally friendly, energy-efficient, renewable, and eco-innovations (Saqib, 2022a, b). Rennings (2000) pointed out that green innovations include new products, services, technologies, and methods for protecting the environment. This idea is widely acknowledged among scientists. Hellström (2007) defined green innovation as the process of creating new products from concepts to market applications. Numerous government agencies also clarified the meaning and connotation of green innovation. The Organisation for Economic Co-operation and Development (OECD) defined green innovations as acts that, consciously or accidentally, produce more significant ecological improvements than previous initiatives (OECD, 2009).

It is challenging to successfully combine green innovation with conventional finance because of the profit-driven nature of capital. According to the 19th Party Congress report, the government is urged to create a market-oriented green innovation institution to aggressively push green finance in various industries to boost the naturally occurring momentum of the energy-saving and clean industries. Green finance is essential for green project financing provided by financial institutions. It also helps businesses manage their financial risks by providing the tools they need to engage in creative green financing. Consequently, the growth of green financing has become a driving force behind green innovation (Xie et al., 2022).

2.1. Triple bottom line and green innovation

Due to the expanding importance of natural resource conservation, Sustainable Development (SD) has gained significant traction among researchers. Environmentalists and ecologists have praised the benefits of incorporating green consciousness into an organization's manufacturing process (Sarkis et al., 2011). The World Commission on Environment and Development (WCED, 1987) defines sustainable development (SD) as 'development that meets present demands without compromising the capacity of future generations to satisfy their needs' (WCED, 1987). The ideas built the TBL long-term assessment structure, which may measure the SD from multiple perspectives (Elkington, 1998)

SD's three pillars (environmental, economic, and social) are recognized as a TBL 'that has an impact on current and future generations' (Elkington, 1998). Furthermore, sustainable theory considers these elements integrative and interdependent (Tseng et al., 2015). Due to growing demands for SD, organizational competitive practices have been extended to encompass traditional ECO, SOC, and ENV sustainability (Delmas & Pekovic, 2013). whereas it is also asserted the rules of the game in a society (North, 1990). Glob regulatory factors are important determinants for GI in the advancement and promulgation phases. The quality of Glob matures due to institutional sequestration, which fosters innovation by allowing green development to be implemented more effectively. The evaluation of sustainability and its features is seen as one of the most important drivers of GI. GI could imply that a company's operations can reduce its negative impact on environmental quality (Shahzad et al., 2020a). Numerous noxious weeds and plants have emerged due to the addition of various chemicals to the soil, significantly harming plants by changing their genetic makeup (Song et al., 2022a, 2022b). Mountains are chopped away to make room for a road or tunnel to pass through them. Large tracts of desolate land have had modern structures built on them (Guo et al., 2021).

Most researchers are now investigating the elements that significantly influence GI (Sharma et al., 2021). According to Chen and Lee (2020), Stakeholder squeeze is a critical factor in determining GI. Furthermore, SD and GI are enabled through creativity and knowledge management (Awan et al., 2021). Lim et al. (2017) also stressed the necessity of the TBL strategy for efficacious governmental advancement. Modern knowledge leads to green development with the impact of the TBL strategy (Zhu et al., 2019). As a result, the TBL technique could help anticipate GI in the context of ICT infrastructure adoption.

2.1.1. Economic sustainability (ECO)

Economic sustainability is viewed from two perspectives: financial prosperity and human capital advancement (Saunila et al., 2018). Following the global economic depression, which revealed the risks of debt and bankruptcy, this SD factor has received the most attention. The level of foreign direct investment (FDI) a nation receives, together with its market capitalization, trade openness, and export volume, affects its economy's ability to sustain it (Maasoumi et al., 2021). As a result, Galbreath (2019) stated that export intensity and GI have a positive link. Reduced production costs have also been recognized as an important driver of GI in previous studies (Saunila et al., 2018). Recycling and cost-cutting are the most important motivators for the most efficient use of energy and raw materials (Aboelmaged & Hashem, 2019). In today's digital economy, investing in human capital development has incontestable affluence on green development, enhancing competitiveness. According to Wanzala and Zhihong (2016), green logistic operations aid in the battle against climate change while also increasing the economic performance of businesses. Luthra et al. (2016) emphasize that incorporating an improvement proposition helps to reduce waste energy. Economic sustainability has a good impact on GI. According to Aboelmaged and Hashem (2019), organizational sustainability promotes the green performance of businesses.

2.1.2. Environment sustainability (ENV)

Natural resource improvement is a major concern around the world. Different economies have different motives for GI implementation. The ecological aspect of SD entails transforming industrial methods to alleviate the negative effects of industrialization (Saunila et al., 2018). Economies with low adoption of the eco-innovation arrangement should explore utilizing creative and eco-friendly technologies that promote resource efficiency and environmental protection (Sun et al., 2021; Maasoumi et al., 2021). Previous studies have shown that promoting green growth has a favorable impact on GI by encouraging investment and public attention (Mensi et al., 2018; Steinhorst & Matthies, 2016). GI is adopted to reduce fuel usage, which causes CO_2 emissions. According to Amin et al. (2020), technological advancement has lowered CO_2 emissions in developing nations and discovered an inverse relationship between advancement and CO_2 emissions (David & Grobler, 2020; Ozturk & Ullah, 2022). Santra (2017) also discovered a link by adopting effective ecological methods and promoting green innovation in the BRICS countries. Environmental sustainability is fundamental to green inventiveness, identity, and strategy that rigour environmental taxes to lower CO_2 emissions (Song & Yu, 2018). This position prompts us to examine the current circular economy's environmental sustainability link with GI. As a result, the following theory was offered.

2.1.3. Social sustainability (SOC)

Social sustainability is defined as a state's environmental adaptability, focusing on human capital, employment design, and social well-being (Saunila et al., 2018). Human capital helps employees to improve their attitudes and behaviours toward environmentally friendly practices by providing environmental training (Awan et al., 2021). Internal learning stimulates the GI process because there is a great link between them (Chang, 2016). Industrial development greatly impacts the workforce and increases productivity (David & Grobler, 2020). The impact of GI on social sustainability can be shown in changes in behaviour by encouraging technology adoption (Ganapathy et al., 2014). Likewise, customers are willing to spend extra for GI and eco-friendly items to improve environmental work by eliminating natural peril (Song & Yu, 2018; Zhuang et al., 2023). The welfare index favorably influences GI (Maasoumi et al., 2021; Global Innovation Index 2018). Previous studies have shown that social sustainability positively impacts GI (Saunila et al., 2018). Organizational skills like green demand and internal knowledge are all thought to have an impact on

GI. As a result, the following theory is put forth: The term 'Glob' gets a lot of attention regarding imports and exports, which may cause serious problems like deforestation. For instance, wood is utilized worldwide for paper, building materials, and home furnishings. Everyone needs paper at some point throughout their lives, but because trees take a while to grow, there is a greater demand than supply. This furthers deforestation-related profiteering (Waheed et al., 2018).

Hojnik and Ruzzier (2016) suggest that Glob is a crucial driver for GI in both the creation and circulation phases. Glob matures the efficacy of institutional and governmental action. Green growth and sustainable agenda are further implemented when Glob has a strong corporate space to foster advancement and development. The evaluation of sustainability and its facets are seen as one of the primary forces behind GI. GI could indicate that a company can lessen the negative environmental effects due to its operations (Shahzad et al., 2020a). Numerous academics are now researching the elements that significantly affect GI. According to Chen and Lee (2020), stakeholder pressure significantly impacts GI. Fundamental GI determinants include environmental, technological capabilities, laws, green demand, and more (Chang, 2016). By lowering CO_2 emissions and creating smart, sustainable cities, ICT infrastructure, including cutting-edge tools and materials, can have a positive environmental impact (Stucki & Woerter, 2019). Lim et al. (2017) also emphasized the significance of the TBL strategy for attaining organizational advancement. Innovation fuels modern knowledge by producing eco-friendly products, sustainable resources, and more effective manufacturing processes (Yu et al., 2020).

A green economy protects the environment from quick climate change while preparing for its immediate and long-term effects. It uses resources efficiently based on green economic growth to ensure future prospects for people and the environment. Even though there is plenty of literature on GI and SD, the topic of how the TBL method affects these is not yet sufficiently explored (Zhu et al., 2019). As a result, this study proposes that GI with the absorption of Glob may be considerably predicted by a TBL method (shown in Figure 1). Following Jin et al. (2022), the below model is proposed.

$$GI, i, t = f(ENVi, t, SOCi, t, ECOi, t, GLOBi, t) \tag{1}$$

The cross-sections are denoted as 'i' in Eq. (1), whereas the time period from 1990 to 2019 is denoted as 't'. Eq. (2) shows the regression form of Eq. (1).

$$GIit = \beta 1 + \beta 2ENVit + \beta 3SOCit + \beta 4ECOit + \beta 5GLOBit + \alpha i + \delta it \tag{2}$$

3. Materials and methods

The current research assesses the influence of social (SOC), environmental (ENV), and economic (ECO) factors on green innovation (GI) in BRICS countries. This study uses thirty years of data spanning from 1990 to 2019. Table 1 shows the details of the variables and their data sources.

Initially, the cross-sectional dependency (CSD) test is conducted for each series. This test aids in using the specific unit root test from previous generations, such as

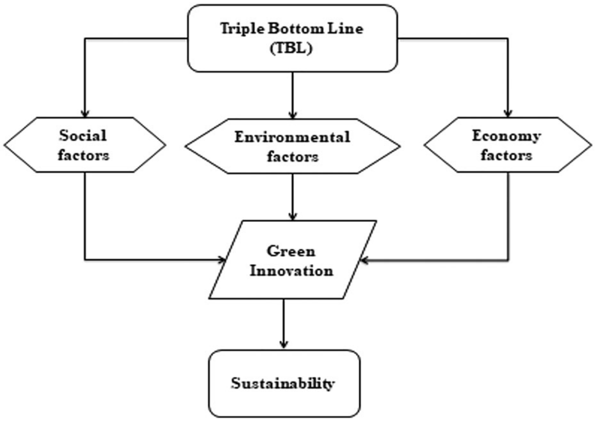

Figure 1. Relationship between the triple bottom line with green innovation.
Source: Author's own

Table 1. Variables description.

Sign	Indicate	Description	Measurement unit	Source
GI	Dependent	Green Innovation	Eco patents % of total patents	OECD.Stat.
Soc	Social Factor	Human Development	Index measured by average year of Schooling	Penworld Table
Eco	Economic Factor	Economic Growth	GDP Per Capita (constant 2010 $)	WDI
Env	Environmental Factor	Environmental Stringency Index	Environmental policy stringency index	OECD.Stat.
Glob	Control	Globalization	KOF Glob Index	KOF Glob. Index.

Source: Author's own.

the first, second, and third, to address the CSD issue. Additionally, it is crucial to tackle CSD concerns with adequate attention to prevent erroneous outcomes. Many elements, including continued interdependence, economic proximity, global recession, demand shocks, abrupt volatility in stock prices, oil prices, and unrecognized and hidden causes, are linked to the CSD (Pesaran, 2015). CSD testing is used to examine the problem of CSD between units, and data stationarity is checked after finding the CSD.

Second, several recent research papers have addressed the problem of non-stationary panel data and its repercussions. The split of generations is further classified by how the homogeneity of data is handled (Levin et al., 2002). The current study focuses on the techniques of Pesaran (2006), which consider the problems of CSD when estimating unit root test statistics.

Third, the study evaluates the existence of slope homogeneity after assessing the unit root or stationarity (Swamy, 1970). The slope parameters are assumed to be homogeneous for the test's null hypothesis, whereas they are assumed to be heterogeneous for the alternative hypothesis. Furthermore, first-generation cointegration techniques cannot produce accurate estimates due to the distortion of size attributes (Pedroni, 2004; Westerlund, 2005). Thus, we used Westerlund and Edgerton (2007)'s panel cointegration test, which accounts for CSD and slope heterogeneity issues while testing long-run cointegrated association.

The existence of CSD may result in biased results. Economic and financial shocks are just one of the many elements contributing to the CSD issue. Demand shocks, macroeconomic shocks, and modifications to economic policies are some of the independent variables in the regression equation. Thus, CS-ARDL is the best suitable estimate in the presence of CSD and slope heterogeneity. The endogenous variable in this study is a green innovation known as GI.

$$GI_{i,t} = \sum_{i=0}^{pw} \gamma_{I,i} GI_{i,t-1} + \sum_{j=0}^{pz} \beta_{I,i} Z_{i,t-1} + u_{i,t} \quad (3)$$

$$GI_{i,t} = \sum_{i=0}^{pw} \gamma_{I,i} GI_{i,t-1} + \sum_{j=0}^{pz} \beta_{I,i} Z_{i,t-1} + \sum_{j=0}^{px} a'_{i,} I\overline{X}_{it-1} + u_{i,t} \quad (4)$$

Where $\overline{X}_{t-1} = (\overline{GI_{i,t\bar{1}}}, \overline{Z_{i,t\bar{1}}},$ the long-run coefficient and the mean group estimator is given as:

$$\hat{\pi}_{CS-ARDL,i} = \frac{\sum_{I=0}^{pz} \hat{\beta}_{I,i}}{1 - \sum_{I=0}^{pw} \gamma_{I,i}} \quad (5)$$

The mean group is given as:

$$\hat{\pi}_{MG} = \Sigma_{i}^{N} \hat{\pi}_{i} \quad (6)$$

Short-run GI coefficients are estimated as

$$\Delta GI_{i,t} = \varphi_i [GI_{i,t-1} - \pi X_{i,t}] - \sum_{I=1}^{pw-1} \gamma_{I,i}, \Delta_I \; GI_{i,t-1} + \sum_{I=0}^{pz} \gamma_{I,i}, \Delta_I \; Z_{i,t} + \sum_{I=0}^{pX} a'_{i} \;, I\overline{X}_{t} + u_{i,t} \quad (7)$$

Where, $\Delta_t = t - (t-1),\ \hat{\tau}_i = -\left(1 - \sum_{I=0}^{pX} \widehat{\gamma_{I,i}}\right)$

$$\hat{\pi}_i = \frac{\sum_{I=0}^{pz} \hat{\beta}_{I,i}}{\hat{\tau}_l} \quad (8)$$

$$\hat{\pi}_{MG} = \Sigma_{i=1}^{N} \hat{\pi}_l \quad (9)$$

The CCEMG equation is as follows:

$$GI^{i/t} = \varphi^1 \overline{SOC^{i,t}} + \varphi^2 \overline{ECO^{i,t}} + \varphi^3 \overline{ENV^{i,t}} + \varphi^4 \overline{GLOB^{i,t}} + W^{i,t} + u^{i/t} \quad (10)$$

The endogenous or dependent variable Wit is a green innovation, while Zi,t 1 denotes all independent factors like SOC, ENV, ECO, and GLOB. Additionally, Xt 1 is the average of exogenous and endogenous variables to reduce the problem of CSD caused by spillover; however, Pw, Pz, and Px show that each variable lags. The CS-ARDL estimator uses the short-run coefficients to estimate the long-run coefficients' values.

The existence of CSD may cause false results by applying traditional methodologies (Yao et al., 2019). Thus, we apply the Augmented Mean Group (AMG) (Eberhardta & Tealb, 2010) and Common Correlated Effect Means Group (CEMG) (Pesaran, 2006) for robustness. These estimators offer reliable outcomes in the presence of heterogeneous slopes, CSD, and structural breaks.

4. Results and discussion

Interdependence on different countries increases vulnerability, leading to unreliable assessment due to CSD issues. From Table 2, the CSD results determined that all variables are statistically significant at a 1 percent significance level, which exhibits the existence of CSD. Shocks in one country produce repercussions across entire countries. Table 2 also reports the results of the slope heterogeneity problem, as demonstrated by the significant (Δ) and (Δadj). Therefore, the null hypothesis is rejected at a 1% significance level.

After getting the results of CSD and slope heterogeneity, the second-generation panel unit root (CIPS and CADF) tests are applied. The CIPS unit root test findings in Table 3 show that all model variables are non-stationary at level; however, it turns stationary at first difference.

The bootstrap panel cointegration test explores the long-run relationship between variables in the BRICS economies. The findings demonstrate that four test statistics are based on the Error Correction Model. The standard error is the error correction

Table 2. Cross-sectional dependency and slope homogeneity test.

	CSD test	
Variables	F-value	P-value
GI	18.325***	0.000
Soc	7.318***	0.000
Eco	12.045***	0.000
Env	15.994***	0.000
Glob	13.587***	0.000
Slope homogeneity test		
Test	Value	P-value
$\hat{\Delta}$	13.068***	0.000
$\hat{\Delta}_{adjusted}$	14.515***	0.000

Note: ***P < 1%.
Source: Author's own.

Table 3. CIPS & CADF unit root tests.

	CIPS		CADF	
Variables	I(0)	I(I)	I(0)	I(I)
GI	−1.843	−3.105***	−1.551	−3.465***
Soc	−0.750	−2.748**	−1.946	−3.044**
Eco	−0.856	−2.895**	−1.136	−2.816*
Env	−1.590	−4.142***	−1.722	−3.958***
Glob	−1.325	−4.190***	−1.351	−4.560***

Note: ***P < 1%, and **P < 5%.
Source: Author's own.

Table 4. Cointegration outcomes.

Statistics	Gt	Ga	Pt	Pa
Value	−2.795***	−3.462**	−3.570***	−4.638***
P-value	0.008	0.004	0.000	0.000

Note: ***P < 1%, and **P < 5%.
Source: Author's own.

Table 5. Findings of CS-ARDL.

	Long-run			Short-run		
Variables	Coefficient	t-stats	Sig.	Coefficient	t-stats	Sig.
ECT-1	–	–	–	−0.318	−3.725	***
Soc	0.175	3.180	***	0.110	3.714	***
Eco	0.290	2.043	**	0.067	1.856	*
Env	0.438	4.612	***	0.192	2.407	**
Glob	0.310	5.712	***	0.105	4.635	****

Note: ***P < 1%, **P < 5% and *P < 10%.
Source: Author's own.

model parameter used to calculate the Gt and Pt. Ga and Pa are for adjusting auto-correlations and heteroskedasticity. According to Westerlund (2008), group mean and panel mean tests are used to assess the cointegration hypothesis. It is more reliable and has constrained normal distributions. The results are presented in two different ways, with the outcome accepting the alternative and rejecting the null hypothesis. Table 4 demonstrates all model variables have a long-run cointegrating relationship, confirmed by significant Gt and Pt statistics.

In Table 5, the results of the CS-ARDL are enumerated. The findings showed that social factors positively impact green innovation, with a coefficient value of 0.138 and a 5% significance level. It implies that green innovation raised by 0.175 percent for every extra 1 percent increase in social factors. According to environmental deterioration and technological advancement findings, social factors have disrupted green technology in many nations (Lin & Zhou, 2022; Jin et al., 2022; Hamdoun et al., 2018; Triguero et al., 2013). It is also suggested that appropriate SOC and improved educational accomplishments concurrently set an innovative basis to lead to higher innovation performance. Due to the information stock already present in business and society, the marginal drop in GI is less than the former if any negative shock occurs in SOC. This study represents the findings of earlier studies that claim that advancing SOC fosters technical innovation (Jin et al., 2022; Hu, 2021; Marvel et al., 2020). The findings suggest that economies with well-developed SOC can profit significantly from knowledge spillover, mainly through implementing new technologies that increase economic growth.

A greater ECO shows improved labour productivity and the capacity to sustain the technology development supporting GI. As a result, ECO has a major impact on GI. The results showed that a 1% increase in ECO brought a 0.290% improvement in green innovation. These findings corroborate earlier research by Hu (2021), who found that ECO encourages technological innovation by increasing R&D spending. Maasoumi et al. (2021) found a deteriorating correlation between ECO and GI. The rising cost of innovation might explain this negative outcome. Such activities are either outsourced or situated in developing economies to address these shortcomings and reduce the cost of innovation. We might infer from these results that controlling GI in BRICS has an asymmetrical and nonlinear impact (Shin et al., 2014). Additionally, during a recession, the government injects money and resources to encourage businesses and industries to innovate and develop cost-effective ways to boost their growth through new technology. Additionally, newcomers hesitate first to dopt the most expensive and cutting-edge solutions to reduce CO_2 emissions. To increase stakeholders' confidence and spur economic activity for growth and development, government support (tax rebates) is crucial. Manifestly, corporations have been encouraged to create particular technologies, support innovations, and steer technological evolution toward greener technologies. Moreover, in the modern world, compliance with pertinent environmental standards and laws is the most important element in increasing efficiency and lowering innovation costs (Ahmad et al., 2021; Soewarno et al., 2019).

Increased clean environment adoption connected local businesses to global leaders, enabling them to virtually global technology. Prior research has identified ENV as one of the forces behind innovation (Higon 2012). ENV impacts GI by creating innovative ICT devices that produce less energy and less pollution (Chen & Lee, 2020; Shahzad et al., 2020c). Additionally, using ENV in R&D puts great pressure on GI results. According to Higón (2012), departments that use ENV are primarily 23%, presumably introducing novel and creative methods. Energy and fuel consumption are reduced during industrial production due to innovative procedures and energy-saving technology, which greatly increases GI. These details significantly corroborate our findings (Jin et al., 2022).

Finally, Glob is also a source of technology transfer; therefore, countries transport their goods and services to reduce carbon emissions. Estimated coefficient results are both adversely correlated with CO_2 emissions, but only innovation has emerged as a statistically significant factor. It is thought that the effects of scale, technology, and composition in Glob can impact the environment. Yang et al. (2021) suggested that Glob can be used to reduce carbon emissions and improve environmental quality for 97 nations between 1990 and 2016. Saud et al. (2020) indicate that Glob has worsened the environment. According to ecological modernization theory, Glob could worsen the environmental quality in 137 nations (Wang et al. (2019a, b). On the other hand, Wen et al. (2021) found evidence of a positive association between Glob and CO_2 emissions. Xiaoman et al. (2021) concluded that, for the MENA countries, economic Glob reduces CO_2 emissions. Shen et al. (2021) discovered that Glob is a factor in environmental degradation in BRICS nations.

The short-run findings of CS-ARDL (in Table 5) show a similar directional relationship but a smaller magnitude, suggesting that the long-run effects of the GI determinants are more significant than the short-run effects. The idea is that the GI protracted process is based on a rational theoretical level. Additionally, the convergence to long-run equilibrium under any shock is confirmed by the error correction term's (ECT) negative coefficient, which is 31.8 percent.

Table 6. Findings of AMG and CCEMG (Robustness).

	AMG			CCEMG		
Variables	Coefficient	t-stats	Sig.	Coefficient	t-stats	Sig.
Soc	0.159	2.254	**	0.160	2.392	**
Eco	0.237	2.165	**	0.296	2.805	***
Env	0.490	4.068	***	0.417	3.641	***
Glob	0.326	3.065	***	0.349	2.523	**

Note: ***P < 1%, **P < 5% and *P < 10%.
Source: Author's own.

The outcomes of the AMG and the CCEMG are compiled in Table 6. The results show that all social, environmental, and economic factors positively affect green innovation. SOC has 0159 and 0.160 coefficient values, ECO has 0.237 and 0.296 coefficient estimates, and ENV has 0.490 and 0.417 values for the AMG and CCEMG estimators, respectively. Lastly, GLOB has 0.326 and 0.349 estimated values. All values are positive and significantly correlated. The findings from the CS-ARDL were supported by the AMG and CCEMG robustness results. The entire set of findings from this empirical investigation concurs with (Zhang et al., 2022) and (Jin et al., 2022). Since ecological factors are core drivers of green growth, thus, due to these (social, environmental, and economic) factors, all nations must consider the quality of various energy resources, including oil, natural gas, and wood. The greenhouse gases produced by these energy sources significantly impact climate change and global warming. Governments that focus on 'energy independence' and heavily rely on energy earnings to support their budgets are more likely to cause issues in the sector by subsidizing or enforcing policies that make switching to sustainable energy more difficult.

5. Conclusion and recommendations

The current study looks at how sustainable practices interact with the Glob to help SD achieve GI goals. The primary goal of this study was to look at what drives GI in terms of TBL in BRICS countries from 1990 to 2019. Using CS-ARDL estimators, the findings show that SOC significantly favors GI (0.175 percent) in the long run but has a smaller impact in the short run. Likewise, a positive change in ECO stimulates GI (0.290 percent), and this effect is lower in the short run. Because GI is a continuous long-term process, it cannot be immediately increased in a shorter time; rather, it requires long-term effects and policy interventions. These findings are crucial since any strategy to reduce CO_2 emissions will impact the innovation process and provide a solution for improving environmental quality and economic growth. Moreover, ENV greatly favors GI (0.438 percent) in the long run. Lastly, Glob positively affects GI, which supports previous research; long-term environmental plans are critical for economic growth. Without implementing sustainable practices and cutting-edge ICT technology, the GI dream can never come true. Climate change impedes economic and social advancement and endangers people's health, safety, and way of life if businesses and society do as they already do. With the help of contemporary technology, environmental sustainability goals were achieved through green growth.

Organizations should create favorable work conditions and rules to allow employees to reach their full potential while encouraging them to further their education and training. R&D in education and skill-building in the field of GI should receive more funding. To sustain the quality of the environment, strategists must use a variety of ways to balance the resources of supply and demand. Developing and rising countries should set strategic objectives for tackling environmental challenges and deploying green technologies. Countries may establish a systematic framework to support green technology and specify standards for green and clean production, depending on the industry. Nations can promote the development of green technologies in the renewable energy industry by creating environmental policies for a low-carbon energy system. By doing this, nations may implement sector-specific regulations that support and stimulate the adoption of eco-friendly technology, resulting in innovations that tackle the issues brought on by climate change.

Governments addressing climate change should be aware of balancing economic growth with environmentally friendly development. Governments in developed and developing nations can improve the efficiency of their regulatory frameworks by achieving their pollution reduction goals. Similar improvements in government efficiency are needed for industrial structures and economic development programs in developing and rising nations. The recent implementation of pollution trading programs by BRICS countries is anticipated to have positive outcomes. Finally, an integrated policy framework work is required which transform BRICS countries in socio-economic and environmental factors.

Disclosure statement

No potential conflict of interest was reported by the authors.

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