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RESEARCH ARTICLE

Examining the nexus between export diversification and environmental pollution: evidence from BRICS nations

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Abstract
In recent years, industrial growth has enabled the BRICS nations to increase their export earnings from both traditional and new products. However, in terms of modernization of industries, these nations can be considered as laggards, because the present production processes appear to be carbon-intensive and energy-inefficient. In this backdrop, the present study, by using the second-generation econometric procedures, is intended to examine the impact of industrialization, export diversification, technological innovation, income inequality, and resource rents on the carbon dioxide emissions in the BRICS nations from 1990 to 2018. The long-run coefficients revealed that the industrial expansion, reduction in export diversification, low concentration on traditional exports, and high concentration on new exports exacerbated the air quality in the BRICS nations. On the other hand, technological advancement contributed to restoring environmental quality during the study period. Furthermore, it is observed that the present research endeavors in the BRICS nations are insufficient in circumventing industrial pollution, as the value of the joint coefficient of technological advancement and industrialization is found insignificant but negative. Hence, based on the computed results, a multipronged policy framework is proposed, so that these nations can achieve the targeted sustainable development goals (SDGs) in the coming years.

Keywords Industrialization · Export diversification · Extensive and intensive export margin · Technological innovation · BRICS nations

JEL classification L0 · O2 · C5 · F1

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Introduction

The developing nations like Brazil, Russia, India, China, and South Africa (hereafter BRICS) have embraced globalization and industrialization endeavors as catalysts for removing their socio-economic despondencies, especially after the 1990s. In order to widen domestic production and subsequently employment opportunities, governments in BRICS nations initiated liberal industrial and trade policies (Santiago 2020). Furthermore, by adopting the digital mechanism for banking and stock market services, governments aimed to create a favorable environment for potential investors (Di Maio 2015; Lee 2019). Consequently, these nations witnessed an upward trend in the number of registered companies (World Bank 2021). At the same time, the existing companies enlarged their capacities and diversified their product portfolios (Santiago 2020). The industrial expansion supported by the liberal trade policies and financial deepening encouraged firms to produce at a large scale for domestic and international markets (UNIDO 2019). As a result, the combined trade share of these five nations in the world trade reached 17% in 2013–2014, which in 2004 was merely 9.9%. Particularly, the exports from BRICS nations registered an annual growth of 15.9%, whereas the annual export growth rate across all nations increased by 8.8% during 2003–2004 to 2013–2014 (Export-Import Bank of India 2014). The escalation of exports unveiled new opportunities for BRICS nations, and these nations witnessed an increased demand for both traditional and new exportable items, which are named as intensive and extensive export margins, respectively in the literature (Shahbaz et al. 2019; Shahzad et al. 2021). However, due to the rising demand in domestic and international markets, manufacturing units might have increased the usage of energy solutions and other factors of production. In that case, the combustion of additional energy solutions might have raised the pollution levels in the BRICS nations, because these nations heavily rely on fossil fuels for energy requirements (Sinha and Sen 2016). In such kind of a situation, the widespread usage of advanced and energy-efficient technologies can reduce energy-led emissions (Chien et al. 2021; Hussain and Dogan 2021), and in order to achieve that, investment in research and development activities can play a crucial role. However, in the case of BRICS nations, the efficacy of research endeavors for reducing the industrial sector-led environmental pollution could be doubted, as the budgetary allocation to endorse research activities remained well below than advanced nations in the preceding years (Export-Import Bank of India 2014). On the other hand, rise in expenditures on industrial and trade promotions might have exerted additional pressure on the established ecosystem.

To corroborate the abovementioned discussion, it is important to investigate, whether industrialization and export diversification contribute to increasing the air pollution in BRICS nations. The incessantly increasing level of carbon emissions, especially in industrial cities like Mumbai, Kolkata, Beijing, Shanghai, Johannesburg, and Sao Paulo, provides support to our discussion. Furthermore, as per the report of IRENA (2018), the fifteen industrial cities of the BRICS nations are placed in the list of the top fifty dirtiest cities in the world. Even the literature supports that the increased usage of nonrenewable energy solutions for transportation, manufacturing, and routine activities (Sinha et al. 2020a) and energy-intense production procedures in industries (Dogan et al. 2020) might have raised the pollution level in industrial areas. If it is the case, then it requires restoring environmental quality without disturbing the economic growth pattern. To do so, there can be two possible solutions. First, it necessitates increasing the production and consumption of renewable energy solutions (Zafar et al. 2020). By implementing the clean energy infrastructure, BRICS nations will be able to achieve the goal of affordable and clean energy (i.e., SDG-7), which subsequently will help to achieve the goal of sustainable climate (i.e., SDG-13). Another route is to adopt the energy-efficient and low carbon–intensive production processes, so that industrial waste and air pollution can be reduced to the minimum level. By doing so, the goal of sustainable and resilient industrialization and innovation (i.e., SDG-9) can be achieved, which might subsequently help to reduce the atmospheric pressure and lead to sustainable economic growth (i.e., SDG-8) (Hussain and Dogan 2021). However, in the absence of synchronization between SDG-7 and SDG-9, the target to achieve SDG-8 and SDG-13 will not be possible, as an abrupt shift from nonrenewable to renewable energy sources may hamper industrial production, and subsequently employment generation and economic growth (Sharma et al. 2021). The continuous usage of nonrenewable energy solutions without investing in research and development (R&D) at the industrial level may foster industrial production and economic growth in the short run, but it may lead to health issues and energy deficiency in the long run. Therefore, by establishing the direct synergy between SDG-7 and SDG-9, both SDG-13 and SDG-8 can be achieved simultaneously. For doing so, these nations need to promote research and development so that green technologies and low carbon–intensive production processes across industries can be employed.

To mitigate the negative consequences of industrialization, the UNFCCC has also mentioned the need for technological innovation. Otherwise, the developing nations may witness an energy crisis, as the energy requirements in developing nations will increase by 50% by 2030 (UNIDO 2019). IEA (2020) in its report also mentioned that energy consumption at the industrial level could be reduced by 26%, if the advanced techniques of production to be adopted for large-scale production. To carry out the research and development agendas, these nations have increased their import bills (Tian et al. 2020). However, imported technologies might have an adverse impact on domestic producers (Mitra et al. 2014). Therefore, Zanello et al. (2016) and Rijesh (2020) advocated that knowledge transfer is more suitable for developing nations than technology imports, as the technology import experiences in the case of developing nations have not been found encouraging (Sharma 2018). Considering the nature of the BRICS nations, increased expenditure on technological improvement can be a solution to address low productivity, BoP deficits, energy deficiency, and, most importantly, environmental pollution. That is the reason the UNDP committee emphasized the need for quality education (i.e., SDG-4).

In this circumstantial setting, our objective is to investigate the impacts of industrial development, export diversification, and technological innovation on the carbon emissions in the BRICS nations. Thereafter, by examining the impacts of intensive and extensive export margins on carbon emissions, we intend to assess whether traditional and new exports can be appraised as the benefactors for environment fortification. Based on the study outcomes, we have recommended a policy framework to address the economic and environmental issues in these nations. While examining the impact of technological innovation on environmental quality, we constructed a technological index, so that the impact of research endeavors on environmental quality could be examined. We selected the post-industrialization period for the study (i.e., 1990–2018), because before this period the industrial base in the BRICS nations was apparently not matured. Generally, it is assumed that the upper stratum of a country receives the maximum benefits of industrial growth. Besides widening the income gap, the overexpansion of industries may put an undue burden on the natural resources of the country. Therefore, in the carbon emission function, we have introduced the Gini coefficient and natural resource rent as control variables. By including these variables, the possibility of the omitted variable bias is reduced.

As mentioned earlier, if industrial and export growth are major drivers of environmental pollution, then we need to develop a multipronged strategy so that these nations can shift from unsustainable to a sustainable growth track, and SDGs can be achieved within 2030. This proposed policy framework can be considered as the major contribution of the study, as we tried weaving the loose economic and environmental threads without disturbing the growth momentum. By spawning research and development atmosphere, these nations may be able to achieve the targeted SDGs, as the United Nations' (2018) latest report also earmarked the urgent need for technological up-gradation in the developing nations to reduce the economic and environmental negative externalities. Considering industrial value-added as a possible driver of environmental pollution, we departed from the previous studies, as most of the empirical studies have carried GDP growth as a proxy for economic growth and industrialization (Sinha et al. 2020a; Ahmed et al. 2021). Similarly, while testing the association between international trade and biodiversity, studies in the past ignored the segregated impacts of traditional and new exports on carbon emissions (Mutascu and Sokic 2020; Shahbaz et al. 2021). In his empirical study, Shahbaz et al. (2019) signified the role of export diversification in driving the demand for energy in the long run. For developing regions like BRICS, the impact of traditional and new exports on energy demand and subsequently carbon emissions cannot be denied. Therefore, it is required to examine whether these exports are exerting negative environmental externalities in the long run. If so, it requires redesigning export policy in such a manner that both targets, i.e., the export promotion and environmental fortification, could be pursued. To strengthen the policy framework, the role of socio-economic conditions and natural resources is vital and imperative. Therefore, we introduced income inequality and natural resource rent in the carbon emission function. These dimensions are an integral part of the economic endeavors; that is why they are placed in the SDGs as well. Lastly, by considering the modern computational approach (i.e., cross-sectional augmented distributed lag approach), we intended to generate reliable results as this approach handles the possible intercountry dependency effectively (Chudik et al. 2013).

The coming sections are organized as follows: the literature overview ("The literature examination"), the mechanism for computation ("Research methodology"), the results based on the considered data set ("Results and discussion"), concluding remarks ("Conclusion"), and policy endorsement ("SDG-based policy framework").

The literature examination

To establish the research direction for the present study, the literature section is bifurcated into two manners. Firstly, we reviewed the relationship between carbon emissions and their possible drivers namely industrialization, economic growth, income inequality, trade expansion, and natural resource rent. Thereafter, in the next section, we ponder upon the need to address the challenges involved in attaining the SDGs in both developed and developing nations.

Drivers of environmental pollution

Numerous studies have examined the nexus between environmental pollution and trade expansion (Ertugrul et al. 2016; Sharma et al. 2020; Dauda et al. 2021). These studies have considered the overall trade volume as a driver of environmental pollution. For example, the outcomes of the Hdom and Fuinhas' (2020) study reported that trade expansion is a key driver for carbon emissions in Brazil. Furthermore, the study found that the increased consumption of natural gases has also led to an increase in carbon emissions, whereas hydroelectricity and renewable energy fortified the air quality in the country. While examining the impact of trade expansion on carbon emission in India, Shahbaz et al. (2021) considered a nonlinear approach. The study reported that both upside and downside variations in trade expansion have influenced carbon emissions differently in the long run. By considering the sample of BRICS nations, Aydin and Turan (2020) revealed that the expansion in trade activities has reduced the ecological footprint in India and China during the study period (1996–2016). Contrarily, the increased usage of energy led to the deterioration of the environmental quality in all five countries. By deviating from the traditional proxy (i.e., trade openness), the study carried by Usman et al. (2020) captured the impact of trade uncertainty on the ecological footprint in the USA. For calculating the trade policy index, both exports and imports are considered in their study. Similarly, to assess the separate impacts of exports and imports on carbon emissions, Hasanov et al. (2018) considered the sample of oil-exporting countries. The computed long-run results confirmed that increased imports led to an increase in CO_2 emissions. On the other hand, the increased exports fortified the air quality because consumption-based carbon emissions were found negatively associated with the exports in the nine oil-exporting countries. Thus, based on the results, the study highlighted the need for the segregated examination of exports and imports while framing the environmental policy.

While examining the association between trade index and ecological footprint, Ahmed et al. (2021) followed the symmetric and asymmetric econometric procedures in their study. In the symmetric model, the association between both variables was found direct. It means globalization led to an increase in ecological footprint. However, in the asymmetric model, the impact of upside variation in globalization on ecological footprint remained negative, whereas downside variations led to an increase in ecological footprint. Similarly, Saud et al. (2020) in their study reported that increased globalization contributed to reducing the ecological footprint in the selected group of countries during the study period (1990–2014). Due to the extensive usage of advanced and energy-efficient production processes, the increased trade might have improved the established ecosystem in the considered nations. Therefore, from these diversified results, it can be contemplated that the association between carbon emissions and trade expansion may vary across times and countries, and these conflicting results motivated us to examine the association between export diversification and CO_2 emissions in the case of BRICS nations.

The literature confirms that economic growth may contribute to damaging the environmental quality of a country (Shyamal and Rabindra 2004; Kasman and Duman 2015; Adom et al. 2018; Alshubiri and Elheddad 2020). However, with the widespread usage of advanced techniques of production and low carbon–intensive energy solutions, the harmful impact of economic endeavors on air quality can be reduced (Alola et al. 2019; Sharma et al. 2020a). In the case of developed (Lazăr et al. 2019; Ahmed et al. 2021) and developing nations (Sinha and Bhattacharya 2016, 2017; Zaidi et al. 2019), this inverted U-shaped association is confirmed by various studies. Using the sample of BRICS nations, Chien et al. (2021) in their study confirmed a nonlinear and significant association between domestic production and carbon emissions. Furthermore, the study revealed a weak and strong association between both variables at the lower and higher quantiles, respectively. Similarly, Rehman et al. (2021) and Altinoz and Dogan (2021) confirmed a harmful impact of economic growth on the ecological quality in their respective studies during the study period. Similarly, by using the advanced econometric procedures, Sun et al. (2020), in their study reported that the increased domestic production initially widened the carbon emissions, but later on, its growth helped in fortifying the air quality in the OECED nations.

By considering the case of China, Liu and Bae (2018) in their study considered the industrial value-added as a determinant of carbon emissions. The results of this study confirmed the long-run harmful impacts of industrial value-added and economic growth on carbon emissions during the study period (1970–2015). Here, it needs to mention that the industrial infrastructure and scale of production may vary across countries. Therefore, the industrialization that led to carbon emissions may also differ significantly across nations. For example, the results of Sheinbaum-Pardo et al.'s (2012) study revealed that the manufacturing industries led carbon emissions in Mexico reduced significantly during the study period (i.e., 1990–2008). The widespread usage of modern techniques of production reduced the energy consumption in manufacturing industries, which in turn, reduced carbon emissions. Contrary, heavy industries (Zhongping et al. 2011) such as cement (Ke et al. 2012), iron and steel (Schino 2019), and thermal electricity plants (Sharma and Kautish 2020) are reported as the significant drivers of carbon emissions in the literature. In the support of this notion, Nejat et al. (2015) revealed that the excessive expansion of heavy industries is one of the major reasons for the growing environmental concerns in the top ten highly polluted countries. Therefore, it can be contemplated that industrial development can spur environmental pollution if adopted production techniques are not energy-efficient.

Besides environmental pollution, income inequality is another challenge for policymakers in developing regions, as a wider income gap in society may lead to consumption and production distortions (World Social Report 2020). The empirical studies support that income inequality may invigorate environmental pollution in the long run. For instance, the results of Chen et al.'s (2020) study confirmed that income inequality led to a reduction in carbon emissions in developing countries, whereas in the developed nations, the income gap has an insignificant effect on carbon emissions. Similarly, by considering the state-level data of the USA, Jorgenson et al. (2017) in their study confirmed that the influence of the top 10% income group on environmental quality remained more harmful than the bottom 50%. On the other hand, Hao et al. (2016) in their study revealed that the increased income gap widened the carbon emissions in China as a whole and more specifically in the eastern states of the country. In terms of pollution-inequality nexus, the results of Ridzuan's (2019) study are crucial, as the study has considered a sample of 174 countries. The computed results revealed that income inequality not only directly deteriorated the environmental quality but also influenced the turning points of the environmental Kuznets curve significantly. However, the results of Huang and Duan's (2020) study are contradictory to the previous study. In this study, Huang and Duan (2020) considered a pool of 92 countries and revealed a negative relationship between inequality and pollution. Furthermore, the study confirmed that the relationship varied at the different levels of income inequality. This kind of contradictory results motivated us to look at the association between income inequality and carbon emissions in the BRICS nations.

The need to strengthen the research and development to fortify the environmental quality is discussed through the literature in recent years, as modern production techniques may reduce all sorts of emissions in the long run. In this regard, the results of Jordaan et al.'s (2017) study exhibited that Canada needs to increase its research expenditure so that the widespread usage of cleaner energy solutions can be ensured. By promoting green energy, the country may address two issues simultaneously. Firstly, it will reduce fossil fuel dependency, and secondly, it will help in fortifying the environmental quality. In conformity with this, the UNCTAD (2019), in its report, acknowledged that technological advancement might enable developing nations to reduce production inefficiencies, environmental pollution, and income inequality. Similarly, Sinha et al. (2020b), by considering the sample of MENA countries, established an association between technological innovation and environmental quality. In the case of Bahrain, Iraq, Oman, and Libya, technological advancement fortified environmental quality in the long run. Contrarily, in the case of Israel, Kuwait, Qatar, and Saudi Arabia, the study recommended technological improvements, as at the higher quintiles, technological advancement deteriorated the environmental quality. Similar to the previous study, the results of Sinha et al.'s (2020a) study recommended improvement in technological investment in Asia Pacific nations because technological advancement contributed to raising the pollution level in the long run.

Industrial and economic growth not only exerts negative pressure on human beings but also on natural resources. For example, if the extraction costs of natural resources are high, the net economic gain from the extracted natural resources (i.e., natural resource rent) may reduce significantly. Furthermore, the extraction with redundant technologies may invigorate environmental pollution. Studies in the past also confirmed the long-run association between natural resources and environmental quality (Ahmed et al. 2016; Balsalobre-Lorente et al. 2018). In this regard, Bekun et al. (2019) in their study revealed that the increased natural resource rent distorted the air quality in EU-16 countries. The possible harmful environmental impact of natural resource rent may be due to the overextraction of the natural resources to realize the economic growth targets. In the same way, Nassani et al. (2019) confirmed mineral and gas rent led to an increase in carbon emission in the selected countries during the study period (1975–2017). Stating differently, the increased material pricing may have a positive economic effect but a negative environmental effect. In the context of BRICS nations, it is well justified to investigate the links between natural resource rent and carbon emissions because these nations appear to be the mass consumers of natural resources.

Focus to address SDGs

Focusing only on few SDGs such as SDG-8 and SDG-9 may deviate us from other SDGs. Therefore, it is necessary to develop a sustainable growth path so that the SDG-7, SDG-13, and subsequently SDG-4 can also be achieved. In this regard, Shahbaz et al. (2021), Reckien et al. (2017) and Kedir (2017), and Chien et al. (2021) provided directions to achieve sustainable growth where environmental conservation is also considered. In this connection, Sinha et al. (2020a) introduced the role of technological advancement to address the environmental challenges imposed by economic endeavors in Asia Pacific nations. Similarly, Dialoke (2017) highlighted the need for basic and technological education to sensitize society about the need for preserving the established ecosystem. Imaz and Sheinbaum (2017) designed the policy framework to strengthen economic growth and environmental quality through technology transfer. Consequently, Imaz and Sheinbaum (2017) recommended expediting inter-disciplinary researches so that all stakeholders could be benefited in the long run. Thus, in the present study, the policy void for addressing the environmental pollution led by export diversification and industrialization to be intended to bridge through technological innovation. Table 1 provides a summary of the past studies where different drivers of carbon emissions are being considered.

The examination of the literature suggests that the trade expansion (Hdom and Fuinhas 2020; Shahbaz et al. 2021), imports and exports (Salman et al. 2019; (Doytch 2020), domestic production (Rehman et al. 2021), and income inequality (Chen et al. 2020) could drive the carbon emissions in the long run. However, by considering the export quality and industrial value-added as drivers of carbon emissions, we may able to fill the existing research gap because developing nations heavily rely on exports and industrial output to pursue their growth-related targets. In this case, it is worth examining their potential impact on air quality so that economic growth could help in reducing environmental challenges in the coming years.

Research methodology

Theoretical underpinning

Production of diversified exportable items can be possible if a country has established different kinds of endogenous export-oriented industries. Furthermore, to ensure the regular supply of exportable items, the country needs to maintain the regular supply of human, technological, and natural resources. Here lies the caveat, because the additional usage of machinery and energy resources may widen the scope for environmental degradation, especially when these techniques and energy

Table 1 Detail summary of the literature

Author(s)	Region	Period	Method	Drivers	Impact on CO_2/ecological footprint
Ahmed et al. (2021)	Japan	1971–2016	NARDL	Globalization index	-ve coefficient
Alshubiri and Elheddad (2020)	OECD	1990–2015	GMM	GDP	N-shaped
Dogan et al. (2020)	BRICST	1980–2014	FMOLS, DOLS, AMG	GDP, energy structure	EKC not valid
Shahbaz et al. (2021)	India	1980–2019	NARDL	Trade openness	-ve coefficient
Mutascu and Sokic (2020)	EU	1960–2014	Wavelet	Imports	+ve coefficient
Rehman et al. (2021)	Pakistan	1971–2019	Quantile	Industrialization	+ve coefficient
Tian et al. (2020)	BRICS	1995–2015	Input-output model	GDP	+ve coefficient
Sharma et al. (2020)	South Asian nations	1980–2015	GMM	Trade openness	+ve coefficient
Huang and Duan (2020)	92 countries	1991–2015	Threshold effect	Income inequality	+ve coefficient
Sinha et al. (2020b)	Asia Pacific countries	1990–2017	Quantile	Technological	+ve coefficient
Sinha et al. (2020a)	MENA	1992–2016	Quantile-on-quantile	Technological	Mixed results
Jorgenson et al. (2017)	USA	1997–2002	Prais-Winsten regression	Income inequality	Mixed results
Bekun et al. (2019)	EU	1996–2014	PMG-ARDL	Resource rent	+ve coefficient
Zafar et al. (2021a, b)	Asian countries	1990–2018	CUP-FM	Resource rent	+ve coefficient

Source: Compiled by author(s)

resources are carbon-intensive. Even Shahbaz et al. (2019) and Shahzad et al. (2021) in their respective studies reported that the improvement in extensive and intensive export margins has driven energy demand in the USA and newly industrialized nations in the long run. As mentioned earlier, the industrial growth and export diversification in the BRICS nations have shown an upward trend, which in turn might have intensified the fossil fuel demand and subsequently environmental pollution. If this is the case, then these nations need to strengthen their research and development, so that the widespread usage of advanced techniques of production and low carbon–intensive energy solutions can be promoted across industries. At the same time, the promotion of technological innovation and renewable energy generation may improve the employment opportunities in the BRICS nations, which in turn may reduce the possible negative environmental impact of income inequality.

Sequentially, the industrialization might have allowed BRICS nations to diversify their export product basket. At the same time, it might have widened energy consumption, overutilization of natural resources, and environmental pollution. Another distinguishing feature in these nations is widening income inequality with the increased industrialization, which might be the outcome of a distorted socio-political environment. To break this sequencing, the investment in technological innovations can work as a savior provided all the stakeholders would share the benefits of the R&D. To be more specific, the effective usage of research and development may enable these nations to generate cost-effective, cleaner, and energy-efficient production processes. Besides, by generating green energy infrastructure in the far-flung areas, the negative pressure exerted on the natural resources can be reduced and new job opportunities in the rural areas can be created. In failing so, industrialization led to additional fossil fuel consumption, export promotion, and income inequality that may impose new challenges in the coming years. The BRICS nations can be considered in the group of industrialized nations or newly industrialized nations. However, these nations have yet to reap the benefits of technological innovations, especially in the industrial sector because the existing techniques of production appear to carbon-intensive. It means, in the nations, it is required to establish a synergy between economic and environmental endeavors, industrial and technological advancement, production and cleaner energy solutions, and socio-political and natural environment.

In the given scenario, we examined the impact of export diversification, extensive and intensive export margins, technological innovation, resources rent, and income inequality on carbon emissions in the BRICS nations from 1990 to 2018 where long-run elasticity coefficients are calculated using the CS-ARDL econometric approach (Chudik et al. 2013). The rationality behind using the CS-ARDL approach is mentioned in the subsequent section. Before using this procedure, we confirmed that data series are stationary and establish a long-run association. For the data stationary, we employed the CSADF and CIPS procedures, and for the cointegration, we relied on Westerlund's (2007) test values. Except for export diversification, all other series are retrieved from the World

Bank's (2021) database. For export diversification, the IMF (2019) has compiled the country-level data, which is based on the Theil index. The increasing values of this index represent the low level of both types of exports, whereas the decreasing values indicate the growing basket of exportable items where both types of exports expand. The results of correlation and multicollinearity are mentioned in Appendix (1A) and (3A), respectively. The data sources and definitions of the comprised variables are mentioned in Table 2.

By considering the long-run economic and conceptual linkages among considered variables, we proposed the econometric model, which is motivated by studies of Sinha et al. (2020a, b), Zafar et al. (2021a, b), and Shahzad et al. (2021):

$$EMI_{it} = \alpha_0 + \alpha_1 IND_{it} + \alpha_2 EXD_{it} + \alpha_3 TEC_{it} + \alpha_4 RRE_{it} + \alpha_5 INQ_{it} + \epsilon_{it} \quad (1)$$

In Eq. (1), EMI, IND, EXD, TEC, RRE, and INQ are carried to represent carbon emissions, industrialization, export diversification, technological index, resource rent, and income inequality, respectively. For the selected nations and period, we used symbols i and t, respectively. To assess the impact of the increased volume of the traditional exports, Eq. (1) to be replaced with equation (1a) where ITM represents the intensive export margin:

$$EMI_{it} = \alpha_0 + \alpha_1 IND_{it} + \alpha_2 ITM_{it} + \alpha_3 TEC_{it} + \alpha_4 RRE_{it} + \alpha_5 INQ_{it} + \epsilon_{it} \quad (1a)$$

Thereafter, to examine the environmental impact of the increased export demand for the new products in the BRICS nations, we employed Eq. (1b) where EXM is used to represent extensive export margin:

$$EMI_{it} = \alpha_0 + \alpha_1 IND_{it} + \alpha_2 EXM_{it} + \alpha_3 TEC_{it} + \alpha_4 RRE_{it} + \alpha_5 INQ_{it} + \epsilon_{it} \quad (1b)$$

Lastly, by calculating the value for the interaction coefficient (TEC*IND), we examined via Eq. (1c) whether the interaction between technological innovation and industrialization fortified the environmental quality in the BRICS nations. If the value of the interaction coefficient remains negative and significant, it signifies that technological advancement helps industries to reduce industrial production-led environmental pollution in the selected nations.

$$EMI_{it} = \alpha_0 + \alpha_1 IND_{it} + \alpha_2 EXD_{it} + \alpha_3 TEC_{it} + \alpha_4 \mathrm{RRE}_{it} + \alpha_5 INQ_{it} + \alpha_6 TEC{*}IND_{it} + \epsilon_{it} \quad (1c)$$

To create the technological index, we considered the number of submitted trademarks (TMK), patents (PTN), and trade grants received (GRA) in the $US by each country annually.

Table 2 Data sources and definitions

Name (variable)	Definition	Source	Positioning
CO_2 (EMI)	CO_2 emissions (m/t per head)	(World Bank 2021)	Variable to be explained
Industrialization (IND)	The companies listed in the share market (domestic companies, including foreign companies at the end of the year)	(World Bank 2021)	Focused independent variable
Export product diversification (EXD)	Overall change in the exports (in terms of existing and new products)	IMF	Focused independent variable
Intensive margin (ITM)	Addition in the value of exports due to the traditional products	IMF	Focused independent variable
Extensive margin (EXM)	Addition in the value of exports due to the new products and markets	IMF	Control variable
Resources rent (RRE)	It is calculated by adding oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents (% of GDP)	(World Bank 2021)	Control variable
Income inequality (INQ)	It is based on the distribution of income in society (Gini value 0 = perfect equality and 1 = perfect inequality)	SWIID, i.e., Standardized World Income Inequality Database	Control variable
Technology index (TEC)	Technology index is created using PCA where the log values of TMK, PTN, and GRA are considered	(World Bank 2021)	Control variable
Trademarks submitted (TMK)	Count of trademark submitted in each year	(World Bank 2021)	Control variable
Patents submitted (PTN)	Count of patents submitted in each year	(World Bank 2021)	Control variable
Research grant received (GRA)	Research grants received in each year ($US)	(World Bank 2021)	Control variable

The results are calculated using the natural logarithm values of the abovementioned variables

Source: Compiled by author(s)

After employing the principal component analysis on equation (2), we constructed the technological index.

$$TEC_{it} = \gamma_0 + \gamma_1 TMK_{it} + \gamma_2 PTN_{it} + \gamma_3 GRA_{it} + \epsilon_{it} \quad (2)$$

Figure 1 reveals that one variable has an eigenvalue of more than one; however, the other two factors are given weight according to the calculated factor loading values. The correlation among the considered R&D variables is given in Appendix (2A).

Mechanism to calculate export product diversification

As mentioned earlier, with the industrial and economic growth of a country, the export demand for new products in the existing and new markets may increase, which is named as the extensive export margin. On the other hand, the increased export demand for the existing or traditional export items is mentioned as the intensive export margin. The increased demand for the existing products and new products in the existing markets and new markets together is known as export diversification. By using the extensive and intensive trade margin data, which is given by the IMF (2019), we constructed the export diversification index. Developing the Theil index, the annual export diversification is calculated using Eq. (3) for each country:

$$EXM_b = \sum \mathrm{n}\left(\frac{E_n}{E}\right)\left(\frac{M_n}{M}\right)\ln\left(\frac{M_n}{M}\right) \quad (3)$$

In Eq. (3), existing, new, and nontraded items are represented by n. The symbol E_n represents the total exported items and M_n/M is used to represent the relative average value of exports by each country. Similarly, we calculated the Theil index for the intensive margin by using equation (3a):

$$ITM_b = \sum \mathrm{n}\left(\frac{E_n}{E}\right)\left(\frac{M_n}{M}\right)\left\{\frac{1}{E_n}\right\}\sum \mathrm{i}\psi 1\mathrm{n}\left(\frac{y_i}{M_n}\right)\ln\left(\frac{y_i}{M_n}\right) \quad (3b)$$

In Eq. (3b), y represents the export worth for i nation. The export diversification index is calculated based on the average values of both types of margins.

Second-generation tests for cross-country convergence, stability, and cointegration

Due to globalization, the BRICS nations have gone through socio-economic transitions. Therefore, the possibility of interdependency in terms of production and consumption cannot be denied. In this expectation, we employed Pesaran's (2004) and Breusch and Pagan's (1980) tests, which are capable of confirming/rejecting cross-nations dependency. The insignificant p-values of these tests are against the cross-country dependency, whereas the significant p-values confirm the inter-country convergence. Pesaran's (2004) CD test is appropriate if the paneled countries are sufficiently large and the considered period is short. On the other hand, the Lagrangian Multiplier test needs to employ in the case of a small group of countries. In Eq. (4), pair-wise correlation (co), period (pe), and country-panel (cp) are used to confirm the possible interdependency (acd) among BRICS nations.

$$acd = \frac{\sqrt{2pe}}{cp(cp-1)}\left(\sum_{i=1}^{cp-1}\sum_{q=l+1}^{cp}\mathrm{co}_{iq}\right) \quad (4)$$

We employed the second-generation stationarity tests, i.e., augmented Dickey-Fuller and Im-Pesaran-Shin, which confirm/reject series stationarity in the presence of the inter-country convergence. These tests in the study are named CADF and CIPS, respectively. The CADF test values are to be calculated by considering the mean-value-based inter-country dependency, whereas the CIPS test computes statistics for each country after addressing the cross-country reliance (Sharma et al. 2020a). To save space, we ignored the econometric treatment for these tests.

In succession, the next target to confirm the long-run association between carbon emissions and considered independent

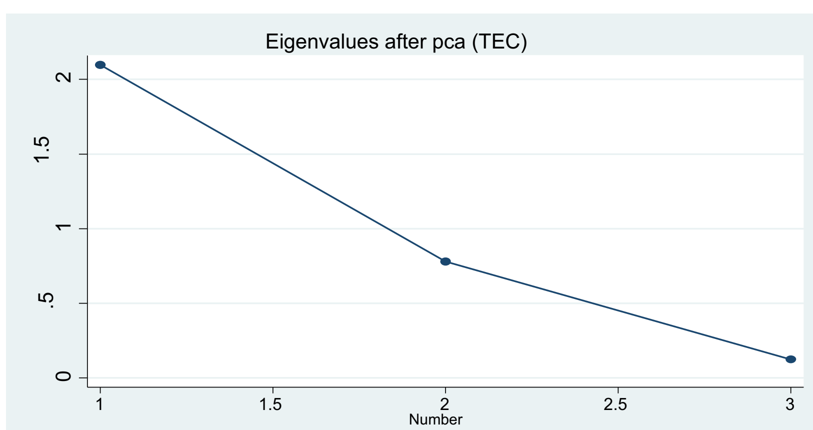

Fig. 1 Results of the principal component analysis

variables. For doing so, we considered the Westerlund (2007) test because it confirms/rejects association by addressing the inter-country dependency. This test generates four distinct values and considers the error correction term while calculating the cointegration. The calculated significant values represent the long-run association among model variables.

Mechanism to calculate the long-run and short-run coefficients, i.e., the CS-ARDL approach

Chudik et al. (2013) proposed the mechanism to calculate the long-run common coefficients if the considered variables depict the inter-country dependency. The CS-ARDL approach generates the speed of adjustment and short-run and long-run coefficients for the considered model. Another advantage of this approach is that it navigates the common inter-country economic shocks. Besides, this approach efficiently handles the structural discontinuity if it is there during the study period. However, in comparison to CS-DL (cross-sectional distributed lag approach), this approach is more sensitive towards lag-length selection. All the diagnostic tests are in favor of the CS-ARDL approach; therefore, in the next section, we provided the computed long-run and short-run results and their analysis.

Results and discussion

To begin with, by employing the cross-sectional dependence tests, we observed that the comprised variables have exhibited inter-country dependency during the study period, as the results mentioned in Table 3 are against the null hypothesis of the absence of cross-sectional dependency. It means the traditional stationarity tests are not sufficient for establishing the stationarity properties. Therefore, we considered the CADF and CIPS tests for this purpose. Table 4 reveals the results of these tests, where we confirmed that all the series possess stationarity properties at the first lag. Stating differently, despite having inter-country dependency, at the first level, all series are stable. For doing so, we confirmed the stationarity with constant and trends; however, to save space, the results with the constant are exhibited in Table 4.

In succession, it is required to confirm the long-run association between carbon dioxide emissions and its considered drivers, so that the common policy framework can be developed. In this regard, we employed Westerlund's (2007) test because the traditional cointegration tests in the presence of the cross-country convergence may provide misleading outcomes. Westerlund's (2007) test results mentioned in Table 5 are in the support of the adopted modeling frameworks, as the three different carbon dioxide functions with export diversification, extensive, and intensive export margins, respectively, are found cointegrated in the long run. The statistical verifications of the abovementioned tests allow us to adopt the CS-ARDL econometric approach to calculate the common coefficients for the BRICS nations.

The CS-ARDL results

While examining the impact of industrialization on carbon emissions, all models confirmed that the environmental quality deteriorated with the expansion of industries in BRICS nations, as the coefficients for industrialization are found positive and statistically significant. It means the industrial growth generates an exodus from the SDG-13. Therefore, it can be contemplated that the industrial growth pattern is not environmentally sustainable in the BRICS nations. While considering the case of developing Asian economies, Zafar et al. (2020) in their study observed that industrialization has invigorated environmental pollution in the long run. Therefore, developing nations need to cultivate a long-term industrial strategy, which should be pro-environment and not pro-growth alone.

As far as the role of technological advancement is concerned, it is observed that the R&D endeavors helped in reducing carbon emissions in the BRICS nations, as the coefficients of technological innovation (TEC) are found negative and significant in all models (i.e., Model I to Model IV). Therefore, it can be considered that technological advancement helped these nations to restore the established ecosystem in the BRICS nations. However, the results of Sinha et al. (2020a) are different from our study, as the study reported the harmful effect of technological advancement on environmental quality in the Asia Pacific nations. The harmful impact of technological advancement may be due to the difference in industrial development and technological investment. As we know, the majority of Asia Pacific countries have not invested a sufficient amount in strengthening the research and development environment. Thus, it can be ascertained that technological advancement may widen the environmental pollution if the investment in developing research infrastructure is not sufficient and the overall research environment in a country is distorted.

While examining the impact of natural resource rent on carbon emissions, we observed that the relationship between both remained positive but insignificant across all models. However, the calculated p-values in these models are found near to 15% significance level. Therefore, it can be considered as a warning signal because overutilization of natural resources in the BRICS nations may impose serious environmental challenges in the coming years. Bekun et al. (2019) in their study revealed that the natural resource rent widened the scope for carbon emissions in the European Union countries. Similarly, by using the case of Asian countries, Zafar et al. (2021a) in their study observed a direct impact of resource rent on carbon emissions in the long run. Thus, instead of relying

Table 3 Test for cross-sectional dependency

Variables	Breusch-Pagan LM	p-value	Pesaran scaled LM	p-value	Pesaran CD	p-value
EMI	92.529***	0.000	17.336***	0.000	4.861***	0.000
IND	140.555***	0.000	28.075***	0.000	−2.948***	0.003
EXM	101.450***	0.003	19.330***	0.006	−2.738***	0.006
ITM	159.615***	0.000	32.337***	0.000	12.444***	0.000
TEC	210.194***	0.000	43.646***	0.000	14.443***	0.000
RRE	126.063***	0.000	24.834***	0.000	10.789***	0.000
INQ	138.914***	0.000	27.708***	0.000	10.778***	0.000

Source: Based on the author(s) calculations

Notes: "***" confirms alternative hypothesis of cross-country dependency at the 1% significance level

on nonrenewable natural resources such as oil, coal, and metals, the BRICS nations need to develop a sustainable growth strategy where the usage of renewable natural resources should be promoted. Otherwise, the excessive exploration of natural resources may deteriorate the air quality significantly if industries in the BRICS nations continued their production with the present techniques of production.

Another distinguishing feature in the BRICS nations is the widening income gap in society. It appears that the income gap has not only raised socio-economic challenges but also environmental concerns in the BRICS nations. It is evident from the association between the Gini coefficient and CO_2 emissions, as in all models the coefficients of income inequality are found positive and significant. It means the income gap has contributed to raising the environmental pollution in the BRICS nations. Now, a relevant question arises that why income inequality raises carbon emissions. A society with equal distribution of income is considered more sensitive towards social and environmental aspects and encourages people to embrace new production techniques and hygienic lifestyle (Vona and Patriarca 2011). Contrarily, the society with the unequal distribution of income prefers to rely on cheaper energy resources such as kerosene oil, coal, biomass, and wood. Therefore, income inequality with a mass population base may generate a departure from environmental conservation. In the confirmation of the above discussion, Chen et al. (2020) in their study revealed that income inequality has invigorated the carbon emissions in the G-20 nations in the long run. Similarly, by considering the case of India and China, Wolde-Rufael and Idowu (2017) reported the harmful impact of income inequality on environmental quality in the long run.

In Model (1), we observed the direct association between export diversification and carbon emissions in both periods. As we know, the increased value of the Theil index represents the low level of export diversification. Therefore, we can ascertain from the results of Table 6 that the lack of export diversification exacerbated carbon emissions in the BRICS nations. Here, it appears that the BRICS nations have not reaped the benefits of exports because the present export basket appears to be energy-inefficient and carbon-intensive. In support of this notion, the results of Khan et al. (2020) revealed that the energy demand in the 10 developing economies intensified due to the low level of product diversification during the study period. As we know, the increased energy demand may contribute to raising the carbon emissions if the additional energy requirements are fulfilled by using nonrenewable energy solutions. In the case of the BRICS nations, the widespread usage of nonrenewable energy usage in export-oriented industries appears to be a cause of the export-led carbon emissions. Stating differently, the low level of export diversification (i.e., sticking with the traditional product in the traditional markets) might have discouraged exporters to operate with the advanced techniques of production, and the usage of obsolete machinery might have led to carbon emissions during the study period.

To get comprehensive information about the export-environment nexus, we segregated the export diversification index into intensive and extensive export margins. As mentioned earlier, the intensive export margin is based on the

Table 4 Second-generation unit root tests (CIPS and CADF)

Variables	CIPS (level)	CIPS (1st diff.)	CADF (level)	CADF (1st diff.)
EMI	−2.733	−3.856***	−2.703	−3.841***
IND	−1.522	−2.388**	−1.525	−2.573**
EXM	−1.426	−3.232***	−1.739	−2.858*
ITM	−1.257	−4.426***	−1.766	−3.587***
TEC	−2.687	−4.492***	−2.867	−4.655***
RRE	−1.225	−5.227***	−1.589	−5.383***
INQ	−2.169	−2.541**	−2.455	−2.988**

Source: Based on the author(s) calculations

Notes: "***", "**", and "*" are confirming alternative hypothesis of series stability at the 1%, 5%, and 10% significance levels, respectively

Table 5 Westerlund's cointegration test

Statistic	(Z value) With export diversification	(p-value)	(Z value) With extensive margin	(p-value)	(Z value) With intensive margin	(p-value)
Gt	−3.367***	0.003	−2.988***	0.008	−3.033***	0.025
Ga	−9.922**	0.018	−10.169***	0.008	−9.951***	0.028
Pt	−11.063***	0.000	−7.882***	0.000	−11.499***	0.000
Pa	−14.742***	0.000	−12.106***	0.000	−15.710***	0.000

Source: Based on the author(s) calculations

Notes: "***", "**", and "*" confirming the alternative hypothesis of long-run association at 1%, 5%, and 10% significance levels, respectively

exports of the existing or traditional exportable products whereas the extensive margin is based on the new exportable products in new markets. In Model (II), the coefficient (0.155, p-value 0.038) of the intensive margin (Model II) is found positive and significant. This indicates that the decreased concentration on traditional exports (i.e., the increased Theil index values for intensive export margin) led to an increase in the carbon emissions in the BRICS nations. In other words, by increasing the exports of traditional products, these nations can have twin benefits; firstly, it will generate export earnings;

Table 6 The CS-ARDL results

Variables	Coef. With EXD (Model I)	p-value	Coef. With ITM (Model II)	p-value	Coef. With EXM (Model III)	p-value	Coef. With TEC*IND (Model IV)	p-value
Long-run results								
IND	0.326***	0.001	0.144**	0.022	0.300***	0.007	0.334***	0.001
TEC	−0.065*	0.070	−0.031**	0.040	−0.108*	0.068	−0.070*	0.073
RRE	0.023	0.110	0.024	0.150	0.035	0.150	0.035	0.163
INQ	0.109*	0.023	0.155**	0.038	0.153	0.108	0.142*	0.002
EXD	0.253***	0.005	-	-	-	-	0.250***	0.003
ITM	-	-	0.318***	0.003	-	-	-	-
EXM	-	-	-	-	−0.154**	0.042	-	-
TEC*IND	-	-	-	-	-	-	−0.023	0.428
Short-run results								
ECM	−0.423**	0.029	−0.192**	0.016	−0.335*	0.099	−0.437*	0.066
IND	0.510***	0.001	0.180**	0.022	0.422***	0.004	0.524**	0.003
TEC	−0.103	0.111	−0.037**	0.027	−0.014	0.824	−0.103*	0.080
RRE	0.036*	0.095	0.026	0.232	0.048	0.136	0.067	0.138
INQ	0.186**	0.034	0.209**	0.035	0.274	0.106	0.231***	0.004
EXD	0.413**	0.012	-	-	-	-	0.391***	0.005
ITM	-	-	0.397***	0.002	-	-	-	-
EXM	-	-	-	-	−0.258	0.120	-	-
TEC*IND	-	-	-	-	-	-	−0.015	0.671
CD test	−1.62	1.110	−0.810	0.419	−1.42	0.155	−0.16	0.871
F-stat	2.65***	0.00	2.640***	0.00	6.44***	0.00	1.68*	0.070
Test for omitted variables (Ramsey RESET)	1.350	0.256	1.540	0.161	0.131	0.274	1.80	0.149
Test for normality (Breusch-Pagan)	0.610	0.435	0.170	0.676	1.04	0.307	0.64	0.422

Source: Based on the author(s) calculations

Notes: "***", "**", and "*" are confirming significant impacts at the 1%, 5%, and 10% significance levels, respectively and secondly, it will help in conserving environmental quality in the long run. In the international markets, the export opportunities for traditional products are limited because other exporters, quality of the products, supply uncertainty, and socio-political tie-ups may challenge the expansion of traditional exports (Anand et al. 2015). This appears to be the case for BRICS nations; otherwise, by increasing the intensive export margin, these countries might have generated the economic and environmental externalities.

In Model (III), we intended to examine the impact of extensive export margin on carbon emissions. The long-run coefficient (−0.154, p-value = 0.042) of the extensive export margin revealed that the increased exports of new products in the new markets damaged the environmental quality in the selected nations. To increase the exports of new products and to capture new markets, the BRICS nations might have used the energy-inefficient and carbon-intensive production procedures, which in turn might have widened the scope for carbon emissions in the long run. Here, it needs to be remembered that the market for a new exportable product will be more competitive. As to penetrate the new market, the price and quality or at least the price of the product should be competitive. In the quest to remain competitive in the international markets, the exporting firms may produce at the bulk level so that they can enjoy the economy of large-scale production like China. However, this approach may generate an exodus from environmental conservation drive because the existing techniques may intensify the energy consumption, which in turn may lead to an increase in carbon emissions. In the case of the BRICS nations, the excessive dependency on nonrenewable energy by the export-oriented industries might have generated environmental externalities in the same fashion. To sum up, by increasing the exports of traditional products and by improving the production techniques for new exportable products, the BRICS nations will be able to improve their export earnings without compromising environmental quality. In the past, studies have ignored the role of export diversification on environmental quality. Therefore, the results of the study are vital to frame a synchronized strategy for the newly industrialized nations, as these nations often witness a tradeoff between economic growth and environmental pollution, renewable and nonrenewable energy solutions, and domestic trade and international trade. While determining the energy demand function, Shahzad et al. (2021) in their study observed that the increased export diversification contributed to reducing energy demand in the long run. Subsequently, the reduced energy usage might have led to a decrease in carbon emissions in the selected newly industrialized nations.

Furthermore, to examine the synergy between technological advancement and industrial expansion in achieving the low carbon economy, we introduced a joint coefficient (TEC*IND) in Model (IV). It is evident from the joint coefficient that technological advancement combined with industrialization unable to reduce carbon emissions in the BRICS nations. In other words, investment in research and development might have driven industrial expansion. However, the usage of advanced technologies in the industrial sector unable to reduce carbon emissions significantly because the value of the joint coefficient (−0.023, p-value = 0.428) is found negative but insignificant. It means the BRICS nations have to increase their R&D activities so that the industrial development, export diversification, and subsequently environmental conservation drive can be carried out. To examine the direction of the association between considered variables, we employed the panel causality test. The results of this test are given in Appendix (A4).

From these results, we can ascertain that the growth in industrialization and widening income inequality contributed to raising the carbon emissions in the long run because coefficients of these two variables are found positive across models. Similarly, carbon emissions are directly influenced by export diversification (Model 1) and intensive exports (Model II) during the study period. On the other hand, across models, the impact of technological innovation on carbon emissions remained negative in the BRICS nations. Similarly, an increase in new exports (i.e., extensive margin) helped to reduce carbon emissions during the study period. While examining the association between resource rent and carbon emissions, we observed that the coefficients of resource rent remained positive but insignificant across models. Thus, the BRICS governments need to employ such kind of strategy that may reduce the excessive usage of natural resources so that the possible harmful impacts of resource rent on air quality could be avoided.

Conclusion

The ongoing policy framework enabled BRICS nations to widen their industrial base; consequently, the per-capita income and export diversification witnessed an upturn in the recent past. However, it appears that the industrial expansion might have exacerbated the environmental quality in these nations because the R&D endeavors to reduce industrial pollution are not initiated seriously in the BRICS nations. Thus, in terms of achieving the SDG-13, SDG-7, SDG-4, and SDG-8, these nations need to consider a holistic framework. Otherwise, the tradeoff between economic growth and the established ecosystem may continue to prevail in the coming years as well.

In this setting, in the present study, firstly, we intended to investigate the impact of industrialization, export diversification, and technological innovation on carbon emissions for the period of 1990–2018. Income inequality and natural resource rent are carried as the controlled variables. Thereafter, we designed a policy framework, which is based on the needed synergy between identified SDGs. In this process, we segregated the export product diversification into the extensive and intensive export margin so that the influence of traditional exports and new exports on environmental quality can be measured. Considering cross-country dependence, we employed second-generation diagnostic tests. To calculate the coefficients, we adopted the CS-ARDL approach, which allowed obtaining short-run and long-run coefficients after addressing the inter-country convergence.

The outcomes of the study revealed that industrial growth, less-diversified export-basket, low concentration on traditional exports, and high concentration on new exports exacerbated the air quality in the BRICS nations. On the other hand, the impact of technological advancement on carbon emissions is found negative in the selected countries. From the computed results, it can be contemplated that technological advancement and more concentration on traditional exportable products might contribute to fortifying the environmental quality in the BRICS nations. By weaving a policy framework around technological advancement, these nations can address several issues (i.e., equitable distribution of income, modernization of industries, export earnings, economic growth, and most importantly, environmental conservation) simultaneously.

SDG-based policy framework

In terms of the policy framework, the abovementioned results are vital because they highlighted the need for synergy among various economic and environmental issues. The computed results revealed that the industrial growth pattern, income inequality, natural resource rent, export diversification, and extensive export margin are harmful to the environment in the BRICS nations. However, the increased R&D and intensive export margin are found environment-friendly during the study period (i.e., 1990–2018). Here, it can be argued that the existing growth pattern is socially and environmentally unsustainable in these nations because despite expanding the industrial base and per-capita income level, the income distribution is highly imbalanced and appears to be a cause of unsustainable consumption. Therefore, it is recommended to reframe their economic and environmental strategy where technological advancement can work as a positive mediator.

To reduce industrial pollution, these nations need to embrace advanced and energy-efficient techniques of production. However, merely promoting technological advancement at the industrial level might not be sufficient to safeguard the environmental quality, as the demographic structure of BRICS nations is dominated by majorly marginalized population. Therefore, we need to address the problem from the bottom of the pyramid. In doing so, income inequality needs to be reduced, so that the constructive participation of the population in economic growth can be ensured. Hence, by allocating additional budget for human capital development, policymakers need to uplift the literacy level in the BRICS nations. At the same time, these nations should imbibe vocational education in their curriculum. This strategy may have threefold benefits: first, it will ensure the supply of skilled labor, which may open new employment avenues in the industrial sector. Second, it may strengthen the research environment in these nations, which in turn may improve the existing production processes, and subsequently improve environmental quality. Third, by educating people, the environmental conservation drive might be easier to achieve, as educated society is expected to be more sensitive towards environmental issues. To finance this policy initiative, firms with higher carbon footprint can be considered for special environmental tax, so that the negative environmental externality exerted by those firms can be internalized.

Along with this policy initiative in place, policymakers need to reduce reliance on fossil fuels, and so, the widespread usage of renewable energy solutions across all industries need to be promoted. However, first of all, the firms with higher carbon footprint need to be encouraged to adopt renewable energy–based techniques, provided such production techniques are available against easy availability of credit. Here comes the need to invest in technological innovation. After shifting these firms towards renewable energy solutions, other firms gradually need to be shifted towards renewable energy. At this juncture, it needs to be remembered that a sudden shift from existing practices to new technology may disturb industrial growth, and then it may lead to unemployment. At this level, a country requires a sufficient supply of renewable energy resources. With the help of skilled labor force and technological advancement, new renewable energy plants can be started in rural areas. In this phased manner scheme, without disturbing the industrial production, governments can create new employment avenues in rural areas. This will help in reducing labor migration and income inequality. At the same time, the labor force displaced from the nonrenewable energy sector to be adjusted in the renewable energy generation.

Till the capacity of ingenious technological innovations is built, the policymakers might import green technologies from other countries. Though it may have an adverse effect on the balance of payments, the widespread usage of advanced technologies in the domestic firms may invigorate the extensive export margin, which in turn may reduce the deficit in the balance of payments, while reducing the carbon emissions. At this stage, the industries involved in exporting traditional products should also be forced to adopt advanced techniques of production. For promoting this, once again, governments can provide required subsidies or tax holidays to traditional export-oriented industries, so that both targets, i.e., export earnings and environmental conservation, can be achieved.

To sum up, the goal of sustainable growth (SDG-8) and environmental conservation (SDG-13) is difficult to achieve if people are not contributing positively in the long run. To ensure the positive contribution of all stakeholders, these nations need to reduce income inequality, which can be done by investing in human capital development (i.e., SDG-4). As we know, the skilled labor force not only helps in strengthening the research environment and modernization of industries (SDG-7) but also contributes to preserving the established ecosystem (SDG-13). Subsequently, the modernization of industries will help in increasing extensive and intensive export margins without damaging environmental quality.

The inclusion of variables such as human capital and imports might have provided a comprehensive picture about the phenomenon under study. Due to the data unavailability, we did not consider the fiscal policy indicators, which might have broadened the dimension of the study. Nevertheless, the proposed framework with the considered variables may help to redesign the future growth strategy for other nations as well provided the socio-economic settings of those nations are in line with the BRICS nations.

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Data availability We have prepared the data set, and can be submitted as and when it is required.

Declarations

Ethical approval While preparing the manuscript, to the best of our knowledge, we have followed the required ethical procedures.

Consent to participate We have consent of all authors and respective institutions to communicate the manuscript for consideration in the Journal.

Consent for publication We confirm that if the paper is accepted, it could be published in this prestigious journal.

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