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Political Risk and Sustainable Development: Digitization and Environmental Policy Stringency

Chong Zhang, Menglu Zhang, Yunqiu Zhan, Jiale Yan

Chong Zhang (email: zhangchong@nbufe.edu.cn), College of International Economics and Trade, Ningbo University of Finance and Economics, Ningbo, China; Ningbo Philosophy and Social Science Key Research Base "Research Base on Digital Economy Innovation and Linkage with Hub Free Trade Zones", Ningbo, China

Menglu Zhang (*corresponding author*, email: zhangmenglu0504@outlook.com), School of Public Finance & Taxation, Guangdong University of Finance & Economics, Guangzhou, China

Yunqiu Zhan (email: zhanyunqiu0688@outlook.com), School of Marxism, Chengdu Technological University, Chengdu, China

Jiale Yan (email: jiale230253@outlook.com), College of Letters and Science, University of California, Berkeley, CA, USA

Abstract

Emerging economies are consistently targeting advanced approaches to attain sustainable development while reducing their risk exposure and factors simultaneously. This research examines the influence of political risk, digitization and environmental policies, along with a set of economic and environmental factors, on the sustainable development of the BRICS economies. For the period from 1990 to 2020, the diagnostic tests confirmed a mixed order of integration. Therefore, the autoregressive distributed lag test is utilized and the results show that political risk, mineral resources and exports are harmful to sustainable development in the short run but significantly enhance sustainable development in the long run. On the other hand, environmental technologies are positively associated with sustainable development in the short run but transform into negative development in the long run. These diverse influences occur in the short and long run. The results indicate a consistent influence of digitization (positive) in both the short and long run. The long-run results are authenticated using panel fully modified ordinary least squares (FMOLS). Furthermore, the panel causality test validates diverse inferences regarding the causal association between the variables. Following the empirical outcomes, we recommend policies regarding equitable implementation of digital technologies, enhanced investment in environmental and green technologies, equitable resource management and a reduction in political risk, which could stimulate sustainable development.

Keywords: Political risk, sustainable development, digitization, policy stringency, ARDL, BRICS, mineral resources

Jel Classification: G38; O13; F59

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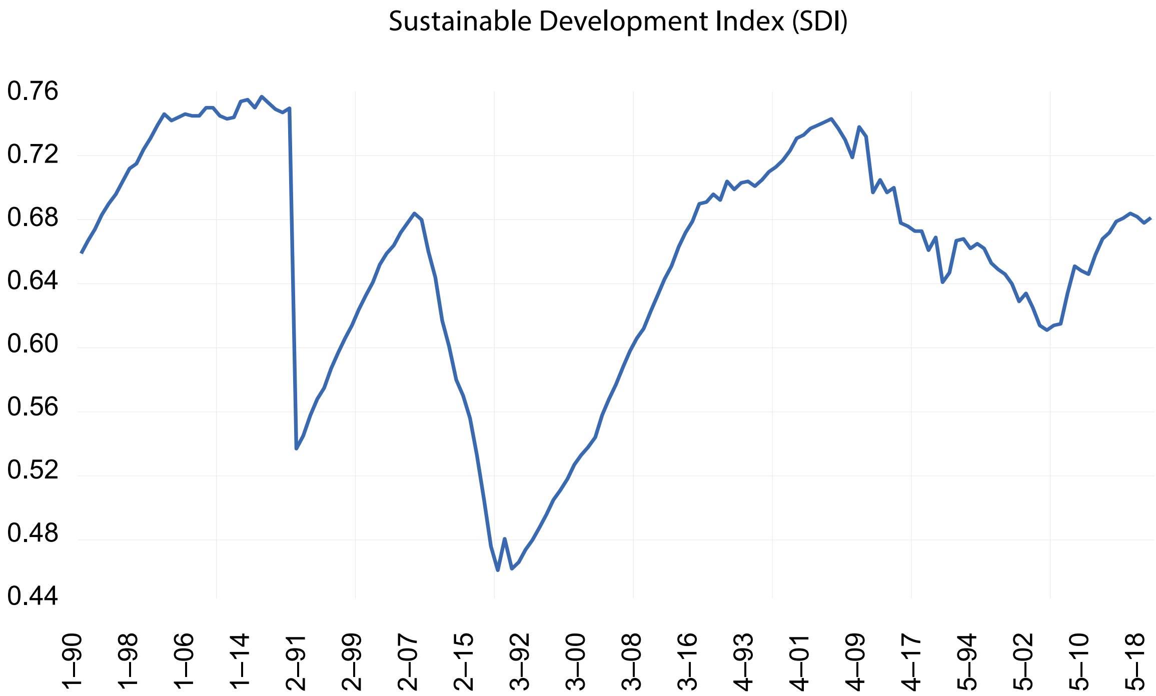
1. Introduction

Sustainable development (SD), which combines economic well-being, social justice and environmental integrity, is one of the most critical objectives pursued by countries globally. SD implies a careful balancing act between economic development and social progress while still ensuring negligible to zero damage to the environment or preserving the capacity to renew prior damage (Navea and Oyarzún, 2024). When viewed through this lens, it becomes clear that no consideration of SD is complete without including BRICS countries. The BRICS bloc includes the world's most significant contributors to economic growth and the environment and they present high levels of complexity regarding achievement of SD outcomes. In this respect, the countries that comprise BRICS differ even more than they do globally and see differentiated causes of systems and market structure inefficiency. Therefore, the primary objective of this research is to evaluate the determinants of SD in BRICS countries, where several important factors, such as political risk, environmental policy stringency and digitization, are of paramount importance. As shown in Figure 1, the sustainable development index (SDI) is rapidly increasing in Brazil (1), Russia (2) and India (3) but is ambiguous in China (4) and South Africa (5). The key reasons for increasing SDI are the improvement of educational level, health care and deforestation reduction in Brazil (O'Neill *et al*., 2018). Also, Russia has improved its life expectancy and educational attainment (O'Neill *et al*., 2018), while India has significantly improved its economic performance, reduced poverty and provided access to basic services (Hickel, 2020). On the contrary, the ambiguous situation in China and South Africa is mainly due to several reasons. These economies have admittedly somehow improved their human capital and educational levels. Still, due to the challenges of increasing environmental risks, these economies are lagging behind compared to the rest of the countries (J. Sachs *et al*., 2022; C. Wang *et al*., 2024). Therefore, there is a need for time to evaluate the drivers of SDI in the said region for the long-term prosperity of the region.

The 28th Conference of the Parties (COP28) to the United Nations Framework Convention on Climate Change, which recently convened in Dubai, could be seen as an important step in achieving the SD goals. The conference was geared to increasing the speed of implementing climate measures and to issues felt by developing countries, particularly the BRICS countries. Another outcome was the decision on the implementation plan of the loss and damage fund, especially for countries and communities on the frontlines of the climate crisis. The conference also pledged to raise the renewable power capacity three times by 2030 and realized the necessity to shift from fossil fuel-based energy systems, as the use of renewable energy is more sustainable (Kirikkaleli and Adebayo, 2021). More specifically, the focus on the emerging economies in tackling global warming was highlighted, specifically as regards technology sharing, funding and capacity development. The COP28 also highlighted a way of showing concern on how the BRICS countries can grow in terms of economy and, at the same time, protect the environment. On that basis, many of the initiative's measures that were signed and praised as progressive during the COP28 were criticized saying that the world needs practical and more radical actions and effective implementation of the SD goals. Therefore, it is crucial to empirically analyse the factors influencing SDI in the context of emerging countries.

Figure 1: Sustainable Development Index of BRICS economies



Source: Authors' own elaboration

Political risk is a relevant determinant of the impact of governance stability and effectiveness on the climate, facilitating economic and social development. This factor has been studied in various sources, notably by Globerman and Shapiro (2003), to exemplify the role of political risk in shaping investment decisions and the effectiveness of policies underlying sustainability theories and perspectives. Political risk is a multidimensional concept that entails political instability, policy uncertainty, regulatory volatility and governance deficiencies, among others, which directly affect the operating environment for businesses, investors and policymakers. Due to this variation, political risk as a determinant of investment determinants and economic performance, similar to the other determinants, may be critical (Kaufmann *et al.*, 2010). For instance, it can be reflected through geopolitical tensions, social instability and governance failures, which in turn reduce confidence in the level of stability and predictability of the environment. Additionally, political risk is instrumental in determining the level of FDI inflow, for instance, and outflow, in most cases, with high levels of political risk being associated with low levels of inflows (Asiedu, 2006). Indeed, political stability patterns are also relevant for determining which investments are likely to reach the developed state; hence, the high level of correlation between political stability investments and growth and sustainability. Beyond intradisciplinary dependencies, political risk also influences policy-making and, during implementation, political instability can easily derail otherwise a sound policy that would have been sustainable.

Similarly, environmental policy stringency is a critical determinant of SD outcomes. That is, stringent environmental policies are necessary and instrumental in reducing environmental degradation, reducing pollution levels and promoting sustainable resource management. Scholars emphasize the critical link between stringency and the outcomes achieved through environmental policies. For instance, countries with stringent environmental policies attract more FDI than those with weaker ones (Lundh, 2017). This means that such policies not only contribute to environmental sustainability but also make a country more attractive to investors. Furthermore, scholars have also proven the relationships between such stringency and environmental quality and health. Specifically, more restrictive environmental policies are related to a significant reduction in air pollution (P. Li *et al*., 2021). In addition, stricter environmental policies correlate with better health outcomes, such as low mortality and respiratory disease incidence (Sohag *et al*., 2021; Xie *et al*., 2023). Such evidence proves the importance of comprehensive environmental policy to protect environmental and public health. Finally, stringent environmental policies are central to encouraging sustainable resource management and combating environmental catastrophes such as climate change. Countries with stringent environmental policies exhibit low carbon intensity. This further spurs change to attain the goals of a low-carbon economy and mitigate climate change. The evidence provided herein demonstrates the necessity of stringent environmental policies for SD.

One of the most promising trends, capable of both fostering and limiting SD, is digitization. At its core, digitization is the widespread adoption of digital technologies and the integration of digital solutions in every sector of the economy. On the one hand, digitization is a powerful tool for increasing efficiency, productivity and innovation in virtually every sector and for making information, services and markets more accessible. However, if the innovation is environmentally specific, it may significantly boost the environmental quality by minimizing pollution emissions (Adebayo and Özkan, 2024). On the other hand, concerning SD, the implications of digitization are multilayered and difficult to estimate, as they affect virtually every aspect of major change. Along the same lines, mineral resources are important assets for many BRICS economies, ensuring inputs for industrial production, infrastructure and energy generation. At the same time, exploitation of mineral resources in BRICS countries is associated with environmental degradation, social tensions and economic inequalities. Once the geopolitics of environmental geography are delineated, the second geopolitical factor that structures the BRICS, the disposition of mineral resources, combines with it to create a fully-fledged conjunction of environmental political forces (Calas, 2017). The assessment of the contributions of both digitization and mineral resources to SD in BRICS countries requires considering their impacts on overall SD, including economic development, environmental quality and social justice.

Following the backdrop, we aim to evaluate the role of political risk in the SDI. Political risk is widely analysed in the context of economic expansion, trade and investments. However, we intend to analyse its significance in SD. Secondly, we intend to examine the influence of digitization and environmental policy stringency. In fact, these variables are comprehensively investigated in contrast to pollution emissions. However, their importance cannot be ignored in SD. In addition, we also aim to scrutinize the impact of mineral resources, exports and the development of environmental technologies on the SD of the BRICS economies.

This research differs from previous studies because it presents a holistic view of the subject matter from a new approach. This research is unique in its methodological approach compared to the previous works, which typically investigated the effects of an individual variable on SD while disregarding the effects of the other variables; political risk, digitization, environmental policy stringency, mineral resources, exports and environmental policies are analysed simultaneously in the present work. As a matter of fact, numerous studies represented SD via several economic and environmental indicators. However, the present research is more sophisticated as it adopts the SD index, which represents not only human development but also an environmental index. As a further enhancement, the analytical findings of ARDL in the BRICS economies, as a global factor to consider while examining the outcome of sustainability, are a valuable departure from the existing literature in undertaking the test for both short-run and long-run effects. Thus, this approach enables us to get a more qualitative analysis of the multifaceted factors that underpin these emerging economies. Also, the context-specific analysis of the BRICS countries makes it easier for the reader to grasp the real situation in these countries when it comes to SD in emerging economies. Concerning the comprehensiveness of the factors under study within this particular setting, contributions of the research extend to the paradigm of policymaking as well as the academic debate on sustainability in emerging economies with serious environmental issues.

2. Literature Review

Generally, SD refers to balanced economic development, environmental protection and social equity. In the literature, studies have considered several economic and environmental indicators for SD. For instance, Behera *et al*. (2024) investigated the factors of achieving SDG-13 in 14 developing economies. They revealed that green energy use and green finance significantly enhance

SD by reducing pollution emissions and political instability is harmful to environmental sustainability. In addition, Liu and Cao (2024) found that there are various other ways in which external political risk may moderate the indirect effect of executive environmental awareness on corporate SD performance through green innovation. Furthermore, Ahmed (2024) demonstrated that enhancement in political globalization is significant in attaining SD in the top seven industrialized economies. In the case of 47 emerging economies, Hunjra *et al*. (2022) analysed panel data from 1991 to 2020 and concluded that enhancement in political risk and uncertainty are the factors that hinder SD in the region. Concerning the G7 countries, Z. Khan *et al*. (2022) used the method of moments quantile regression and concluded that natural resources asymmetrically influence sustainable economic performance, while political risk has an insignificant role in the sustainability of the region. In the case of 141 emerging economies, Y. Khan and Hassan (2024) employed the method of moments quantile regression approach and concluded that high-tech exports, corruption control and natural resources help attain SD as these factors drive environmental sustainability. In contrast, S. Li *et al*. (2024) used the CS-ARDL approach in the case of BRICST economies (BRICS plus Turkey) and asserted that natural resources are significant drivers of environmental degradation, which is a harmful factor of SD. Similarly in a study for the OECD economies, Ahmad *et al*. (2024) used advanced econometric approaches and concluded that rents from non-renewable resources are adversely associated with SD. Concerning emissions, Adebayo *et al*. (2023) used the wavelet approach and concluded that natural gas is positively associated with emissions, which are reduced by green energy in the USA. However, efficiency in both gas and oil could help improve environmental sustainability (Adebayo *et al*., 2024).

Concerning digitization, empirical studies have covered wide-ranging economies in the context of SD. For instance, Ionescu-Feleagă *et al*. (2023) examined European economies before and after the COVID-19 pandemic. The study concluded that there exists a positive and significant association between digitization and SD in the region. For the same region, Kwilinski *et al*. (2023) scrutinized the influence of digitization and the green transport sector on SD. The study revealed that both digitization and green transportation are significant indicators of SD in the region in the long run. Concerning OECD economies, Lei *et al*. (2024) proxied SD via green total factor productivity and asserted that digitization can have both direct and indirect positive influences on the SD of a region. Hence, in countries lagging behind in development, it is crucial to evenly implement SD goals while fostering the transition process to green energy (Mambetova *et al*., 2023). Nonetheless, exports, imports and agricultural production cannot be overlooked in determining SD (Rajeswari *et al*., 2024). Manga *et al*. (2023) analysed the role of exports in SD, proxied by pollution emissions, and concluded that exports have diverse influences on the SD of regions. Therefore, the exports of one sector cannot be significant enough to determine the SD and growth of the country (Nekhoroshkov and Larionov, 2023). For the BRICS countries during

1970–2020, Udeagha and Ngepah (2023c) employed the AMG approach and concluded that exports are harmful to the achievement of SD in the region. However, green technology and green energy support SD. In contrast, Haruna (2023) analysed Nigeria and asserted that there exists a positive and significant association between exports and SD.

In the existing literature, several studies have claimed a positive association between conventional technological innovation and pollution emissions (Adebayo and Kirikkaleli, 2021). However, the empirical examination of the direct and indirect influence of green technologies and environmental policies, (D'Amato *et al*., 2021) uses several statistical methods to conclude that both green technology and stringency in environmental policies may boost environmental performance and lead to SD. In achieving the SDGs, X. Wang *et al*. (2022) revealed that eco-innovation, environmental policies and carbon taxes are the leading drivers of SD and environmental quality enhancement in Central and Eastern European economies. In the OECD economies, Ahmad *et al*. (2024) investigated the period from 1990 to 2019 by employing the CCEMG approach. The results showed that eco-innovation significantly enhances SD in the region. Using the CS-ARDL approach, Udeagha and Ngepah (2023a) analysed the BRICS economies and asserted that green innovation, policy stringency and green energy research and development are significant factors of environmental and overall sustainability in the region. Another study by Udeagha and Ngepah (2023b), also confirmed the progressiveness of eco-innovation and policy stringency in attaining sustainability over the extended period from 1960 to 2020. Using a panel of high-income OECD economies, Xie *et al*. (2023) revealed that eco-innovation and stringent environmental policies were the leading and significant factors of sustainability in the region from 1990 to 2020. Similarly, Lahouel *et al*. (2023) evaluated 26 OECD economies and concluded that stringency in environmental policies is a significant indicator of sustainability in the region. In the case of the G7 economies, Ahmed *et al*. (2022) used second-generation analysis techniques and concluded that economic expansion is the leading cause of environmental degradation. However, environmental regulations and democracy led the economies towards SD during 1985–2017. In addition to these studies, several other studies have validated the favourable influence of green innovation and environmental policy stringency on the SD of different regions (Ahmad *et al*., 2023; Chaaben *et al*., 2024; C. Li *et al*., 2021; Mahalik *et al*., 2024; Manigandan *et al*., 2024; Saqib *et al*., 2024; Sun and Razzaq, 2022).

Research Gap

After analysing the existing literature, this research notes several research gaps. For instance, in order to represent SD, studies have considered different indicators such as CO_2 emissions (Adebayo *et al*., 2023) and the load capacity factor (Adebayo *et al*., 2024). However, these variables only capture environmental sustainability while ignoring social equity and human development. In this sense, there is a need for comprehensive measures to capture the stated qualities. In this sense, the present research tends to use the comprehensive SD index, which not only covers the environmental aspect but also covers social and human development aspects. Furthermore, studies have used conventional technology-related variables instead of environment-oriented technological innovations (Adebayo and Kirikkaleli, 2021). However, economies are targeting environment-related innovations, which is a crucial aspect of SD in the region. Despite the potential of political risk, studies have mostly focused on geopolitical risk (Ahmad *et al*., 2024), which admittedly covers the economic risk. Yet, political risk is more context-specific, which we intend to address within the framework of SD.

3. Data and Methods

3.1 Theoretical framework and model construction

The link between political risk and SD is based on institutional theory and stakeholder theory. Political stability and good governance are important antecedents in the process of putting into practice policies of sustainability (Lim and Tsutsui, 2012). A lower political risk tends to be associated with higher institutions that are able to ensure the implementation of environmental standards and social policies. High political risk may discourage investors from investing in sustainable projects and slow down the implementation of environmental and social policies. Concerning SD, countries with low political risks register better Worldwide Governance Indicators (WGIs) according to the World Bank. However, there is a conflict in this regard because rapid development can be covered by authoritarian regimes and can reduce the sustainable growth and development of a country in the longer run (Hsu *et al*., 2013).

The connection between two perspectives, namely digitization and SD, is based on innovation theory. It is established that globalization increases efficiency and thus fastens the attainment of SD goals, through enhancement of transparency and access to information (J. D. Sachs *et al*., 2019). It improves efficient utilization of resources, optimizes teaching, learning and harmonized healthcare and empowers the shift to a low-carbon recovery through smart grids and intelligent transport systems (Linkov *et al*., 2018). However, the distribution of information technology has not been equal, and the environment in which the digital structures are established also has some issues. The UN E-Government Survey demonstrates how digital tools may help actualize the SD goals but underlines that efforts to digitize should become inclusive to prevent existing inequities from increasing (UN, 2020).

The roles of environmental policy stringency in SD are predicated on the Porter hypothesis and the theory of ecological modernization. Elements such as the increase in minimum standards of environmental performance and the capacity to make improvements lead to the development of innovative techniques that would increase long-term competitiveness (Porter and Linde, 1995). Thus, countries with stricter environmental policies have better environmental results and do not worsen the rate of economic development according to the OECD Environmental Policy Stringency Index. Nevertheless, objective consequences are not always progress-oriented but address SD at large. Stringent measures can result in carbon leakage or negatively affect economic development in the short term and thus negatively affect social sustainability (Ambec *et al.*, 2013).

The relationship between mineral resources and SD is defined by two theories, namely resource curse theory and sustainable resource management. The availability of abundant minerals has the potential to create economic fortunes; however, this aspect of their exploitation results in environmental pollution and social injustice if poorly managed (Auty, 2001). According to the Natural Resource Governance Institute, good governance practices must be integrated in order to enable mineral resources to drive SD. The idea of a circular economy is especially giving more chances to reuse mineral resources through recycling and urban mining. However, new political and socio-economic sustainability issues arise where demand for minerals important in green technologies is on the rise. For SD, there is the need to dematerialize consumption as noted by the UN International Resource Panel (Oberle *et al.*, 2019).

The connections between exports and SD are based on international trade theory and the inverted U-shaped environmental Kuznets curve hypothesis. Export expansion is capable of enhancing the process of economic growth and thus offering funds for social and environmental improvements (Grossman and Krueger, 1995). However, what is exported also plays a crucial role. Despite this, the origin of exports affects the economy considerably. While high resource intensity in exports explains the negative impact on the environment, knowledge intensity reflects positive development effects (Gozgor and Can, 2016). On the other hand, the relationship between environmental technologies and SD is based on the innovation system perspective and the theory of ecological modernization. They further stress the significance of environmental technologies for the ability to grow the economy without harming the environment, cutting across the environmental policy goals (Kemp and Pearson, 2007). It has also been identified that the application of these technologies will help in enhancing the diffusion of a faster move towards a low-carbon and resource-efficient economy in line with the UN scheme outlined in UNEP (2011). The results demonstrated in the Global Cleantech Innovation Index point to the fact that countries which allocate money to environmental technologies have better sustainability levels (Cleantech Group and WWF, 2017). However, some issues are still a hurdle when it comes to technology introduction and usage, especially in the developing world.

Following the objective and theoretical depiction, we have revealed an increasing debate on political risk in various economic and environmental sectors. Therefore, we consider the Political Risk Index the key explanatory variable in determining SD. In addition, we also consider several economic, technological and environmental variables in the model. The constructed regression model is given as follows:

$$SDI_{it} = \alpha_1 + \beta_1 PRI_{it} + \beta_2 DIG_{it} + \beta_3 EPS_{it} + \beta_4 MR_{it} + \beta_5 EXP_{it} + \beta_6 DTI_{it} + \varepsilon_{it} \quad (1)$$

In the above model, the *SDI* is the key dependent variable representing the Sustainable Development Index. The remaining explanatory variables include the Political Risk Index (*PRI*), digitization (*DIG*), environmental policy stringency (*EPS*), mineral rents (*MR*), exports (*EXP*) and the development of environment-related technological innovation (*DTI*). In addition, the model demonstrates that α_1 is the slope of the model, β are the intercepts for each regressor and ε is the error term. The model is based on the BRICS economies, covering the period from 1990 to 2020. A detailed description of variables and data sources is provided in Table 1. Although data for the SDI are available until 2019, we follow Hickel's (2020) methodology for constructing the index for 2020.

Table 1: Description of variables and data sources

Variable	Abbreviation	Unit	Data source
SDI	Sustainable Development Index	Index	SDI (2024)
PRI	Political Risk Index	Index	ICRG (2023)
EPS	Environmental policy stringency	Index	OECD (2024)
EXP	Exports	Percentage of GDP	WB (2023)
DTI	Development of environmental related technological innovation	Percentage of all technologies	
DIG	Digitization	Number of individuals using the internet	
MR	Mineral rents	Percentage of GDP	

Source: Authors' own elaboration

3.2 Estimation approach

A descriptive assessment is conducted in the first step of inspecting the panel dataset. Afterwards, normality checks are performed on each of the components. The median, mean and range (minimum and maximum) values are assessed to determine the statistical properties of each rigorous variable discussed in the panel data. The standard deviations of the data are calculated by statistical methods, in which we are able to check how much dispersion is caused by the changing values of the observations over time. To assess the normality of these data, we use kurtosis and skewness.

Following the normality approach, we use the diagnostic test of Hashem Pesaran and Yamagata (2008) to examine the slope heterogeneity of the panel dataset. This test is essential in panel data analysis as overlooking such a test could lead to biased estimation (Wei *et al*., 2022). This test is based on the null assumption of homogenous slopes, which can be neglected after obtaining significant statistical values. In addition, the cross-sectional dependence test (Pesaran, 2004) is also used to identify the dependence between selected panel variables.

Afterwards, for each chosen parameter, a unit root test is performed. We use different unit root test procedures, based on Phillips and Perron (1988) (PP), Breitung (2000) (Br), Im *et al*. (2003) (IPS), the ADF-Fisher (ADF) test (Maddala and Wu, 1999) and Levin *et al*. (2002) (LLC). In this case, the analysis is processed at level as well as at first difference to validate stationarity. It is to be confirmed that all of these tests show that the unit root exists (refers to H_0). In addition to the first-generation test, the CIPS test (Pesaran, 2007) is also utilized to tackle the issue of slope heterogeneity. After each unit root test is performed, cointegration for the panel is confirmed by using the Kao (1999) residual and Johansen–Fisher cointegration tests. These procedures are used to understand the presence of long-term stable associations among the treated variables. It is to be confirmed that this specification predicts a null hypothesis finding of no cointegration (as H_0). Since the above approaches are limited in tackling the SCH and cross-sectional dependence issues, we also use the second-generation (Westerlund, 2007) error correction model (ECM), which handles the stated issues and offers more efficient and robust cointegration estimates in the context of panel data.

In cases where the relevant parameters are integrated, given that the order of integration is mixed, we can use the panel autoregressive distributed lag (ARDL) model of Pesaran and Shin (1995), which was further improved upon by Pesaran *et al*. (2001). Many empirical approaches to data estimation exist. However, for modelling the mixed order of integration, the panel ARDL is almost certainly the best option available. Estimators such as the pooled mean group (PMG) and dynamic fixed effects (DFE) may be computed. The following research model will be updated into a long-run ARDL model for the purpose of estimating coefficients and parameters:

$$\begin{aligned} SDI_{it} &= \alpha_{1i} + \sum_{l=1}^{p}\beta_1 PRI_{it-l} + \sum_{l=1}^{q}\beta_2 DIG_{it-l} + \sum_{l=1}^{r}\beta_3 EPS_{it-l} + \sum_{l=1}^{s}\beta_4 MR_{it-l} + \\ &+ \sum_{l=1}^{t}\beta_5 EXP_{it-l} + \sum_{l=1}^{u}\beta_6 DTI_{it-l} + e_{it} \end{aligned} \tag{2}$$

where t indicates the index for time and i represents the cross-sections. After the parameterization, the above equation could adopt the following form:

$$\Delta \ln SDI_{it} = \alpha_{1i} + \theta_{1i}\big(SDI_{it-1} + \varphi_1 PRI_{it-l} + \varphi_2 DIG_{it-l} + \varphi_3 EPS_{it-1} + \varphi_4 MR_{it-l} + \\ + \varphi_5 EXP_{it-l} + \varphi_6 DTI_{it-1}\big) + \sum_{l=0}^{p-1}\lambda_{1il}\,\Delta PRI_{it-l} + \sum_{l=0}^{q-1}\lambda_{2il}\,\Delta DIG_{it-l} + \sum_{l=0}^{r-1}\lambda_{3il}\,\Delta EPS_{it-l} + \\ + \sum_{l=0}^{s-1}\lambda_{4il}\,\Delta MR_{it-l} + \sum_{l=0}^{t-1}\lambda_{5il}\,\Delta EXP_{it-l} + \sum_{l=0}^{u-1}\lambda_{6il}\,\Delta DTI_{it-l} + e_{it} \quad (3)$$

In Equation (3), short-run coefficients are represented by λ and long-run coefficients are shown as φ. The speed of adjustment is represented by θ and the error term is represented by e. The PMG estimator rests on the assumption that there is a single long-run equilibrium position among countries, although often at different levels of wealth and population size (Simionescu *et al.*, 2021). Under these conditions, the null hypothesis of the ARDL model assumes that there is no cointegration between variables (H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$). A different hypothesis provides strong evidence of permanent cointegration between variables (H_1: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq 0$).

Once the results are obtained using the ARDL model, we test the model robustness by employing the panel fully modified ordinary least square (FMOLS) method. Unlike the ARDL approach, this approach offers average-based outputs. However, due to limitations in depicting causal associations, we use the panel Granger causality approach proposed by Dumitrescu and Hurlin (2012).

4. Results and Discussion

4.1 Interpretation

We start the empirical assessment of the data by utilizing descriptive and normality statistics, which are provided in Table 2. The mean and median statistical outcomes are not significantly different. However, the difference is greater in the range statistics consisting of the minimum and maximum. As a result, we evaluate the standard deviation for each considered variable. The outcomes show that *DIG* has the highest volatility among the selected variables, followed by *DTI*. However, the volatility in the other variables is minimal compared to the former ones. Moreover, we also evaluate the skewness and kurtosis to assess the distribution of the variables. The results show that the variables have values different from their respective skewness and kurtosis values of 1 and 3. Therefore, nonnormality may prevail in the panel dataset.

Table 2: Descriptive and normality assessment

	DTI	*EPS*	*EXP*	*DIG*	*MR*	*PRI*	*SDI*
Mean	9.603720	0.842294	21.27142	21.56056	0.794626	62.02820	0.653168
Median	9.590000	0.666667	20.79970	8.065375	0.668690	63.58333	0.668000
Maximum	16.92000	3.138889	62.32246	84.99467	2.502245	75.00000	0.757000
Minimum	3.020000	0.055556	6.730210	0.000111	0.099337	32.50000	0.461000
Std. dev.	2.679654	0.757418	8.804135	25.70522	0.579315	7.956897	0.076509
Skewness	−0.015026	1.391739	0.777651	0.948000	1.149564	−1.793921	−0.784905
Kurtosis	2.942502	4.262495	4.911640	2.467180	3.611238	6.968325	2.870691

Source: Authors' own calculations

After the normality testing, we intend to diagnose the slope heterogeneity of the panel data under consideration, and the empirical outcomes are provided in Table 3. The results assert that both the *SCH* and SCH^{adj} provide statistically significant values at the 1% level. Thus, the null assumption of the test, *i.e.*, homogenous slopes, can be neglected and it is concluded that the slope coefficients are heterogeneous.

Table 3: Slope heterogeneity

Test	**Delta**	***p*-value**
SCH	10.344***	0
$SCH^{adj.}$	12.009***	0

Note: *** denote significance at 1% levels.
Source: Authors' own calculations

In addition to the SCH test, we also investigate the issue of panel cross-sectional dependence between variables. In this sense, we use the Pesaran (2004) test, and the outputs are portrayed in Table 4. It is noted that most of the research variables such as *EXP*, *EPS*, *DIG*, *MR* and *PRI* exhibit significant statistical values at the 1% level. Therefore, the null assumption of the test (no cross-sectional dependence) may be rejected and it is concluded that the cross-sectional dependence is valid in the study variables.

Table 4: Panel cross-sectional dependence

Variable	CD-test	*p*-value
SDI	−0.286	0.775
EXP	7.759	0.000
DTI	1.604	0.109
EPS	12.509	0.000
DIG	17.131	0.000
MR	11.324	0.000
PRI	3.958	0.000

Source: Authors' own calculations

In the context of analysing panel data, it is essential to investigate the stationarity of the variables. We use a total of five assessment tools, and the empirical results are reported in Table 5. The results observed offer diverse results, where some of the variables are stationary at I(0) for a few tests, while others are insignificant. For instance, all the variables except *SDI* are found to be significant in a few tests. However, to confirm the absence of a unit root, we evaluate the panel data at I(1). At this stage, all the tests indicate higher values than their respective critical values. Therefore, H_0 for all the tests can be neglected to conclude stationarity of all the variables. Along with the first-generation unit root testing, we also test the stationarity of each variable using the second-generation CIPS test, and the empirical results are offered in Table 5. The results demonstrate that only a few variables, namely *DIG*, *DTI* and *MR*, are significant at I(0) – neglecting the null assumption of unit root presence. However, *EPS*, *EXP*, *PRI* and *SDI* possess unit roots. Therefore, these variables are tested at I(1). In the latter condition, all these variables offer significant statistical values, which leads to the rejection of H_0 and concludes that the variables are stationary, which is enough evidence to test the cointegration of variables.

Table 5: Stationarity testing

Method	*DIG*	*DTI*	*EPS*	*EXP*	*MR*	*PRI*	*SDI*
Panel unit root test: summary [I(0)]							
LLC	−3.525***	−1.332*	0.261	−0.928	−0.434	−6.995***	−1.218
Br	2.195	−2.231**	−2.714***	1.121	−2.227**	−0.683	2.239
IPS	−0.422	−2.083**	−0.212	−1.465*	−0.860	−5.862***	2.678
ADF	18.157*	20.833**	8.418	31.703***	13.579	61.616***	4.787
PP	0.893	32.859***	9.424	16.622*	10.474	15.426	1.235
Panel unit root test: summary [I(1)]							
LLC	−9.266***	–	−6.703***	−7.608***	−3.328***	−5.539***	−0.492
Br	−3.452***	–	−7.099***	−3.192***	−6.475***	−4.569***	2.615
IPS	−10.485***	–	−4.775***	−7.822***	−5.458***	−6.419***	−2.935***
ADF	292.038***	–	39.419***	112.495***	45.740***	54.038***	31.312***
PP	246.658***	–	80.901***	238.848***	93.219***	102.307***	47.101***
Second-generation unit root test							
CIPS [I(0)]	−4.703***	−4.351***	−2.223	−2.703	−2.855**	−2.706	−1.267
CIPS [I(1)]	–	–	−5.043***	−5.543***	–	−4.559***	−3.481***

Note: *, ** and *** denote significance at 10%, 5 %, and 1% levels, respectively.
Source: Authors' own calculations

Table 6 presents the outputs of the cointegration tests using the Kao and Johansen–Fisher panel cointegration tests. The outcomes of the tests show that both estimators offer significant probabilities, as the critical values are lower than the predicted statistical values. In this sense, the tests' H_0 can be neglected and it is concluded that there exists a significant cointegration between the elements considered in this study. Despite the significant statistical values of the first-generation cointegration test, we use the second-generation (Westerlund, 2007) panel cointegration test, for which the results are provided in Table 6. The results assert that the group stats (G^t) and panel statistics (P^t and P^a) are statistically significant. Such significant estimates lead to the rejection of H_0 (no cointegration) and conclude that the ECM is not equal to zero.

Table 6: Cointegration results

Kao residual				
ADF	***t*-stats**	***p*-value**		
	–1.400***	0.081		
Residual variance	4.60E-05			
HAC variance	9.54E-05			
Johansen–Fisher panel cointegration test				
Hyp. no. of CEs	**Fisher stat.* (from trace test)**	***p*-value**	**Fisher stat.* (from max-eigen test)**	***p*-value**
None	262.70***	0.0000	225.20***	0.0000
At most 1	150.60***	0.0000	86.66***	0.0000
At most 2	77.73***	0.0000	28.49***	0.0015
At most 3	54.93***	0.0000	23.34***	0.0096
At most 4	38.31***	0.0000	24.27***	0.0069
At most 5	24.38***	0.0067	18.58**	0.0459
At most 6	21.23**	0.0195	21.23**	0.0195
Second-generation cointegration test				
Stats	**Value**	***Z*-value**	***p*-value**	
G^t	–3.591***	–2.553	0.005	
G^a	–14.406	–0.147	0.442	
P^t	–6.741**	–1.666	0.048	
P^a	–16.574**	–1.677	0.047	

Note: *, ** and *** denote significance at 10%, 5 %, and 1% levels, respectively.
Source: Authors’ own calculations

Table 7: Primary results

ARDL					
Model	**LogL**	**AIC***	**BIC**	**HQ**	**Specification**
6	725.465855	−8.706655	−6.269294	−7.716185	ARDL(2, 3, 3, 3, 3, 3, 3)

Short run				
Variable	**Coef.**	**Std. Er.**	***t*-Stats**	***p*-value**
ΔMR	−0.016***	0.005	−2.776	0.008
ΔPRI	−0.045	0.030	−1.474	0.148
ΔEXP	−0.031**	0.013	−2.351	0.023
ΔEPS	0.016	0.011	1.442	0.157
ΔDTI	0.059***	0.019	3.127	0.003
ΔDIG	−0.014	0.010	−1.375	0.177
C	−0.107***	0.023	−4.582	0.000
Long run				
MR	0.056***	0.009	5.637	0.000
PRI	0.141**	0.053	2.639	0.012
EXP	0.219***	0.039	5.636	0.000
EPS	0.016*	0.008	1.970	0.055
DTI	−0.291***	0.054	−5.409	0.000
DIG	−0.029***	0.008	−3.653	0.000
ECM(−1)	−0.229***	0.031	−7.280	0.000
Root MSE	0.002	**Mean dependent variable**		0.001
S.D. dependent variable	0.007	**S.E. of regression**		0.004
Akaike information criterion	−7.864	**Sum squared resid**		0.001
Schwarz criterion	−5.586	**Log-likelihood**		725.466
Hannan–Quinn information criterion	−6.938			

Note: *, ** and *** denote significance at 10%, 5 %, and 1% levels, respectively.

Source: Authors' own calculations

The validity of the cointegration between variables leads to the evaluation of the coefficient values for each regressor using an appropriate estimator. The variables are found to be cointegrated in mixed order. Therefore, we employ the ARDL approach, and the outputs are described in Table 7. Concerning the short-term analysis, the results indicate diverse influences for various variables. Specifically, the analysis revealed that *MR*, *EXP*, *PRI* and *DIG* adversely influence *SDI*, where the influence of the former two variables is significant. However, *DTI* and *EPS* exhibit a positive and significant influence on the *SDI* in the short term. Among these variables, only *DTI* is found to be significant, while the latter is not significant. This indicates that *DTI* and *EPS* are the only drivers of *SDI*, while *MR*, *EXP*, *PRI* and *DIG* are the leading barriers in the short term. In the long run, we note that all the variables exhibit a significant influence on the *SDI*. The impacts of *MR*, *PRI* and *EXP* change from negative in the short term to positive in the long term. Additionally, the role of *EPS* is found to be constructive in improving the *SDI*. These results are highly significant and consistent with the empirical outcomes of Ahmed (2024), Chaaben *et al*. (2024), Haruna (2023), Y. Khan and Hassan (2024) and Mahalik *et al*. (2024). However, both *DTI* and *DIG* are harmful for longer-term *SDI*. Notably, the impact of *DTI* changes from positive in the short term to negative in the longer term. These influences are highly significant, yet they contrast with the empirical estimates of Ionescu-Feleagă *et al*. (2023), Kwilinski *et al*. (2023), Manigandan *et al*. (2023), Rajeswari *et al*. (2024) and Saqib *et al*. (2023), validating their positive roles. The ARDL model demonstrates that the convergence term (ECM) approaches equilibrium. Here, the ECM value is negative at 0.229, which is also highly significant. This indicates that with each passing year, the short-term equation approaches equilibrium at a speed of adjustment of 22.9.

After the empirical outcomes of the model using ARDL, we test the robustness of the model using the panel FMOLS approach, and the empirical results are described in Table 8. According to the results, the influences of *MR*, *PRI*, *EXP* and *EPS* are positive and significantly correlated with the *SDI* of the BRICS economies. However, the net influence of *DTI* and *DIG* is negative and significant. Both the positive and negative influence of these variables validate the long-run estimated outcomes obtained using the ARDL approach. Additionally, these results are consistent with several empirical findings provided by Haruna (2023), Z. Khan *et al*. (2020) and S. Li *et al*. (2024). Moreover, the goodness of fit for the model can be indicated via more than 90% of the R^2 and adj. R^2 values.

Table 8: Robustness

Panel FMOLS				
Variable	**Coef.**	**Std. er.**	***t*-stats**	***p*-value**
MR	0.026***	0.008	3.066	0.002
PRI	0.111**	0.049	2.262	0.025
EXP	0.083***	0.028	2.885	0.004
EPS	0.023*	0.012	1.758	0.080
DTI	−0.042*	0.021	−1.928	0.055
DIG	−0.017***	0.004	−3.891	0.000
R^2	0.915			
Adj. R^2	0.906			

Note: *, ** and *** denote significance at 10%, 5 %, and 1% levels, respectively.
Source: Authors' own calculations

The above estimators offer crucial coefficient values. Nevertheless, these estimators lack empirical evidence of causal associations between the *SDI* and the regressors. Therefore, we use the Dumitrescu and Hurlin (2012) Granger causality test, and the results are presented in Table 9. The results clarify both unidirectional and bidirectional causal inferences between the study variables. The empirics assert that there is a significant bidirectional causal association of *DTI* and *DIG* with *SDI*. However, unidirectional causality persists from *MR*, *PRI*, *EXP* and *EPS* to *SDI*. This implies that all these variables are significant in designing crucial policies for the sustainability of the region.

Table 9: Causality test

H_0:	*W*-stat.	Zbar-stat.	*p*-value
MR → SDI	4.809***	5.135	3.E-07
SDI → MR	1.342	0.360	0.718
PRI → SDI	6.949***	5.197	0.000
SDI → PRI	0.378	-0.966	0.333
EXP → SDI	5.517***	6.109	1.E-09
SDI → EXP	1.520	0.605	0.544
EPS → SDI	6.578***	7.570	4.E-14
SDI → EPS	1.760	0.937	0.348
DTI → SDI	6.849***	4.317	0.000
SDI → DTI	2.583**	2.070	0.038
DIG → SDI	4.873***	5.222	2.E-07
SDI → DIG	5.551***	6.155	7.E-10

Note: *, ** and *** denote significance at 10%, 5 %, and 1% levels, respectively.
Source: Authors' own calculations

4.2 Discussion

The type of approach used in this study is the best-fitting research methodology that shows a strict pattern of interaction between the identified factors and the SDI in the BRICS economies. The comparison between first-generation and second-generation estimation methods shows the features of the data: different slope coefficients and cross-sectional dependence. These justifications explain why first-generation and second-generation unit root and cointegration tests should be employed, which improves the reliability of the study. Thus, confirming stationarity for each of the variables and establishing the long-run equilibrium relationship between the studied variables are the prerequisites for the analysis. This methodological approach enables recognition of such specific characteristics of each BRICS economy while still taking into account the interaction between them. Such a detailed statistical structure contributes significantly to the conclusion and the further development of concepts for various policy measures as a part of the SD in these emerging economies.

The described findings on the role of mineral resources in SD highlight the complexity of the phenomenon associated with the exploitation of resources. In the short run, a negative impact may result from environmental destruction and social fragmentation related to the process of extracting resources. The latter particularly concerns habitat destruction, water pollution and social tensions around the right to land ownership. On the other hand, the long-term positive influence indicates the benefits of mineral resource use in terms of GDP growth, infrastructure development and poverty reduction. Hence, negative externalities can be avoided through responsible resource management and proper regulation, which enables the sustainable use of these resources and their equitable redistribution (Calas, 2017). The evidence on political risk presented in the respective study also provides valuable insights into the importance of governance stability for SD. Although political risk can impede short-term investment and policy implementation, its profound negative impact on SD, in the long run, highlights the role of institutional breakdown. Political instability can hamper development projects, weaken regulation enforcement and deter international investment, driving the country into economic stagnation and social turmoil (Globerman and Shapiro, 2003).

Furthermore, the findings of this study concerning exports also highlight the controversial role of international trade in SD outcomes. Indeed, in the short run, higher exports may lead to more environmental degradation and higher levels of resource depletion as accelerated innovation and production processes put unbearable pressures on natural ecosystems. In particular, potential negative externalities such as pollution, deforestation and the rapid loss of biodiversity at some point will outweigh the economic benefits of export-led growth. However, in the long term, exports promote SD more positively, as they foster economic diversification and development, boost technological innovation and facilitate knowledge sharing (Dinda, 2004). Thus, to ensure that exports contribute to SD, careful consideration in accordance with economic growth, environmental protection priorities and social justice criteria is crucial. In addition, environmental policy stringency has a significant long-term effect on SD. Specifically, stringent environmental policies stimulate innovation, encourage firms to adopt cleaner production technologies and implement more sustainable resource management practices. Governments also set standards, ensure compliance and provide incentives for the development and implementation of green technologies and approaches (Lundh, 2017). Moreover, setting requirements and incentives allows promotion of civil awareness, developing civil society and engaging various stakeholders in initiating changes to assume responsibility. However, without political will, institutional capacity and stakeholder cooperation, it is challenging to implement an effective environmental policy.

Moreover, the findings on the short-term positive effect of environmental technology on SD signal a nuanced relationship between advances in technology and environmental health. Specifically, in the short run, environmental technology has a positive effect on promoting SD through its impact on resource efficiency, pollution reduction and monitoring and controlling capability.

However, the long-term negative relationship means that innovations in the sector are associated with what amounts to rebound effects or potential unintended consequences. Examples of the same include more efficiencies that increase the demand and consumption of resources or reliance on technological fixes that lead to ignoring governance and systemic problems. Sustainable technology innovation must be achieved using a multidimensional approach that consciously recognizes and adopts environmental and economic capacity while ensuring equitable access to benefitting technology outcomes (H. Li *et al*., 2020).

Finally, our findings on digitization and the long-term negative effect on SD establish the need for caution in adopting digital transformation. While digital technologies present opportunities for efficiency innovation and growth, the focus on sustainability sends negative signals that should be considered. For instance, energy and emissions from the digitization of other sectors increase human activity, while waste in the form of electronics is on the rise and the digital divide between societies is widening. Furthermore, the importance of considering risks regarding information privacy, security and democratic and sustainable sociocultural dynamics could also be considered. Hence, sustainable digitization can only be successful through responsible consumption and production, ensuring access and integrating environmental factors in digital strategies (Bohnsack *et al*., 2022) in the selected region.

5. Concluding Remarks

5.1 Conclusion

This study used a set of rigorous research methods, particularly the autoregressive distributed lag (ARDL) approach, to obtain important insights into the determinants of sustainable development in emerging countries. By analysing political risk, environmental policy stringency, digitization, mineral resources, exports and environmental technologies as independent variables, we have expanded the current knowledge about the complex confluence of factors that determine sustainable development in these highly heterogeneous macroeconomic settings. The results have several implications for sustainable development. More specifically, the identified determinants, when combined, contribute to the overall understanding of the intricate interplay between factors and sustainable development in emerging countries. Political risk appears to be a major determinant of both short-term and long-term effects; thus, a focus on ensuring the absence of risks to sustainability is recommended. Similarly, environmental policy stringency appears to be very important in the long term, which shows that a strong environmental regulatory system makes a difference. Digitization, mineral resources, exports and environmental technologies also matter, and the combinations of various channels through which those factors operate reveal their dynamic nature over the last three decades.

5.2 Policy implications

This study has also identified important policy recommendations for sustainable development based on the established relationships. Firstly, policymakers need to address multiple perspectives, including governance and the rule of law, because the assessment of political risk as a crucial factor over short and long periods suggests ensuring conditions for sustainable development. Secondly, environmental policies need stronger regulatory frameworks in the short and long term because policy stringency truly contributes to sustainable development and minimizes the intensity of environmental degradation processes while ensuring economic expansion. Thirdly, collaboration with other countries should focus on responsible resource management rather than exports of minerals over the long term because dependence on resource-based revenue does not provide a solid solution for achieving sustainable development targets. Export diversification with a focus on environmentally friendly products and services is needed in the long term, which could help overcome environmental hazards and simultaneously encourage the expansion of the industrial sector. Finally, there is a need to develop and implement green technologies, which can only be possible if domestic and international policies support the development of green technologies in both emerging and industrialized economies.

5.3 Research limitations and future research directions

The study on the sustainability of the BRICS economies covers comprehensive factors but still holds the following limitations that should not go unnoticed. The level of data availability and quality may differ in BRICS countries and therefore cause some discrepancies within the results. The emphasis of this paper on the BRICS countries offers a rich and informative understanding of the knowledge gap but may face the issue of generalizability of conclusions to other emerging economies. Besides, there may be an informational vulnerability for the chosen variables and methodology to determine the integrated relations of sustainable development. Fluctuations in policies and the general economic setting could also vary in the long term, thus affecting the generalizability of the findings within the BRICS countries. These limitations, however, can be addressed in future research. Specifically, including other emerging economies in the analysis could strengthen the generalizability of the findings. Subsequent research can explore sustainable development effects within the BRICS countries when such policy measures are adopted, thus offering more tangible policy guidance. The theoretical framework could be built based on examining how cooperation with developed countries and advanced technology can be used for the sustainable development goals in the BRICS countries and could provide insights into the contemporary discourse on worldwide sustainability. Possible research directions to extend the research could be a focus on case studies of effective management of sustainable development processes in the context of the BRICS economies. Analysing the impact of global phenomena such as the COVID-19 pandemic on the sustainability of further development in the BRICS country group can be useful for understanding the sustainability of processes undertaken in these countries.

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