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ENVIRONMENTAL SUSTAINABILITY IN BRICS: THE NEXUS OF TECHNOLOGICAL INNOVATION, LITERACY, AND ICT FOR A SUSTAINABLE FUTURE

Sustentabilidade Ambiental nos BRICS: O Nexo entre Inovação Tecnológica, Alfabetização e TIC para um Futuro Sustentável

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ABSTRACT

There is a growing trend of holding multinational firms responsible for their environmental impact with its constructive and destructive effects on environmental sustainability which is presenting an evident research gap in the literature. This study investigates the impact of technological innovation, ICT, and literacy rate on the environmental sustainability, while controlling the effects of urbanization, economic growth and globalization in the BRICS countries. The data (1998 – 2023) is analyzed through robust econometric methods including unit root tests, cointegration tests of Panel Fully Modified Least Squares (FMOLS). The findings reveal a negative and significant relationship between ICT and literacy rate with environmental sustainability and a positive relationship with technological innovation highlighting eco-friendly pathways to international businesses operating in the BRICS countries. This study explores the dynamics of the BRICS group of developing countries. As a result, it offers specific insights that help close the gap between technology and goals for sustainable development.

Keywords: Multinational corporations, Technological innovation, Sustainability, BRICS, Panel Fully Modified Least Squares

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SUSTENTABILIDADE AMBIENTAL NOS BRICS: O NEXO ENTRE INOVAÇÃO TECNOLÓGICA, ALFABETIZAÇÃO E TIC PARA UM FUTURO SUSTENTÁVEL

Environmental sustainability in BRICS: the nexus of technological innovation, literacy, and TIC for a sustainable future

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RESUMO

Há uma tendência crescente de responsabilizar as empresas multinacionais pelo seu impacto ambiental, com seus efeitos construtivos e destrutivos na sustentabilidade ambiental, o que apresenta uma lacuna de pesquisa evidente na literatura. Este estudo investiga o impacto da inovação tecnológica, das TIC e da taxa de alfabetização na sustentabilidade ambiental, enquanto controla os efeitos da urbanização, do crescimento econômico e da globalização nos países do BRICS. Os dados (1998 – 2023) são analisados através de métodos econométricos robustos, incluindo testes de raiz unitária e testes de cointegração do Painel de Mínimos Quadrados Totalmente Modificados (FMOLS). Os resultados revelam uma relação negativa e significativa entre TIC e taxa de alfabetização com a sustentabilidade ambiental e uma relação positiva com a inovação tecnológica, destacando caminhos ecológicos para empresas internacionais que operam nos países do BRICS. Este estudo explora a dinâmica do grupo BRICS de países em desenvolvimento. Como resultado, oferece insights específicos que ajudam a fechar a lacuna entre a tecnologia e os objetivos de desenvolvimento sustentável.

Palavras-chave: Corporações multinacionais, Inovação tecnológica, Sustentabilidade, BRICS, Painel de Mínimos Quadrados Totalmente Modificados

INTRODUCTION

All economies consider sustainability and viability as one of its major growth goals (Erdoğan et al., 2022). As the economic growth and environmental sustainability are two ends of a continuum that establishes, whenever the economy performs better in terms of stability and growth (Khan et al., 2019). It is the duty of multinational corporations to improve the ecosystems and communities in which they do business. These businesses may raise their social responsibility profiles and support regional and international sustainability initiatives by using green technology. As the increase in productivity harms the environment, whereas in case of lessor production, the environment suffers less (Bian & Zhao, 2020). A balance between growth of economy and the environment can be obtained by some solutions, including the use of efficient reverse logistics (Khoei et al., 2022), use of green innovative methods of supply chain (Yang & Lin, 2020). Moreover, utilizing green technology to update current practices for the best resource usage (Ahmed et al., 2022), the environmental scientists and academicians have focused on switching to those sources of energy that are renewable in order to regenerate and reproduce with least amount of damage to the environment (Raihan et al., 2022).

Numerous researchers have been discussing economic activities and their impact on the quality of environment ever since the 19th century (Rurek et al., 2022). Recently, the attention of many researchers have been focused on the problem of global warming, highlighting its concerns, causes along with its potential (Reid, 2019). Past researchers have also highlighted that various actions of humans leads to environmental degradation such as improper plastic management, improper disposal of electronic waste (Ukaogo et al., 2020), excessive and unnecessary consumption, as well as an increase in energy sources (coal and oil) and failing to follow the governmental regulations regarding resource preservation and environmental protection (Jin, 2020; De Oliveira et al, 2021).

Additionally, it is believed that human activity is one of the main causes of the earth's unusual change toward a rise in temperature. Abnormal flooding, shifting weather patterns, and irregular and unexpected glacier melting are just a few examples (Ahmad et al., 2020). Gases from greenhouse are the result of human activity which destroy the environment (Yoro & Dramola, 2020). As per a study, the discharge of carbon accounts for 81% of the total gases of greenhouse that account for the majority of these gases (Kauffman et al., 2018). Thus, national and regional governments must actively participate in the implementation phase in order to achieve the previous and current net-zero carbon emissions target set by COP26 resolutions (Ibrahim et al., 2022). A significant portion of the world's carbon emitters includes the countries that make up the BRICS. For instance, China alone accounts for approximately 30 percent of the BRICS group's greenhouse gas emissions, while India, Brazil, and South Africa account for 4.71 percent, 1.29 percent, and 1.09 percent, respectively (Shen & Hasnaoui, 2021).

In such a scenario, in overcoming technological constraints, the trade of goods and services related to information and communications technology (ICT) may play crucial roles (Khan et al., 2020). It is believed that the import of ICT goods facilitates the development of the importing nations' where progress of technology is low (Lee et al., 2022). In addition, innovation in ICT is also reducing fair cost of forming renewable electricity (Bol et al., 2021). Hence, ICT increases the percentage of renewable energy in total power generation. On the other hand, ICT also helps to improve energy efficiency by identifying the sources of irregularities in the power network usually, also in the near environment real time (Murshed, 2020). Similarly, the role of urbanization and education are undeniable with reference to environmental sustainability. Past studies have revealed that urbanization leads to increase industrialization which ultimately increases CO2 emissions (Ahmed et al., 2019; Ali et al., 2019). Thus, making urbanization one of the important research variable within the context of environmental protection. Likewise, literacy rate is known to stimulate the awareness about environmental sustainability and its significance. Further, education is amongst the leading factor causing to increase energy conservation and recycling methods, however, mixed results have been reported about the role of education in CO2 emissions (Li & Ullah, 2022; Sart et al., 2022).

Thus, there is a dearth of literature studying the relationship between technological innovation, ICT, and literacy rate with environmental sustainability in the BRICS countries. This study aims to fill a potential gap in the present body of knowledge considering the aforementioned research gaps and in the rise of technological advancement in the BRICS countries. This study highlights that international businesses need to adjust to various regulatory frameworks

in order to stay out of trouble and continue operating. Understanding and implementing cutting-edge, ecologically friendly techniques will put these companies in a favorable position to comply with changing requirements.

The subsequent segments of the study are described in the following manner. In section one, the introduction of the study is explained, in section two a detailed summary of related research studies is provided. The data source and methodology are described in the third section. The empirical outcomes with discussion are presented in the section four. In the fifth section, we provide the conclusion along with essential policy insights.

1 LITERATURE REVIEW

1.1 Theoretical Framework

In this research, the theoretical foundation of Endogenous growth theory (EGT) is used. This theory states that the efforts made by businessmen for economic advancement lead to technological changes, therefore, anything boosting such efforts including education, research, and development can affect economic development. Past researchers have highlighted that technological innovation helps in increasing productivity and economic advancement. Although technological innovation may also cause CO2e still it has positive effects on the environment (Welfens et al., 2017; Balsalobre-Lorente et al., 2018). This theory also explains that by doing investment in technology and innovation, higher returns can be earned which will ultimately improve economic development. Concerning ICT and urbanization, this theory implies that when a society transforms from an industrial sector to an information sector, the country achieves higher growth. ICT, urbanization, and education can enhance innovation processes through the creation of new and advanced business models, reduce transaction expenses, and also provides worldwide information (Adams, 2022). Thus, the framework proposed and tested in this study is based on EGT for investigating the role of urbanization, ICT, technological innovation, and literacy rate on environmental sustainability.

2.2 Relationship Between Technological Innovation and Co2 Emissions

The importance of green technology innovation in the search of environmental sustainability and excellence of economy is undeniable (Fernando et al., 2019). Notwithstanding the fact that some studies focus on treating it as merely an expense that raises overall costs for the business or economy (Hsu et al., 2021), however, the financial benefits accumulate over time (You et al.2019).

In the past, the development of technology and its link to other processes have been examined from a variety of angles across the globe (Ambos et. al., 2021). Such as, using the Generalized Method of Moments (GMM) technique on the data set from 1996 to 2008, Bujari and Martinez (2016) examined the role of R&D investment in the development of economy in Latin American nations. Similarly, a few empirical studies have conducted research on BRICS economies regarding environmental sustainability issue. Ibrahim et al. (2022) analyzed monthly datasets from 1990 to 2017 and estimated the empirical link between technology innovation and CO2e in BRICS economies using a quantile-on-quantile framework and reported that CO2 is reduced significantly due to green innovation methods. Further, Chien et al. (2021) have also the relationship between technology innovation and CO2e and found the relationship is significant over the long term but insignificant over the short term, with developed nations being significant over developing nations.

2.3 Relationship of Literacy Rate and ICT With Co2 Emissions

The role of education is significant in spreading information regarding environment protection (Zhu et al., 2021). It is a well-known fact that people with higher levels of education use ICT equipment more frequently, while developing nations with lower levels of education have lower ICT penetration. On the other hand, the ongoing ICT revolution affects education, and better education results in higher returns, more growth of economy, and more human development (Ahmed et al., 2021). Ahmed et al. (2020) demonstrated that human capital makes a progressive difference in the sustainability of the environment by raising awareness of environmental issues, which in turn

encourages environment friendly behavior and increases energy recycling and conservation methods. On the other hand, education leads to activities that use a lot of energy, like trade and manufacturing. Thus, access to invent polluting technologies have also been increase due to latest knowledge and education (Magazzino et al. 2021).

The research on the effects of ICT on CO2 emissions has produced contradictory results. Such as, on one hand, it is considered that increase in demand of electricity, is linked to CO2 emissions and higher energy consumption (Moyer & Hughes 2012). On the other hand, the greening of the ICT industry is recognized in lowering CO2 emissions (Shen et al., 2021). Moreover, the link between use of ICT and outflows of CO2 depicted a relationship in reversed U-shaped highlighting the positive effects of ICT advancement on ecological quality (Faisal et al. 2020). Thus, mixed findings have been reported by aforementioned studies and this highlights the empirical research gap for more studies.

The consumption of goods and services of ICT have been found to exacerbate direct emissions of CO2 into the air, but the impact could be reversed indirectly through ICT energy efficiency improvements and the greening of the ICT sector (Williams et al., 2022). Additionally, the use of ICT allows for the substitution of traditional, polluting cooking fuels with more environmentally friendly, cleaner alternatives (Mahapatra et al., 2021). A switch to cleaner cooking fuels would also play a significant role in lowering carbon dioxide emissions, which would further contribute to improved environmental conditions. Thus, it is vital to comprehend the relationship between these variables in the economies of the BRICS as there is a significant potential to get deeper insights about this research gap.

Therefore, the authors of this study were motivated by all of the above mentioned factors to investigate the potential impact of ICT, technological innovation, literacy rate on the CO2 emissions for providing empirical insights. Further, in contrast to mainstream literature, the current work uses the novel econometric methods for analyzing the data including unit root tests, cointegration tests of Panel Fully Modified Least Squares (FMOLS). Additionally, comprehending the role of ICT in environmental sustainability will benefit from a new perspective adopted to measure of ICT. Therefore, the research direction used in this study is unique as it has not been extensively explored in the literature.

1 DATA SOURCES

This research examines the relationship between technological innovation (TIN), information and communication technology (ICT), and literacy rate (LR) with environmental sustainability for the period from 1998 – 2023. The environmental sustainability is measured as carbon emissions per capita (CO2) measured in kiloton and the data is collected from world development indicators (WDI). For measuring technological innovation, a proxy of research and development expenditure as a percentage of gross domestic product is used, collected from WDI. For evaluating ICT, the ICT service exports is used and the data is collected from World Bank. The literacy rate is assessed through the percentage of youth's total literacy rate and the data is collected from World Bank. Three control variables in this study are urbanization, globalization and economic growth. The data of urbanization is examined in terms of percentage of total population collected from WDI. The globalization is measured in terms of exports of goods and services and its data is collected from World Bank. While the economic growth is assessed in terms of GDP per capita constant data from WDI.

2 MODEL CONSTRUCTION

This research has adopted the stochastic effect through regression method on population, technology and affluence framework (STIRPAT). The STIRPAT equation is described below.

$$I_t = \alpha P_t^{\beta} A_t^{\gamma} T_t^{\delta} \mu_{it} \quad (1)$$

In equation (1) 'I' represents the impact of environment, 'A' represents affluence, T represents technology and 'P' represents population. The CO2 presents the environmental indicator, economic growth in terms of GDP per capital presents the affluence, the demographic variable is urbanization and ICT presents technology factor. Due to the significance of urbanization, technological innovation and literacy rate in influencing environmental sustainability, the STIRPAT model in the equation 3 is presented as follows:

$$\ln CO2_{it} = \alpha + \beta(\ln GDP_{it}) + \gamma(\ln GLOB_{it}) + \pi(\ln ICT_{it}) + \tau(\ln URB_{it}) + \rho(\ln TIN_{it}) + \omega(LR_{it}) + \mu_{it} \quad (2)$$

In equation 2, the natural logarithm of selected variables is presented along with their parameters. The intercept is α and μ is the random variable.

3 METHODOLOGY

This research applies panel econometric methods which are widely applied on panels having large number of variables and time period. Initially, the cross sectional dependence test is applied, then unit root test along with cointegration tests are used before the application of long run panel data estimation with casualty test.

a. Cross Sectional Dependence Tests

The cross-sectional dependence test is one of the significant tests as cross dependence is a crucial issue that needs to be resolved before conducting the main analysis (Munir et al., 2020). The failure in resolving the issue of cross-sectional dependence leads to estimator and parameter inefficiency along with useless results. In this research, cross sectional dependence is anticipated among the BRICS economies due to the similar characteristics existing among the selected countries. For conducting cross sectional dependence test, we have applied the widely applicable Pesaran Scaled LM with Breusch Pagan LM tests (Musah et al., 2021). The outcome revealed the existence of cross sectional dependence in the data.

5.1 Unit Root Tests

After this we applied the cross-sectional augmented ADF and PP tests. These tests are applied in order to avoid spurious regression results. Further, both these tests are very suitable for heterogeneous panel data in comparison to the first generation test.

b. Cointegration Tests

In this research, a rigorous cointegration techniques are used for examining the cointegration among the variables. We applied Panel Fully Modified Least Squares (FMOLS) as it is known as one of the most widely applied methodology. Further, it also helps in obtaining reliable outputs and it is known as one of the most consistent methodology. In this test, H_o states no cointegration is present among variables. While H1 states that there exists cointegration among variables.

5.2 Parameter Estimation

In order to observe the presence of factors, the widely applicable method of FMOLS method and following equation is presented.

$$\beta_{FMOLS} = [1/N \frac{1}{N} \sum_{i=1}^{N} (\sum_{t-1}^{t} (x_{it} - \overline{x_i})^2]^{-1} [(\sum_{t-1}^{t} (x_{it} - \overline{x_i}) \widehat{y_{it}} - T \Delta \epsilon\mu)] \quad (5)$$

4 RESULTS

The table 1 presents the outcome of Pearson correlation, it is evident that positive correlation exist among all selected variables. As per the results the correlation between CO2 and globalization and literacy rate is strongly negative as compared to other variables.

Table 1 - Pearson correlation

	CO2	GDP	GLOB	ICT	LR	TIN	URB
CO2	1						
GDP	-0.2096	1					
GLOB	0.7827	-0.1055	1				
ICT	-0.2298	0.5449	0.0126	1			
LR	-0.3962	-0.0164	-0.3570	-0.1766	1		
TIN	-0.1137	0.6021	-0.0146	0.2093	0.1183	1	
URB	-0.3855	0.241	-0.4456	0.2352	0.0773	-0.1257	1

In order to identify the issues of multicollinearity the variance inflation factor (VIF) is calculated and the values of VIF are presented in table 2. As per the outcome obtained, all variables have the value of VIF lesser than 10, thus the data is free from multicollinearity issue.

Table 2 - Vif analysis

Variable	VIF	1/VIF
GLOB	1.47	0.6802
URB	1.08	0.9259
LR	1.06	0.9433
TIN	1.20	0.8333
ICT	1.25	0.8000
GDP	1.55	0.6451
Mean VIF	1.26	

After performing preliminary tests, the test for identifying cross-sectional dependence are applied. This phase is very crucial in order to choose the most appropriate cointegration, unit root, and estimation methods in the long run. It is important because if the cross-sectional dependence is not considered then it may cause loss in the efficiency of results. In this research, Breusch Pagan LM test with Scaled Methods of Pearson is applied for testing the interdependence among the selected variables. The results are presented in table 3, which confirms the acceptance of our hypothesis, therefore, no interdependence is found which shows the existence of dependence among the cross sections.

Table 3 - Cross-sectional dependence test

Test	Statistic	Probability
Breusch-Pagan LM	166.3214	0.0000
Pearson scaled LM	34.95452	0.0000

After the confirmation of cross-sectional dependence tests. These tests are widely used in existing literature due to their reliability of results to manage cross-sectional dependence (Zhang et al., 2020). The table 4 presents the results and it shows that the variables analyzed in this research are not stationery. Thus, the criteria required to apply the cointegration analysis is met.

Table 4 - Results of unit root analysis

Method	Statistic	Prob.**
Im, Pesaran and Shin W-stat	-4.93498	0.0000
ADF - Fisher Chi-square	42.3332	0.0000
PP - Fisher Chi-square	139.479	0.0000

Table 5 - Fmols cointegration analysis

Variable	Coefficient	Std. Error	Prob.
ICT	-1.700	6.120	0.0069
LR	-0.001	0.000	0.0000
TIN	0.120	0.019	0.0000
URB	0.047	0.040	0.2491
GDP	-8.120	8.680	0.0000
GLOB	-0.014	0.004	0.0007

The results are presented in the table 5, shows that all selected variables are at significant level. The negative coefficient with significant value of ICT presents that environmental degradation can be controlled if appropriate policies on ICT are developed. While, the coefficient value of technological innovation (TIN) is significant and positive, which shows that technological innovation (TIN) leads to increase CO2 emissions. Further, literacy rate (LR) presents a negative and significant relationship, which shows that with an increase in literacy among population, the environmental degradation will be controlled.

Among the control variables, urbanization presents a positive and significant link with CO2 emissions. It means with 1% increase in urbanization, the CO2 will increase by the value of 0.047. This shows that urbanization plays a critical role in increasing CO2 emissions. The coefficient of GDP and globalization shows a negative and significant relationship with CO2 emissions.

5 DISCUSSION

The results reveal that one of the major cause of environmental degradation is technological innovation. This finding is consistent with the findings of (Adebayo et al., 2022) who examined the effects of renewable energy, consumption and technological innovation on CO2 emissions. This study highlights that environmental sustainability is an essential component of corporate operations going forward, not just a fad. To maintain business continuity and resilience, multinational corporations will be better equipped to handle upcoming environmental issues and legislative changes if they proactively implement environmentally friendly practices. Further, the results are also in line with the findings of Khan et al (2020) who reported that the technological progress particularly in the construction field leads to positively influence CO2 emissions in Pakistan for the period 1991 – 2017.

The association between literacy rate and CO2 emissions is negative and significant which is in line with past studies (Eyuboglu & Uzar, 2021). This shows that if BRICS economies invest more capital in education, it will foster innovative techniques to be used in businesses which will ultimately decrease CO2 emissions. Therefore, the government should invest more in improving the existing strategies for making environment friendly products by offering free trainings and educational programs in collaboration with universities in order to formulate advanced methods which will reduce energy consumption and consequently CO2 emissions. Further, to overcome this obstacle, multinational corporations must make sure that the technical breakthroughs they make are truly sustainable. This entails giving green technology top priority and regularly evaluating how their discoveries will affect the environment. The relationship between ICT and CO2 emissions is also found to be negative which is in line to the study of (Godil

et al., 2020). The reason lies behind the fact that because ICT has been penetrating in BRICS economies over the last decade and people have switched to modern energy consuming equipment. Thus, an increase in the use of more information communication and technologies leads to decrease CO2 emissions.

The positive relationship between urbanization and CO2 is in line with literature (Wang et al., 2016) The reason behind this finding shows a new perspective that with an increase in urbanization, people switch to use more advanced energy methods due to which CO2 emissions increases. Further as urbanization increases, people prefers to purchase more modern energy products and thus leading towards new energy patterns which gradually increases CO2 emissions. A negative relationship is found for globalization and economic growth with CO2 emissions and this finding is in line with literature (Acheampong, 2018; Bakhsh et al., 2017) as researchers believe that due to the enhancement in economic growth and globalization, CO2 emissions also increases.

CONCLUSION

This research investigated the impact of technological innovation, ICT, and literacy rate on the environmental sustainability while controlling the effects of economic growth, urbanization and globalization over the period from 1998 - 2023. Though past studies on CO2 emissions and economic growth has shown a tremendous growth over the last decade, however, there is a dearth of literature on BRICS economies and the role of selected key variables in environmental sustainability. This research has applied rigorous econometric methods which includes unit root tests, cross sectional dependence test and panel cointegrated tests. We found that by investing in and creating eco-friendly technology, multinational corporations may establish themselves as leaders in the field. This kind of leadership may develop collaborations, open new markets, and provide prospects for technology transfer or licensing. In a global market that is evolving quickly, firms may stay competitive and relevant by staying ahead of technology innovations. Our findings have revealed the presence of long-run equilibrium among the variables. A positive and significant relationship is found between technological innovation and CO2 emissions.

Considering the findings of this study, we recommend following practical implications; The government in BRICS economies should adopt environmental friendly innovative methods in the business sector to achieve environmental sustainability, the results also revealed that by increasing technological innovations, the use of more harmful strategies will be increased leading to increase CO2 emissions. Thus, there is dire need to explore more technologically advanced environment friendly methods. Further, the countries should invest more in ICT infrastructure and improve it with the help of revised online banking, money transfer processes and traffic monitoring systems. The government should give substantial tax reliefs to the investors investing in the ICT sector. The BRICS region should take practical measures to execute ICT in each sector through reliable and sustainable systems in order to achieve environmental sustainability. Moreover, the policymakers should design more effective policies considering the sustainability lifestyle and its role in the economic development.

Policymakers should work with educational institutes and revise the syllabus for increasing the sustainable environment awareness and the positive mindset for tackling the issue of environmental degradation. The environmental effect of multinational enterprises is a subject of constant investigation, especially in emerging countries. These companies may dramatically lessen their total environmental effect and carbon footprint by using creative, eco-friendly methods. This not only helps achieve corporate social responsibility (CSR) objectives, but it also reduces the possibility of environmental damage, which might result in negative publicity and legal ramifications. Hence, this study reveals the role of technological innovation, literacy rate, ICT and urbanization in understanding the environmental sustainability in the BRICS economies.

The study's conclusion emphasizes how important it is for multinational corporations operating in the BRICS economies to use cutting-edge, ecologically friendly practices. In addition to assisting in the achievement of environmental sustainability, this approach has other strategic advantages, such as improved business reputation, cost savings, market differentiation, and regulatory compliance. To ensure a sustainable future, multinational corporations need to understand how important it is to strike a balance between environmental responsibility and technological growth.

There exist a few limitations as well, this study has been conducted on BRICS economies, and therefore, future studies can be on a time series data in other regions of the world. In order to get deeper insights, future studies can consider each city within a country and replicate the model of this research. Lastly, future studies can explore the relationship between selected variables with inclusion of different mediators and moderators such as energy consumption, green innovation and environmental dynamism.

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