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Exploring the Dynamics of CO2 Emissions, FDI, and Technological Innovation on Economic Growth: Evidence from BRICS Nations by Using CS-ARDL

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ABSTRACT

This research paper aims to determine the relationship between CO2 emissions, FDI, TR, TI, GCF, and LFPR on GDPP in the BRICS region, and finding emphases on the period between 2000-2023. The study further examined the relationship between the dependent and independent variable in the long-run and in the short-run by using the CS-ARDL. The outcomes from CS-ARDL reveal that CO2 emissions, FDI, TI, and GCF affect GDPP significantly. CO2 is, undoubtedly, an adverse phenomenon to the environment but corresponds to the increased level of industrial production and temporary EG. While trade and labor force participation rate have an insignificant relationship with GDP per capita. These findings mean that policy initiatives aimed at technology development, FDI attraction, and encouragement of capital investment should remain priorities in BRICS countries; at the same time, concerns about environmental issues such as CO2 emissions should also be on the agenda for sustainable long-run growth.

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1. Introduction

Hence, this research is particularly relevant at this time when the world is struggling to find middle ways; between fostering economic growth and achieving environmental sustainability. UN Sustainable Development Goals reflects this necessity primarily with SDG 8 and SDG13 challenges. These objectives warrant the need for growth of the economy while at the same time carefully managing the ravaging social cost of industrialization and globalization on the natural environment. Again, CO_2 emissions are very relevant to climate change and are necessary to this conversation. Limiting them is essential if the ecosystem should be preserved and economic development should continue to a successive level of sustainability. Understanding of activity and impact between the CO_2 emissions, domestic investment and trade openness is critical because these variables are dependent on one another within concept of sustainable development. Investment within a country often lead to growth within the country because it stimulates the improvement if the infrastructure, technological development, and creates employment opportunities. Trade openness can have a positive impact in a country by expanding the markets and competition; but this can have a negative effect when it encourages production that will cause emissions. The nature of these linkages must be analyzed in order to develop appropriate economic policies and to define strategies which are favorable for as far as sustainability targets of the global world. Comparing all these factors makes it easy to see how economic development can be promoting economic growth and environmentally solving the problems that come with it. Consequently, this research contributes towards the overall sustainability agenda by providing tested and triangulated methods for enhancing the target economy whilst respecting and conserving ecological limits (OECD, 2019; Shafiq & Zafar, 2023; Stern, 2007).

GDP per capita correlates with CO_2 emissions and shows that the correlations are not linear. On one side it has been observed that augmented level of CO_2 emission is positively associated with increased in short run (Sheng & Guo, 2016). Sorted it is so due to extra investment in energy-intensive industries in developing economies. On the other hand, Ibukun and Osinubi (2020) stated that the external costs associated with high CO_2 emissions for instance, degradation of environment and poor health will consequently drag down sustainable economic growth. Expenditure on pollution control or that for climate change adaptation might lower productive investment, and, therefore, lower GDP per capita in the long-run. FDI is also an important tool that can be used to stimulate economic growth (EG) (Adams, 2009). First, FDI mobilizes foreign capital for directing domestic investment in infrastructure, manufacturing, and services sectors which in turn raises productivity and EG per capita income. Second, FDI helps to transfer technologies, managerial skills and innovation from the developed to the developing countries therefore enhancing the efficiency of the domestic markets and promoting growth (Sabir, Rafique, & Abbas, 2019). However, if FDI contributes to capital flight or profit taking, and an insignificant amount of these capitals are re-injected in the host economy, then FDI will have a regressive effect on the host economy's future economic growth, hence the reduced impact on the per capita GDP figure (Mazzocchi & Tamborini, 2021).

Trade openness normally leads to EG in a way that enhances import and export of goods and services by allowing countries export goods or services in areas they have a competitive edge (Chang, Kaltani, & Loayza, 2009). This specialization raises output and thus adds to a higher GDP per head that is the aim total economic growth. Furthermore, open trade policies mean more competitiveness via foreign Players resulting to competitive productivity. Further,Rodrik (2017) stated that trade openness can be vulnerable to global shocks and competition that compels depreciation of well-established industries at the expense of GDP per capita if precaution has not been taken. Technology advancement is thus an important source of growth to the economy especially to the developed economies (Daud & Ahmad, 2023). Afzal and Kalra (2024) stated that leads to generation of advanced products and technological processes in the production system, making the productivity and efficiency in the economy to rise and result in higher economic production and GDP per capital. Alvarado, Murshed, Cifuentes-Faura, Işık, Razib Hossain, and Tillaguango (2023) argued that technology also helps in the development of new sectors and proper high-level jobs, which in turn pace up the economic development. Nevertheless, inadequate physical infrastructure or skilled workforce can work against such an economy and hinder effectively exploiting the new technologies leading to skewed and potentially dampening effects of this resource on the GDP per capita.

Gross capital formation refers to investment on man-made non-residential structures, machinery and equipment goods that are essential for increasing the series of production in an economy (Ruggeri, 2023). Expenditure on fixed capital increases the capacity of industries to deliver goods and services hence ill. Effects on the economic growth and GDP per capita. Moreover, strong GCF is associated with technological transfer and the improvement of industries, and the continuation of the growth process. But, wrong placement of capital or more appropriately wrongly deployed investments tend to cause stagnation of economic activities, thereby reducing the possible gains accruing from GCF on the aspects of enhanced GDP per capita (Chowdhury, Rahman, Majumder, & Esquivias, 2023). The labor force participation rate determines the proportion of the given population within the working age that remain economically active within the labor market. In present case, a higher LFPR means a larger population size within the economically active age thus an increased work force results to high productivity which enhances economic output and hence a high GDP per capita (Su, Li, Tao, & Lobonţ, 2019). Kabir (2019) youthful population and increased number of people provide increased potentiality for the formation of more novelties, increased rate of receiving innovations, increased numbers of new companies, and companies' growth rates. However, Tjahjanto, Tuhana, Mafruhah, Istiqomah, and Ismoyowati (2023) stated that an increase in labor force participation rate is not complemented with job creation activities, or else the population becomes a 'sure' work force, that is, the work force is used sub-optimally, then such an increase is likely to enhance the unemployment or underemployment level hence reduce the impact of increase in GDP per capita.

This research topic is especially significant in the context of the BRICS countries, which include Brazil, Russia, India, China, and South Africa. These nations hold a crucial position in terms of geography and economy, acting as a link between Africa, the Middle East, and Europe.

However, they face different troubles which make both their economic and environmental status more critical. The BRICS countries are endowed with great economic strength and they have enormous natural resources, young population and strategic gateways and markets. However, a significant environmentally related vulnerability in the country is exemplified by water crises, desert disciplines and climate change impacts. Also, the area has been characterized differently in terms of the political stability and economic volatility, which has contributed to making the attainment of sustainable development even harder (World Bank, 2020). That is why, the impact of CO_2 emissions on the EG in these countries is appreciated as rather high, since a number of preconditions are connected with it. High emission levels therefore cause climate change and impact the immediate surroundings in such a way as to possibly harm the social and economic production. This study is crucial for addressing the question regarding the interaction between the growth of gross fixed capital formation in BRICS economies and sustainability of the environment.

2. Literature Review

Acheampong et al 2021 investigated the relationship between renewable energy, CO_2 emissions, and EG in SSA. The findings stated that economic growth boosts the CO_2 emission. Though the study fails to establish a direct relationship between carbon emission and renewable energy but it shows that while necessary, economic development leads to increased CO_2 emissions. This discovery is important to decision makers in SSA, where quality institutions and acceptance of renewable energy are central to fighting climate change while also charging the region's economy forward. Hubacek and colleagues further refine the disentanglement of CO_2 emissions from growth, with the help of consumption perspective in this 2021 research paper. Researcher also noted that despite the fact that some developed countries have achieved the state of decoupling the latter is rather unstable and relies more on the constant reduction of emission intensity across the supply chain. This research pays a special attention to the role of cooperation in achieving sustainable decoupling and assert that initiatives should go beyond the national level to cover the level of global supply chain. Namely, Joo, Kim, and Yoo (2015) disaggregated the effects of EC and CO_2 emission on EG in the case of Chile. The result from the ganger causality test and the result from the error correction model also show the existence of a unidirectional Relationship between the EG and the CO_2 emission. The findings indicated that EC strongly contributes to the EG.

Abbasi, Shahbaz, Jiao, and Tufail (2021) investigates the fresh fact of an effect of CO_2 emission, EC, and urbanization on EG particularly within the Pakistani context. According to them what they pointed out was the fact that carbon emissions are good for growth in the short term but the sustainability of this kind of growth in the long run is more often than not questionable. Inal et al., based on the research about African oil-exporting countries in 2022, found out that CO_2 emissions affect the EG in a positive manner more specifically it applies to countries like Algeria and Egypt. However, independence of renewable energy on economic expansion points to incomplete utilization of renewable inputs. This find means that it's high time to reconsider energy policies in these states to tandem the rates of economic growth with the protection of the environment. Gao and colleagues continued with their analysis and argue that most provinces have only a weak decoupling between CO_2 emissions and EG in China. The study establishes that emission originate from economic activities whereby capital investment and total factor productivity are key determinants. The synchronization of decoupling trends across different provinces suggests that China has been transitioning towards a low carbon economy but some barriers exist in achieving growth dematerialization. In studying the decoupling of CO_2 emissions from EG, Hu et al. (2020) specify the BRI as a case study of the Belt and Road Initiative (BRI). According to their findings, developed countries often post higher decoupling performances while developing countries struggle with the emission rise associated with EG. The result of this study has demonstrated the importance of reducing energy intensity and managing population growth as the effective measures to decrease CO_2 emissions in the developing regions. Raheem, Tiwari, and Balsalobre-Lorente (2020) differentiated between the existence of a link of CO_2 emission with financial development and the impact of ICT in EG in G7 countries. The outcomes reported a negative but significant impact in the short run while negative relationship in long-run.

Onofrei, Vatamanu, and Cigu (2022) looks at the co-integration between economic development and CO_2 emissions in the EU countries. According to the research, the EG in the EU has been associated with the increase in the emission of CO_2 where every percentage increase

in the GDP has accompanied a 0.072% increase of CO2 emissions . This relationship shows that adjustment has been a challenge for developed economies to achieve a balance between growth and the environment. The findings show that at high income levels and economy development, people show higher willingness to protect the environment. This means there is need to come up with policies that can deal with emission reduction measures more so during instances of EG. Later, Anser et al. (2021) empirically examine the causal nexus between globalization and economic advancement and CO_2 emission in South Asian countries and found that they are co-related. From the research it is clear that while EG is essential for development it often leads to deterioration of the environment. The findings also point towards the fact that non-renewable energy greatly contribute to the occurrence of CO_2 emissions and EG enhances the effect. The outcomes are aligned with the Environmental Kuznets Curve (EKC) hypothesis, stating that with an increase in the level of development the negative effects intensity rises but upon a certain income level, these negative impacts decrease because more money is being invested in environmental protection. Li and Wei (2021) analyze the relationship between CO_2 emissions and EG in China that depends on regions and has nonlinear properties. The study points out that concerning both northern and southern parts of the studied country, EG makes the greatest impact on CO_2 emissions; however, the nature and intensity of this impact may vary. The results further illustrate that with higher levels of carbon emissions, economic growth is negatively skewed most especially in regions where industries thrive. This research has accorded importance to the regional efforts which are developed to address the environmental challenges that result from the development of the economy. Adebayo (2021) examine that ether CO_2 emission, EC globalization and trade openness have a negative effect on the EG in Japan. From the fully modified ordinary least square estimation it was revealed that CO2 emission, energy usage and globalization increase the EG while trade openness has no direct relation with EG.

In the iron and steel industry of China, X. Wang, Wei, and Shao (2020) observed a very poor decoupling of carbon emission from GDP. Decomposing the 'factors affecting decoupling' the research stresses on emissions reduction and value addition as two cardinal areas that define important decoupling ratio, while also stating that improvement in energy efficiency is central to achieving better forms of decoupling. The findings show that sustaining and intensifying current efforts remain crucial for energy saving and emission reduction in industries that use much energy. According to Burgess, Ritchie, Shapland, and Pielke (2021), IPCC baseline scenarios are flawed since they have made high estimates of CO_2 emissions and GDP growth. Their analysis focuses on the difference between the real trends and the scenario approaches and casts questions towards the feasibility of achieving the higher growth rates of the economy necessary in order to meet future emission reduction targets. This research calls for reconsideration of the basic assumptions of climate scenarios better to capture ontological actualities and probabilistic futures. Chishti, Ahmed, Murshed, Namkambe, and Ulucak (2021) noted that non-linearities from economic development on CO_2 emissions got worse with rising environmental degradations in economies affected by terrorism and FDI intensity. This research pays attention to the positive economic shocks of FDI, which are most of time significantly likely to cause a high emission of CO2 hence supporting the Pollution Haven hypothesis. The implication arising from the results is that with economic growth especially under conditions of economic risk there is likely to be more damage to the environment, suggesting the require need for policies that promote use of cleaner technologies and better environmental standards. Like this, Namahoro, Wu, Zhou, and Xue (2021) examine the link between EG and CO2 emission in African countries by introducing regional and income group differentiation. The work proves an inverted U-shape relationship where economic development either increases or decreases CO_2 emissions based on the area's type and level of development. The findings of the study also showed that in Africa, economic growth enhances the emission of CO_2, especially in regions with high energy intensity. Still, these effects have been proven to be relieved by promotion of renewable energy showing importance of clean energy in eradicating the effects of economic development on the environment.

J. Zhang and Zhang (2021) examines the link between tourism, EG EC and CO_2 emission with regard to China. Their research reveals that the use of power with CO_2 emissions was a function of economic development and EC, and that touristic activities also posed a threat to the environment. The research focuses on the implications of sustainable tourism and energy policies in minimizing environmental impacts of economic development in fast growing economies like China. Urbanization level and economic development are identified as the key determinants of CO_2 emissions in Far East Asian countries, hence the study by Anwar, Younis, and Ullah (2020). Another revealed fact points out that the alarming rates of the urbanization process and economic

development cause a substantial increase of CO_2 emissions in these countries. The writers suggest that it is possible to avoid excessive environmental cultural or geographical imprint in this part of the world only if sustainable urban development applies enhanced industrial frameworks meant to increase the dependency on renewable energy. Leitão and Lorente (2020) explored this relationship in the European Union focusing on EG, RE, Tourism, Trade Openness and CO_2 emissions. They noted that while trade openness and renewable energy helped reduce CO_2 emission, EG increases the number of emissions. This discovery notes environmental trades associated with the economy regardless of their environmentally friendly locations. The research affirms adoption of renewable energy and sustainable approaches in development plans to minimize the impact the economic activities have on environment. Karaaslan and Çamkaya (2022) aimed at the analysis of the relationship between GDP, health expenditure, renewable and non-renewable EC and CO_2 emissions for the case of Turkey. For short-term and long-term analysis of CO_2 emissions, they found that GDP and non-renewable energy are the determinants of higher emission used and on the other hand health spending and renewable energy are the determinants of lower emissions. The study explains why – Turkish leadership should encourage the further development of renewable energy and health sectors to reduce the adverse effects of economic development. Muhammad (2019) used the same dependent variable to examine the nexus between CO_2 emission and EG whereby data of 68 countries (developed, emerging and MENA countries) was used. The conclusion from the generalized method of moments said that there was positive relationship between CO_2 emission and EG in the developed and emerging economies.

Chen (2023) concluded that TI has influence on EG and this reiterate the fact that there is necessity for timely and focused attention on innovation for improved business performance in Tunisia. Likewise, in India, patents are associated with increased investment and Economic growth, but it hampers employment (Rooj & Kaushik, 2024). Hysaj and Sulçaj (2024) reported that shows that in a creative output and infrastructure have a significant positive impact on the GDP after the year 2024, on the other hand the institutional factor a negative impact. H. Zhang, Shao, Han, and Chang (2022) TI has enhanced efficiency in the different industries and sectors, while at the same time contribute to the social inequality in China. The above results highlight the fact that technological development is not linear with economic development and this in turns calls for a cautious approach on the benefits of technology to avoid the loss of certain negative effects. Abdulkarim (2023) stated that trade openness is beneficial to growth in Nigeria. On the other hand, an arrange of trade openness above or beyond the average of the developing countries will have a negative effect on GDP growth because trade barriers in the developing countries are relatively low, while higher trade volume will have a positive effect on growth rates (Nam & Ryu, 2023). Based on the case of OECD countries, Jošić (2023) reported that trade openness actually benefited economic development in most cases although disparity arises with regards to different quantiles of performance. Besides, a kind of non-linear causality whereby trade openness enhances growth only at given income levels is also established (Ondaye, 2023). However, trade may worsen the rate of growth of GDP in LDCs, the bifurcation effect rises over time (Blancas & Ángeles-Castro, 2024). This is because trade openness has been evidenced as having various dimensions, which call for policy strategies that would unlock the many benefits while avoiding the many vices. There is no such study found in the literature that explore the impact of CO2 emission, FDI, TR, TI, GCF and LFPR on GDPP in the BRICS countries. We fill this gap by conducting this research.

3. Theoretical Framework

The section describes that how Co2 emission, FDI, TR, TI, GCF and LFCP impact on the GGDP. Hariyani, Prasetyo, Ha, Dam, and Nguyen (2024) argued that growth in economic activities results in high emissions of CO_2 mainly in the developing countries that are experiencing the process of industrialization. Nevertheless, many of these emissions can be avoided as economies continue to develop through embracing cleaner technologies, and the use of renewable energy sources (Kayani, Nasim, Aysan, Bashir, & Iqbal, 2023). FDI also enhances the EG. Through the infusion of FDI the economy may improve through new technologies and practices that curb emissions (Mi, 2024). This is not a simple kind of relationship FDI can bring economic development for a country but can also bring pollution if not checked (Bhandari & Chowdhury, 2024). Trade liberalization allows access to CCS technologies and intensifies competition, hence encouraging Research and Development and possible elimination of emissions (Hariyani et al., 2024). However, it can also contribute to the improved production and

utilization, which can stimulate the augmentation of CO_2 emissions in the short-term, as stated by Zhang et al., 2024. As such, Technological advancements refer to making EG untangled from carbon emissions, resourcefulness of undertakings, and purer output methods (Kayani et al., 2023). The paper advocates for embedding of green technologies as fundamental to realize sustainable EG especially in sectors that contribute to high emission levels (Mi, 2024). By combing all these, we formulated the model as follow:

$$GDDP_{it} = \alpha_o CO_{2_{it}} + \alpha_1 FDI_{it} + \alpha_{o2} TI_{it} + \alpha_3 TR_{it} + \alpha_4 GCF_{it} + \alpha_5 IFPR_{it} + e_{it}$$

Where:
GDDP = Economic Growth
CO_2 = Carbon Dioxide Emission
FDI = Foreign Direct Investment
TI = Technological Innovation
TR = Trade Openness
GCF = Gross Capital Formation
IFPR = Labor Force Participation Rate

Further, (i) and (t) shows the cross section and time respectively, while e_{it} denotes the error term.

3.1. Data

The main objective of this research is to investigate the impact of CO_2 emission, foreign direct investment, trade openness, technological innovation, gross fixed formation and labor ratio participation rate on GDP per capita. The countries taken for this study is the BRICS countries i.e. Brazil, Russia, India, China and South Africa. BRICS countries contain the economic activities on a large scale and contribute significantly in the global GDP. The data from 2000-2023 is used in this study is collected from the World Development Indicator (WDI).

Table 1: Description of Variables

Variable	Symbol	Proxy	Data Source
Economic Growth	GDDP	GDP Per capita (constant 2015 US$)	WDI
Carbon Dioxide Emission	CO_2 Emissions	Metric tons Per Capita	WDI
Foreign Direct Investment	FDI	net inflows (% of GDP)	WDI
Technological Innovation	TR	Research and development expenditure (% of GDP)	WDI
Trade Openness	TR	% of GDP	WDI
Gross Capital Formation	GCF	% of GDP	WDI
Labor force participation rate	IFPR	% of total population ages 15-64	WDI

4. Methodology

This study adopts the CS-ARDL model to explore how CO_2 emission, FDI, TI, TR, GCF and LFPR influence the EG in the BRICS nations. This will enable us to justify the bilateral economic stakes of the BRICS countries. In an attempt to mitigate the cross-sectional correlation in the error term, Chudik, Mohaddes, Pesaran, and Raissi (2016) proposed that the CS-ARDL model modify the ARDL model where the model adds a linear combination of the average cross sectional of the dependent and independent variables. Sohag et al, using the error correction paradigm of CS-ARDL, also found the regressed variable to be socially weak exogenous with one year lag. By applying the CS-ARDL technique, the unobservable factors in the regression model can be identified to predict long run effects. As following Chudik et al. (2016); Samargandi, Sohag, Kutan, and Alandejani (2021), this work analyzes the both long-run and short-run CD issues. Based on the account of Pesaran and Yamagata (2008) the CD test is suitable for inferring of co-correlation effects with substantial economic integration between nations. CD test efficiently measures the cross-section independence in the sample item, (Islam, Sohag, & Alam, 2022). Mathematically, CD test is represented as follow:

$$CD = \left(\frac{TN(N-1}{2}\right)^{1/2/p}$$

Augmented Dickey-Fuller (ADF) regression model interlinks the cross-sectional residuals of the two variables into $\hat{P}$. The used variables are N for cross-sectional unit and T for time.

From the identification results of the investigation, it has been established that the cross-sectional dependence as well as the test of panel unit roots captures the homogeneity of slope between operating entities in the panels. CS-ARDL analysis in the present study is applied in the analysis of both short-run and long-run endogenous relationship between variables in the context of the co-integration technique. Particular rationale that influenced the paper to choose the CS-ARDL model are as follows. Also, the same is true for the long-term, as well as the short-term elasticities taken into account by the CSARDL model (Fedoseeva & Zeidan, 2018). The model enables primarily or purely, or a combination of single I (0), I (1) adaption according to the evidence detailed by Shin Yu, and Greenwood-Nimmo, 2014. This is done using CSARDL while endogeneity results when there is the simultaneity between the independent variable and the error term, (Adewuyi, 2016). Nevertheless, in the framework of CSARDL used for error correction, regressed variable with a one year lag is included as a weakly endogenous variable. Heavy hidden challenges, which have been used in assessing the impact of long-run regression models, are impacts arising from employ of this method. In the short and long term, they manage to keep CD in check (Sohag, Chukavina, & Samargandi, 2021) By using the CS-ARDL, the baseline model for GDPP is as follow:

$$\Delta GDDP_{it} = \mu i + \gamma_i\left(\Delta GDDP_{it-1} - \alpha_i U_{it-1} - \overline{\Delta GDDP_{t-1}} - \beta_{2i} U_{t-1}\right) + \sum_{j=1}^{p-1} \pi ij \Delta GDDP_{it-j} + \sum_{j=1}^{q-1} \varphi ij \Delta U_{it-j} + \overline{\omega_{1i} \Delta GDDP_t} + \omega_{2i} \Delta U + \varepsilon_{it}$$

GGDP, GDP per capita growth is represented by the $\Delta GDDP_{it}$ while the independent variables are represented by the U_{it}. $\Delta\overline{GDDP_{t-1}}$ is the long run coefficient of the dependent variable while U_{t-1} is the long run investigated coefficient of the independent variable while $\Delta GDDP_{it-j}$ and U_{it-1} are the short run coefficients of the dependent and independent variable. T shows the time while J shows the cross-sectional units and they represented as T = 1…. T and J=1……. J respectively. At the end, ε is the error correction term. ω_{1i} and ω_{2i} are the short run coefficient of the mean of the dependent and independent variable.

5. Results and Discussion

The Table shows the summary statistics and explaining that the mean value of the GDPP, CO2, FDI, TR, TI, IFPR and GCF are 3.68, 5.63, 2.24, 44.41, 1.083, 44.275 and 26.797 while the value of the standard deviation is 3.941, 3.768, 1.461, 11.725, 0.444, 12.031 and 10.284 respectively. TR shows the highest while TI shows the lowest variation among all the variables. The correlation matrix of the variables is shown in Table 3. Table 4 presents the results of the CD test. The null hypothesis for this test asserts that cross-sectional dependence does not exist. Reject the null hypothesis and accept the alternative hypothesis that CD exists if the significance level is below 5%. This study shows a p-value of less than 0.05, which indicates cross-sectional dependence is present.

Table 2: Summary Statistics

Variable	GDPP	Co2	FDI	TR	TI	IFPR	GCF
Mean	3.684	5.636	2.248	44.441	1.083	44.275	26.797
Std.Dev.	3.941	3.768	1.461	11.725	0.444	12.031	10.284
Min***	-7.828	0.884	-1.756	22.106	0.604	26.15	12.538
Max	13.636	11.88	9.678	68.094	2.433	67.918	46.66

Table 3: Correlation Matrix

Variables	GDPP	Co2	FDI	TR	TI	LFPR	GCF
GGDP	1						
Co2	-0.048	1					
FDI	0.185	-0.182	1				
TR	0.254	0.552	-0.097	1			
TI	0.269	0.205	0.115	-0.204	1		
LFPR	0.281	-0.374	0.465	-0.512	0.508	1	
GCF	0.614	-0.169	0.01	0.072	0.545	0.232	1

Table 4: Cross-Sectional Dependency Test

Variable	CD-test	p-value
GDPP	8.31	0.00***
LFPR	12.55	0.00***
GCF	6.41	0.00***

*for p<0.1, ** for p<0.05, ***for p<0.01

Considering the evidence of cross-dependence (CD), it is essential to employ the second-generation unit root test, which provides more accurate and reliable results, since the first-generation unit root test generates incorrect outcomes in the presence of CD (Gyamfi, Agozie, & Bekun, 2022). Table 5 displays the outcomes of the second-generation unit test. We employed the CIPS and CADF tests to evaluate the stationarity of the variables. The findings from both experiments indicate a varied order of integration, where some variables are stationary at their original level, while others achieve stationarity only after the first difference is applied.

Table 5: CIPS Unit root test

Variable	At Level		At 1st Difference	
GDPP	-3.194***	-2.51	-	-
CO2	-2.66***	-2.1	-	-
FDI	-1.926*	-2.1	-5.594***	-2.1
TR	-1.13*	-2.1	-3.26***	-2.1
TI	-2.6*	-2.12	-	-
LFPR	-0.88*	-2.1	-3.6***	-2.1
GCF	-2.4***	-2.1	-	-

*for p<0.1, ** for p<0.05, ***for p<0.0

1% = -2.51
5% = -2.25
10% = -2.12

Table 6: Short Run & Long Run estimations

Variables	Coefficient	p-value
Short Run Estimations		
_cons	29.242***	0.002
LD.gdppc_g	-0.36**	0.011
D.co2_mt	15.573*	0.073
Fdi	0.648**	0.023
L.trade	-0.08	0.573
D.rd	-14.26**	0.025
D.lfpr	1.035	0.17
LD.gcf	-0.285**	0.015
Long Run Est.		
lr__cons	22.93***	0.004
lr_co2_mt	13.917*	0.093
lr_fdi	0.478**	0.022
lr_gcf	-0.231**	0.02
lr_lfpr	0.857	0.21
lr_rd	-11.445	0.051
lr_trade	-0.043	0.706

*for p<0.1, ** for p<0.05, ***for p<0.01

By seeing the results, it is stated that CO_2 has a positive significant impact on the GDDP. The outcomes seeing that 1% increase in CO_2 emission results a decrease of 0.36% in GDPP in the short run. There is evidence showing that high CO_2 emissions led to a lower GDP per capita; degradation of resources that adversely affects labour productivity, cost escalation in healthcare, and damage to natural resources, restrict EG (Hannesson, 2019). On the other hand, 1% increase in the CO_2 emission results an increase of 13.91% in the GDDP in the long-run. Although, the effect of rising GDP per capita with rising CO_2 emissions in the long run may be maximizing short term gains from industrialization, output over efficiency, and pollution which are usually associated with high emissions (Khalfaoui, Tiwari, Khalid, & Shahbaz, 2023). The outcomes are familiar with the Wu et al. (2024) and Ratna, Akhter, Chowdhury, and Ahmed (2024). FDI has a positive and significant impact on GGDP both in the long run and short run. A 1% increase in the FDI results an increase of 0.64% in the GGDP in the short run. In the short run, FDI boosts up the per capita GDP because; first, it brings quick cash into the host country; second, FDI creates employment; third; FDI raises tendency to consume hence provides boost to the economy and

improves the output (Dinh, Vo, The Vo, & Nguyen, 2019). Also, FDI significantly enhance GGDP in the long run. The results stated that 1% increase in the FDI results an enhance of 0.47% in the GGDP in the long run. In the long run, FDI contributes to the development of a soundly based economy through technology acquisition expertise, productivity, and facility development to support improved EG and, therefore, a higher GDP per capita (Makris & Stavroyiannis, 2019). The findings are familiar with the Q. Wang, Yang, Li, and Wang (2023) and Nam and Ryu (2023).

Like that, TI has a negative but significant impact on the GGDP in the short run and the long run. It means that 1 unit increase in the technological innovation results a decrease of 14.26% in the GDDP. In the short run, technological innovation adversely impacts GDP per capita because it causes disruptions in labor markets with risks that exceed the benefits of a short-term increased productivity (Khan, Yuan, Yahong, & Xu, 2024). In the long run, 1% increase in the TI results a decrease of 11.45% in the GDDP emission. In the long run the inequality and the out growers of old technologies can lead to the presence a stringer negative than TIs in the case of GDP per capita (Hongqiao, Xinjun, Ahmad, & Zhonghua, 2022). The results of our research are familiar with the Alvarado et al. (2023) and Martial, Dechun, Voumik, Islam, and Majumder (2023). Similar to this, a negative but significant relationship has been seen between the GCF and GDP capita. The results stated that GDDP decrease 0.28% by increasing one unit of GCF in the short run. In the short run, gross capital formation can substantially demerit GDP per capita, because it is characterized by high initial investment expenditures, and the value of capital investments in the short term can be less than the cost of capital, thereby decreasing the overall level of production (Meng, Li, Ahmad, Qiao, & Bai, 2022). Also, 1% increase in the GCF results a decrease of 0.23% in the GDDP in the long run. When gross capital formation is incurred negatively towards the GDP per capita in the long run, it's because more resources were invested on unproductive or outdated sectors leading to slow down returns in growth of per capita (Rahman & Ahmad, 2019). Further, the outcomes are familiar with the Kesar, Bandi, Jena, and Yadav (2023) and Musa, Magaji, and Adewale (2023). Moreover, TR and LFPR have an insignificant impact on the GDP per capita.

6. Conclusion

The aim of this study is to establish empirically the effect of CO_2 emissions, FDI, TR, TI, GCF and LFPR on GDPP in BRICS countries by using the annual data from 2000-2023. Completing the CS-ARDL procedure, it was possible to analyse how CO_2 emissions, FDI, TI and GCF influence the GDP per capita: each of the variables is statistically significant. This implies that emissions of higher concentrations of CO_2 although have environmental implications still bear positive relations to industrialism and economic activity hence short-term economic benefits to these nations. The elevated value of FDI also emphasizes the contribution of external capital to the growth rates and the stimulation of effectiveness and innovations. In a similar manner technological progress is presented as an important force in EG, stressing the place of research and development and innovation as a way to build up productivity and boost levels of value-added industries in the BRICS context. Another component of the GDPP which is also regarded as an indicator of the extremely high rate of capital accumulation is gross capital formation, which reveals the necessity of investment in physical capital and the necessary infrastructure equitably per capita. On the same note, the analysis demonstrates that trade openness and, in particular, labor force participation rate does not significantly affect GDPP per capita of the BRICS countries. This might suggest that in spite of trade being critical in globalization its gains in economic development are not as straight forward in some of these economies because of trade deficits or other external linkages to the international commerce systems. Again, minimal reductions in LFPR could indicate structural problems within the labor market, consultation, or disparity in skills which restraints the effectiveness of labor force participation to the EG. Hence the current policies employed by the BRICS countries intensify efforts towards the improvement of technology and also exploitation of FDI as well as strategic capital investments that can foster sustainable economic development in the future.

6.1. Policy Implications

The conclusions of this paper have significant policy implications for the BRICS countries about the future of their EG. This means that policymakers need to find ways to reconcile the growth of industrialization while reducing CO_2 emissions that slow the increase in per capita. This requires more clean technologies and clear environmental standards that will reduce emission of CO_2 as industries continue pushing their outputs. Policies that would lead to FDI include enhanced

indicators for the ease of doing business, incentives offered to foreign investors and improved, and regulatory structures within given countries that would lead to FDI that in the end acts as a boost to capital per capita income. Since technological development is one of the measures of EG, BRICS countries should spend in research and development, develop models for encouraging innovation from private sector and upgrade the educational system for production of a skilled workforce in technology. In the same way, a high abundance of GCF underscores the value of investing on structures, equipment, manufacturing assets, capital goods among others missions on GDP per capita. The policymakers should focus on balancing industrial growth with environmental sustainability. This calls for the adoption of cleaner technologies and stringent environmental regulations that minimize CO_2 emissions while maintaining industrial output. The significant influence of FDI on GDP per capita highlights the need for policies that attract and retain FDI, such as improving the ease of doing business, offering incentives for foreign investors, and enhancing regulatory frameworks to ensure that FDI translates into long-term economic gains.

TI, being a key driver of EG, suggests that BRICS countries should invest in research and development foster public-private partnerships for innovation, and improve the education system to create a skilled workforce that can drive technological advancements. Similarly, the significant role of GCF underlines the importance of investing in infrastructure, manufacturing capabilities, and productive assets. To this end, the bulk of capital investments, spending should be directed to business areas with high potential in terms of economic payback, especially those related to production of technology and industrial growth. Low values registered for both trade and labor force participation rate suggest that BRICS needs to critically redesign its trade structure to ensure that increase in trade openness results into benefits. Policy makers should focus on balancing industrial growth with environmental sustainability. This calls for the adoption of cleaner technologies and stringent environmental regulations that minimize CO2 emissions while maintaining industrial output. Governments should prioritize capital investments in sectors that have a high potential for economic returns, particularly those that contribute to technological development and industrialization. The BRICS countries need to reassess their trade policies to ensure that trade openness translates into economic benefits. LFPR including skill development interventions, enhanced labor fluidity and high-quality employment opportunities will enhance the role of labor in contributing to GDP per capita.

This study has some limitations. This study only focuses on the BRICS countries. So, the findings may not be applicable on the other countries. Further, this study ignores some other control variables such as human capital etc. In future, researchers can work on the flaws to enhance the scope of this research.

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