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Green finance, financial development, and industrial growth: insights from the BRICS economies

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Abstract

Industrialization is as indispensable to the BRICS economies as they are to the global economy. Given the current focus on sustainable production and improvements in financial services, this study aims to analyze the impact of green finance and financial development on industrial growth, both individually and in interaction. Focusing on the five BRICS member states (Brazil, Russia, India, China and South Africa), the study covers the period from 2000 to 2023. Long-run estimates were obtained using panel FMOLS and DOLS estimators, and robustness checks were performed using the PCSE estimator and the Panel Dumitrescu and Hurlin (2012) causality test. The results of the long-run estimators suggest that the combined effect of green finance and financial development significantly benefits industrial growth in the BRICS countries. So far, green finance has overlooked their industrial sectors but its true flourishing is only possible if it is integrated into financial development policies. The research uses three long-run panel estimators — panel FMOLS, DOLS and PCSE — to confirm and validate its results. The validity of the PCSE estimator is assessed in terms of cross-sectional dependence. The results will inform the industrial, financial, and environmental policies of the BRICS countries.

Keywords

BRICS, industrial growth, green finance, financial development, synergic influence.

JEL: O10, O30.

1. Introduction

For the BRICS countries (Brazil, Russia, India, China, and South Africa), industrialization is the primary driver of economic growth, and industrial expansion is often seen as a significant and suitable indicator of economic development. Data shows that in recent years there has been a general decline in industrial growth in the five BRICS member states. China, the most industrialized of the group, saw its industrial sector's share of GDP shrink from 45.5% in 2000 to 38.28% in 2023. Similarly, the industrial sectors of the other member countries continued to decline. This could be a reflection of both domestic and global development policies, which appear to be in a slow technological transition towards sustainability (Gu et al., 2018). This paper argues that if industrial processes are not incorporated into environmental improvement agendas, the industrial sector may be substantially neglected, which would jeopardize the economic significance of the BRICS economies. To avoid this, the financial sector must not only provide traditional finance for industrial expansion, but also fund initiatives that promote the well-being of people in the BRICS countries. (Zhang, 2024).

Financial development is important not only for supporting economic activities and the development of green financial instruments, but also for industrial processes and upgrades in BRICS countries. (Zhu et al., 2023; Xiao et al., 2023). To this end, the BRICS countries have introduced various policies to promote financial development, all of which aim to improve financial inclusion. More inclusiveness and better financial service delivery can influence green financing by making funding cheaper for projects related to environmental initiatives. Green finance, in its turn, will enhance the sustainability of industrial systems by reducing financing costs for green enterprises and thus increasing their competitiveness (Xiong et al. 2023). In support of this, the BRICS countries have adopted green finance as a policy option. For example, China's financial system is committed to supporting ecological sustainability (Udeagha & Ngepah, 2023). Despite facing challenges at different levels of operation, green finance could help the BRICS nations achieve positive environmental outcomes. However, there is a lack of understanding of how financial development and green finance interact to impact industrial growth, particularly with regard to the relationship between conventional financial development and the environmentally friendly funding of green finance in the BRICS.

Several studies have examined the impact of financial development on industrialization (Enilolobo et al., 2024; He et al., 2024; Oyeyemi et al., 2024; Xiao et al., 2023; Yan & Chen, 2023; Appiah et al., 2022), as well as the impact of green finance on industrialization (Chen et al., (2024); Nchofoung et al. (2024); Xia et al. (2024); Yue et al. (2024); Zhao et al. (2024); Zhang (2024). These studies have shown that financial development and green finance both significantly impact industrialization. The consensus is that both financial development and green finance promote industrial output, modernization, optimization, and green innovation. However, few studies have examined how green finance tools, such as green bonds, can be integrated into

broader financial development frameworks to promote industrial growth. This study examines whether the effects of green finance on industrialization in the BRICS countries differ from those of financial development, and whether the interaction effects reveal anything different.

Our study makes three major contributions to the existing body of knowledge regarding financial development, green finance, and industrialization. Firstly, it addresses a knowledge gap by examining the available literature on financial development and green finance, and how they can work together to promote industrialization in the BRICS countries. Secondly, it recognizes that financial development fulfils a dual function: supporting traditional industrial processes and growth and also enhancing environmentally sustainable financing initiatives through green financing mechanisms, such as green bonds. Thirdly, the study examines the importance of striking a balance between environmental protection and industrial growth in the context of the BRICS countries. It emphasizes that green finance policies can be integrated into industrial sector operations while retaining their economic significance. After section one, the rest of the study is divided into four sections. Section two provides a review of related theories and empirical studies. Section three discusses the data and the most suitable methodologies for the data dynamics. Section four presents the findings and results of the analysis, and section five contains the conclusions and recommendations.

2. Literature Review

2.1. Industrial and financial sectors of the BRICS

Over the past decade, Brazil, Russia, India, China and South Africa (the BRICS countries) have emerged as major players in the global economy, primarily thanks to increased industrialization. For BRICS, industrialization is not just an option, but a strategic necessity for their economies (Biyase et al., 2023). This means that the BRICS countries should prioritize sustaining the industrial process. They have already implemented common policies to achieve this goal. For example, they hold regular meetings of their respective Industry Ministers to encourage economic cooperation on industrial development (Santiago, 2020). At the first meeting in Moscow in 2015, it was decided that the BRICS countries should increase trade, support sustainable economic growth, strengthen industrial connections, promote technology transfer and innovation, and improve investment and job creation. This was followed by the decision in Hangzhou, China, to create a seven-point action plan to harness the growing interlinkages of the manufacturing and digital sectors to create new industries. The plan reiterates the commitments of the BRICS countries to improve industrial collaboration, develop small and medium-sized enterprises (SMEs), coordinate industrial policies, setup standards, create new industrial infrastructure, and support technology and innovation projects.

All of this is intended to sustain a new global economic influence based on modern industrial processes. This indicates that the BRICS countries are moving towards green industrialization.

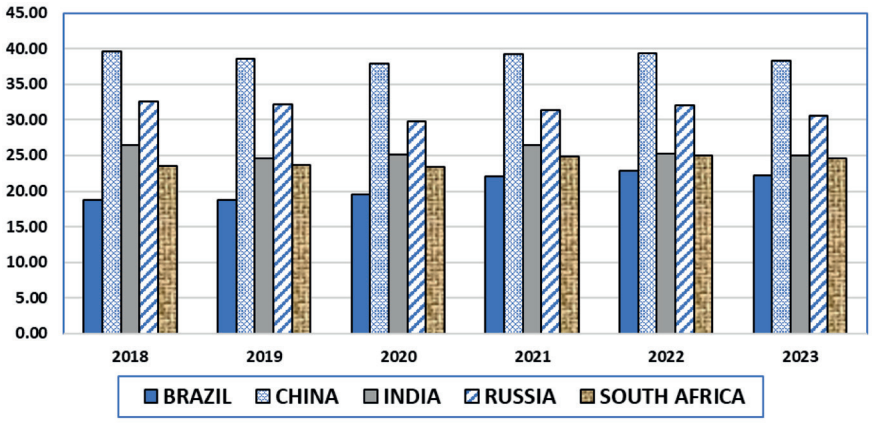

Figure 1. Industrial value added to GDP (%)

Similar patterns have emerged in the industrial sector across the BRICS countries, which can be seen in Figure 1. On average, the industrial sector accounted for 38.8%, 31.43%, 25.48%, 24.15% and 20.70% of GDP in China, Russia, India, South Africa and Brazil, respectively, between 2019 and 2023. Although industrial performance in the BRICS remained stable, as evidenced by their shared industrial policy, there were also signs of relative decline. This decline reflects sectoral shifts towards the services sector, as well as limited industrial expansion and external economic conditions.

Evidently, technological innovation and financial development have been instrumental in driving industrial growth in BRICS. Shahbaz et al. (2023) found that the BRICS group of countries' potential for economic dominance over stronger economic blocs depend on their ability to leverage robust financial relationships within the group. In their pursuit of financial development, the BRICS countries have introduced various policies tailored to each country's specific needs, ultimately aiming to achieve financial inclusion (Thakur, 2023): India targeted financial literacy and participation, Russia aimed to improve access to financial services, China focused on financial integration in the rural areas, South Africa's policy target was to reduce the costs of financial transactions and Brazil's major goal was to increase branchless banking services. Beyond this, they are currently driving forward with green finance. For example, China's green financial system grew significantly at the end of 2020, with green bonds and loans reaching approximately USD 125 billion and USD 1.8 trillion, respectively (Xiong et al., 2023). To achieve sustainable growth, China is relying on green financing to optimize its energy structure and industrial upgrading (Xu et al., 2024).

2.2. Financial development, green finance and industrialization: theoretical approaches to interdependence

The theoretical foundation of financial development and green finance effects on industrial growth can be traced to the finance-growth nexus. Beck et al. (2012) advanced the finance-growth argument by introducing the "recipient factor". The authors theorized that the effect of credit financing on economic growth is ambiguous, especially knowing that both households and enterprises are recipients of private sector loans. They concluded that enterprise credit, rather than household credit, drives economic growth. Law and Singh (2014) proposed that the effect of financial development on economic growth is nonlinear. This means that the impact of financial development is only beneficial up to a certain point, beyond which it becomes harmful. Sahay et al. (2015) made a significant theoretical contribution in their work on the nonlinearity and threshold effect of the financial development index that was created to capture the various dimensions of a developing financial system. Similar to Law and Singh (2014), Sahay et al. (2015) also demonstrated that the financial development index positively impacts economic growth up to a certain threshold. Although the context of thresholds, recipient effects and indices in financial development is important, the financial system must also be efficient to support economic growth and responsible financing. Cihak et al. (2012) argue that a well-functioning financial system ensures long-term growth through efficient allocation of resources. This view is relevant to this study because of the environmental practices required by industrial processes in the BRICS countries. While traditional finance can meet the capital, liquidity and expansion needs of industries, it is not enough to encourage environmental practices among industrial firms. Firms seeking to upgrade and optimise their environmental responsibilities expect the financial system to provide a framework within which green finance can emerge and develop. Once this has been achieved, the financial system will be able to fulfil its role of allocating resources efficiently.

The earliest ideas about the importance of green finance and financial development for industrialization stem from Schumpeter's influential work in 1911 and Hicks's in 1969 (Udeaja et al., 2021). They posit that financing helps secure the funding needed to accelerate industrialization. Both Lucas (1988) and Miller (1998) argue that finance plays a crucial role in stimulating economic activity, and that this role must be recognized in order to fully understand the process of economic growth. By this, they mean that finance is pivotal in mobilizing funds to support ongoing production processes. Funds will therefore find their way to profitable industrial activities that guarantee a profitable outcome. The neoclassical theory of demand and supply is consistent with this idea. It is based on the simple principles that factors of production can move around freely, that information is perfect and that the economy functions without friction. (Udeaja et al. 2021).

In 1911, Schumpeter emphasized the role of entrepreneurs and innovations in the production process, which comprises physical and non-physical factors (Udeaja et al., 2021). According to the Schumpeterian model, output growth stems from technological

progress, productive factors, and a socio-cultural environment that encourages investment. Innovation is the outcome of new production processes that contribute to output growth. Levine (1997) argues that funding for the most viable and innovative ideas comes from a well-functioning financial system that links technological innovation to finance. There are two channels through which innovation can occur: administrative power and debt finance, which are based on the financial system that acts as an intermediary between innovators and owners of capital. Although debt finance is very important in the early stages of innovation, it is soon replaced by accrued profits as firms approach a steady state of production (Udeaja et al, 2021).

Theoretical literature can also be applied to the development of green finance as an extension of financial development theory. Green finance emerged from the need to make the economy more environmentally friendly by integrating environmental preservation into technological innovation and systemic changes in economic and industrial processes (Jinping et al., 2024). This aligns with the theory of the green economy, which emphasizes environmental protection and resource preservation. The theory argues that people's health and wellbeing depend on natural resources. Zhang (2024) views green finance as a new approach to financial development, highlighting environmental sustainability and economic growth. It involves market-based instruments that aim to provide funding guarantees for green innovations, projects and enterprises through capital allocation (Nchofoung et al., 2024). Green finance is therefore an integral part of financial innovation and development. It is also becoming a significant component of countries' financial systems, as they recognise the importance of tackling climate change and improving the environment (Lv et al., 2022).

2.3. Empirical review

2.3.1. Financial development and industrial growth

Existing literature on the relationship between finance and industrialization focuses on the influence of financial development on industrial growth and development. From a digital perspective, Xiao et al. (2023) found that digital finance had significantly boosted the modernization of industrial chains in 30 Chinese provinces. Zare and Jokar (2014), adopting a financial depth perspective, found that financial depth and repression had different effects on industrial development in Iran: the former provided substantial positive support, while the latter had a marginal inhibitory effect. This reemphasizes the importance of policies that promote growth in the industrial sector. In Nigeria, Ogbuagu et al. (2021) identified a financial depth threshold of 36.8% as being necessary to stimulate a significant increase in industrial output. Meanwhile, Egbetunde et al. (2019) and Sibanda et al. (2019) adopted a more holistic approach to financial development, concluding that financial development plays a supportive role in industrial output in Nigeria. Dehghan Shabani (2017) showed that financial development in Iran had little impact on industry concentration, but had a positive

influence on regional economic growth. This implies that the effects of financial development on industrialization are spatially dispersed. Together, these studies demonstrated the various dimensions through which financial development influences the industrial sector, including financial depth, digital finance, and financial market development.

Enilolobo et al. (2024) used panel ordinary least squares regression analysis on 18 countries in Sub-Saharan Africa between 2005 and 2019 to find that the financial sector support for industrial growth depended on agriculture. However, Oyeyemi et al. (2024) argued that the positive influence of financial development on industrial value-added in the 38 sampled Sub-Saharan African countries depended on institutional quality. Even when countries do not have strong and developed financial sector, Iwegbu et al. (2022) showed that their industrial sector could still benefit from institutional quality and regional financial integration. A developed financial system contributes to the efficient allocation of financial resources for industrial innovation and growth (Xiang et al., 2024). These benefits can outweigh the adverse effects of external funding and foreign investment (Appiah et al., 2022). Financial development has driven technological advancements and increased the efficiency of industrial processes (He et al., 2024; Yan & Chen, 2023). By extension, this can support the efficiency of green technology innovation and industrial upgrading. Abokyi et al. (2019) used the ARDL technique to find that the impact of financial development on carbon emissions was insignificant, unlike the positive contribution of industrial output, which prompted the environmental sustainability dimension of industrialization. This highlights the importance of financial development involving environmental support instruments, such as green finance, to reverse this outcome.

2.3. Green Finance and Industrial Growth

A number of studies have demonstrated the positive impact of green finance on industrial growth. Chen et al. (2024) examined the data of 30 developing countries from 1990 to 2018 using the Generalised Method of Moments (GMM) and found a strong correlation between green finance and the renewable energy industry. This perspective aligns with the findings of Xu et al. (2024), Nchofoung et al. (2024) and Zhao et al. (2024), who show that green finance significantly supports industrialisation and is a vital component in reducing industrial carbon emissions and promoting sustainable industrial practices. Following the same line of reasoning with regard to the enhancement of sustainable industrialisation, Xia et al. (2024) demonstrate that green finance relies on green technological innovation and spillover effects to increase industrial efficiency. Furthermore, Xiao et al. (2024) reveal that carbon emissions can be mitigated through technological innovation and industrial restructuring. Zhao et al. (2024) demonstrate how green finance can promote industrial upgrading and reduce carbon emissions. Similarly, Zhang (2024) identified spatial spillover from green finance to industrial optimisation. Yue et al. (2024) found that green finance development greatly increased industrial productivity, highlighting its importance in

improving industrial performance nationwide. Together, these studies emphasise the potential of green finance to encourage different countries' conventional industries to adopt sustainable practices.

Given the overwhelming support for green finance in the studies above, one might think that green finance poses no challenges to industrial growth. However, some findings suggest that this is not always the case. Zhao et al. (2023) found that the relationship between green finance and industrial green transformation varies between different Chinese regions and different levels of effectiveness. Xiong et al. (2023) identified an imbalance in the relationship between green finance and the optimisation of China's industrial structure, advocating for improvements to achieve balance and ensure China's sustainable growth. Nguyen et al. (2024) found that green finance had a negative impact on green growth when the regulatory effects of green energy and green production were not considered. However, when these factors were integrated, green finance was found to have a positive influence on green growth, emphasizing the importance of regulatory frameworks in driving sustainable industrial progress.

2.4. Gap in Literature

Existing literature on financial development, green finance and industrial growth provides valuable insights that highlight gaps in our knowledge, particularly in the context of the BRICS countries. Most research is region-specific, so there is a lack of comparative studies on the effects of financial development and green finance on industrial growth in the BRICS. While the existing papers acknowledge the supporting role of green finance in industrial processes, there has been limited exploration of how green finance integrates with broader financial development in BRICS, particularly with regard to the industrial sector. Studies are yet to show the significance of green financial development, a factor that suggests the moderating role of green finance and financial development. The available literature (e.g. Nguyen et al., 2024) also highlights the importance of an appropriate structural framework and institutional quality to support green finance and industrialization. Our study suggests that poor institutional quality can result in low industrial productivity and inadequate industrial skills. These two factors can be observed in industrial output per unit and industrial employment. A comprehensive study addressing this gap would provide crucial insights into the comparative and synergistic effects of green finance and financial development on industrial growth in BRICS.

3. Data and Methodology

3.1. Data and variables

Our study aims to examine the impact of green finance and financial development on industrial growth in BRICS countries (Brazil, Russia, India, China and South Africa)

between 2000 and 2023. The choice of the sample period is based on the availability of relevant data for this study's objectives. BRICS were chosen because of their global economic significance and geographical representation of the world's major continental regions: Asia, America, Europe and Africa. Therefore, the findings can be applied to other emerging global economies. The BRICS economies are industrially advanced and face various environmental, social and economic issues that require re-evaluation through green finance. This study uses data from the World Development Indicators (WDI) database.

In line with the objectives of our study, the dataset includes industrial growth (INDY) as the dependent variable, with green finance (GRFI) and financial development (FINDV) as target independent variables. The interaction between green finance and financial development (GRFI_FINDV) is also included. Industrial productivity (INPK) and industrial employment (INEM) are the study's control variables. Industrial growth is proxied by industrial value-added to GDP ratio, green finance is represented by green bond to GDP ratio, and financial development is the composite index of three financial indicators: depth, access, and efficiency. The composite index follows the same technique of depth, access and efficiency model used by the International Monetary Fund (IMF). This was achieved by applying the Principal Component Analysis (PCA) technique, which uses correlation to assign weights to financial component indicators. Following this approach, financial efficiency for the five BRICS countries is represented by interest rate spreads, financial access by the number of ATMs per 100,000 adults (Oyeyemi et al., 2024), and financial depth by credit to the private sector (Iwegbu et al., 2022). According to Svirydzenka (2016), the IMF financial development index is a normalized composite index calculated for institutions and markets. This study, however, opted for the institutional index due to the unavailability of harmonized data from the BRICS countries. Table 1 shows the results of the principal component analysis (PCA) that led to the composite index for the BRICS countries' panel financial development index.

Table 1. Principal Component Analysis (PCA) for BRICS financial development index.

Number	Value	Diff.	Prop.	Cum. Value	Cum. Prop.
Financial Access	1.443	0.489	0.481	1.443	0.481
Financial Depth	0.955	0.353	0.318	2.398	0.799
Financial Efficiency	0.602	---	0.201	3.000	1.000

The first principal component of financial development, financial access, accounts for approximately 48.1% of the total weighting. The second component, financial depth, accounts for around 31.8 %, while the third component, financial efficiency, accounts for

around 20.1 %. Due to the significant weight of each financial development indicator, they are all considered principal components and were involved in developing the final composite financial development index. The financial development estimates range from approximately -2.5 (lowest level of financial development) to 2.5 (highest of financial development).

There is ample empirical literature addressing the relationship between green finance and industrial growth and development, (e.g. Chen et al., 2024; Xu et al., 2024; Nchofoung et al., 2024; Xia et al., 2024; Yue et al., 2024), as well as the relationship between financial development and industrialisation (e.g. Enilolobo et al., 2024; He et al., 2024; Xiang et al., 2024; Oyeyemi et al., 2024; Xiao et al., 2023; Yan & Chen, 2023). These papers also used the data adopted in this study. The present study relies on a panel of the five BRICS countries, covering the period from 2000 to 2023. The main variable of interest is industrial growth (INDY), which is measured as the percentage of GDP contributed by industrial value added. This is calculated by subtracting intermediate inputs from the total output. Industrial value added reflects the productivity and efficiency of a country's industrial process and also shows industrial improvements. This measure has been used in previous studies by researchers such as Appiah et al. (2021), Abokyi et al. (2019) and Oyeyemi et al. (2024), but most notably by Iwegbu et al. (2022), who examined the impact of institutional quality on the relationship between regional financial integration, financial development and industrial growth in the ECOWAS region.

We also include the interactive element of financial development and green finance. This variable helps us determine the synergic influence of financial development and green finance on industrial growth in the BRICS countries. Considering the growing integration of green financing into the general financial system through the banking sector in the form of green loans, and into the financial markets in the form of green bonds (Chen et al., 2024), it has become imperative to consider this synergic influence. This synergy has also enabled green finance to alleviate the financing difficulties faced by energy-intensive ventures (Xu et al., 2024). At the core of financial development and green finance effects on industrial growth lies industrial productivity. Industrial productivity is mainly manifested through industrial employment and per capita output. The work of Yue et al. (2024) suggest that improving productivity is important for industrial performance. By emphasizing green technological innovation and efficiency, Xia et al. (2024) and Zhao et al. (2024) suggest that the development of green finance can promote industrial growth by fostering efficiency gains. Therefore, productivity and finance are both important for industrial growth. To this end, this study will use industrial per capita output and employment as proxies for productivity. Table 2 below provides literature-based definitions of the variables and their sources.

Table 2. Variables and their sources.

Variable	Acronym	Description	Source
Dependent Variable			
Industrial growth	INDY	Value-added of industrial output to GDP	WDI
Independent Variable			
Green finance	GRFI	The ratio of green bond to GDP ratio	IMF Climate Dashboard
Financial development	FINDV	The composite index of financial depth, efficiency and access	PCA from WDI
Control Variable			
Industrial per capita	INPK	Industrial output per capita	WDI
Industrial employment	INEM	Employment ratio in the industrial sector	WDI

3.2. Methodology

Following the integration of the green finance–industrialisation and financial development–industrialisation models in related literature (Xiong et al., 2023; Xu et al., 2024; Yue et al., 2024; Appiah et al., 2022; Egbetunde et al., 2019; Iwegbu et al., 2022), with the addition of an interactive element of green finance and financial development, the general form of the econometric model of this study is

$$INDY_{it} = \partial_{it} + \varnothing_{1,it} GRFI_{it} + \varnothing_{1,it} FINDV_{it} + \varnothing_{j,it} GRFI\_FINDV_{it} + \varnothing_{j,it} V_{it} + e_{it} \quad (1)$$

In the equation, $INDY_{it}$ is the dependent variable and represents industrial growth. GRFI_it represents green finance, FINDV_it financial development, and GRFI_FINDV the interaction between financial development and green finance. V_it is a vector of control variables identified as industrial per capita (INPK) and industrial employment (INEM).

3.3. Model estimation technique

The study used the following techniques to estimate the long-run panel cointegrating relationship between industrial growth, green finance and financial development as dependent variables:

- fully modified ordinary least squares (FMOLS)
- panel dynamic least squares (DOLS)
- panel-corrected standard errors (PCSE)

It also used a dynamic analysis with the panel quantile regression technique.

Panel FMOLS and DOLS

FMOLS was developed by Phillips and Hansen (1990) to provide the best possible regression estimates from a cointegrating relationship. However, our study will rely on the heterogeneous FMOLS estimator proposed by Pedroni (2001), which is an extension of the original model. The Pedroni (2001) version is used for panel cointegrating regression and corrects for bias due to endogeneity and serial correlation (Özdemir & Kayhan, 2021; Khan et al., 2019). Assuming a panel relationship like equation 2:

$$I_{it} = \delta_i + \beta_i fx_{it} + \in_{it}, \quad t = 1, 2, \ldots, N; \quad t = 1, 2, \ldots, T \tag{2}$$

where, I_{it} is the industrial growth for country i at time t, fx_{it} is the vector of green finance, financial development, industrial employment and industrial productivity for country i at time t, δ_i is the country-specific fixed effects, β_i is the cointegration slope parameter to be estimated, and $\in_{it}$ is the Error term, assumed to be serially correlated.

To estimate cointegrated relationships between industrial growth and the effects from green finance and financial development, the Pedroni (2001) Group-Mean FMOLS specify the estimation for β_i in equation 2 as follows:

$$\beta^*_{NT} - \beta = \left(\sum_{i=1}^{N} L_{22i}^{-2} \sum_{i=1}^{T} \left(\chi_{it} - \overline{\chi}_i \right)^2 \right)^{-1} \sum_{i=1}^{N} L_{11i}^{-1} L_{22i}^{-1} \left(\sum_{i=1}^{T} \left(\chi_{it} - \overline{\chi}_i \right) \phi^*_{it} + T\hat{\gamma}^*_i \right) \tag{3}$$

Where, $\phi^*_{it} = \phi_{it} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \Delta\chi_{it}$, $\hat{\gamma}^*_i = \hat{\Gamma}_{21i}\hat{\Omega}^0_{21i} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \left(\hat{\Gamma}_{22i} - \hat{\Omega}^0_{22i} \right)$ and $\hat{L}_i$ was the lower triangulation of $\hat{\Omega}_i$. As derived by Pedroni (1996), the asymptotic distribution of the DOLS estimator is the same as that of panel FMOLS estimation. Therefore, both DOLS and FMOLS estimations are be performed to confirm if the outcomes are consistent.

The Panel-corrected standard errors (PCSE) estimator is also applied for robustness.

Panel Dumitrescu and Hurlin (2012) Causality test

To confirm the link between the variables, our study employs Dumitrescu and Hurlin's (2012) panel causality analysis. The Dumitrescu and Hurlin (2012) test procedure has three advantages: (i) it uses standard Wald statistics to convey a standard normal asymptotic distribution; (ii) it does not require any specific panel estimation; and (iii) it is dynamic and can accommodate cross-sectional dependence irrespective of the sizes of N and T (Ahmed & Le, 2021). This is specified in equation 4:

$$INDY_{it} = a_i + \sum_{k=1}^{k} d_i^k INDY_{i,t-k} + \sum_{k=1}^{k} b_i^k V_{i,t-k} + e_{i,t} \tag{4}$$

Equation 4 represents Granger causality between V (the vectors of green finance, financial development, industrial development per capita and industrial employment) and INDY. It shows that there is no homogeneous Granger causality connection in any

of the countries. This means that the Dumitrescu-Hurlin panel Granger causality test relies on heterogeneous models. The null hypothesis indicates homogeneity. The Wald statistics is also used to test the null hypothesis, as represented by equation 5:

$$W_{N,T}^{Hnc} = \frac{1}{N} + \sum_{i=1}^{N} W_{it} \tag{5}$$

Where, W_{it} is the Wald statistics on the basis of i countries.

4. Analysis and Results

The descriptive statistics of these variables reveal significant differences in their mean values, data spread, and normality, providing valuable insights for comparison. The robust industrial growth rate of 29.78% of GDP points to a consistently strong industrial production throughout our study period. The low levels of green finance integration with financial development (GRFI_FINDV), as indicated by their respective averages of 0.03 and 0.04, highlight the underdevelopment of the green finance sub-sector in the BRICS countries. With means of 23.58 and 14,793.49, respectively, the industrial sector's employment and productivity demonstrate the high productivity of the industrial workforce. Financial development (FINDV) has an average value of zero, with a peak of 2.26 and trough of -3.65. Similarly, green finance data have minimum and maximum values of 0.00 and 0.64 respectively. The value of their interaction ranges from -0.32 to 1.06, indicating stable patterns and relationships in green finance. Meanwhile, industrial output growth and employment levels remain moderately stable, though they show significant year-on-year changes.

Table 3. Descriptive Analysis.

	INDY	GRFI	FINDV	GRFI_FINDV	INEMP	INPK
Mean	29.78	0.03	0.00	0.04	23.58	14793.49
Max.	47.56	0.64	2.26	1.06	32.15	26882.65
Min.	18.19	0.00	-3.65	-0.32	0.00	0.00
Std. Dev.	7.72	0.09	1.38	0.14	6.27	7204.83
Jarque-Bera	18.18	2682.19	9.28	4213.69	257.09	9.66
Prob.	0.00	0.00	0.01	0.00	0.00	0.01
Obs.	120	120	120	120	120	120

Source: Authors' computation, 2025

The Jarque-Bera test results reveal that most variables in our study exhibit substantial non-normal distributions. The weak state of green finance development

becomes clear from its strong non-normal pattern, demonstrating inconsistent expansion and minimal impact on overall financial and industrial operations. Our analysis also shows that the behaviour of each variable differs. Despite experiencing different stability patterns, the data shows that industrial activity and job market performance remain moderately to strongly present. Financial development and productivity respond strongly to economic changes as evidenced by their high fluctuation rate. The interactions between green finance and financial development are emerging slowly and show limited business variation. These findings highlight the urgent need for targeted initiatives to promote the adoption of green finance and its impact on financial and industrial outcomes.

Table 4. Correlation Analysis.

Correlation/Prob.	INDY	GRFI	FINDV	GRFI_FINDV	INEMP
INDY	1				
GRFI	0.194**	1			
	(0.034)				
FINDV	-0.134	0.271***	1		
	(0.144)	(0.003)			
GRFI-FINDV	0.223**	0.914***	0.332***	1	
	(0.014)	(0.000)	(0.000)		
INEMP	0.316***	0.260***	0.179**	0.273***	1
	(0.000)	(0.004)	(0.050)	(0.003)	

Source: Authors' computation, 2025

Our research demonstrates the relationship between industrial growth, green finance and financial development, as well as their combined impact on industrial employment. The interaction between financial development and green finance results in a stronger positive correlation with industrial growth than financial development alone achieves. The strongest link is between industrial growth and industrial employment, with a highly significant relationship of 0.316. This highlights the importance of a skilled workforce in the BRICS countries for industrial growth. Green finance (GRFI) effectively supports industrial growth, employment, productivity and financial development because its fundamental purpose is to promote environmentally friendly economic growth. Given its positive association with industrial growth, industrial processes can be transitioned, upgraded and optimised to support eco-friendly practices within BRICS (Zhang, 2024; Xiong et al., 2023). The same applies to the interaction between green finance and financial development. In other words, green finance helps to improve the relationship between financial development and

industrialization. Financial development with green finance practices delivers better outcomes than financial development alone. The combination of financial development and green finance creates powerful results, demonstrating how sustainable finance can promote industrial growth and increase employment opportunities. The analysis shows that the interaction between green finance and financial development is the most important factor because it has a strong positive impact on every all other variables connected to industrial growth. Financial development requires green financing to have a significant impact on industrial progress and job creation. The present study shows that sustainable industrial growth depends on combining green finance with financial development and employment policies.

Table 5. Panel Stationarity tests.

Variables	Levin, Lin and Chu Test: Levels		Levin, Lin and Chu Tests: First Difference		Order of Integration
	Test Statistic	p-values	Test Statistic	p-values	
INDY	-1.301	0.097*	-6.551	0.000***	*I(1)*
GRFI	1.329	0.908	-11.442	0.000***	*I(1)*
FINDV	-0.449	0.327	-3.994	0.000***	*I(1)*
GRFI_FINDV	-1.714	0.043**	-8.216	0.000***	*I(1)*
INEMP	9.604	1.000	-1.710	0.044**	*I(1)*
INPK	-3.275	0.001***			*I(0)*

Note: ***, ** and * are significant at 1%, 5% and 10%, respectively

Table 5 shows the results of the Levin, Lin and Chu (LLC) unit root test for panel data stationarity. INDY (Industrial Growth), GRFI (Green Finance), INEMP (Industrial Employment) and FINDV (Financial Development) fail to achieve stationarity at the conventional 5% threshold at level observation. The tests revealed no unit root after differencing, as the test statistic produced probability values of less than 0.05. First differencing was required to achieve stationarity, and so they are referred to as I(1) variables in this study. The test on GRFI-FINDV for Green Finance Development produced weak results against the null hypothesis at the 10% level (test statistic = -1.714, p-value = 0.043), showing signs of stationarity without the need for further differencing. The series clearly becomes stationary after differencing, as shown by a test statistic of -8.216 and a p-value of 0.000. The results demonstrate that GRFI-FINDV transitions to stable values in a single state change.

The LLC unit root test reveals that INPK (industrial productivity) has no unit root at levels with strong evidence of stationarity demonstrated by a test statistic of -3.275 and a p-value of 0.001. Its stationary state at this level means differencing tests are unnecessary. INPK exists in its stationary form without the need to transform its level values; therefore, it is referred to as I(0) variable. In summary, the study confirms that the first differencing of five key indicators (INDY, GRFI, FINDV, GRFI_FINDV and

INEMP) makes them stationary, whereas INPK shows stationary behaviour when measured at its level without transformation.

Table 6. Panel Cointegration Tests.

Kao Residual Cointegration Test	Johansen Fisher Panel Cointegration Test	
	Fisher Stat. (trace test)	Fisher Stat. (max-eigen test)
-2.289***		
(0.000)		
None	194.4***	125.2***
	(0.000)	(0.000)
At most 1	141.2***	87.43***
	(0.000)	(0.000)
At most 2	85.93***	58.79***
	(0.000)	(0.000)
At most 3	38.06***	23.55***
	(0.000)	(0.009
At most 4	24.17***	14.36
	(0.007)	(0.157)
At most 5	28.37***	28.37***
	(0.002)	(0.002)

Note: ( ) is prob.; ***, ** and * are sig. at 1%, 5% and 10%

According to the Kao Residual Cointegration Test, our model variables (INDY, GFFI, FINDV, GRFI_FINDV, INEMP, and INPK) demonstrate a robust long-run relationship based on the score -2.289 at a significance level of 0.000. At the 1% statistical level, it is evident that these variables exhibit similar temporal trends, confirming their enduring connection. The Johansen-Fisher panel cointegration test identifies a key cointegration link with highly significant Fisher statistics and associated p-values below the threshold level of 0.05, using both the trace and maximum-eigenvalue tests. The data shows that these variables maintain a stable long-term connection through at least one equilibrium relationship. Both statistical tests reveal clear evidence that the variables move together in cointegrated relationships, particularly when the ranks are smaller. The results show that the variables are permanently linked. These five economic factors behave as a connected system over time, affecting each other in predictable ways.

Table 7. Tests for Cross-section dependence.

	CD of OLS without PCSE Estimator			CD of OLS with PCSE Estimator		
Test	Stat.	d.f.	Prob.	Stat.	d.f.	Prob.
Breusch-Pagan LM	49.68	10	0.000***	2.285	10	0.994
Pesaran scaled LM	8.87		0.000***	-1.725		0.085
Bias-corrected scaled LM				-1.834		0.067
Pesaran CD	2.09		0.036**	0.448		0.654

Note: ***, ** and * are sig. at 1%, 5% and 10%

Before we can adopt the long-run estimation of the model parameters, we must first determine the nature of the cross-sectional dependence because this condition can invalidate the results of our model estimates. The literature shows that the panel-corrected standard error (PCSE) can be used to analyze panel data with heterogeneous attributes (Ikpesu et al., 2019). For example, it can be applied to data from the BRICS countries that are located on different continents. PSCE estimation techniques address cross-sectional dependence. Table 7 is used to test for evidence of cross-sectional dependence in pooled OLS, both with and without the PSCE technique. The pooled OLS model with the PSCE technique provides compelling evidence of cross-sectional dependence. The respective p-values for the Breusch-Pagan LM test, the Pesaran scaled LM test, the bias-corrected scaled LM test and the Pesaran CD test are all significant at the 1% and 5% levels. By contrast, we found that applying PSCE techniques resolved the issue of cross-sectional dependence. This demonstrates the effectiveness of the PSCE technique in addressing cross-sectional dependence, which is why the PSCE estimator is used alongside panel FMOLS and DOLS.

Table 8. Estimates of combining green finance and financial development policies.

	Pooled OLS with PCSE estimator	FMOLS	DOLS
GRFI	-12.640**	-47.214***	-45.065***
	(0.012)	(0.000)	(0.000)
FINDV	-0.159	-0.820***	-0.841**
	(0.320)	(0.001)	(0.012)
GRFI_FINDV	7.409**	21.009***	21.624**
	(0.020)	(0.001)	(0.018)
INPK	-0.00024***	0.00013	-0.00004
	(0.000)	(0.525)	(0.896)
INEMP	0.265***	0.160**	0.223**
	(0.000)	(0.026)	(0.045)
C	26.951***		
	(0.000)		
R-Squared	0.5005	0.744	0.799
F(prob)	22.845 (0.000)		
Jarque-Bera (prob)	5.648 (0.059)	4.028 (0.133)	1.659 (0.436)

Note: ( ) is prob.; ***, ** and * are sig. at 1%, 5% and 10%

The effect of green finance alone is significantly detrimental to industrial growth in the BRICS. Some previous studies partly support these findings. For instance, Nguyen et al. (2024) discovered that green finance could hinder growth, though this could be offset by policies that promote green production and renewable energy. This highlights the importance of industrial upgrading for green innovation. It should be born in mind that green innovation is fundamental to the role that green finance can play in achieving sustainable industrialization. Some papers challenge the empirical findings of the present study, such as those by Xia et al. (2024) and Xiao et al. (2024), who both identified the crucial role of green finance in driving industrial green innovation and reducing carbon emissions. Their findings suggest that, while green finance may not inherently promote industrial growth, fundamental factors such as regulatory frameworks, innovation, and industrial adaptation can amplify its positive impact.

Similarly, financial development alone has a significantly negative effect on industrial growth in the BRICS. The study that most closely aligns with our findings is that of Iwegbu et al. (2022), who identified credit to the private sector as an inefficient sole enhancer of industrial output, despite the supportive roles of financial integration and institutional quality. Many other studies collectively disagree with the finding that financial development alone significantly hinders industrial growth in BRICS countries. Enilolobo et al. (2024), Appiah et al. (2022) and Ogbuagu et al. (2021), for example, demonstrated that the industrial sector in sub-Saharan Africa has benefited from financial development. This implies that the level of financial development in Africa, as measured by financial intermediation and depth, is sufficient for its level of industrial growth. He et al. (2024), Xiang et al. (2024), and Xiao et al. (2023) provided evidence from China showing that financial development enhanced industrial efficiency, technological innovation, and industrial chain modernization. These studies suggest that financial development is generally beneficial for industrial growth, contradicting the claim that its effect alone is detrimental in the BRICS countries.

However, the synergic or interactive influence of green finance and financial development is significantly beneficial to industrial growth in BRICS. Some Chinese studies, particularly those by Yue et al. (2024), Zhao et al. (2024), Zhang (2024) and Xiong et al. (2023), provide compelling evidence that the synergy between green finance and financial development supports industrial growth through increased productivity, optimized industrial structure and reduced carbon emissions. These studies suggest that green finance and green technological innovation drive industrial transformation and sustainable industrial practices. This is irrespective of the imbalances identified by Xiong et al. (2023). In contrast, studies focusing mainly on financial development in Nigeria, Ghana and Iran have found it to significantly support industrial output in the long term (Egbetunde et al., 2019; Sibanda et al., 2019; Zare & Jokar, 2014). While these studies do not contradict the main finding of our study on the synergistic contribution of green finance and financial development, they highlight the different contexts in which financial development alone has had a more significant impact on industrialization than green finance.

There is also positive support for industrial growth from industrial employment (INEMP). The PSCE estimator results show a positive coefficient of 0.265, which is statistically significant at the 1% level. Furthermore, the FMOLS and DOLS models both indicate that industrial growth responds significantly and positively to industrial employment. According to the data, industrial employment can facilitate synergy between green finance and financial development, resulting in stronger industrial growth despite the detrimental effects on industrial productivity. The FMOLS and DOLS panel models better match the data than the PSCE estimator, achieving R-squared values of 0.744 and 0.799 respectively, whereas the PSCE estimator achieves an R-squared value of only 0.5005.

Table 9. Pairwise Dumitrescu Hurlin Panel Causality Tests without interaction.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
GRFI ≠ INDY	0.759	-0.460	0.646
INDY ≠ GRFI	10.920	12.808	0.000***
FINDV ≠ INDY	1.616	0.659	0.510
INDY ≠ FINDV	0.346	-0.999	0.318
INEMP ≠ INDY	4.326	4.198	0.000***
INDY ≠ INEMP	1.056	-0.072	0.943
INPK ≠ INDY	2.030	1.200	0.230
INDY ≠ INPK	0.756	-0.463	0.643
FINDV ≠ GRFI	3.443	3.046	0.002***
GRFI ≠ FINDV	30.288	38.101	0.000***
INEMP ≠ GRFI	3.779	3.484	0.001***
GRFI ≠ INEMP	16.195	19.697	0.000***
INPK ≠ GRFI	6.513	7.055	0.000***
GRFI ≠ INPK	12.108	14.361	0.000***
INEMP ≠ FINDV	2.236	1.468	0.142
FINDV ≠ INEMP	49.009	62.548	0.000***
INPK ≠ FINDV	2.883	2.314	0.021**
FINDV ≠ INPK	28.996	36.413	0.000***
INPK ≠ INEMP	1.046	-0.085	0.932
INEMP ≠ INPK	1.344	0.304	0.761

Note: ***, ** and * are significant at 1%, 5% and 10%, respectively.

The Pairwise Dumitrescu-Hurlin panel causality tests show that variable pairs cause each other either unidirectionally or bidirectionally. Table 8 shows that

industrial growth causes green finance, but not the reverse. There is also evidence of unidirectional causality from industrial growth to green finance development, but not from green finance investment to industrial growth. Again, industrial employment leads to industrial growth, but there is no statistical evidence to support the reverse causality. Furthermore, our results demonstrate that green finance leads to industrial employment. They also show that, although financial development supports other economic sectors, it does not drive industrial growth.

As can be seen from Table 9, green finance (GRFI) and financial development reinforce each other, driving growth in both areas: financial development engenders green finance, while green finance significantly contributes to financial development. This two-way connection reveals a pattern whereby progress in either green finance or financial development drives progress in the other, creating ongoing mutual benefits. The causality between green finance and industrial employment goes both ways because improvements in GRFI lead to growth in INEMP and enhanced INEMP supports GRFI development. The expansion of green finance generates industrial jobs while strong industrial employment drives green finance development, possibly through sustainable investment and eco-friendly industry regulations. Again, financial development causes industrial productivity as shown by p-value (0.000) and industrial productivity helps develop the financial systems, which is proven by p-value (0.021) in the analysis. When financial development provides industry with essential resources, it boosts productivity, leading to higher industrial output and new, profitable investments in the financial sector.

Table 10. Pairwise Dumitrescu Hurlin Panel Causality Tests with interaction.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
GRFI_FINDV ≠ INDY	0.786	-0.425	0.671
INDY ≠ GRFI_FINDV	4.484	4.404	0.000***
GRFI_FINDV ≠ GRFI	2.815	2.225	0.026***
GRFI ≠ GRFI_FINDV	1.687	0.752	0.452
GRFI_FINDV ≠ FINDV	5.951	6.320	0.000***
FINDV ≠ GRFI_FINDV	3.790	3.499	0.001***
INEMP ≠ GRFI_FINDV	1.914	1.049	0.294
GRFI_FINDV ≠ INEMP	32.890	41.498	0.000***
INPK ≠ GRFI_FINDV	3.367	2.945	0.003***
GRFI_FINDV ≠ INPK	55.613	71.172	0.000***

Note: ***, ** and * are significant at 1%, 5% and 10%, respectively

The Pairwise Dumitrescu-Hurlin panel causality tests report unidirectional causality from industrial growth to the interaction between green finance and

financial development, based on statistical evidence with a p-value of less than 5%. This indicates that the interaction between green finance and financial development is heavily dependent on growth in the industrial sector. There is also unidirectional causality between green finance and financial development. When financial development incorporates green finance instruments, it is only logical that green finance will benefit from this synergy. Table 10 also shows that there is bidirectional causality between green finance, financial development and industrial productivity: green finance interacts with financial development to drive industrial productivity, and industrial productivity creates opportunities for green finance to interact with financial development. When industries produce more, green finance grows; yet further improvements in green finance also help to raise industrial output. The growth of sustainable finance and modern industrialization depend on each other.

5. Conclusion

Industrialization is as indispensable to the BRICS economies as they are to the world economy. Anything that deemphasizes industrialization in the BRICS will have a most detrimental effect on these economies. Given the current concerns about sustainable production and the emphasis placed on remedial models such as green finance, it is important to examine whether growing industrial sectors in the BRICS countries employ environmentally friendly practices. If they do, then the literature on industrial optimization and upgrading would be correct. Our study considers the role of financial development and its interaction with green finance in promoting industrial growth in the BRICS countries. To this end, we examined the independent influence of financial development and green finance on industrial growth and the effects of their interaction.

The study focuses on the five BRICS member states (Brazil, Russia, India, China and South Africa) and covers the period from 2010 to 2023. Long-run estimators (panel FMOLS and DOLS) were used to estimate the model parameters, and the robustness of the results was tested using the panel corrected standard errors (PCSE) estimator and the Panel Dumitrescu and Hurlin (2012) causality test. The financial development proxy is a composite index derived from three financial indicators — depth, access and efficiency — using the PCA technique. Firstly, the long-run estimators collectively established that the effects of green finance or financial development, when considered in isolation, are significantly detrimental to industrial growth in BRICS countries. Secondly, the combined influence of green finance and financial development is significantly beneficial to industrial growth in BRICS countries.

This study made a significant contribution to knowledge by empirically validating the effects of green finance and financial development, both independently and in combination. With regard to industrial growth in the BRICS countries, it was demonstrated that financial development and green finance were detrimental to industrial growth when considered in isolation. This finding closes

an important gap relating to their respective effectiveness. The study also revealed the synergistic relationship between green finance and financial development. This means that neither supports industrial growth in the BRICS independently, except when they work together. Financial development provides a platform for green finance, promoting industrial upgrading and optimization while supporting industrial output and environmental sustainability. Ultimately, evidence of their interactive influence in promoting industrial growth emphasizes the importance of balancing industrial advancement with environmental sustainability. The findings demonstrate that green finance requires a robust financial system and innovation in order to remain relevant to industry and help the BRICS countries achieve their environmental goals.

BRICS policymakers should prioritize the development of enabling policies that support energy transition and green innovations to ensure that green finance contributes positively to industrial growth, rather than acting as a constraint. Also, strategies for financial development in the BRICS countries should focus not only on enhancing depth, access and efficiency, but also on improving the economic and institutional environment. Finally, the BRICS countries would reap greater benefits from the financial sector if green finance were integrated into broader financial development policies.

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