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Enhancing Resource Efficiency in BRICS through Fintech: A Multi-Dimensional Analysis of Green Growth and Socio-Economic Impacts

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ABSTRACT

Resource efficiency entails eliminating waste and managing natural resources wisely in order to minimise environmental harm and sustain it over time. It postulates as the intersection of modern technology and financial services has emerged as a catalyst for revolutionary change across a variety of industries. It can optimise financial transactions, simplify supply chains, and promote sustainable investing practices, which have the ability to transform economic paradigms and make resource efficiency simpler. The study aims to investigate the impact of FinTech Innovation, green growth, and economic and social development on resource efficiency in BRICS countries covering the period 1998-2022. To analyse the relationship between the variables, the Cross sectional Autoregressive Distributed Lag Model (CS-ARDL) and recently introduced Method of Moments Quantile regression (MMQR) approaches are used. The findings of the study reveal the positive association of green growth and social development with natural resource efficiency, however, results suggest the negative association between economic growth and resource efficiency. In contrast, fintech is not found to have any significant impact on resource efficiency. As a robustness check, the findings of MMQR estimation approach validate the estimation findings of the CS-ARDL analysis with significance of the variables varying at different quantiles. The findings suggest a need for strategic interventions and policy measures that prioritize investment toward the upswing thrust in FinTech innovation, green growth initiative, social development activities and environmentally sustainable practices. Policymakers in BRICS countries need to bolster their financial technology infrastructure, educate the public about its advantages and foster the collaborations between government and financial sector entities to leverage the positive impacts of FinTech on sustainable development. Similarly, ensuring economic policies are motivated by green growth practices that are aligned with resource efficiency goals should be at the center of their purview.

Keywords: Resource Efficiency, BRICS, CS-ARDL, MMQR
JEL Classifications: O13, B55, Q01, Q56, R11

1. INTRODUCTION

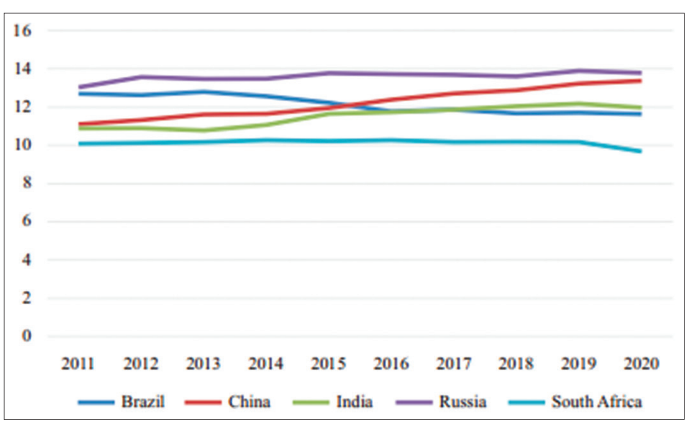
Resource utilization indicates that an economy has an ability to plan and manage its resource consumption. According to He et al. (2022), resource utilization outlines that at what % the available resources are being utilized in a particular sector. Considering the principle of economics, it is necessary to divert attention toward effective resource utilization because of its scarcity. Besides, increasing resource efficiency is also a parameter of successful economy as it allows nations to monitor the consumption of available resources. It is also argued natural resource efficiency is a needed factor to achieve socio-economic and environmental resilience, hence, can't be ignored (Ayomitunde et al., 2019; Mufan et al., 2022).

Particularly talking about BRICS nations, they are experiencing consequential challenges in managing their natural resources in sustainable manner (Nawaz et al., 2021). Challenges such as soil degradation, water scarcity, biodiversity loss, pollution, deforestation are one such issues that warrant dire attention. There is a saying that the rapid advancement in BRICS nations made significant growth in their economies (Bai et al., 2021; Xu et al., 2022). Figure 1 shows the pattern of the economic performance index of the BRICS countries in 2011-2020:

However, this growth comes up with cost in the form of natural resource depletion and environmental damage. This calls for an urgent need of identifying sustainable pathways that create balance between economic growth and resource efficiency (Pattak et al., 2023; Rajendran et al., 2023). The amalgamation of fintech, socio-economic development and green growth offers an ingenious solution, however, their collective impact on natural resource efficiency is not clearly understood (Huang, 2024 ; Khan et al., 2019). It is assumed that their collective impact can lead to sustainable ways to extract natural resources that are derived by social equity, effectual strategies and technological innovation. Addressing barriers, challenges and securing global equity are crucial for optimizing their positive effect on natural resource efficiency. For example, fintech based solutions can be used to fund sustainable projects, on the other hand, programs related with social development show support toward the adoption of sustainable practices (Bell et al., 2019; Ma et al., 2023). Moreover, it can optimize financial transactions, streamline supply chains and support sustainable investment practices which are potential to change economic paradigms making the resource-efficient practice easier (Marimuthu et al., 2021). Figure 2 shows BRICS nations adopting the digital economy transformation:

Prior researches also claim that the benefits reaped from socio-economic development, fintech and green growth are not allocated uniformly in BRICS economies. There are several challenges still these economies have to face which are posing as a barrier to resource efficiency. For example, in Brazil, rate of deforestation increased by 22% in 2021 which happens to be the highest rate in last 15 years (INPE, 2021). Deforestation means major loss of biodiversity which increases several risks for human and environment (UNEP, 2022). Russia on the other hand heavily relies on non-renewable extraction that cause environmental destruction, land and water pollution and habitat destruction. India is in the same lead as it faces intense water scarcity due to overexploitation (GreenPeace Russia, 2023; WWF Russia, 2022). According to resources, India is expected to have water deficit by 2030 (NITI Aayog, 2021; WHO, 2022). While in the case of China, although the efforts have been made, however, the country is still struggling because of air and water pollution. Intense industrial activities and increase in urban population are also one of the challenges that country has to address (Ministry of Ecology and Environment of the People's Republic of China, 2023; FAO, 2022). Finally, Africa is another one such example that experience critical water shortage issue because of overexploitation of mineral resources. This greatly affect resilience of natural system (DWS, 2023; SANBI, 2022).

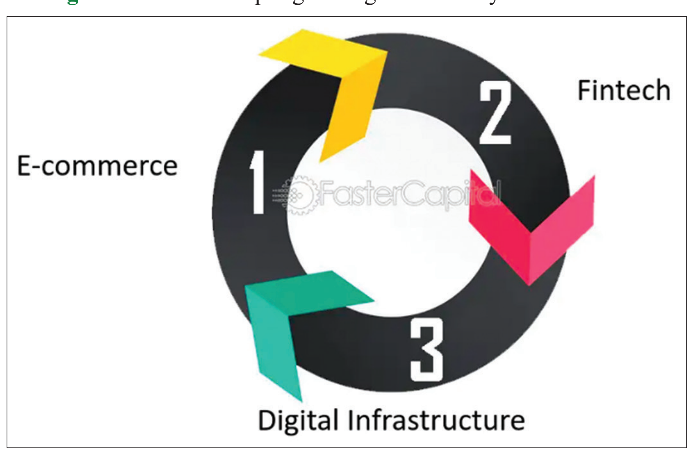
Figure 1: The pattern of the economic performance index of the BRICS countries in 2011-2020



Source: Nguyen and Khominich (2023)

The BRICS countries have to reconcile economic expansion demands for resources with ecological harmony, sustainability and resistance to shortages (Khan et al., 2020). Since environmental degradation and social inequality go hand in hand with traditional development, BRICS must negotiate the resource-intensive industries to guarantee inclusive futures that are sustainable (Yingchao and Xiang, 2024). As a potential cure, fintech innovation is gaining ground but few know how it impacts the BRICS countries' use of assets. Hence, the problem is associated with a lack of adequate comprehensive research that analyse intricate relations between green growth and Fintech innovation as well as their impact on social and economic development in BRICS countries. To overcome the barriers, one should have a broad understanding of the complicated relationships between economic growth, resource use and social progress. Using a systematic analysis of the effect Fintech innovation has on resource efficiency in BRICS countries, this paper seeks to address that knowledge breakdown and offer insights for guiding efficient company practices processes, policy decisions, and such nations' progress toward stronger paths. This research is very instrumental because BRICS members grapple with rising resource demand, environmental degradation, and socioeconomic disparities. Investigation of the role that Fintech plays in resource efficiency is very important for creating proper sustainability policies and practices to ensure constant harmonious growth over time, environmental preservation, fair social development payment

Figure 2: BRICS adopting the digital economy transformation



Source: https://fastercapital.com/content/Digital-Economy--BRICS--Embracing-the-Digital-Economy-Revolution.html system. The conclusions of the study will offer valuable insights that these countries can use to develop ways for inclusive and resilient development while dealing with pressing issues such as resource constraint, climate change, setbacks in socioeconomic inequality. Many prior studies have also discussed the relevance of doing interdisciplinary research on stimulating resource efficiency in BRICS nations. For example, study by Tabrizian (2019) on sustainable development in developing economies focused on the requirement of innovative approaches to resource-related problems. Along the same lines, work of Udeagha and Ngepah (2023) on financial technology for sustainable development revealed fintech potential in promoting environmental activities. Together, these studies support the idea of a detailed study on fintech connections to green growth and social welfare with regard to resource efficiency within BRICS economies.

This paper has five sections. Section 1 comprises of the introduction. The literature is reviewed in Section 2. Section 3 contains an overview of the data and approach is provided. In Section 4, the study presents the empirical results whereas ramifications as well as limitations and future research directions are provided in Section 5.

2. LITERATURE REVIEW

2.1. Economic Development and Natural Resource Efficiency

According to environmental Kuznets curve which is also known as EKC hypothesis, when economies experience development, their environmental quality decreases up to certain point, however, it starts improving in post-industrial phase (Ahmad et al., 2020; Stiglitz, 2017). This indicates that economic development initially is responsible of excessive use of resource and increased pollution, however, when reaching up to certain level of incomes, countries are able to make efficient use of resource because of better technology and effective environmental policies (Balsalobre-Lorentre et al., 2018; Nawaz et al., 2019). Research also indicates that economic development often brings significant improvement in resource energy efficiency. For suppose, studies have revealed that economic development means lots of technological advancement which further indicates a shift toward less energy-intensive industries. Thus, contributing to more efficient ways of energy usage (Jahanger et al., 2022; Umar et al., 2020). Similar patterns can be observed in the context of material efficiency. Because when economies grow, they tend to opt for efficient manufacturing processes and procedures, thus, minimizing raw material amount which is required for per unit output (Arslan et al., 2022; Rahim et al., 2021).

Literature also argues that stronger environmental policies in developed nations often brings significant amount of improvement in natural resource efficiency. Also, international agreements such as SDG goals also play major role in increasing resource efficiency. (Chen et al., 2024; Guan et al., 2020). It is further argued that develop countries prefer to shift from manufacturing based economic structures to service based structures which are quietly less resource-intensive. Hence, the whole structural shift makes the resources more efficient (Awosusi et al., 2022; Wang et al., 2023). Studies also argued that with high economic development, environmental awareness and educational level improve, hence, consumers demand for green products pressure firms to prefer resource-efficient practices (Dabbous and Tarhini, 2021; Razzaq et al., 2021). It is also arguable that market dynamics often encourage innovative practices that would also lead to resource efficiency. It is due to the fact that competitive markets stimulate firms to upgrade production processes and minimize resources usage that means low cost and high profitability. Some studies also support this resource curse notion by implying that resource abundant economies might experience steady growth due to over reliance on natural resources and their lacking in diversification (Tang et al., 2022; Ulucak and Khan, 2020). To conclude the debate, it can be deduced that economic development and natural resource efficiency relationship is complex in nature due to involvement of several factors. However, the one fact which cannot be neglected is that in initial phase economic growth demands high resource usage but with time the situation gets improved.

2.2. Social Development and Natural Resource Efficiency

Social development has an intense effect on natural resource efficiency. Apparently, social development brings improvement in various sectors such as healthcare, education and simultaneously advocates good governance and social equity (Pata et al., 2021; Perez and Claveria, 2020). Thus, makes societies responsible to utilize resource efficiently. In other words, good governance and equal distribution of resources are critical for reaping social benefit that would bring further improvement in natural resource efficiency. Since, it is imperative that education is crucial for increasing awareness regarding environmental issues and natural resources, therefore, studies have embarked that high level of education is positively correlated to sustainable patterns of resource consumption (Saleh et al., 2020; Sinha and Sengupta, 2019). Besides, education also helps in building skills due to which workforce is capable of choosing innovative path for resource-efficient technologies. This becomes more important especially in the context of sectors that heavily rely on natural resources (George et al., 2018). Studies also argued that social development often results in slow population growth, thus, easing the burden on natural resources. In addition to this, healthier nations are also a major contributor of stable and efficient usage of natural resources. Since, social development improves standard of life, thus, allowing a marginal shift of societal values toward sustainability (Sun et al., 2022; Zallé, 2019). It is because of the fact that when all the basic needs are fulfilled, individuals are more focused toward long-term environmental governance rather than temporary exploitation of natural resources. Studies indicate that when economies hold accountable governance mechanisms, they gain a power to handle the use of natural resources with more efficiently. As corrupt practices are responsible of resource exploitation, therefore, reduction in the area automatically improves natural resource management (Jahanger et al., 2022; Zaidi et al., 2019).

Studies also advocate that social development fosters equitable access to natural resources, thereby, minimizing the odds of overutilization by privileged members of society (Lashitew and Werker, 2020). It means inclusive social practices encourage participation of individuals in natural resource management. Evidences from behavioural economics also pinpoint that social development has a potential to nudge organizations and stakeholders to shift toward resource-efficient practices (Raheem et al., 2018).

2.3. Green Growth and Natural Resource Efficiency

Studies on green growth and natural resource efficiency scanned that how economic practices focusing on environment and sustainability can be beneficial for natural resource efficiency (Lee and He, 2022; Yahyaoui and Bouchoucha, 2021). Green growth advocates the idea that how environmental consideration in economic plans can minimize resource exploitation and improve environmental quality while promoting economic growth. Green growth as a concept bolsters the decoupling of economic growth from natural resource usage and environmental damage (Xu, 2022; Zhang et al., 2019). It aims to civilize the efficiency of natural resources while maintaining environmental sustainability and stimulating social equity. With these objectives, green growth promises sustainable economic model that breaks the reliance on natural resources and curtail environmental issues (Cheng et al., 2020). Scholars stipulate that green growth nurtures the idea of adopting green technologies that cultivate resource efficiency. Studies have also claimed that making huge investment in energy efficient technologies can minimize energy consumption in various energy intensive sectors (Gu et al., 2023; Lin and Yuan, 2023). Studies also argued that adequate green growth strategies often depend on sturdy environmental policies that arouse resource efficiency. However, corporation at national and global level are a requisite of green growth. It is also argued that green growth makes nations less dependent on natural resources, thus increases economic resilience and reduces various risk factors such as resource scarcity and environmental damage (Jabeen and Khan, 2022). Green growth strategies also allow economies to share equitable benefits consumed from resource, thus, improving quality of life.

Along with multiple benefits, there are certain barriers that countries might face to achieve green growth. Studies argued that green growth demands adoption of new technologies and practices which can be costly (Hickel and Kallis, 2020; Li et al., 2023). In addition to this, if there is an inconsistency in green growth policies and lack of coordination among institutions, then government efforts might be wasted in terms of improving resource efficiency (Khan et al., 2023; Tan et al., 2023). Also, market failures can also create difficulties for economies in embracing resource-efficient technologies. One such study in European context indicates that policies related to renewable energy and energy efficiency can have a promising effect on resource efficiency (Dogaru, 2021). Studies conducted in the context of China and South Korea also proclaimed that green growth initiatives such as adopting low carbon technologies, gigantic investment in renewable energy produce heterogeneous outcomes. Indeed, it brings improvement in certain territories, however, regional disparities and enforcement problems are one such big challenges that may strike the positive outcome (Shen et al., 2021; Topcu et al., 2020). To conclude the debate, it can be argued that green growth spills positive and significant effect on natural resource efficiency, however, certain challenges and barriers might affect the relationship in negative way.

2.4. Fintech and Natural Resource Efficiency

Research on fintech and natural resource efficiency debates that how digital finance development can be helpful for economies to make sustainable use of natural resources. Fintech envelopes extensive range of technologies which have cathartic effect on resource efficiency (Berentsen and Schär, 2018; Yadav et al., 2024). Scholars declared that fintech gracefully modernizes investment procedures and deviating funds toward sustainable projects. Digital platforms are capable of assessing environmental affect of finances, hence, prioritizing those fundings that aim to improve overall resource allocation (Gomber et al., 2018). Green bonds which are a part of fintech, make greater contribution toward the efficient use of natural resources. Meanwhile, blockchain technology escalates the need of transparency in supply chain processes, thus, assuring that resources are derived sustainably. Blockchain corroborates that all the material sources are sourced efficiently and ethically (Zeng et al., 2020).

Studies also asserted that fintech solutions can track and monitor product lifecycle which help firms to make sure of resource-efficiency practices. Other than that, fintech applications can optimize the need of energy distribution leading to significant shift in energy efficiency (Carlin and Olafsson, 2019; Zhang et al., 2019). According to Chen and Volz (2020), fintech permits peer to peer trading of energy which lessens transmission losses and improve efficiency of energy usage. Study of Dabbous and Tarhini (2019) also explained that fintech is capable of predicting resource consumption patterns which aids government and firms to forge informed decisions related to natural resource management. From consumer perspective, fintech increases access to finance for deprived individuals. This inclusion empowers small-scale agriculturalist and entrepreneurs to make investment in sustainable technologies that eventually brush up resource efficiency (Iqbal et al., 2024; Lisha et al., 2023).

However, there is a pile of literature which explains that fintech benefits for resource efficiency can be restricted and tightened due to digital divide. It implies and financial literacy and access to digital technologies are pivotal for worldwide adoption (He et al., 2024; Xia and Liu, 2024). Other studies also claim that because of expeditious adaptation of fintech, regulatory challenges are mandatory to be faced. It is necessary to make sure that available fintech solution act in accordance with environmental as well as financial regulation. With its absence, resource efficiency cannot be achieved. In addition to this, fintech technologies such as AI and big data also increase concerns related to data security and privacy. According to Muhammad et al. (2022), fintech solutions such as mobile banking and digital market platforms assist farmers to go for efficient agricultural practices. Another study reveals that blockchain adoption for energy trading particularly in EU nations explain that how fintech is helpful for increasing resource efficiency by reducing transaction cost. In the context of Asia, Jia et al. (2024) revealed that fintech platforms are preferred for investment in order to invest in sustainable projects. Resultantly, resource efficiency improves especially in rapidly emerging nations.

3. RESEARCH METHODS AND DATA

3.1. Data Description

The present study aims to catalyse resource efficiency within the context of BRICS countries. As the major benefit of secondary research is that the data collected from secondary sources or reliable platforms contributes to enhancing the probability of research adequacy (Fletcher, 1976; Vartanian, 2010). For this purpose, the researcher has analysed the influence of FinTech Innovation, green growth, economic and social development on resource efficiency. GDP growth was measured as an indicator of the economic development. The second independent variable was life expectancy at birth and was measured as total years. It was undertaken to measure the social development. Net financial account was also measured as an independent variable where BoP and current US$ were utilized to measure this variable. The researcher studied the impact of these variables on the energy intensity level of primary energy. It was measured in terms of MJ/$2017 PPP and GDP. In this regard, resource efficiency was measured as the dependent variable. In this study, control variables are the political stability and absence of violence/terrorism. Green growth which is the independent variable of this study involves four key aspects including GDP growth, level of water stress (freshwater withdrawal as a proportion of available freshwater resources, PM 2.5 air pollution which means annual exposure (micrograms per cubic meter). The renewable energy has been measured as the percentage of total final energy consumption.

The model of the study is specified as:

$$RE = f\,(GG, ED, SD, FINTECH, PS) \quad (1)$$

Where, RE=Resource efficiency, ED=Economic development, SD=Social development, FINTECH=Fintech innovations, PS=Political stability.

The equation (1) can be expressed in its econometric form as follows:

$$RE_{it} = \beta_0 + \beta_1\, GG_{it} + \beta_2\, ED_{it} + \beta_3\, SD_{it} + \beta_4\, FINTECH_{it} + \beta_5\, PS_{it} + \varepsilon_{it} \quad (2)$$

3.2. Data Collection and Time frame

The researcher has accessed two important databases to collect data regarding the studied constructs. These involved world development indicators (WDI) and organization for economic cooperation and development (OECD). These platforms have authentic and reliable information regarding the variables which have been included in this study. Moreover, the researcher implemented a time frame between 2000 and 2022 to observe the change within these variables clearly and effectively. Moreover, incorporating the time series of 2000-2022 also enabled the researcher to observe frequency of change in variables such as GDP within the context of BRICS countries.

3.3. Statistical Techniques

3.3.1. Cross-sectional dependency (CSD) test

In order to obtain the robust and reliable estimation results, first of all the present study applies CSD test proposed by Pesaran (2004). In addition to being a critical issue in panel data estimation, the CSD can lead to serious issues with dimensional distortion, cointegration testing, and the choice of suitable unit root tests.

The mathematical equation of the selected CSD test is formulated as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \sim N(0,1)\,i,j \quad (3)$$

$\hat{\rho}_{ij}^{2}$ indicates the pair-wise correlation coefficient.

3.3.2. Slope heterogeneity test

Next important step in empirical estimation is to assess the slope homogeneity in panel data using the slope heterogeneity test proposed by Pesaran and Yamagata (2008). The null hypothesis of the test assumes the homogeneity of slope parameters whereas the alternative hypothesis assumes the heterogeneity in slope parameters. The mathematical formulation of the test is given in equation 4 and 5 as follows:

$$\tilde{\Delta} = \sqrt{N}\,\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right) \quad (4)$$

$$\tilde{\Delta}_{adj} = \frac{\sqrt{N}\left[N^{-1}\tilde{S} - E(\tilde{Z}_{it})\right]}{\sqrt{Var(\tilde{Z}_{it})}} \quad (5)$$

$\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ show delta tilde and adjusted delta tilde respectively.

3.3.3. Unit root tests

In the third stage of the empirical estimation, the stationarity properties of the concerned data are to be determined. For this purpose, two second generation panel unit root tests namely cross-sectionally augmented IPS (CIPS) and cross-sectionally augmented Dickey-Fuller (CADF) proposed by (Pesaran, 2007) are used in the present study. The CIPS test is robust to be used in the presence of CSD and slope heterogeneity. The mathematical expression of the test can be written as follows:

$$\Delta AC_{it} = \delta_i + \delta_i X_{it-1} + \delta_i \overline{AC}_{t-1} + \sum_{j=0}^{p}\delta_{ij}\overline{\Delta AC}_{t-j} + \sum_{j=0}^{p}\delta_{ij}\Delta AC_{i,t-j} + \mu_{it} \quad (6)$$

In above equation, $\overline{AC}_{t-1}$ and $\overline{\Delta AC}_{t-j}$ represents the cross sectional averages or mean. The CIPS statistics is represented as follows:

$$\text{CIPS} = \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (7)$$

The CADF statistics can be estimated as follows:

$$\Delta y_{it} = \alpha_i + \rho_i^{*} y_{it-1} + d_0\overline{y}_{t-1} + \sum_{j=0}^{p} d_{j+1}\overline{\Delta y}_{t-j} + \sum_{k=1}^{p} c_k \Delta y_{it-k} + \varepsilon_{it} \quad (8)$$

3.3.4. CS-ARDL approach

Finally to estimate the long run and short run parameters, the study uses the CS-ARDL estimation approach which was introduced by utilizing the approach developed by (Chudik and Pesaran, 2015; Pesaran, 2021). This approach is the most appropriate to apply as it has the capability to solve the problems of unobserved common factors, endogeneity, CSD and slope heterogeneity. The CS-ARDL model is expressed as follows:

$$Y_{it} = \sum_{i=1}^{py} \pi_{it} Y_{it} + \sum_{i=0}^{pz} \theta_{il} X_{it-1} + \sum_{i=0}^{pT} \varphi_{il} Z_{it-1} + \mu_{it} \quad (9)$$

Where, the mean cross-sections are represented by Z_t and Y_t in above equation. In addition, X_{t-1} shows the mean of the dependent and independent variables both. Results generated by the CS-ARDL are robust to heterogeneity, endogeneity, misspecification bias, CSD and mixed integration (He et al., 2021).

3.3.5. MMQR estimation

In addition to CS-ARDL estimation approach, the present study applies recently introduced MMQR approach proposed by (Machado and Silva, 2019) to find the quantile based relationship between the dependent and independent variables. This approach is advantageous over first generation quantile estimation approach such as the one proposed by Koenker and Bassett Jr (1978) because of its ability to take unobserved heterogeneity across panel cross sections and data points which first generation quantile based regression approaches fail to consider and therefore provide misleading and inefficient findings (Zheng et al.). We can capture the heterogeneous and distributional differences between RE and its chosen co-variates across different quantiles within the BRICS countries using the MMQR model. Apart from this, MMQR technique also possesses some supremacies. Specifically, the covariance effect over the entire distribution can be accommodated by the MMQR method, which is not possible with first generation quantile methods. Furthermore, MMQR estimation approach has the capability to reveal the co-variates' asymmetries with focus on locations and also deal with the issue of the endogeneity in regressors. Furthermore, the MMQR approach provides reliable, robust, replicable and comparable estimates in non-linear data. The conditional quantile of any random variable QH(τ|R) can be expressed as follows:

$$\dot{Y}_{it} = \dot{\alpha}_i + X_{it}\varnothing + (\lambda_i + Z'_{it}\psi)\ddot{U}_{it} \quad (10)$$

(λi + Z'it $\psi > 0$) in equation (10) represent probability which is equal to 1. ($\dot{\alpha}$, $\varnothing$ and ψ) denote the parameters to estimate. Moreover, ($\dot{\alpha}_i$, and λ_i) = 1 to n represents the specific fixed effects and Z shows k vector of $\ddot{X}$ specified modules given as:

$$Z_u = Z_u(\ddot{X}), u = 1, \ldots.., k \quad (11)$$

Where, X_{it} is separately and equivalently distributed for fixed individual effects (i) and time period (t). Error term (μ_{it}) is separately and equally distributed over time and among individuals and are orthogonal to the explained variable. The corresponding equation (12) is written as follows:

$$Q_y(\delta ! \ddot{X}\,\text{it}) = \ddot{X}_{it}\phi + Z'_{it}\Psi q(\delta) + (\dot{\alpha}_i + \lambda_i q(\delta)) \quad (12)$$

In equation (12) X'_{it} shows the vectors of the independent variables i.e., ED, SD, GG, FINTECH and PS. $Q_y(\tau|X_{it})$ represents the quantile distribution of the dependent variables (Y_{it}) conditional on the independent variable's location. In above equation, X_{it}.- $\alpha_i(\tau) \equiv S_i p(\tau) + \alpha_i$ shows the coefficient of fixed effects of the quantile for cross sections. q(τ) shows the τth quantile which can be computed by solving the following optimization.

$$Min_q = \sum_i \sum t\eta\delta\,(R_{it} - (\lambda_i + Z'_{it}\gamma)q) \quad (13)$$

4. FINDINGS AND DISCUSSION

4.1. Summary Statistics

The summary statistics test was developed to identify basic data characteristics including mean, standard deviation, data range (minimum and maximum values) and data distribution. The test yielded no results other than the planned high and low values. The corresponding estimations are given in Table 1. It can be observed that SD has the highest mean/average value of 68.646 among all series with standard deviation of 5.995, while the lowest mean value is observed for PS with standard deviation of 0.427. The results of J-B test indicate that test statistics are significant for all variables except PS indicating that all series exhibit non normal distribution of data.

In addition, the normality of data distribution is assessed graphically by plotting histograms of all data series as shown in Figure 3. The histograms clearly indicate that data of the selected variables is non-normally distributed.

4.2. CSD Test

CSD is one of the most crucial factors to consider when performing a panel data analysis. This estimation is important because it suggests that if a population of cross sections with uniform slope parameters is pooled but CSD is neglected, the efficiency improvements promised over conducting individual conventional least-squares regressions will be lost. Therefore, the findings of Pesaran (2004) CSD test are given Table 2. The results indicate that the null hypothesis of "no CSD" is rejected at the 1% level of significance. Therefore, we need to keep creating and assessing methods that can take CSD into consideration.

Table 1: Descriptive summary

Variables	Mean	Standard deviation	Minimum value	Maximum value	J-B statistics
RE	6.977	2.343	3.74	12.14	5.265*
ED	4.417	3.973	−7.799	14.230	6.201**
SD	68.646	5.995	53.98	78.211	8.114**
FINTECH	2.051	8.801	−1.5411	4.4211	267.9***
GG	15.093	7.988	0.1559	28.054	8.647**
PS	−0.577	0.427	−1.5145	0.3278	4.008

*P>0.05, **P<0.05 and ***P<0.01

4.3. Testing the Correlation among Variables

The next step of the analysis involves finding the correlation among variables of the study. The correlation matrix given in Table 3 shows that significant and negative correlation exists between GG and RE. Moreover, significant and positive correlation is found to exist between PS and SD and negative and significant association exists between PS and FINTECH. Besides, no significant correlation is found to be present among the rest of the variables.

Furthermore, the relationship between dependent and independent variables is plotted graphically using scatter plot matrices as shown in Figure 4. The multiple charts shown in the following figure indicate the presence of the non-linear relationship between the dependent and independent variables. After knowing the absence of data normality as well as the presence of the non-linear

Table 2: Cross-sectional dependence test

Test	Statistic	Prob.
RE	4.833***	0.000
ED	8.823	0.000
SD	13.679***	0.000
FINTECH	1.926*	0.054
GG	4.283***	0.000
PS	−1.484	0.138

*P>0.05 and ***P<0.01

Table 3: Correlation matrix

Variables	RE	ED	SD	GG	FINTECH	PS
RE	1.000					
ED	0.253	1.000				
SD	−0.223	0.133	1.000			
GG	−0.072*	0.554	−0.152	1.000		
FINTECH	0.461	0.309	0.269	−0.015**	1.000	
PS	−0.169	−0.208	0.024**	−0.197	−0.096*	1.000

Where, * and **denote significance at 10% and 5% respectively

Figure 3: Histograms of variables

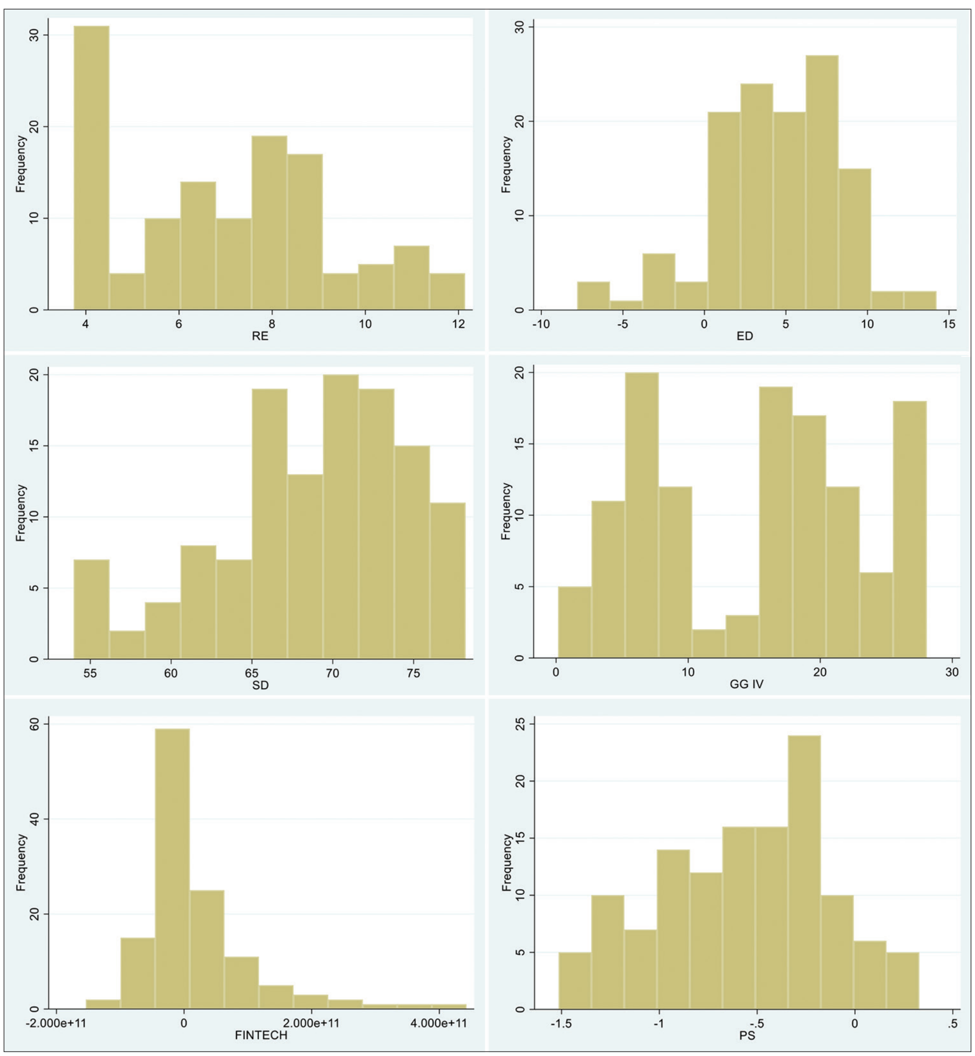
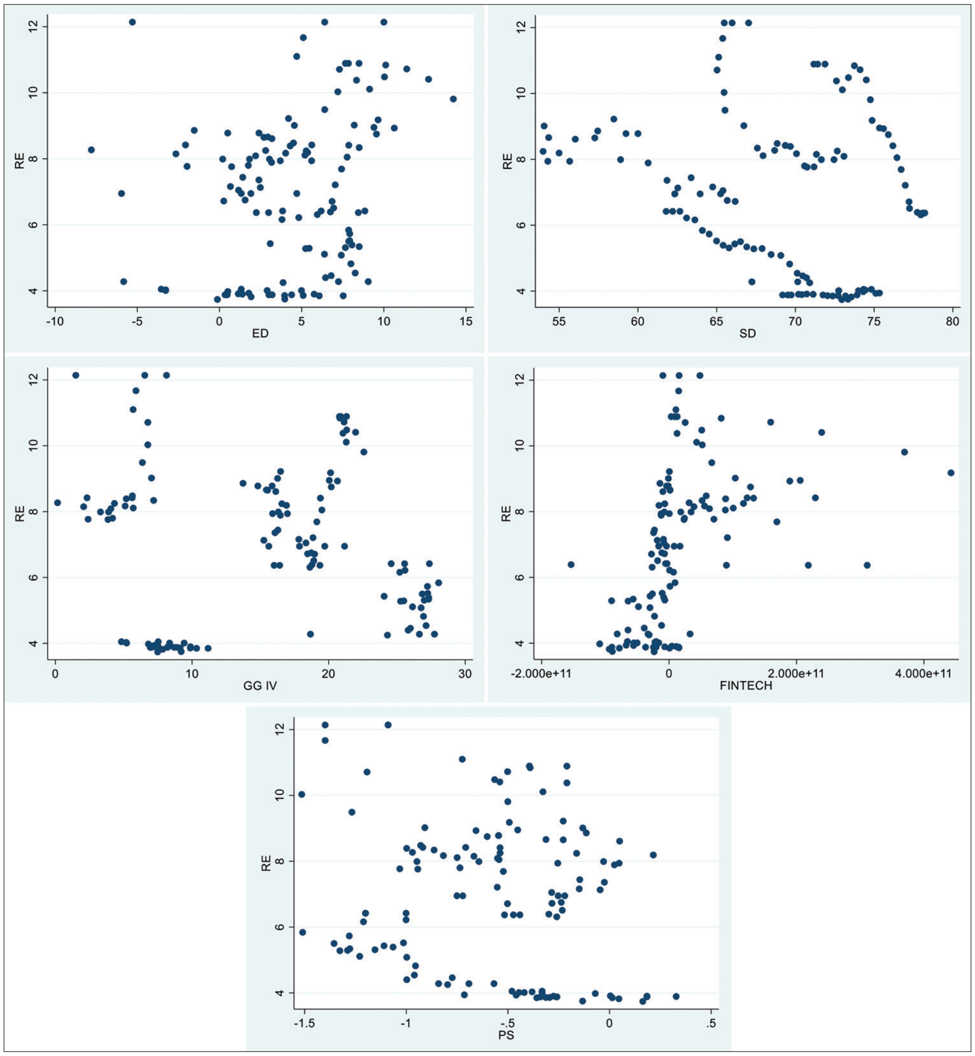


Figure 4: Graphical picture of the relationship between dependent and independent variables



relationships, the application of MMQR estimation approach is clearly justifiable.

4.4. Slope Heterogeneity Test

In addition to CSD analysis, the slope heterogeneity is assessed in the present study using (Pesaran and Yamagata, 2008) and its findings are presented in Table 4. The null hypothesis of the test assumes the existence of slope homogeneity whereas the alternative hypothesis reflects the existence of the slope heterogeneity in coefficients. The findings of the test indicate the highly significant output, which indicates the presence of slope heterogeneity in parameters of the model.

4.5. Unit Root Tests

In addition, the second-generation unit root tests namely CIPS and CADF are widely suggested and applied in the literature to check the unit root properties of the variables in the presence of CSD and slope heterogeneity issues. These tests are applied in the current study and their results are reported in Table 5. Both the CIPS and CADF statistics reflect that the study variables have mixed order of integration i.e., some of the variables are integrated of order 1 and the others are integrated of order 0.

Table 4: Slope heterogeneity test

DV=RE	Statistics	P-value
Delta	5.541***	0.000
Adj.delta	6.530***	0.000

Where,** denote significance at 5%

Table 5: Panel unit root tests

CIPS CADF				
Variables	**Level**	**1st difference**	**Level**	**1st difference**
RE	−1.655	−3.615***	−1.916	−2.935 **
ED	−3.240***	---------	−2.586**	-------
SD	−3.353***	---------	−3.375	-------
FINTECH	−1.783	−4.494***	0.078	−4.608***
GG	−2.120	−5.817***	−0.318	−4.886***
PS	−1.612	−4.894***	1.132	−4.365***

Where, * and ** denote significance at 10% and 5% respectively

4.6. Long and Short Run Parameter Estimation using CS-ARDL Approach

Next, the study proceeds to estimate the long run (LR) and the short run (SR) parameters using CS-ARDL estimation approach. Findings of LR and SR parameter estimations using CS-ARDL are given in Table 6. Let's discuss them one by one. According to

Table 6: Short run and long run findings of CS-ARDL estimation

Dependent variable: Resource efficiency						
Variables	Long run			Short run		
	Coefficients	t-stat	P-value	Coefficients	t-stat	P-value
ED	0.0409*	1.65	0.098	0.0553	1.63	0.102
GGIV	−0.1155**	−2.12	0.034	−0.1612	−1.54	0.123
PSCONTROL	−0.2137**	−2.34	0.019	−0.3151**	−2.27	0.023
SD	−0.2653*	−1.66	0.098	−0.3720*	−1.79	0.073
FINTECH	−1.782	−1.47	0.141	−2.501	−1.46	0.144

Where *P>0.05, **P<0.05 and ***P<0.01

the results, first of all, ED has significant impact on RE only in the long run. In terms of the magnitude of the coefficients, a 1% increase in economic development leads to 0.04 units decrease in resource efficiency as it has positive impact on energy intensity in long run. However, the effect of ED on resource efficiency is insignificant in short run. These findings are justifiable in the light of a number of the arguments. First, ED is associated with the decline in resource efficiency because as economies start to grow, their consumption of natural resources increases especially in emerging economies and the rapid growth in economy results in inefficient usage of natural resources because of weak infrastructure, poor regulatory enforcement, obsolete technologies. This inefficiency of economies aggravates resource depletion and environmental dissipation (Balsalobre-Lorentre et al., 2018; Nawaz et al., 2019). Second the industrial initiatives linked with ED often result in water, air and soil pollution which deter natural resource availability and quality and ultimately slashing the resource efficiency (Awosusi et al., 2022). Thirdly, the finding can also be justified with the fact that ED often turns natural outlook into urban and industrial areas which creates several issues such as deforestation, biodiversity loss, soil erosion, water, soil and air pollution. This lowers the efficiency of natural resources (Guan et al., 2020). From existing literature, the findings are consistent with the substantial number of evidences which outline the negative relationship between economic development and resource efficiency (Ahmad et al., 2020; Stiglitz, 2017).

As can be seen in Table 6, GG also has positive and significant impact on resource efficiency in the long run as the sign of the coefficient is negative indicating that GG reduces energy intensity which ultimately increases resource efficiency. However, its effect is negative and insignificant in the short run. A one unit increment in GG increases resource efficiency by 0.115 units in the long run. Thus the finding indicates that GG which aims at achieving economic growth while maintaining environmental quality simultaneously enables the economies to use natural resources efficiently consistent with the studies of (Gu et al., 2023; Lin and Yuan, 2023). Also, in line with the findings of (Lashitew and Werker, 2020), the present study confirms that GG strategies encourage the use of renewable sources which are more efficient as compared to non-renewable resources. GG also encourages the adoption of waste management practices while lead to resource efficiency. The findings are also in line with the findings of Dogaru (2021), as according to them that sound GG strategies caused the countries to experience 30% growth in energy efficiency because of adopting clean technologies.

Third, we find that the impact of SD is significant and negative on energy intensity both in SR and LR. Specifically, a unit increase in SD is found to be associated with 0.26 units and 0.37 units decline in energy intensity in LR and SR respectively. Thus the negative coefficients indicate that SD leads to efficient utilization of the resources. These findings are also consistent with the studies of (Sun et al., 2022; Zallé, 2019) who argued that SD is crucial for natural resource efficiency. This finding is justified in the light of the fact that social development increases human capital, and motivates the communities to engage in effective resource management. The finding is also in line with the studies of (Saleh et al., 2020; Sinha and Sengupta, 2019) who also pinpoint that SD increases community participation in resource management policies by making sure that all the gained knowledge and practices are embraced correctly to develop sustainable natural resource use strategies. Exceptional health outcomes emerged from social development activities also increase individuals' productivity and their ability to adopt resource-efficient practices.

Our findings also suggest that increase in FINTECH will bring increase in resource efficiency as the sign of the coefficient is negative in LR and SR both. However, this effect is statistically insignificant in LR and SR both. The negative sign indicates that FINTECH reduces energy intensity and therefore promotes resource efficiency in BRICS countries. This positive and relationship between FINTECH and resource efficiency is consistent with literature which proclaim that fintech is a powerful tool to make resource efficient by optimizing the use of resources and upgrading financial resources (Berentsen and Schär, 2018; Yadav et al., 2024). However, against the author's expectations, the effect is insignificant. This is consistent with the earlier estimations provided by Alquliti (2022) and (Li et al., 2024) as the authors claimed that FINTECH does not impact energy efficiency and environmental quality significantly. Lastly, the findings indicate that PS helps in promoting resource efficiency in BRICS countries in LR and SR. The finding is in line with Elfarra et al. (2024) as the authors found that countries having better or higher PS perform better in terms of energy efficiency as compared to the countries with weak PS. The finding is also consistent with Khan and Farooq (2019) as the authors claimed that PS promotes energy efficiency and sustainable development.

Moreover, as a robustness check, this study proceeds to examine the effect of GG, ED, SD, FINTECH and PS on resource efficiency at different quantile ranges (lower, medium, and higher) using the advance MMQR estimation approach. The results are given in Table 7, where it can be observed that the effect of ED is

Table 7: MMQR estimation results

Series	Location	Scale	Quantiles								
			0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
BRICS countries											
ED	0.0461***	0.0036	0.0408**	0.0417**	0.0430***	0.0446***	0.0473***	0.0481***	0.0489***	0.0496***	0.0510***
	(0.000)	(0.448)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
SD	−0.0280***	0.0144***	−0.0490***	−0.0456***	−0.040***	−0.0340***	−0.0234**	−0.0202**	−0.016**	−0.0143**	−0.008
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.002)	(0.006)	(0.027)	(0.252)
GG	−0.4349***	0.0369	−0.4886***	−0.4799***	−0.466***	−0.450***	−0.423***	−0.4147***	−0.406***	−0.3998***	−0.3854***
	(0.000)	(0.423)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
FINTECH	0.0734	−0.0762	0.1841	0.1663	0.1393	0.104	0.0488	0.0318	0.0148	0.0010	−0.028
	(0.296)	(0.133)	(0.151)	(0.162)	(0.194)	(0.170)	(0.487)	(0.647)	(0.830)	(0.989)	(0.713)
PS	−0.0404	0.0871**	−0.1669**	−0.1466*	−0.1157	−0.7649	−0.1247	0.0070	0.0263	0.0422	0.0761
	(0.506)	(0.005)	(0.040)	(0.057)	(0.112)	(0.256)	(0.840)	(0.908)	(0.660)	(0.493)	(0.267)

Where, ***P<0.01, **P<0.05 and *P<0.01. P-values are enclosed in brackets

significant and positive on energy intensity at all quantiles (1st-9th). More specifically, the higher order quantiles indicate highly significant coefficients as compared to lower-order quantiles. Likewise, the impact of SD on energy intensity is negative and significant over lower to higher quantiles except the highest one (0.9). Likewise, GG is observed to have highly significant and negative impact on energy intensity over all ranges of quantiles. Thus both SD and GG play positive role in promoting resource efficiency by reducing energy intensity. In addition, Table 7 reports that FINTECH has no significant impact on resource efficiency at all quantiles, whereas the effect of PS is negative and significant only at lowest quantile (1st and 2nd).

5. CONCLUSION AND RECOMMENDATIONS

The catalysis of resource efficiency within the context of BRICS countries is examined in this study. The objective of this study is to analyze the effects of economic development, green growth, fintech innovation and social development in resource efficiency in BRICS countries over the period 1998-2022. The empirical estimation involves checking for CSD, slope heterogeneity, unit root estimation and long run and short run parameter estimation. To assess the LR and SR parameters, the CS-ARDL approach is applied because of the issues of CSD and slope heterogeneity issues in panel data. Moreover, the non-normal data distribution and nonlinear relationship among variables motivated the researchers to assess the effect of the selected variables on different quantiles of the dependent variables. Therefore, as a robustness check, the MMQR approach is used also.

From CS-ARDL benchmarking results, the complex interaction of economic, technological, environmental, and social factors on resource efficiency can be inferred (Ahmed et al., 2022). GDP growth has a negative implication for resource efficiency, revealing that economic progress needs to be balanced by resource conservation efforts. The positive relationship with green growth and social development suggests that environmentally conscious policies can enhance resource efficiency (Rizvi et al., 2024). However, fintech does not turn out to be a significant determinant of resource efficiency in BRICS countries. Thus the findings of this investigation might help us in completely following the procedure on which the BRICS region may follow the path for the sustainability development.

5.1. Implications

Theoretical contribution and policy implication of this paper are important to accelerate the understanding of sustainable growth of the largest economies of BRICS in contrast to recent literature. In addition, it contributes to the theoretical literature by fostering the positive link between green growth and resource efficiency therefore implying how the green practices can enhance total sustainability. Adding to the complexity of these relationships, the literature suggests that the impact of economic development on resource efficiency may not be linear or simple; while in a general sense development is likely to contribute positively to the future trajectory of the efficiency, there may be certain trade-offs or challenges associated with individual aspects.

These theoretical insights provide valuable foundations for policy makers, researchers, and practitioners to understand the dynamics of sustainable development in these countries as well as encourage decision makers to take an integrated approach to sustainable development incorporating the relative impacts of social development, financial technology on resource efficiency and challenges the dominance of gross economy growth as the definition of economic success to take account of the environment.

The findings suggest a need for strategic interventions and policy measures that prioritize investment toward the upswing thrust in FinTech innovation, green growth initiative, social development activities and environmentally sustainable practices. Policymakers in BRICS countries need to bolster their financial technology infrastructure to leverage the positive impacts of FinTech on sustainable development. Particularly, to make its contribution significant in fostering resource efficiency, there is need to educate the public about technological advancements in financial products and practices to laverage its use in financial services. Moreover, there is dire need to encourage collaborations between governmental and financial entities to create and execute resource-efficient strategies. Similarly, ensuring economic policies are motivated by green growth practices that are aligned with resource efficiency goals should be at the center of their purview. The study suggests significant investments in environmental protection campaigns, coupled with well-financed research and development effort will help substantially cushion the negative environmental footprints associated with economic activities. The implications of these findings suggest that to promote sustainable development in BRICS, a harmonized and intersectional approach to policy-making is critical.

5.2. Limitations and Future Directions

Several limitations need to be recognized despite the valuable insights that are provided by our study. First, focusing on BRICS nations which are developed countries and represent an area of the world has its specific characteristics may limit the generalizability of our findings for instance to less economically developed countries or other regions. Second, in terms of data sources, secondary data is mainly used in this study which facilitates the study overall but may retarded the depth and extent of our analysis. Finally, the study also does not include some potential determinants that may be influential in sustainable development. Specifically, we are focused on some specific variables related to FinTech, green growth, and resource efficiency. However, other variables which are not taken into this study can also affect sustainable development. Thus, it is recommended to scholars to investigate other determinants and use a comprehensive approach to measure each decisive factor. Further studies could be conducted with different econometric models, alternative statistical techniques, or other regressing variables to make the findings of the research more robust. These limitations of this estimation can be a guide to future researchers who can further this study and to refine it so that they can get a better and more advanced information relating the economic development, environmental sustainability, and social progress under diverse circumstances.

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