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Political Economy Perspective of Government Effectiveness for Clean Energy Transition: Empirical Evidence from BRICS Economies

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Abstract

Energy efficiency is the cost-effective utilization of energy in the production process, whereby energy waste is minimized and the overall depletion of primary energy resources is curtailed. Improving energy efficiency enables countries to abate the rising CO_2 emissions by efficient utilization of energy. Hence, energy efficiency is a source of improving environmental performance. This study examines the deep determinants of energy efficiency in BRICS countries. The main objective of the study is to examine the impact of effective governance on energy efficiency in BRICS countries. This study utilizes both fixed-effect and random-effect approaches to examine the determinants of energy efficiency. To check the cross-sectional dependence, this study utilizes residual cross-sectional dependence tests. The results of the fixed-effect approach show that government effectiveness and oil rents improve energy efficiency in BRICS countries. However, mineral rents negatively affect energy efficiency. The study finds that an increase in R&D negatively affects energy efficiency; however, after achieving a certain level of R&D expenditures, a further increase in R&D is linked to improved energy efficiency. This nonlinear relationship suggests that while initial investments in R&D may not immediately translate into energy efficiency gains, continued investment beyond a certain threshold can lead to significant improvements in energy efficiency through technological innovation and advancements. The findings highlight the pivotal role of government effectiveness in driving energy efficiency improvements. Countries with more effective governance structures demonstrate higher levels of energy efficiency, emphasizing the importance of transparent, accountable and coherent policy frameworks in promoting sustainable development agendas. These findings have significant policy implications for policymakers and stakeholders in BRICS countries aiming to foster sustainable energy transitions and enhance energy efficiency.

Keywords: Resource rents, government effectiveness, energy efficiency

JEL Classification: Q30, O38, P28

1. Introduction

Environmental degradation has been a significant global issue in recent decades. Environmental degradation is worsening through the weakening of resources such as air, water, soil, plants, animals and many more elements of the earth that constitute the environment. As the environment fluctuates for natural selection, species are persistently regenerating, and human action is the key driver (Ray and Ray, 2011). Countries around the globe are striving to attain net zero emissions. At COP28, several countries including BRICS showed their willingness to attain net zero emissions by 2050. Countries presented their climate action plans in order to abate the rising CO_2 emissions in the next two decades. Countries are shifting their energy use from nonrenewable to renewable sources. It has been generally known that renewable energy consumption plays a key role in improving environmental performance (Adebayo and Özkan, 2024a; Kirikkaleli and Adebayo, 2021).

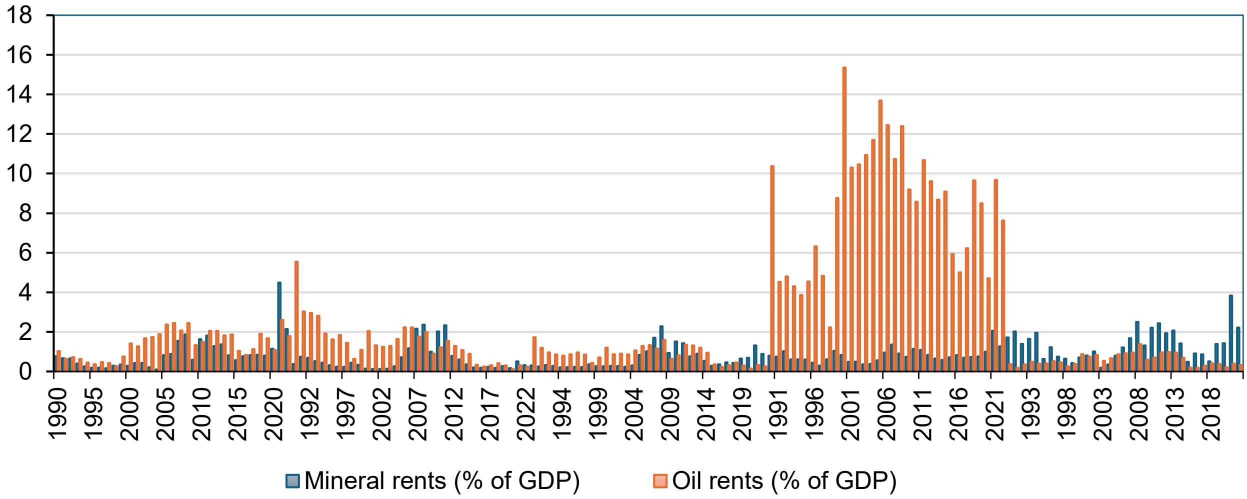
Energy consumption is one of the basic components of development and is considered an engine of economic growth. Despite its several benefits, energy consumption has several negative impacts. The most prominent negative impact of energy use is environmental degradation. However, efficient use of energy could minimize the damaging impacts of energy consumption, while still permitting the same growth and development. Energy efficiency is the cost-effective utilization of energy in the production process, whereby energy waste is minimized and the overall depletion of primary energy resources is curtailed. Improving energy efficiency enables countries to abate the rising CO_2 emissions by efficient utilization of energy. Hence, energy efficiency is a source of improving environmental performance. Improved energy efficiency enables countries to leave the scarce energy resources for others. Moreover, by improving energy efficiency, countries can improve the economic well-being of their citizens. The shift towards green energy, characterized primarily by renewable energy sources, represents a multifaceted endeavour influenced by a myriad of factors (Adebayo *et al*., 2024; Adebayo and Özkan, 2024b). One such factor is the abundance and exploitation of mineral resources, which often play a pivotal role in shaping a country's economic landscape. The extraction and utilization of minerals, including fossil fuels such as oil, not only contribute to economic growth but also pose environmental challenges, including carbon emissions and resource depletion. Thus, comprehending the interplay between mineral resource abundance and the adoption of green energy is vital for reconciling economic development with environmental sustainability. The continuous extraction of natural resources significantly affects environmental quality. The majority of the world's population directly relies on natural resources for their livelihood. Moreover, people depend on natural resources to obtain food, fuel, *etc*. (Sachs *et al*., 1999a, 1999b). However, the excessive use of these resources poses severe environmental challenges for humans on earth. The degradation of soil quality, loss of agricultural land fertility and degradation of quality crops are the results of the use of agricultural fertilizers. Similarly, water for drinking and irrigation is scarce and polluted due to the overexploitation of groundwater aquifers. Moreover, the fishery industry is declining and the air quality is continuously worsening. These air, land and water pollutants are harmful to human life (Kirikkaleli *et al*., 2021). Environmental deterioration poses a significant risk not only to human health but also to the development of countries. Sometimes, it is fallaciously associated with the luxury for the beauty of wealthy countries. The role of infection in reducing poverty is enormous. Development agencies must consider the environmental threats that stimulate their schemes to reduce poverty (Qin *et al*., 2021; Ali *et al*., 2021).

A wealth of natural resources, in general, may be beneficial to the transformation to renewable energy, and certain natural resources may be damaging due to their economic effects and management. Because renewable energy generation necessitates development and technological change, it can be impeded by rent-seeking. As a result of these factors, the majority of the countries could be considered to be in a carbon lock-in, relying on a fossil fuel-intensive economy due to its long history of fossil fuel consumption. First, when fossil fuel sectors, notably the hydrocarbon sector, are created, incumbent governments receive unnaturally high rents. They also provide essential items to the economy, create jobs and can play a significant role in infrastructure development. As a result, foregoing petroleum rents in exchange for the unknown chances of growing renewable energy output can be a challenge.

Countries abundant in natural capital earn substantial revenues from their resources. Natural resources not only generate wealth for countries abundant in resources but also serve as the basis of rural economies in developing countries. If managed wisely through effective institutions and practices, these resources can be utilized to foster growth that benefits the most disadvantaged segments of the community. Non-agricultural revenue generated from natural resources has a substantial role in sustaining rural livelihoods in transition countries (Badeeb *et al*., 2020). Similarly, natural resources are extracted, traded and processed in a similar manner to accommodate the development requirements. The increasing demand for natural resources is fuelled by the infrastructural needs and social advancements observed in growing and transitional economies, particularly in Asia. Therefore, the extraction of natural resources offers an opportunity to enhance infrastructure and initiate structural transformations in developing countries. Mineral resource extraction and exploitation sometimes serve as the main catalysts for economic growth in countries abundant in resources, which heavily depend on these activities. However, the dependence on these finite resources often leads to a deterioration in environmental efficacy.

Figure 1 illustrates the trajectory of oil and mineral rents in BRICS countries from 1990 to 2022. The mineral and oil rents of BRICS countries have exhibited significant fluctuations, influenced by factors such as global commodity prices, demand-supply dynamics and local policy actions. From the early to mid-2010s, the BRICS countries witnessed a significant increase in mineral and oil revenues. The observed phenomenon can be ascribed to the expeditious process of industrialization, urbanization and infrastructure advancement that transpired inside this specific temporal framework. During the latter part of the decade, the global commodities markets experienced increased volatility due to geopolitical tensions, trade conflicts and the rise of renewable energy alternatives. Several variables played a role in the fluctuations observed in mineral and oil rents.

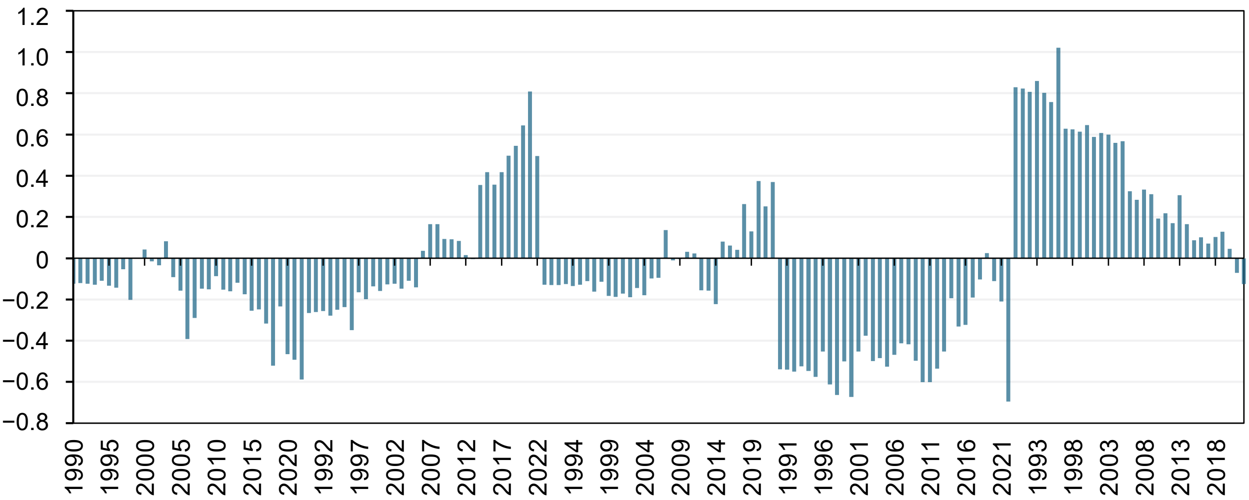
Figure 1: Trends in oil and mineral rents in BRICS countries



Source: World Bank (2024)

Figure 2 presents the trend in government effectiveness in BRICS countries over the period from 1990 to 2022. It is evident that the trend in government effectiveness of BRICS countries (aggregates) has demonstrated both advancements and challenges, reflecting the diverse socioeconomic and political landscapes within the group. Initially, in the early 1990s, following the end of the Cold War and the subsequent wave of democratization and economic reforms, there were significant strides in improving government effectiveness across many BRICS countries.

Figure 2: Trend in government effectiveness in Brick countries



Source: World Bank (2024)

This study examines the impact of resource rents, R&D expenditures and government effectiveness on green energy in BRICS countries (Brazil, Russia, India, China and South Africa). This study provides empirical evidence on the determinants of green energy uptake within BRICS countries. This study will specifically concentrate on mining resources. The BRICS countries are selected due to their significant contribution to global income, energy consumption and CO_2 emissions. Moreover, the BRICS countries have abundant mineral and oil resources. Hence, these factors make BRICS countries a good sample for examining the issue of resource rents and energy efficiency.

2. Literature Review

The possible impact of resource rents on environmental performance has been an important issue for researchers in the last few decades (Tang, Irfan, *et al.*, 2022; Sharma and Paramati, 2022; Safi *et al.*, 2021; Chi *et al.*, 2021; Wang *et al.*, 2020; Van der Ploeg, 2011; Balsalobre-Lorente *et al.*, 2018; Danish *et al.*, 2019). There is a general consensus among researchers that exploitation of natural resource rents leads to environmental degradation. It is generally argued that countries with greater economic benefits from oil extraction tend to have greater CO_2 emissions (Han *et al.*, 2023; Cavalcanti *et al.*, 2011; Ali *et al.*, 2014; Mahmood *et al.*, 2020; Fuinhas *et al.*, 2016; Arezki and Van der Ploeg, 2010). The majority of the world's population directly relies on natural resources for their livelihood. However, the excessive use of these resources poses severe environmental challenges for humans on earth.

The relationship between natural resource rents and energy efficiency is a debatable issue among the academia and research (Ousama *et al.*, 2021; Li *et al.*, 2022; Alola *et al.*, 2022). It is widely recognized that resource rents have the capacity to yield both positive and negative consequences for economic growth and environmental sustainability (Ji *et al*., 2020; Awosusi *et al*., 2022). Hence, the existing literature provides mixed findings on the relationship between natural resource rents and energy efficiency. Some studies suggest that high levels of oil and gas resource rents create economic incentives for governments to invest in renewable energy development (Gu *et al*., 2023). Badeeb *et al*. (2020) found that resource-rich countries get more revenue from their natural capital and hence form the basis for development in resource-rich regions. The authors further argued that countries with quality institutions and better governance systems get advantages from their natural resources. Hence, the efficient management of natural resources produces substantial revenue for resource-rich counties. Moreover, the efficient utilization of natural resources generates growth that benefits the most disadvantaged parts of the community.

The non-agricultural revenue derived from natural resources plays a crucial role in sustaining rural livelihoods in countries experiencing transition. According to Gu *et al*. (2023), oil-rich countries have higher levels of energy efficiency compared to other resource-rich countries. Investment in energy-efficient technologies could also imply a certain level of dependence on oil-based energy sources. Hence, resource-rich countries excessively allocate their resources towards the development of renewable energy sources. The authors stated that natural resource rents have the capacity to influence technological innovation. Moreover, natural resource rents provide a gateway for knowledge spillover. Dramani *et al*. (2022) argued that institutional quality and effective governance moderate the relationship between natural resource rents and green energy. Countries with quality institutions get more advantages from natural resources. These countries are more energy-efficient.

Jiang *et al*. (2021) studied the influence of political economics in the relationship between natural resource rents and green energy. The study highlighted the potential for rent-seeking behaviour and corrupt practices to exacerbate adverse impacts on the environment.

The literature on the relationship between government effectiveness and green energy in scarce. Only few studies have examined the linkage between government effectiveness and green energy. It is generally agreed upon that government effectiveness is important for sustainable green energy. Countries with effective governance structures demonstrate higher levels of energy efficiency. Hence, effective governance plays a significant role in promoting the adoption and implementation of policies that are conducive to gains in energy efficiency. Wang *et al*. (2022) argued that government effectiveness is an essential factor in the emergence of environmentally friendly energy resources. Moreover, government effectiveness promotes sustainable energy projects, which are important for energy efficiency. According to Guo *et al*. (2023), countries with effective governance have a stronger capacity to successfully administer their energy structures.

The literature on the role of investment in R&D in affecting green energy is rich (Mahmood *et al*., 2021; Pan *et al*., 2022; Ravšelj and Aristovnik, 2020; Han *et al*., 2023). According

Inglesi-Lotz (2017), investment in R&D plays a crucial role in promoting innovation and technological advancements. Moreover, investment in R&D also encourages extensive utilization of environmentally friendly energy technologies. An increase in R&D expenditures promotes advancement in renewable energy technologies, which are less harmful to the environment and also promote energy efficiency (Colapinto *et al*., 2020; Lee *et al*., 2019). An increase in R&D expenditures also promotes competitiveness of green energy technology, which contributes to decreasing costs associated with green energy technology. Ravšelj and Aristovnik (2020) and Han *et al*. (2023) found that the costs of generating renewable energy decrease due to technological innovations, which are the outcome of investment in R&D. This not only makes environmentally friendly energy sources more appealing to consumers but also makes them more economically feasible.

This research paper contributes significantly to the literature by providing empirical evidence on the determinants of green energy uptake within BRICS countries. Our primary objective is to examine the impact of government effectiveness and mineral resource availability on energy efficiency in BRICS countries. We select BRICS countries due to their diverse socioeconomic backgrounds. Moreover, BRICS countries are rich in mineral resources. Furthermore, these countries have a significant influence on global energy consumption and greenhouse gas emissions.

3. Methodology

3.1 Theoretical framework

This study utilizes the resource curse theory, which states that resource-rich countries may face less economic development due to political instability, income inequality and corruption. The idea of resource curse was presented by Auty (1993). The author argued that resource-rich countries face difficulties in governance and environmental degradation. Moreover, abundant natural resources often lead to a slowdown of economic growth. The exploitation of natural resources has serious consequences in terms of greenhouse gas emissions.

This study examines the impact of resource rents on green energy. The study utilizes the economic dependency model in a perspective of environmental externalities. Extraction and utilization of natural resources often give rise to adverse environmental externalities. Externalities can exert a deleterious influence on energy efficiency due to their potential to result in heightened resource wastage, diminished total energy conversion efficiency and adverse effects on ecological well-being. Hence, the extraction of nonrenewable resources can lead to an escalation in resource rents, potentially resulting in elevated environmental expenses that may impede the attainment of energy efficiency. Furthermore, overexposure to resource rents can lead to economic distortions and inefficiencies, both of which have unfavourable consequences. We include government effectiveness and investment in R&D in the model of resource rents leading to green energy.

The effectiveness of government initiatives significantly influences the outcome of green energy endeavours. Therefore, this study examines the impact of resource rents, government effectiveness and investments in R&D on energy efficiency.

3.2 Model specification

Based on the theoretical framework, we propose the following econometric model:

$$GRE_{i,t} = \delta_0 + \delta_1 RDE_{i,t} + \delta_2 RDES_{i,t} + \delta_3 MRT_{i,t} + \delta_3 ORT_{i,t} + \delta_5 GEF_{i,t} + \varepsilon_{i,t} \tag{1}$$

where *GRE* represents green energy and is measured by renewable energy consumption (% of total final energy consumption) and *MRT* and *ORT* are mineral rents and oil rents, respectively. Both types of rents are represented as percentages of GDP. *RDE* represents research and development expenditures (% of GDP). We use the square term of the *RDE* in the model due to the nonlinear relationship between *RDE* and *GRE*. *GEF* represents government effectiveness. This variable is used to capture government effectiveness. The data are collected from the World Bank (2024). The descriptive statistics of the variables are given in Table 1.

Table 1: Descriptive statistics

	GRE	*RDE*	*RDES*	*MRT*	*ORT*	*GEF*
Mean	1.233913	0.989645	1.138659	0.861804	0.108380	−0.036246
Median	1.268810	0.987830	0.975808	0.693511	0.061508	−0.123713
Maximum	1.723870	2.432600	5.917543	4.488940	1.186280	1.020500
Minimum	0.502427	0.526940	0.277666	0.099337	−0.941937	−0.695411
Std. dev.	0.422680	0.400292	1.092172	0.698652	0.495927	0.369448
Skewness	−0.518437	1.722386	2.637576	1.865217	0.370177	0.662163
Kurtosis	1.841204	6.059651	9.985990	8.073869	2.450086	3.040385
Jarque–Bera	16.62318	145.9420	526.8401	272.6645	5.847389	12.06885
Probability	0.000246	0.000000	0.000000	0.000000	0.053735	0.002395
Sum	203.5956	163.2914	187.8787	142.1976	17.88263	−5.980633
Sum sq. dev.	29.29997	26.27831	195.6257	80.05077	40.33471	22.38460
Observations	165	165	165	165	165	165

Source: Authors' own calculations

3.3 Econometric methods

3.3.1 Diagnostic check

Cross-sectional dependence and slope heterogeneity are the two potential problems in panel data. To check the cross-sectional dependence (CD), this study uses a residual cross-sectional dependence test. It checks the presence of cross-sectional correlation among the residuals in panel data models. Diagnosing cross-sectional dependence is important because violating the assumption of independence among observations can lead to biased parameter estimates. This study also uses the Breusch–Pagan LM test and the Pesaran CD test to check the CD. These tests check whether residuals from a panel data regression model exhibit spatial autocorrelation. The Pesaran CD test is a widely used test in panel data models.

3.3.2 Unit root tests

This study uses the Levin, Lin and Chu (LLC) test and the Breitung *t*-test to check the unit root of variables. One of the advantages of the LLC test is that it deals with the problems of cross-sectional dependence and slope heterogeneity. This study also uses the Breitung panel unit root test, which provides efficient results in the case of small sample size.

3.3.3 Cointegration tests

To check the long-run relationship among variables, this study uses the Westerlund test, the Kao residual cointegration test and the panel period heteroscedasticity LR tests. The Westerlund test takes into account CD (Ali and Malik, 2020). The Westerlund test uses the following test statistics:

$$G_t = \frac{1}{N} \sum_{i-1}^{N} \frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \tag{2}$$

$$G_\alpha = \frac{1}{N} \sum_{i-1}^{N} \frac{T\acute{\alpha}_i}{SE(1)} \tag{3}$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \tag{4}$$

$$P_\alpha = T\acute{\alpha} \tag{5}$$

where G_α and G_t are group statistics and P_α and P_t are panel statistics.

The Kao residual cointegration test is conducted by regressing the residuals obtained from individual unit root tests on the lagged residuals to account for cross-sectional dependence. To assess the impact of the explanatory factors on energy efficiency, this study uses random-effect and fixed-effect methods. Random effect is a panel data regression technique that allows estimation of both time-invariant and time-varying effects across individual entities (in this case, BRICS countries). The key assumption underlying the random-effect model is that the individual-specific effects are uncorrelated with the explanatory variables, but they may still be correlated with each other. The random-effect model assumes that the individual-specific effects are unobserved but constant over time for each entity. In addition, the Hausman specification test is performed to determine the most suitable method for the selected model among the fixed effect and random effect. This study employs the Dumitrescu–Hurlin (D–H) test is also employed.

4. Results and Discussion

The results of the residual-based cross-sectional dependence (CD) test are reported in Table 2. The significance test statistics of all three CD tests indicate that the variables in Model 1 are cross-sectionally dependent.

Table 2: Residual-based cross-sectional dependence test

CD test	Test statistics
Breusch-Pagan LM	83.0379*
Pesaran scaled LM	16.3317*
Pesaran CD	5.42394*

Source: Authors' own calculations

The results of the CIPS unit root test indicate that all the variables are stationary at first difference. These data demonstrate that both the mean and the variance of the variables used in the model change over time.

The Westerlund test is aided by the findings of cross-sectional dependence and unit root tests. The test identifies the cointegration of panel time-series data in settings of CD concerns. The group mean statistics for the overall cointegration are displayed in the first two rows of Table 4, labelled "G_t" and "G_a". The panel statistics are displayed in the second and third columns of the table, labelled "P_t" and "P_a", respectively. According to the findings provided in Table 4, RDE, RDES, MRT, ORT, and GEF are all cointegrated with GRE.

Table 3: Unit root test – CIPS

Variable	Levin, Lin & Chu test		Breitung *t*-stat	
	I(0)	I(1)	I(0)	I(1)
GEF	−0.4148	−3.2826*	1.3787	0.3466
GRE	1.4532	−2.6403**	0.8414	−2.3576*
MRT	0.3905	−1.6590**	0.0315	−4.7809*
ORT	−1.3707***	−9.4411*	−3.3486*	−8.1739*
RDE	−0.4942	−5.0424*	0.5266	−3.2786*
RDES	−1.3308	−5.9519*	0.5654	−2.3642***

Source: Authors' own calculations

Table 4: Cointegration test

	Westerlund test		
Statistic	**Value**	***Z*-value**	***p*-value**
G_t	−4.791*	−5.699	0.000
G_a	−22.302*	−3.081	0.001
P_t	−12.629*	−6.891	0.000
P_a	−25.027*	−4.779	0.000
	B. Kao residual cointegration test		
	***t*-statistic**		
ADF	−1.292167*		
Residual variance	0.000473		
HAC variance	0.000658		
	C. Panel period heteroscedasticity LR test		
Likelihood ratio	22.1931*		

Source: Authors' own calculations

The results of the fixed-effect and random-effect estimators are presented in Table 5. The purpose of the results is to determine whether the variables of interest are correlated with country-specific errors, which is based on the Hausman tests in Table 5. A significant chi-square statistic clearly indicates that the difference in the coefficients is systematic. Additionally, it shows the dominance of the fixed effect over the random effect. Therefore, we will focus on the interpretation of fixed-effect estimates. The results of the fixed-effect estimator show that government effectiveness and oil rents have a positive and significant impact on energy efficiency. Mineral rents are, however, negatively and significantly related to energy efficiency. The positive and significant coefficient of government effectiveness indicates that countries with more effective governance structures tend to exhibit higher levels of energy efficiency. This suggests that countries with effective governance have a stronger capacity to successfully administer the energy structures and hence get advantages from their natural resources. It is generally agreed upon that government effectiveness is important for sustainable green energy. Effective governance plays a significant role in promoting the adoption and implementation of policies that are conducive to gains in energy efficiency. Thus, effective governance is important for resource-rich counties to produce sustainable energy. It is generally argued that government effectiveness is an essential factor in the emergence of environmentally friendly energy resources. Moreover, government effectiveness promotes sustainable energy projects, which are important for energy efficiency.

The positive and significant coefficient of oil rents indicates that oil-rich countries demonstrate higher levels of energy efficiency. In contrast, the negative coefficient of mineral rents indicates that mineral resource-rich countries demonstrate lower levels of energy efficiency. This finding highlights the potential challenges associated with resource-dependent economies, such as environmental degradation and economic vulnerability.

The coefficient of R&D expenditures is negative and significant, which suggests that an increase in R&D leads to re-education in energy efficiency. However, the square term of R&D expenditures (*i.e.*, *RDES*) is positive and significant, which indicates that after achieving a certain level of R&D expenditures, a further increase in R&D is linked to increasing energy efficiency. This nonlinear relationship suggests that while initial investments in R&D may not immediately translate into energy efficiency gains, continued investment beyond a certain threshold can lead to significant improvements in energy efficiency through technological innovation and advancements. The allocation of resources towards R&D plays a crucial role in nurturing innovation, facilitating technological advancements and encouraging widespread utilization of environmentally friendly energy technologies. An increase in R&D expenditures also promotes competitiveness of green energy technology, which contributes to decreasing costs associated with green energy technology. Moreover, an increase in R&D expenditures leads to considerable breakthroughs in renewable energy technologies such as solar photovoltaics, wind turbines and energy storage devices. The results support the earlier findings of Adebayo and Kirikkaleli (2021), Andrew *et al*. (2024), Ozkan *et al*. (2024), Ravšelj and Aristovnik (2020) and Han *et al*. (2023).

Table 5: Random-effect and fixed-effect estimates

	Random-effect estimates	Fixed-effect estimates	Difference [std. err.]	χ^2 [Hausman Test]
RDE	0.8530 [0.6837]	−0.71041*** [0.1290]	1.5634 [0.6715]	125.10***
RDES	−0.3740 [0.2313]	0.1595*** [0.0516]	−0.5335 [0.2254]	
GEF	−0.3125*** [0.0670]	0.1219** [0.0533]	−0.4345 [0.0406]	
MRT	−0.0637* [0.0355]	−0.0230** [0.0104]	−0.0406 [0.0339]	
ORT	−0.7010*** [0.0950]	0.0808 ** [0.0365]	−0.7818 [0.0877]	
Constant	0.9351** [0.4352]	1.77089*** [0.0684]		

Source: Authors' own calculations

For a robustness check, we use the FMOLS and DOLS methods. The estimates of FMOLS and DOLS are consistent with the estimates of the fixed-effect model. The results show that R&D expenditures, mineral rents, oil rents and government effectiveness are crucial determinants of green energy. The results of the FMOLS and DOLS estimators show that government effectiveness and oil rents have a positive and significant impact on energy efficiency. Mineral rents are, however, negatively and significantly related to energy efficiency. Compared to the fixed-effect approach and the DOLS approach, the FMOLS method overestimates the coefficients.

Table 6: Robustness check

	FMOLS estimates	DOLS estimates
RDE	−0.8997*** [0.1914]	−0.7104*** [0.1994]
RDES	0.2352*** [0.0694]	0.1595 [0.0726]
MRT	−0.0268*** [0.015]	−0.0230 [0.0162]
ORT	0.1182*** [0.0427]	0.0808* [0.0441]
GEF	0.1362*** [0.0483]	0.1219** [0.0510]

Source: Authors' own calculations

The results of the pairwise Granger causality test are reported in Table 7. It is evident that there is one-way causality from the *MRT*, *ORNT*, *RDE* and *RDES* Granger causes of *GRE*. Nevertheless, there is two-way causality between the *GEF* and *GRE*.

Table 7: Pairwise Granger causality tests

Null hypothesis	*W*-stat.	*Z*-bar stat.	Prob.
MRT* → *GRE	2.49224	1.97267	0.0485
GRE* → *MRT	1.12780	0.07474	0.9404
ORNT* → *GRE	2.94493	2.60235	0.0093
GRE* → *ORNT	1.12591	0.07210	0.9425
RDE* → *GRE	3.49082	3.36170	0.0008
GRE* → *RDE	1.63564	0.78113	0.4347
RDES* → *GRE	4.09504	4.20215	0.00003
GRE* → *RDES	2.12740	1.46517	0.1429
GEF* → *GRE	5.43947	4.50826	0.0013
GRE* → *GEF	3.00012	2.67913	0.0074

5. Conclusion

Improving energy efficiency enables countries to abate the rising CO_2 emissions by efficient utilization of energy. Thus, energy efficiency is a source of improving environmental performance. This study examined the deep determinants of energy efficiency in BRICS countries. We examined the impact of mineral resources, government effectiveness and research and development (R&D) expenditures on energy efficiency in BRICS countries. This study provides empirical evidence on the determinants of green energy uptake within BRICS countries. The BRICS countries were selected due to their significant contributions to global energy consumption and greenhouse gas emissions, coupled with their diverse socioeconomic landscapes and varying degrees of reliance on mineral resources.

We utilized both fixed-effect and random-effect approaches to examine the determinants of energy efficiency. To check the cross-sectional dependence, we utilized residual cross-sectional dependence tests. The results of the fixed-effect estimator show that government effectiveness and oil rents have a positive and significant impact on energy efficiency. However, mineral rents negatively affect energy efficiency. The findings highlight the pivotal role of government effectiveness in driving energy efficiency. We conclude that oil rents lead to enhancement in energy efficiency.

In contrast, mineral resource rents lead to deterioration in energy efficiency. We conclude that an increase in R&D leads to reduction in energy efficiency; however, after achieving a certain level of R&D expenditures, a further increase in R&D is linked to increasing energy efficiency. This nonlinear relationship suggests that while initial investments in R&D may not immediately translate into energy efficiency gains, continued investment beyond a certain threshold leads to improvements in energy efficiency. This increase in energy efficiency is due to technological innovation and advancements. We conclude that government effectiveness plays an important role in affecting energy efficiency. Countries with more effective governance structures demonstrate higher levels of energy efficiency, emphasizing the importance of transparent, accountable and coherent policy frameworks in promoting sustainable development agendas.

These findings have significant policy implications for policymakers in BRICS countries. The positive link between government effectiveness and energy efficiency suggests that effective governance is vital for adoption of energy-efficient policies. Policymakers need to prioritize the resources related to diverse types of energy efficiency policies. The BRICS countries need to minimize energy use during the production process of goods and services. Moreover, the revenue earned from natural resources should be allocated to support R&D activities, which will improve energy-efficient technologies. Policymakers should prioritize the allocation of resources towards fostering innovation in clean energy technologies. Furthermore, the governments need to establish minimum efficiency standards for high-tech appliances.

List of Abbreviations

BRICS:	Brazil, Russia, India, China and South Africa
CD:	Cross-sectional Dependence
CO_2:	Carbon Dioxide
COP28:	28^{th} meeting of the Conference of the Parties
DOLS:	Dynamic Ordinary Least Square
FMOLS:	Fully Modified Ordinary Least Square
GDP:	Gross Domestic Product
GRE:	Green energy
LLC:	Levin, Lin and Chu
MRT:	Mineral rents
ORT:	Oil rents
R&D:	Research and development
RDE:	R&D Expenditure
RDES:	Squared of R&D Expenditure
REC:	Renewable energy consumption

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