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Article

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Interlinkages of Fiscal Decentralization, Financial Development, and Carbon Emissions: The Underlying Significance of Natural Resources

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ABSTRACT

This study investigates a fresh perspective on how natural resource rents (NRR) and quantity of natural resources (QNR) modulate the influence of fiscal decentralization (FD) and the Financial Development Index (FDI) on energy efficiency (ENE) and carbon dioxide (CO2) Emissions. We draw upon the Stochastic Impacts of Regression on population, affluence, and Technology framework, taking the Brazil, Russia, India, China and South Africa (BRICS) countries as the subject of investigation from 1986- 2021. Using a panel Method of Moments Quantile Regression with fixed effects, our results suggest that fiscal decentralization is favourable for environmental stability, particularly in BRICS countries with higher energy efficiency and CO2 emission levels. Increased FDI proves environmentally harmful, with pronounced effects in more energy-efficient nations. Regarding direct influences, NRR and QNR hinder energy and CO2 efficiency, notably in countries with lower energy efficiency and CO2 emissions.Regarding indirect effects, NRR and QNR positively steer the impact of fiscal decentralization and the Financial Development Index on energy efficiency and CO2 Emissions, exhibiting more potent effects in energy-efficient nations. Among other control variables, Eco-Innovation (ECO_INNO), Solar energy production (SEP), Population (POP), and Economic Growth (GDP) foster environmental stability. Fiscal decentralization should be based on a clear and responsible subnational government framework to counter rent-seeking behaviours and weak environmental conservation. Further, inclusive finance must strengthen the accessibility and cost-effectiveness of financial solutions for economic agents, promoting green consumption and investment initiatives to reach environmental stability and other Sustainable Development Goals.

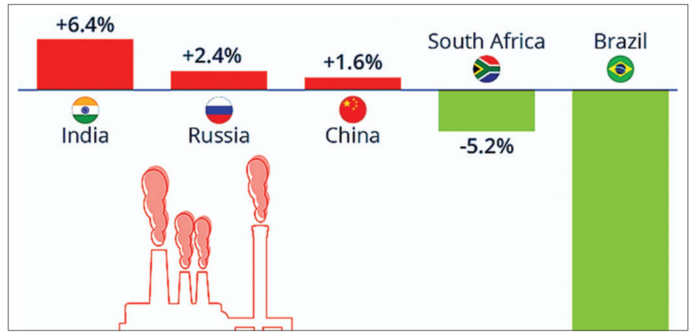
Keywords: Natural resource rents (NRR); fiscal decentralization (FD); energy efficiency (ENE); CO_2 Emission; BRICS countries
JEL Classifications: N50, P28, Q43

1. INTRODUCTION

The complex interconnections among fiscal decentralization, financial development, and carbon emissions have recently garnered considerable scholarly interest in economics and environmental studies (Tufail et al., 2021). The increased attention stems from the increasing recognition that the interactions among these variables are crucial in determining sustainable development trajectories for countries worldwide (Khan et al., 2022). Balancing climate change mitigation and economic growth has become a significant concern for nations. The interdependence between fiscal policies, financial systems, and environmental consequences has garnered considerable attention in scholarly discourse (Kassouri, 2022). budgetary decentralization, which involves the transfer of budgetary responsibility from central governments to lower levels of administration, has emerged as a prominent phenomenon in several nations aiming to bolster local autonomy and improve the efficiency of public services (Chen, 2024). The emergence of this phenomenon has resulted in many forms of governance systems that significantly affect the distribution of resources, the development of infrastructure, and the management of the environment at lower administrative levels (Shan et al., 2021). Redistributing fiscal authorities can impact environmental policy concerning carbon emissions (Hsu et al., 2023). To get insight into the impact of fiscal decentralization on carbon emissions, it is necessary to investigate its complex associations with financial development. The impact of financial development on economic activity, investment patterns, and environmental results is substantial since it involves the progression of financial markets, institutions, and tools (Ali et al., 2022). The presence of a robust financial sector is frequently linked to greater accessibility to money, higher risk management capabilities, and heightened investments in environmentally sustainable technology (Ali et al., 2023). The availability of financial resources for environmentally friendly initiatives becomes crucial as countries shift towards sustainable economic models (Sun et al., 2023). Hence, it is imperative to analyze thoroughly the degree to which financial growth supports or hinders the execution of carbon-reducing initiatives in the framework of fiscal decentralization. In 2022, the Figure 1 presents the year-on-year (YoY) changes in CO_2 emissions from electricity generation within the BRICS economies.

The importance of natural resources is a highly relevant factor that is sometimes ignored within the complex network of interactions. The interconnections between fiscal decentralization, financial development, and carbon emissions are influenced by various natural resources, including fossil fuels and renewable energy (Zastempowski, 2023). Resource-rich areas frequently express a desire for increased fiscal autonomy in order to manage their income derived from natural resources effectively. This desire directly impacts the level of fiscal decentralization within these regions (Dar and Asif, 2023). The effective exploitation of natural resources sustainably is contingent upon providing financial backing to conduct research, facilitate development, and implement clean technologies. This responsibility may be fulfilled by a robust and advanced financial sector, as highlighted by Çetin et al. (2023). In brief, the intricate relationship among fiscal decentralization, financial development, and carbon emissions, influenced by the crucial role of natural resources, has significant consequences for worldwide endeavors to reconcile economic growth with environmental conservation. This work seeks to enhance understanding of the interconnected dynamics between many factors, provide valuable insights for policymakers, and promote a comprehensive approach to sustainable development. It is particularly relevant when the importance and urgency of addressing these issues have reached unprecedented levels (Liu et al., 2022). The interconnections among these aspects require a comprehensive comprehension that considers particular countries' varied settings and intricacies (Doğan et al., 2022; Liu et al., 2022). In light of the global imperative to simultaneously tackle climate change and promote economic development, the present study aims to offer significant contributions by examining the potential strategies to facilitate a mutually beneficial relationship between human advancement and environmental welfare (Li et al., 2022). Comprehending the intricate dynamics of fiscal decentralization, financial development, carbon emissions, and the underlying importance of natural resources presents a multifaceted study endeavor. In light of the pressing imperative to confront climate

Figure 1: The variation in CO_2 emission from electricity generation (Hsu et al., 2023)



change and guide economies toward sustainable paths, it is imperative to comprehensively examine the intricate dynamics and possible interplay between these elements (Khurshid et al., 2023).

One of the main difficulties in examining these connections stems from fiscal decentralization's varied and situation-dependent characteristics. There is considerable variation in the extent to which subnational entities are granted fiscal authority, which differs among nations, regions, and administrative structures. This results in a diverse array of governance systems characterized by their complexity (Zhang et al., 2022). Therefore, conducting a comprehensive analysis of each specific situation is important to learn how various fiscal decentralization arrangements affect environmental policies and shape carbon emissions (Xin and Qian, 2022). Financial growth is a crucial element that presents challenges due to its many characteristics. According to Makhdoom et al. (2023), a robust financial sector may effectively support and enable environmentally friendly investments, direct capital towards sustainable initiatives, and encourage the widespread use of cleaner technology. The financial development in BRICS economies has been smooth throughout the years except for COVID-19 (Figure 2). The correlation between financial development and environmental consequences is complex and may be influenced by several variables, including regulatory frameworks, institutional capacity, and investor preferences (Mariani et al., 2023). Moreover, the research topic is further complicated by the involvement of natural resources. Jahanger et al. (2022) argue that regions abundant in resources can utilize their fiscal autonomy to handle resource income effectively, exerting an influence on the dynamics of fiscal decentralization.

The viability of economies reliant on resources is contingent upon securing financial assistance to advance cleaner technology and adopt environmentally conscious methodologies (Bhatnagar and Sharma, 2022). Including natural resources as both catalysts for fiscal policies and enablers of environmental initiatives introduces additional complexity to the research conundrum. The process of empirically separating and understanding these interconnected interactions poses methodological difficulties. In order to assess the impact of fiscal decentralization on environmental policies and carbon emissions, it is necessary to have access to complete data about governance structures, fiscal transfers, and policy results (Rizos and Bryhn, 2022). Similarly, assessing the influence of financial development on carbon emissions necessitates using precise metrics for evaluating the progress of financial markets,

Figure 2: Financial development of BRICS economies (2000-2028)

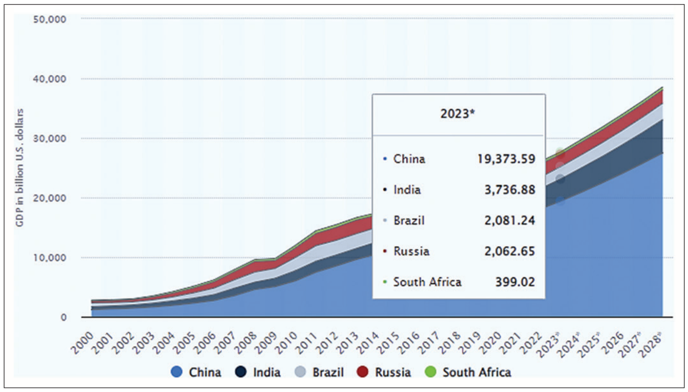
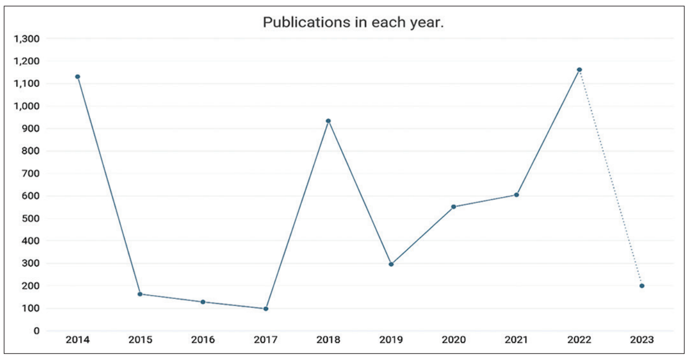


Figure 3: Publication years for retrieved papers



the availability of environmentally friendly financial options, and the patterns of investment (Kumar et al., 2022). In addition, determining causation from the observed correlations presents methodological challenges. Previous research has examined the connections between fiscal decentralization, financial development, and carbon emissions. However, determining the causal relationship and comprehending potential feedback mechanisms is complex (Zhang et al., 2023). The assessment of whether fiscal decentralization contributes to adopting environmentally sustainable policies, the influence of financial development on investment in green technology, and the potential moderating role of natural resource endowments necessitate the utilization of advanced analytical methodologies.

The paper's structure is arranged in the following manner: Section 1 is a comprehensive examination of the theoretical frameworks and conceptual foundations that inform the analysis of fiscal decentralization, financial development, carbon emissions, and natural resources. Section 3 extensively examines the current body of literature, emphasizing noteworthy discoveries, ongoing discussions, and areas of limited understanding in this field. Section 3 outlines the technique utilized to examine the interconnections, encompassing a combination of qualitative and quantitative methodologies to enhance the robustness and comprehensiveness of the research. Section 5 of the study includes the empirical data, revealing the complex correlations identified among the investigated variables. Section 5 of the paper delves into an examination of the policy implications that arise from the Findings, providing valuable perspectives on alternative approaches to attaining sustainable development goals while considering the distinct conditions of each nation. In conclusion, Section 6 summarizes the main findings and highlights potential areas for future research to further our comprehension of this intricate interconnection.

2. LITERATURE REVIEW

The scholarly community has shown considerable interest in the complex relationship between fiscal decentralization, financial development, and carbon emissions, which is influenced by the importance of natural resources. This attention is primarily driven by the implications of this relationship for sustainable development and the responsible management of the environment (Jiakui et al., 2023; Mungai and Ndiritu, 2023). This section provides a critical analysis of the current corpus of research to shed light on important discoveries, ongoing disputes, and areas that require more investigation concerning these interconnections. Extensive research has been conducted on fiscal decentralization, which pertains to the delegation of budgetary duties to subnational governments, particularly in the context of environmental policies and their resultant effects. Scholars have investigated the effects of varying levels of budgetary autonomy bestowed upon local governing bodies on their capacity to enforce environmental rules and promote sustainable behaviors (Sun et al., 2023). Research conducted by Ma et al. (2023) has brought attention to the fact that increased fiscal decentralization can result in disparities in the strictness of environmental regulations among various areas, which may, therefore, have varying impacts on carbon emissions.

The relationship between fiscal decentralization and carbon emissions is intricately linked to the governance systems that arise as a consequence. There has been ongoing scholarly discourse on the impact of fiscal decentralization on environmental results. Some scholars contend that local governments may emphasize immediate economic benefits at the expense of long-term ecological considerations (Azam et al., 2023). The processes mentioned above are especially evident in places abundant in resources, where fiscal decentralization might serve as a means to effectively handle the funds generated from the extraction of natural resources (Wang et al., 2021). Financial development has become increasingly important in mediating the connection between economic progress and the preservation of the environment. A comprehensive financial sector is crucial in granting individuals and businesses access to finance, enabling effective risk management, and promoting sustainable investing practices (Khalid and Okitasari, 2023; Quayson et al., 2023). According to Grijalvo and García-Wang (2023), there is empirical evidence supporting the notion that a strong financial system can enhance green funding and promote the uptake of cleaner technology. Scholars have investigated the mechanisms through which financial development might impact environmental results. The study by Usman and Balsalobre-Lorente (2022) supports the notion that financial institutions significantly impact the advancement of green innovation by allocating funding to environmentally sustainable initiatives. Nevertheless, there is ongoing discourse over the effects of financialization, as some have expressed apprehensions about possible conflicts between profit-oriented financial interests and objectives related to sustainability (Xu et al., 2022).

The role of natural resources in influencing the interplay between fiscal decentralization, financial development, and carbon emissions has been well recognized. Regions that own abundant natural resources and desire more authority over local resource earnings may request increased fiscal autonomy, which can impact fiscal decentralization (Zakhour et al., 2023). Nevertheless, the effective stewardship of these resources requires financial backing to facilitate the advancement of environmentally friendly technology, thereby including the participation of the financial sector (Zastempowski, 2023). The existing body of research emphasizes the intricate interplay between these elements, indicating the presence of possible feedback mechanisms and trade-offs. According to the Findings of Doğan et al. (2022), fiscal decentralization has the potential to facilitate the development of environmental policies at the local level. However, it is important to note that this decentralization may also pose difficulties in effectively coordinating national efforts toward reducing emissions. Similarly, the advancement of financial development presents prospects for green investments; apprehensions emerge about its capacity to redirect resources from sustainable endeavors (Mariani et al., 2023).

Scholars have used several methodological techniques to analyze the interconnectedness of these phenomena. Lingyan et al. (2021) have employed econometric models to evaluate the causal connections among fiscal decentralization, financial development, and carbon emissions. Ameli et al. (2023) have observed that many scholars have employed case studies to investigate the intricate contextual factors that influence these dynamics within certain nations. Despite the advancements in comprehending these interconnections, significant deficiencies remain in the existing body of literature. It is imperative to conduct further comprehensive cross-country evaluations considering the diversity of institutional environments and policy frameworks (Quayson et al., 2023).

Furthermore, it is imperative to conduct a more comprehensive examination of the role played by natural resources in mediating these connections, especially within the framework of evolving resource landscapes (Zakhour et al., 2023). In order to effectively address the intricacies and deficiencies highlighted in the existing body of literature, forthcoming research endeavors must prioritize numerous crucial domains. Conduct comparative research across different nations would be advantageous to understand better the diverse effects of fiscal decentralization on environmental policy and carbon emissions. Researchers can uncover shared patterns and determine the elements that influence various outcomes by considering a range of institutional, political, and economic settings (Tufail et al., 2021). Further investigation is required to have a deeper understanding of the impact of financial development on the facilitation of green investments.

Examining the processes through which financial systems facilitate the adoption of sustainable behaviors while considering potential paradoxes and unintended outcomes might enhance our comprehension of this dynamic relationship (Khurshid et al., 2023). Moreover, a comprehensive analysis of the impact of various financial institutions, including commercial banks and development banks, on facilitating green financing might yield significant findings that can inform policy actions. Furthermore, the ever-changing characteristics of natural resources necessitate research capable of adjusting to fluctuations in resource availability and worldwide patterns. In light of the pressing need to transition towards more environmentally friendly energy sources, there is significant value in examining the effects of changes in energy landscapes on the interplay between fiscal decentralization, financial development, and carbon emissions (Gabler et al., 2023). Additionally, researching the possible feedback loops and interactions among these variables might contribute to a more comprehensive knowledge of their collective impacts. An illustration of this may be found in the study conducted by Xin and Qian (2022), which explores the potential relationship between fiscal decentralization and financial development. The research investigates the reciprocal influence between these two factors and examines their potential cascading effects on carbon emissions. This research has the potential to assist policymakers in effectively navigating the intricate nature of the subject matter and developing comprehensive measures. Finally, the integration of qualitative methodologies, such as case studies and interviews, has the potential to offer a comprehensive contextual comprehension that enhances quantitative analysis. According to Khurshid et al. (2023), qualitative methodologies have the potential to provide insights into the motives and decision-making processes of various actors, such as local governments, financial institutions, and other stakeholders. By employing qualitative techniques, researchers can find complex dynamics that may not be captured by quantitative data alone.

3. DATA AND METHODS

3.1. Data

The members of the BRICS countries have been collated to assess the correlations between the analyzed variables. According to Shang et al. (2023) figures, various nations achieved a notable position in their budget allocation for renewable energy study, development, and example, relative to their gross national product (GDP). Balancing panel data is collected annually from 1976 to 3031. Table 1 presents a comprehensive overview of the information's details, sources, and units of measurement associated with the variables.

Table 1: Variables and expression

Indicator name and measurement	Abbreviation	Sources
Economic growth - (GDP)	GDP	WB
Eco-innovation	ECO_INNO	BRICS
Solar energy production	SEP	BRICS
Population	POP	WB
Fiscal decentralization	FD	IMF
Financial development index	FDI	IMF
Natural resource rents	NRR	WB
Quantity of natural resources	QNR	WB
Energy efficiency	ENE	BRICS
Carbon emission	CO3 emission	BRICS

FDI: Financial development index, SEP: Solar energy production, FD: Fiscal decentralization, IMF: International Monetary Fund's, WB: World Bank's, ENE: Energy efficiency, GDP: Gross national product, NR: Natural resources, QNR: Quantity of natural resources, NRR: Natural resource rents

Table 2: Summary statistics

Country	Statistic	ENE	GDP	Eco_INNO	SEP	POP	FD	FDI	NRR	QNR	CO3E
AUS	Mean	3.79	55,679.56	1.57	70.55	56.35	30.79	61.33	0.17	5.70×10^{07}	7.76
	SD	0.3	3999.17	0.55	5.35	1	0.7	7.37	0.05	3.00×10^{07}	0.63
	Skewness	−0.377	−0.757	−0.353	0.375	−0.673	−0.573	−0.576	0.557	0.555	0.377
	Kurtosis	3.356	3.315	3.371	3.393	3.397	5.591	3.375	3.36	3.073	3.232
	Minimum	3.36	36,537	0.65	60.67	53.5	37.71	55.16	0.09	3.00×10^{07}	6.91
	Maximum	5.1	50,051.7	3.56	71.55	57.79	33.16	75.06	0.37	1.30×10^{09}	9.03
GER	Mean	5.05	50,676.5	3.12	15.34	45.63	37.26	73.57	0.13	3.73×10^{09}	9.61
	SD	0.3	3770.37	0.33	10.05	3.36	1.53	4.25	0.06	3.55×10^{09}	0.66
	Skewness	−0.557	0.155	0.379	0.605	0.506	−1.715	−3.546	1.135	1.371	0.06
	Kurtosis	1.975	1.7	1.795	3.05	1.755	7.336	9.906	5.023	5.309	3.157
	Minimum	3.63	35,776.7	3.7	5.31	51.51	33.07	53.3	0.05	1.00×10^{09}	7.36
	Maximum	5.37	57,313.7	3.75	35.39	57.77	50.11	77.91	0.3	1.10×10^{10}	10.91
NETHL	Mean	5.67	47,625.73	1.71	7.73	60.07	33.65	86.64	0.48	5.37×10^{09}	9.95
	SD	0.35	5393.57	1.35	5.56	3.15	3	5.55	0.33	3.17×10^{09}	0.63
	Skewness	−0.605	−0.777	0.559	0.33	−1.331	1.569	−0.560	0.503	0.666	−0.191
	Kurtosis	3.356	3.735	1.717	1.739	5.356	7.307	3.553	3.137	3.135	3.067
	Minimum	5.31	37,676.1	0.05	1.73	54.35	39.51	63.33	0.09	5.30×10^{07}	7.75
	Maximum	5.97	55,795.1	5.36	16.5	63.56	39.57	73.95	1.19	1.00×10^{07}	11.13
NOR	Mean	5.71	75,506.35	3.53	97.57	63.05	33.91	65.05	7.3	3.77×10^{10}	7.53
	SD	0.51	5957.17	0.35	1.3	1.5	3.53	7.99	3.69	1.59×10^{10}	0.5
	Skewness	0.776	−1.066	−0.735	−0.757	−0.573	0.153	−0.597	−0.579	0.376	0.367
	Kurtosis	3.915	3.195	3.656	3.533	3.191	3.193	3.13	3.7	3.017	3.751
	Minimum	5.19	70,509.7	1.79	95.75	59.15	30.16	53.79	1.67	3.60×10^{09}	6.73
	Maximum	6.73	91,965.3	3.03	99.73	65.7	37.63	76.59	13.3	5.70×10^{10}	7.33
SPN	Mean	3.71	39,573.35	3.65	35.75	56.51	53.13	70.77	0.05	5.73×10^{07}	6.15
	SD	0.36	3553.35	1.05	9.03	5.05	5.05	10.53	0.01	3.63×10^{07}	0.76
	Skewness	0.367	−0.797	−0.131	0.553	−0.333	−0.551	−3.013	0.119	0.55	0.371
	Kurtosis	1.651	3.935	3.337	1.775	3.551	3.137	5.967	1.971	1.765	1.631
	Minimum	3.55	33,737.5	1.73	13.33	37.66	33.7	50.09	0.05	3.50×10^{07}	5.96
	Maximum	3.31	33,959.1	5.53	50.11	53.33	59.76	90.07	0.07	1.10×10^{09}	7.57
SWED	Mean	5.37	59,575.65	1.65	53.39	57.69	55.16	73.73	0.5	1.76×10^{09}	5.15
	SD	0.37	6300.37	0.51	5.73	0.95	3.73	7.31	0.15	1.03×10^{09}	1.05
	Skewness	−0.561	−0.535	−0.117	−0.559	−0.395	−0.135	−1.571	1.367	1.093	−0.005
	Kurtosis	3.339	3.075	3.566	3.955	3.571	3.393	5.199	3.773	3.501	1.766
	Minimum	4.65	37,770.9	0.75	37.5	56.57	37.19	50.59	0.35	7.50×10^{07}	3.56
	Maximum	5.75	57,911.3	3.35	63.37	60.39	51.03	79.61	0.77	5.50×10^{09}	7.05
UK	Mean	3.35	37,577.63	3.3	9.55	57.01	36.77	75.95	0.75	1.76×10^{10}	7.71
	SD	0.55	3659.77	0.53	9.73	1.17	1.77	6.67	0.37	7.60×10^{09}	1.33
	Skewness	−0.533	−0.715	0.339	1.396	−0.311	−0.617	−1.335	−0.361	0.379	−0.731
	Kurtosis	1.557	3.635	1.965	3.303	3.611	3.155	5.009	3.57	3.703	3.059
	Minimum	3.61	30,596.5	1.6	1.63	55.55	33.13	67.5	0.16	3.60×10^{09}	5.35
	Maximum	3.77	53,356.3	3.03	33.59	60.35	39.33	95.59	1.31	3.70×10^{10}	9.19
Cumulative	Mean	5.37	57,157.65	3.36	39.71	56.75	35.76	73.33	1.57	7.07×10^{09}	7.71
	SD	1.05	17,137.35	1.03	33.33	5.31	6.77	10.73	3.95	1.19×10^{10}	1.7
	Skewness	0.191	1.335	0.331	0.55	−1.177	0.57	−0.571	3.393	3.097	−0.356
	Kurtosis	3.159	3.973	3.173	1.935	5.595	3.366	3.715	7.391	7.077	3.317
	Minimum	3.55	33,737.5	0.05	1.63	37.66	33.13	53.79	0.05	3.00×10^{07}	3.56
	Maximum	6.73	91,965.3	5.53	99.73	65.7	51.03	95.59	13.3	5.70×10^{10}	11.13

SD: Standard deviation, FDI: Financial development index, SEP: Solar energy production, FD: Fiscal decentralization, ENE: Energy efficiency, GDP: Gross national product, QNR: Quantity of natural resources, NRR: Natural resource rents

The data about real GDP per capita, the employment-to-population ratio, and revenue derived from natural resources (NR) have been gathered from the World Bank's (WB) indicators dataset for the calendar year 3031. The data about energy efficiency (ENE), carbon emissions (CO_2 emission), the proportion of solar energy production (SEP), and research and development (R&D) expenditures has been collected from the OECD's dataset for the year 3030. The statistical data about fiscal decentralization (FD) and financial development index (FDI) has been derived from the International Monetary Fund's (IMF) database, encompassing the years 3030 and 3031. The selection of the data collecting period was determined by the availability of FD statistics covering 1976 to 3031. Table 2 provides a concise overview of the primary statistical measures of the variables under investigation.

Table 3 demonstrate that all the parameters examined had favourable medians. The parameter representing QNR demonstrated the highest average value. The QNR value for AUS in 1997 was 3.00 × □10 □^07, the lowest number. On the other hand, NOR recorded the most excellent QNR value in 3007, amounting to 5.70 × 1010. When analyzing ENE, it was observed that SPN exhibited the lowest value of 3.55 in the year 3015, while NOR exhibited the most significant value of 6.73 in the year 3007. It is worth noting that the NETHL exhibited the highest ENE score (11.13), while SWE

Table 3: Correlation matrix

Variables	ENE	GDP	ECO_INNO	SEP	POP	FD	FDI	NRR	QNR	CO3E
ENE	1									
GDP	0.767[a] (0.000)	1								
ECO_INNO	−0.310[a] (0.000)	−0.331[a] (0.003)	1							
SEP	0.505[a] (0.000)	0.757[a] (0.000)	−0.191[b] (0.013)	1						
POP	0.731[a] (0.000)	0.753[a] (0.000)	−0.555[a] (0.000)	0.376[a] (0.000)	1					
FD	0.110 (0.156)	−0.113 (0.157)	0.307[a] (0.000)	0.053 (0.573)	−0.393[a] (0.000)	1				
FDI	−0.355[a] (0.000)	−0.310[a] (0.000)	0.316[a] (0.005)	−0.561[a] (0.000)	−0.137[c] (0.099)	0.133[c] (0.077)	1			
NRR	0.603[a] (0.000)	0.767[a] (0.000)	−0.003 (0.971)	0.656[a] (0.000)	0.519[a] (0.000)	−0.167[b] (0.030)	−0.353[a] (0.001)	1		
QNR	0.357[a] (0.000)	0.651[a] (0.000)	−0.036 (0.737)	0.336[a] (0.000)	0.575[a] (0.000)	−0.373[a] (0.000)	0.093 (0.337)	0.795[a] (0.000)	1	
CO_2 emission	0.056 (0.570)	−0.065 (0.501)	0.033 (0.673)	−0.533[a] (0.000)	0.175[b] (0.035)	−0.561[a] (0.000)	−0.070 (0.365)	−0.057 (0.535)	0.030 (0.795)	1

FDI: Financial development index, SEP: Solar energy production, FD: Fiscal decentralization, ENE: Energy efficiency, GDP: Gross national product, QNR: Quantity of natural resources, NRR: Natural resource rents, POP: Population

rated at the bottom concerning ENE. The mean real GDP per capita was $57,157.65, measured in a steady 3010 US dollars. The mean percentage of government R&D funding dedicated to environmental initiatives across the seven nations tested by the Organization for Economic Co-operation and Development (OECD) was 3.36%. SEP contributed 39.71% on average, while the POP ratio was estimated at 56.75%. The average level of FD was observed to be 35.76%, whereas the mean percentage for FDI was recorded as 73.33%.

Furthermore, the kurtosis and skewness stats present compelling evidence that challenges the premise of data normalcy for every factor. Table 3 displays the associations among different variables examined in the study. The data reveals statistically significant positive correlations concerning ENE among GDP, SEP, POP ratio, and NRR. A significant inverse relationship between research and development (R&D) spending, FDI, and ENE may be observed. The findings also underscore a favorable correlation between the POP ratio and CO_2 emission. The examination of the regression matrix shows a statistically significant inverse relationship between SEP, FD, and CO_2 emission.

3.2. Developing a Theoretical Framework

The first framework, STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology), was developed by Pattak et al. (2023). This study aims to build theoretical connections between our potential determinants and environmental sustainability (ES). In order to begin this procedure, we employ the commonly acknowledged formula, which may be restated as follows:

$$I_{it} = \alpha_{it} P_{it}^{\beta 1} A_{it}^{\beta 3} T_{it}^{\beta 3} \varepsilon_{it} \quad (1)$$

Concerning equation (1), the present analysis illustrates ecological consequences, comprising both positive and negative aspects. The repercussions discussed in this context are contingent upon three primary factors: The population variable, represented as P, the amount of economic development designated by A, and the effectiveness of technology, symbolized as T. The nations being analyzed are labeled as "i," while the progression of time is indicated by "t," where "i" ranges from 1 to N and "t" ranges from 1 to T. The variable α is responsible for encapsulating the distinct effects that are distinctive to each object, whereas the error term ε_it contains any unexplained variances. The symbols β1, β3, and β3 correspondingly represent the factors associated with the variables P, A, and T. It is worth noting that the factors in question transform the utilization of natural logarithms. In this situation, the logarithmic-linear representation of equation (1) is given as Equation (3).

$$LI_{it} = \alpha_{it} + \beta_1 LP_{it} + \beta_3 LA_{it} + \beta_3 LT_{it} + \varepsilon_{it} \quad (2)$$

The sign "*L*" is typically used to denote the logarithmic operator. Equation (3) is further enhanced by integrating supplementary components into the affluent dimension (A), including FD, FDI, NRR, and QNR. ECO_INNO and the use of RES sources are included to address the aspect of environmental efficiency (EE) within the realm of technology (T). Furthermore, traditional indicators like real GDP per capita indicate economic prosperity, while the POP ratio is a proxy for the population variable (P). The equation obtained for the continuing investigation is denoted as Equation (3) in this study.

$$LES = \alpha_{it} + \beta_1 LGDP_{it} + \beta_3 \mathrm{LECO\_INNO}_{it} + \beta_3 LSEP_{it} + \beta_5 LPOP_{it} + \beta_5 LFD_{it} + \beta_6 LFINDI_{it} + \beta_7 LNR_{it} + \varepsilon_{it} \quad (3)$$

During our investigation, we have implemented alterations to the usual STIRPAT model, which centers its attention on several elements associated with environmental sustainability. Rather than just focusing on conventional ecological metrics, we have adopted a more inclusive strategy by integrating ENE and CO3 emission metrics. These indicators offer a more comprehensive outlook on economic operations' environmental impacts (EI). Furthermore, we have incorporated FD as a variable that influences prosperity. The effect of FD is examined from two divergent perspectives. One approach, commonly known as the "race to the top," posits that FD may catalyze governments to engage in creative endeavors. The methodology mentioned above has the potential to result in policies that foster competition and place increased importance on public goods, such as the environment, as elucidated in the research conducted by Pattak et al. (2023).

On the contrary, another perspective advocates for a "race to the bottom." In the given context, administrations adopting FD may prioritize attracting foreign investors by relaxing environmental restrictions. The probable consequences of this action may lead to a compromise in ecological quality (EQ), as elucidated by Pattak et al. (2023). Consequently, the impact of FD on ES may exhibit either a positive relationship $\frac{\partial ES_{i,t}}{\partial FDEX_{i,t}} > 0$ or a negative or < 0.

The final alteration pertains to incorporating FDI as a supplementary variable in our examination of wealth. Acknowledging the significance of inexpensive financial services (FS) in promoting citizens' incorporation into economies, we propose that such access has the potential to foster both economic growth (EG) and ES. According to Xing et al. (2023), the provision of FS can motivate enterprises to engage in innovation, expand their product offerings, and create job possibilities, ultimately contributing to the promotion of EG. Improved financial accessibility (FA) might increase expenditure by economic entities such as families and enterprises. From a certain standpoint, companies may choose to increase their output by utilizing energy-intensive techniques, which might give rise to ES issues. Likewise, families with enhanced FA may partake in greater spending on energy-intensive commodities, thus indirectly amplifying carbon emissions. On the other hand, enhanced FDI may catalyze enterprises to allocate resources towards energy-efficient and technologically sophisticated initiatives, fostering vertical industrialization and boosting EFF (Xing et al., 2023). Furthermore, it is plausible that families possessing greater accessibility to financial services may exhibit a higher propensity to embrace renewable energy (RE) solutions, hence potentially yielding favorable outcomes for ES (Hu et al., 2023). Therefore, FDI can have either beneficial or adverse EI, as shown by the partial derivative of environmental sustainability (∂ES) concerning financial inclusion (∂FDI), which can be greater than zero (∂ES/[∂FDI] > 0) or <0 (∂ES/[∂FDI] < 0).

In the fourth iteration of our study, we examine the inclusion of two dimensions related to natural resources (NRs), namely NRR and QNR, as supplementary indicators of prosperity. On the one hand, the dependence of NRR industries on NRs has been linked to declining returns and a probable decrease in investments towards ecological conservation. Nevertheless, an opposing perspective posits that economies that depend largely on NRs may be motivated to allocate resources to produce environmental benefits. Moreover, the Resource Curse Phenomenon (RCP) posits that civilizations abundant in natural resources may encounter economic inefficiencies as a result of variables such as the entrapment of capital. Consequently, the QNR framework has the potential to contribute to the depletion of NR in many nations, thereby posing a risk to ES due to the subsequent rise in CO3 emission. However, advocates of efficient resource administration contend that nations endowed with abundant resources have the potential to attain economic growth and favorable EI via the implementation of appropriate institutional frameworks and technical breakthroughs. In brief, the impact of NR on ES might exhibit a beneficial or detrimental relationship (∂ES/[∂NR] > 0 or < 0).

The metric of opulence adopted in the STIRPAT framework is the real GDP per capita, which aligns with previous research conducted by (Pattak et al., 2023). Nevertheless, empirical data demonstrates the presence of both ecological degradation and enhancement concerning the increase of Gross Domestic Product (GDP) (Ahmad et al., 2019). Consequently, real GDP per capita may be considered a variable that has the potential to either facilitate or impede the achievement of ES. In other words, the partial derivative of ES concerning GDP (∂ES/[∂GDP]) can be either positive or negative. In addition, when examining the technological element (T), it is proposed that incorporating ECO_INNO might lead to improvements in EFF and, thus, a reduction in emissions (Mao et al., 3031). However, it is essential to consider the opposite point, which is that the enhancement of effectiveness might result in a surge in the demand for power-efficient items, which in turn may contribute to a rise in total energy consumption (ENC). This could offset innovation's beneficial effects, as highlighted by Liu et al. (2022). Hence, it is plausible that ECO_INNO may have either a positive or negative impact on ES, as shown by the derivative (∂ES/(∂ECO_INNO)) being more than zero or less than zero, respectively. Moreover, SEP, which falls under the technology element, is well recognized for its benefits compared to non-sources.

Consequently, it is expected that there would be a favourable influence on the preservation of the environment, as shown by the positive derivative (∂ES/(∂SEP) > 0). In assessing ES, the POP ratio is used as the population (P) variable due to its capacity to accurately reflect how much people with jobs contribute to this objective. As a result, it is anticipated that the POP ratio would have a detrimental effect on ES, as shown by the negative partial derivative of ES concerning the POP ratio (∂ES/(∂POP) < 0). The fifth change of our study pertains to including NRR and QNR as moderating factors in the analysis of the ES effects of FD within the enlarged STIRPAT methodology. The enhanced model is mathematically expressed by equation (5), as the referenced source describes.

$$\ddot{u}\ddot{u}\ddot{u}\ddot{u}\ddot{u} = \alpha_{it} + \beta_1 \quad _{it} + \beta_3 \quad \_ \quad _{it} + \beta_3 \quad _{it}$$
$$+\beta_5 LPOP_{it} + \beta_5 LFD_{it} + \beta_6 LFINDI_{it} + \beta_7 L(NR_{it} * FD_{it}) + \varepsilon_{it} \quad (4)$$

The (NR * FD) framework is applied to encompass the interplay between NRs and FD to assess their collective influence on ES comprehensively. The present study incorporates an interaction concept that considers the interrelationship between the availability of NR and the level of dependence on them within the framework of FD. This aspect has been previously emphasized in the works of Pattak et al. (2023). According to Usman and Balsalobre-Lorente (2022), a particular viewpoint posits that governments endowed with NR riches may partake in corrupt activities through resource exploitation, giving rise to the RCP. On the contrary, an alternative perspective argues that governments that exhibit clear decision-making procedures and strong mechanisms for oversight may effectively harness NR to foster favorable EG (Chishti and Patel, 2023). This research paper presents two novel procedures to examine how NR influences the connection between FD and ES. In nations where FD is implemented, regions with ample NR can utilize this framework to attain a more equal allocation of resource advantages. Consequently, this might enable comprehensive regional development and promote competition among local authorities, cultivating environmentally sensitive strategies and ultimately enhancing ES. Furthermore, political circumstances about NR are prone to rent-seeking behavior, which can potentially result in detrimental impacts on EG and ES. The prevalence of these systems is contingent upon the FD level and the political framework's strength. In the context of NRR, decentralized governments may capitalize on the chance to enact advantageous policies that facilitate the shift from petroleum-based energies to renewable ones. This proactive approach can have a favorable impact on ES. On the contrary, in places with inadequate governance, those relying on natural resources may engage in exploitative behaviors to exploit their dependence, leading to adverse EI. The impact of RA and reliance on ES is determined by the level of openness and accountability exhibited by the nation's political systems. Based on the theoretical underpinnings discussed, it is evident that both the abundance of resources and the level of reliance on them can result in either positive or negative consequences regarding ES. However, these results depend upon the effectiveness and robustness of the political structure. The correlations mentioned above may be expressed as (∂ES_[i,t])/(∂[NR_it*FD_it]) > 0 or < 0, showing the possible beneficial or detrimental impact of the interplay between NR and FD on ES.

The analysis has been augmented by including the relationship between NRs and FDI, represented as (NR * FDI). This inclusiveness aims to consider the mitigating impact of NRR and QNR on the correlation between FDI and ES. The experimental paradigm that has undergone refinement may be mathematically expressed through equation (5).

$$\ddot{u}\ddot{u}\ddot{u}\ddot{u}\ddot{u} = \alpha_{it} + \beta_1 \quad _{it} + \beta_3 \quad \_ \quad _{it} + \beta_3 \quad _{it}$$
$$+\beta_5 LPOP_{it} + \beta_5 LFD_{it} + \beta_6 LFINDI_{it} + \beta_7 L(NR_{it} * FINDI_{it}) + \varepsilon_{it} \quad (5)$$

The complex interplay between NRs and FDI occurs through several mechanisms. In resource-abundant environments, abundant NRs may impede the progress of financial services due to profit-seeking tendencies and inadequate institutional quality (INSQ). This circumstance can impede INSQ, as institutions may limit profit-seeking behaviors (Chishti and Patel, 2023). The phenomenon commonly known as the RCP has been characterized as an "institutional curse (IC)," in which the presence of insufficient institutions amplifies the negative economic consequences linked to NRs (Chishti and Patel, 2023). On the other hand, healthy institutions have the potential to use NR rents in order to generate profits. This study presents three key routes that explain how NR influences the dynamic relationship between FDI and ES. (a) Within countries with a significant abundance of NRs, there is a tendency for factors used in manufacturing to reallocate from other industries towards the resource industry. This transition has the potential to result in decreased investments and less diversity in other financial sectors, eventually impeding economic expansion and exacerbating ecological deterioration. When a country that possesses abundant resources engages in the exportation of NRs, it frequently amasses surpluses of foreign money, resulting in the appreciation of its home currency. This expression of gratitude has the potential to decrease inflation, which can lead to a reduction in interest rates (IRs). This can serve as a motivation for customers to use loans to acquire ecologically sustainable items. Simultaneously, investors may borrow to support green projects, promoting ES's progress.

Nevertheless, the effectiveness of this approach relies heavily on the inclination of both consumers and firms towards environmentally friendly alternatives. Resource reliance may lead to an escalation in the importation of NRs, resulting in a devaluation of the native currency, a rise in inflation and IRs, and a discouragement of customer credit-based purchasing of environmentally friendly items. This circumstance has the potential to exert a detrimental influence on the overall quality of the environment. Decreased spending on non-environmentally friendly items and investments can positively impact the natural world. Based on the observations mentioned above, it can be inferred that both reliance on NRs and the quantity of NRs have the potential to either support or impede the achievement of ES. The connection between the partial derivative of ES concerning the product of NR and FDI can be stated as (∂ES_[i,t])/(∂ [NRit * FDI_it]) > 0 or < 0. In addition, the simulations consider the ENE during manufacturing as an additional measure to quantify the impacts on ES. The objective of this technique is to comprehensively examine the relationship between resource connections, FDI, and their long-term effects on EI.

3.3. Econometric Framework

The empirical evaluation conducted in this work comprises three essential steps. In the first stage, a thorough evaluation is performed to determine if the data demonstrates cross-sectional dependency (CSD). Afterward, the researchers conduct unit root tests (URTs) to assess the stationarity of the factors. This is followed by examining the characteristics of the link between the detected factors using panel quantile regressions (PQR). Considering the possibility for CSD to introduce flaws in the findings, this research uses three separate tests to mitigate this issue. As Polcyn et al. (2023) suggested, the initial test assesses CSD within the dataset. The subsequent examination, formulated by Polcyn et al. (2023), uses a scaling Lagrange multiplier (LM) method to evaluate CSD additionally. Finally, the third assessment, referred to as the Breusch and Pagan LM test (Polcyn et al., 2023), also aids in ascertaining the existence of CSD. The potential CSD is quantified by the Polcyn et al. (2023) LM test, represented as Eq. (6) in the research. In order to enhance the validity of the outcomes, these tests together contribute to the determination of the presence of CSD in the evaluation, hence facilitating the accurate understanding of future outcomes.

$$CSD = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{3} \tag{6}$$

(Polcyn et al., 2023) CSD testing is demonstrated in Eq. (7) as:

$$CSD = \sqrt{\frac{3T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij} \tag{7}$$

Accrding to Eqs. (6) and (7), the correlation factor is denoted by the symbol _ij, whereas T denotes the time component and N denotes the total number of participating nations.

The current work uses Polcyn et al.'s second-generational technique (2023) to address the above-noted worry with CSD. This method uses the CIPS (Cross-sectionally Augmented) assessment, called cross-sectionally augmented panel unit root testing. The CIPS testing results are calculated using the Cross-sectional Augmented Dickey-Fuller (CADF) model. This test examines the CS and tPOPral aspects to determine whether UR exists in the results. The CIPS test is expressed in the paper as Eq. (7). This process assists in ensuring the robustness and correctness of future analysis and outcomes, as well as helping to resolve any CSD concerns.

$$CIPS = N^{-1}\sum_{i=1}^{n}CADF \tag{8}$$

The present research uses the Panel Method of Moments Quantile Regression (MMQR) technique, which includes fixed effects (FE), for the study's concluding stage. The approach developed by Pattak et al. (2023) seeks to thoroughly analyze the changing impact of several factors, such as GDP, POP ratio, NRs, FDI, FD, ECO_INNO, and SEP, on the ES of the selected OECD countries. The MMQR method's adaptability for handling irregular data, where traditional contractors could falter, is a standout benefit. Particularly, it manages panel data scenarios with individualized FEs, a crucial component, adequately. As Kassouri (2022) noted, MMQR is also well-suited for situations including innate repressors. It is crucial to emphasize that MMQR generates estimates across different quantiles, offering a thorough grasp of the connections within the data.

This strategy is reliable even when confronting outliers that may normally skew data. Eq. (9) in the research is the eq. that represents the Panel MMQR with FEs. This framework is essential for identifying the complex connections between the factors above and ES in the setting of the chosen OECD nations.

$$Q_{Y_{i,t}}(\tau \mid X_{it}) = \alpha(\tau)' X_{it} + \beta_i, i = 1,\ldots,N, t = 1,\ldots,T \tag{9}$$

In the calculation, the reliant factors are designated as Y_(i,t), particularly designating either LENE or LCO3E. The unidentified is written as a(τ), and X_{it} indicates the explanation factors. Furthermore, β_i stands for the undetected personal effects.

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} \\ &+ a_{6\tau}LFINDI_{it} + a_{7\tau}LNRR_{it} + \beta_i \end{aligned} \tag{10}$$

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} \\ &+ a_{6\tau}LFINDI_{it} + a_{7\tau}Mod1_{it} + \beta_i \end{aligned} \tag{11}$$

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} \\ &+ a_{6\tau}LFINDI_{it} + a_{7\tau}Mod3_{it} + \beta_i \end{aligned} \tag{12}$$

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} + a_{6\tau}LFINDI_{it} \\ &+ a_{7\tau}LQNR_{it} + \beta_i \end{aligned} \tag{13}$$

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} + a_{6\tau}LFINDI_{it} \\ &+ a_{7\tau}Mod3_{it} + \beta_i \end{aligned} \tag{14}$$

$$\begin{aligned} Q_{LENIN|LCOIN}(\tau \mid X_{it}) &= a_{1\tau}LGDP_{it} + a_{3\tau}LECO\_INNO_{it} \\ &+ a_{3\tau}LSEP_{it} + a_{5\tau}LPOP_{it} + a_{5\tau}LFD_{it} + a_{6\tau}LFINDI_{it} \\ &+ a_{7\tau}Mod5_{it} + \beta_i \end{aligned} \tag{15}$$

The notations in equations (10), (11), (13), (13), (15), and (15) refer to various frameworks and factors. The relationship between FD and NRR is explored in Model 1, also known as Mod1. Like Model 1, Model 3 (Mod3) examines how NRR and FDI relate. Model 3 emphasizes the connection between the availability of QNR and FD, while Model 5 (Mod5) investigates the relationship between the QNR and FDI. In addition, the parameter CO_2E represents CO_2 emissions. These equations and frameworks shed light on the intricate connections and linkages among these factors in the research setting.

4. RESULTS AND DISCUSSION

4.1. Pre-Estimation Diagnostics

The evidence will likely show interactions between the mistakes across multiple units when analyzing countries experiencing

Table 4: Cross-sectional dependency test

Model/test	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD	Model/test	Breusch-Pagan LM	Pesaran scaled LM	Pesaran CD
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, LNRR)	105.97[a] (0.000)	11.77[a] (0.000)	7.63[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, LNRR)	165.07[a] (0.000)	31.00[a] (0.000)	11.07[a] (0.000)
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod1)	105.97[a] (0.000)	11.77[a] (0.000)	7.63[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod1)	165.07[a] (0.000)	31.00[a] (0.000)	11.07[a] (0.000)
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod3)	105.97[a] (0.000)	11.77[a] (0.000)	7.63[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod3)	165.07[a] (0.000)	31.00[a] (0.000)	11.07[a] (0.000)
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, LQNR)	163.65[a] (0.000)	30.93[a] (0.000)	11.30[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, LQNR)	135.67[a] (0.000)	16.56[a] (0.000)	7.33[a] (0.000)
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod3)	163.65[a] (0.000)	30.93[a] (0.000)	11.30[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod3)	135.67[a] (0.000)	16.56[a] (0.000)	7.33[a] (0.000)
LENE=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod5)	163.65[a] (0.000)	30.93[a] (0.000)	11.30[a] (0.000)	LCO3E=f (LGDP, LECO_INNO, LSEP, LPOP, LFD, LFDI, Mod5)	135.67[a] (0.000)	16.56[a] (0.000)	7.33[a] (0.000)

P-values in brackets, a ($P<0.01$), b ($P<0.05$), c ($P<0.10$), Mod1=NRR*FD, Mod3=NRR*FDI, Mod3=QNR*FD, Mod5=QNR*FDI. FDI: Financial Development Index, SEP: Solar energy production, FD: Fiscal decentralization, ENE: Energy efficiency, GDP: Gross national product, NR: Natural resources, QNR: Quantity of natural resources, NRR: Natural resource rents, POP: Population

continual ecological, financial, and monetary integration. This cross-sectional dependency (CSD) may result in incorrect estimations if not adequately handled.

Table 4 presents the results concerning CSD and the test results' notable values in all twelve requirements present compelling proof of CSD within the flaws. The outcomes of this study indicate that the presumption of cross-sectional (CS) independence among the analyzed nations in the BRICS region needs to be supported. This finding strengthens the concept that from 1995 to 2017, significant growth in global trade and investments has led to greater interdependence among member nations of the BRICS. The increased interconnectedness suggests that underlying shared variables are associated with FD, FDI, NRs, POP ratio, SEP, and economic development within one OECD country that might have spillage impacts on other member countries. In order to enhance the trustworthiness of the FDIngs, this research utilizes approaches that tackle the concern of CSD. Given the existence of CSD, it is crucial to acknowledge that conventional first-generation UR approaches may produce uncertain results. Consequently, the present study used the second-generational CIPS panel unit assessment introduced by Polcyn et al. (2023). The results of the CIPS examination are displayed in Table 5.

In the second evaluation phase, we explore the level of coherence among the parameters. It is worth mentioning that the test results show a lack of relevance for five factors (LENE, LGDP, LECO_INNO, LPOP, and L CO_2E) when examined at their original values. This finding suggests that the null assumption about a UR remains valid, even when accounting for including a fixed component only. Regarding CSD, a more detailed analysis of Table 5 shows that of the 15 factors, four (LENE, LGDP, LECO_INNO, and LPOP) exhibit irregular characteristics at respective levels, encompassing fixed and trend elements. Upon analyzing the initial distinctions, it is evident from Table 5 that every factor exhibits stationarity after undergoing the procedure for differentiation. This holds regardless of whether only a fixed term or both fixed and trend factors are considered. The findings obtained from the CIPS test support the conclusion that the factors being examined exhibit a similar level of incorporation. The results displayed in Table 5 provide support

Table 5: CIPS unit root tests results

VRs	Degrees		Initialdistinction		VRs	Degrees		Initialdistinction	
	No trend	With trend	No trend	With trend		No trend	With trend	No trend	With trend
LENE	−1.53	−3.33	−5.73[a]	−5.67[a]	LNRR	−3.55[a]	−3.53[a]	−5.79[a]	−6.01[a]
LGDP	−1.67	−1.77	−3.70[a]	−3.75[c]	LQNR	−3.17[a]	−3.59[a]	−5.97[a]	−5.95[a]
LECO_INNO	−1.75	−1.71	−5.00[a]	−3.95[a]	Mod1	−3.55[a]	−3.93[a]	−5.99[a]	−6.06[a]
LSEP	−3.37[c]	−3.16[a]	−5.35[a]	−5.39[a]	Mod3	−3.55[a]	−3.69[a]	−5.93[a]	−6.09[a]
LPOP	−1.17	3.06	−3.07[a]	−3.95[b]	Mod3	−3.06[a]	−3.70[a]	−5.97[a]	−5.97[a]
LFD	−3.37[c]	−3.56[a]	−5.07[a]	−5.59[a]	Mod5	−3.16[a]	−3.93[a]	−5.99[a]	−5.95[a]
LFDI	−3.65[a]	−3.06[b]	−5.97[a]	−5.96[a]	LCO3E	−3.30	−3.16[a]	−5.75[a]	−5.76[a]

[a](P < 0.01), [b](P < 0.05), [c](P < 0.10), Mod1=NRR*FD, Mod3=NRR*FDI, Mod 3=QNR*FD, Mod 5=QNR*FDI. FD: Fiscal decentralization, ENE: Energy efficiency, GDP: Gross national product, NR: Natural resources, QNR: Quantity of natural resources, NRR: Natural resource rents

for the claim that the parameters exhibit a shared incorporation order, namely an integrating order of one, represented as I(1).

4.2. Main Estimating Results and Robustness Assessment

According to the results of the normalcy tests, as shown in Table 3, all the factors subjected to the study had non-normal allocations. This finding confirms Ameli et al. (2023) recommendation that PQR is a suitable technique. As a result, a unique strategy is chosen: The use of panel data and the MMQR with FEs. The study's findings are shown in Table 6, emphasizing the effects found at odd quantiles of ENE, the reliant factor.

The first Findings of our study show that the FD has a detrimental effect on ENE in all examined simulations. This suggests that FD has a positive role in promoting ES. The FDI shows a considerable upward trend throughout the 50th to 90th quantiles. This shows that FD has a pronounced positive impact on ES in OECD countries with increased energy and CO_2E. This implies that nations with lesser levels of ES may use more FD to attain significant enhancements in ENE and reductions in releases. Significantly, this discovery challenges the notion of a "race to the bottom" since it suggests that the OECD nations under scrutiny do not implement lax domestic ecological policies to attract international investments to the detriment of EI. On the contrary, FD appears to facilitate a positive atmosphere of competition between local governing bodies, incentivizing them to engage in endeavors related to ecological preservation actively. This is consistent with the concept that such competitiveness encourages national authorities to embrace market-focused strategies, enhancing the efficacy of ecologically helpful public services. The impact is notably significant for the quantiles ranging from the 50th to the 90th. This implies that promoting greater FDI may harm ENE, particularly in OECD nations characterized by higher levels of ENE. The rationale behind this phenomenon may be attributed to the correlation between the availability of monetary services, the potential stimulation of consumer appetite for power-intensive products, and the expansion of power-demanding industrial operations by manufacturers.

The QNR contributes to the escalation of ENE by endorsing resource-intensive technology and manufacturing procedures. Furthermore, our fourth discovery highlights the substantial impact of NRR and QNR in mitigating the effects of FD and FDI on ENE. This exchange highlights the potential negative impact of heightened FD on ES, particularly when accompanied by elevated levels of NRR and QNR. This implies that FD's impact on ES depends on reliance on NRs and the availability of such resources. Additionally, ECO_INNO has a diverse, though predominantly adverse, influence on ENE. The findings exhibit variation among frameworks and quantiles, showing that increased budgets allocated to ECO_INNO can potentially improve ENE, particularly in nations with lower ENE.

In the same way, it has been shown that an inverse correlation exists between SEP and ENE. The focus placed by the OECD on developing sustainable power sources and RES as viable replacements to fossil fuels (FFs) may account for this. We have seen a noteworthy pattern whereby a stronger POP ratio is associated with heightened ENE, showing that increasing economic engagement can adversely affect ES. This observation suggests the necessity of harmonizing employment markets with the objectives of sustainable economic development. In a positive vein, an inverse correlation exists between economic advancement and ENE, showing that economic development approaches that target ecologically sustainable changes contribute to enhancements in ENE. Finally, we evaluate the strength and reliability of our first results by employing additional approaches that provide similar results. This serves to enhance the credibility and reliability of our experimental conclusions. The research results highlight the complex interconnections between FD, FDI, NRs, and other relevant issues. These elements collectively shape the multifaceted terrain of the ES within the framework of OECD nations.

5. DISCUSSION AND PRACTICAL IMPLICATIONS

The examination of the research digs into the complex web of relationships, including CO3E, FDI, FD, and the significant significance of NRs. A thorough dataset covering several years was made available by carefully collecting data from dependable sources, including the World Bank (WB), OECD, and IMF. Real GDP per capita, POP ratio, NRs, ENE, CO_2E, SEP, R&D spending, and FD were among the various factors for which statistics showed beneficial median numbers. The analysis of the interactions between these factors showed intricate linkages that support ES. The close ties between EG, EC, and EI are seen in the beneficial associations among GDP, SEP, POP ratio, NR revenue, and ENE. The negative link between R&D investment, FDI, and ENE suggests the complex dynamics of inventiveness, monetary

Table 6: Estimating results from panel quantile regressions framework (energy efficiency - reliant factor)

Model	Variable/QR	0.1 QR		0.3 QR		0.5 QR		0.7 QR		0.9 QR	
		Coeffecent	P>z	Coeffecent	P>z	Coeffecent	P>z	Coeffecent	P>z	Coeffecent	P>z
1	LGDP	−0.170	0.356	−0.190[c]	0.055	−0.307[b]	0.01	−0.331[b]	0.033	−0.353	0.111
	LECO_INNO	−0.037[a]	0.006	−0.037[a]	0	−0.037[a]	0	−0.036[a]	0	−0.036[b]	0.01
	LSEP	−0.139[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0
	LPOP	0.777[a]	0	0.917[a]	0	0.955[a]	0	0.973[a]	0	1.036[a]	0
	LFD	−0.057	0.619	−0.101	0.176	−0.139[b]	0.036	−0.171[b]	0.033	−0.317[c]	0.065
	LFDI	0.079	0.355	0.107[b]	0.059	0.133[a]	0.003	0.155[a]	0.005	0.176[b]	0.037
	LNRR	0.056[a]	0.005	0.050[a]	0	0.035[a]	0	0.030[a]	0.003	0.035	0.137
3	LGDP	−0.170	0.356	−0.190[c]	0.055	−0.307[b]	0.01	−0.331[b]	0.033	−0.353	0.111
	LECO_INNO	−0.037[a]	0.006	−0.037[a]	0	−0.037[a]	0	−0.036[a]	0	−0.036[b]	0.01
	LSEP	−0.139[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0
	LPOP	0.777[a]	0	0.917[a]	0	0.955[a]	0	0.973[a]	0	1.036[a]	0
	LFD	−0.105	0.377	−0.151[c]	0.067	−0.175[a]	0.006	−0.301[a]	0.007	−0.353[b]	0.053
	LFDI	0.079	0.355	0.107[b]	0.059	0.133[a]	0.003	0.155[a]	0.005	0.176[b]	0.037
	LMod1	0.056[a]	0.005	0.050[a]	0	0.035[a]	0	0.030[a]	0.003	0.035	0.137
3	LGDP	−0.170	0.356	−0.190[c]	0.055	−0.307[b]	0.01	−0.331[b]	0.033	−0.353	0.111
	LECO_INNO	−0.037[a]	0.006	−0.037[a]	0	−0.037[a]	0	−0.036[a]	0	−0.036[b]	0.01
	LSEP	−0.139[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0	−0.137[a]	0
	LPOP	0.777[a]	0	0.917[a]	0	0.955[a]	0	0.973[a]	0	1.036[a]	0
	LFD	−0.057	0.619	−0.101	0.176	−0.139[b]	0.036	−0.171[b]	0.033	−0.317[c]	0.065
	LFDI	0.033	0.7	0.067	0.335	0.099[b]	0.031	0.135[b]	0.033	0.163[c]	0.059
	LMod3	0.056[a]	0.005	0.050[a]	0	0.035[a]	0	0.030[a]	0.003	0.035	0.137
5	LGDP	−0.373[c]	0.071	−0.375[a]	0.005	−0.395[a]	0	−0.305[a]	0.003	−0.317[b]	0.055
	LECO_INNO	−0.037[a]	0.007	−0.037[a]	0	−0.037[a]	0	−0.037[a]	0	−0.039[a]	0.005
	LSEP	−0.133[a]	0	−0.130[a]	0	−0.137[a]	0	−0.137[a]	0	−0.135[a]	0
	LPOP	0.935[a]	0	0.955[a]	0	0.970[a]	0	0.976[a]	0	1.007[a]	0
	LFD	−0.076	0.599	−0.110	0.135	−0.135[b]	0.039	−0.159[b]	0.03	−0.195[c]	0.093
	LFDI	0.077	0.337	0.110[b]	0.037	0.133[a]	0.003	0.157[a]	0.003	0.193[b]	0.031
	LQNR	0.037[a]	0.003	0.035[a]	0	0.031[a]	0	0.037[a]	0.001	0.035[c]	0.059
5	LGDP	−0.373[c]	0.071	−0.375[a]	0.005	−0.395[a]	0	−0.305[a]	0.003	−0.317[b]	0.055
	LECO_INNO	−0.037[a]	0.007	−0.037[a]	0	−0.037[a]	0	−0.037[a]	0	−0.039[a]	0.005
	LSEP	−0.133[a]	0	−0.130[a]	0	−0.137[a]	0	−0.137[a]	0	−0.135[a]	0
	LPOP	0.935[a]	0	0.955[a]	0	0.970[a]	0	0.976[a]	0	1.007[a]	0
	LFD	−0.115	0.316	−0.155[c]	0.053	−0.165[a]	0.007	−0.177[b]	0.011	−0.317[c]	0.06
	LFDI	0.077	0.337	0.110[b]	0.037	0.133[a]	0.003	0.157[a]	0.003	0.193[b]	0.031
	LMod3	0.037[a]	0.003	0.035[a]	0	0.031[a]	0	0.037[a]	0.001	0.035[c]	0.059
6	LGDP	−0.373[c]	0.071	−0.375[a]	0.005	−0.395[a]	0	−0.305[a]	0.003	−0.317[b]	0.055
	LECO_INNO	−0.037[a]	0.007	−0.037[a]	0	−0.037[a]	0	−0.037[a]	0	−0.039[a]	0.005
	LSEP	−0.133[a]	0	−0.130[a]	0	−0.137[a]	0	−0.137[a]	0	−0.135[a]	0
	LPOP	0.935[a]	0	0.955[a]	0	0.970[a]	0	0.976[a]	0	1.007[a]	0
	LFD	−0.076	0.599	−0.110	0.135	−0.135[b]	0.039	−0.159[b]	0.03	−0.195[c]	0.093
	LFDI	0.05	0.637	0.076	0.155	0.103[b]	0.033	0.139[b]	0.015	0.167[b]	0.055
	LMod5	0.037[a]	0.003	0.035[a]	0	0.031[a]	0	0.037[a]	0.001	0.035[c]	0.059

[a](P<0.01), [b](P<0.05), [c](P<0.10), Mod 1=NRR*FD, Mod 3=NRR*FDI, Mod 3=QNR*FD, Mod 5=QNR*FDI.

QR: Quantile regression, FD: Fiscal decentralization, ENE: Energy efficiency, GDP: Gross national product, NR: Natural resources, QNR: Quantity of natural resources, NRR: Natural resource rents

systems, and ENE. The positive association between the POP ratio and CO3E highlights the significance of populace dynamics in EI. The study's emphasis on CSD revealed a more profound interconnection across factors. The common underlying causes that cut across national borders in the setting of the OECD are highlighted by denying the null theory of CSD. The employment of innovative approaches to solve CSD was required because of this interconnection, a sign of rising global commerce and investment. Using the second-generational CS, an augmented panel unit test (CIPS) was added to validate the levels of variability incorporation.

It should be noted that certain components showed UR at their initial levels, highlighting the necessity for distinction. This meticulous methodology enhanced the study's validity. In a few different ways, the results are consistent with earlier studies. The favorable effect of FD on ENE is consistent with previous research on its advantages for ES. The study's conclusions on FDI also confirm earlier results about the complicated link between this factor and EI. The study's conclusions on the moderating impact of NRR and dependency (NRD) offer a complex view of how these factors influence ES. The study's discovery of the beneficial impact of SEP on ENE is consistent with studies highlighting the possibility of decreases in emissions from clean energy. In summary, the research's results provide important new information to discuss NR use, fiscal management, and economic development. Due to the interdependence of these factors, comprehensive policy measures are required to strike a balance between ES and EG. In order to get a deeper knowledge of the processes behind these relationships, future research directions may consider institutional elements and political systems.

The analytical conclusions have policy and practical implications for ES, FD, FDI, and NR management. These consequences help policymakers, governments, and investors balance EG with ecological health. Integration is crucial since FD, FDI, and NRs are interrelated. Synergistic strategies can be more successful and durable; thus, policymakers should examine these variables comprehensively when creating plans. Countries may improve financial and ecological prospects by integrating fiscal strategies with ecological aims, supporting green finance, and using resources responsibly. FD may boost ENE. This knowledge can help policymakers enable municipalities to choose ecologically friendly initiatives and investments. Clear spending and decision-making may redirect FD advantages toward greener projects, boosting local competitiveness and invention for greener economic growth. FDI's complex implications on ENE require policy change. Governments should promote green development and responsible consumption through monetary services. Countries may use economies to improve biodiversity by aligning FDI with eco-friendly goals and promoting sustainable lending and trading. NR management is crucial, and effective resource administration is needed because of NR dependency and abundance of moderate FD, FDI, and ENE. Resource-rich countries ought to embrace clean technologies and oppose resource-driven renting. Technology drives ES. Policymakers should prioritize ENE, SEP, and environmentally friendly manufacturing research. Governments may expedite eco-friendly technology adoption by encouraging private sector engagement and innovations.

6. CONCLUSION

Finally, this paper explores the complex interconnections among FD, FDI, NR sustainability, and ES, illuminating their policy and future study ramifications. A thorough review of data from a few OECD nations reveals numerous important conclusions. First, FD has a complex effect on the sustainability of the ecosystem. According to the research, increased FD might encourage municipalities to implement ecologically friendly measures by encouraging competition. Nevertheless, the impact of FD depends on variables like the abundance and dependence on NRs, which can either accentuate or reduce its beneficial benefits. Second, FDI compromises ES even though it is good for economic growth. According to the study, more FDI is linked to higher energy use and CO_2E, particularly in nations with high ENE. This study emphasizes the necessity for legislative initiatives that link economic development with ecologically responsible behavior. Thirdly, the existence of NRs influences ecological consequences in various complicated ways. The resource abundance and reliance on them can raise ENE and thwart attempts to preserve the ecosystem. A balancing strategy for asset management is crucial, as the connection between NRs and FD or FDI can intensify these consequences.

The investigation sheds light on FD, FDI, REs, and ES, but it has limits. Recognizing these limitations can drive future studies to clarify these complicated interactions. First, the research uses CS data from a single time duration, making it difficult to track rapid shifts. Longitudinal examinations of these interactions over time may help researchers grasp causative processes. Second, the research's concentration on OECD nations may restrict its applicability to other economic and social circumstances. Extending the research to include other nations and areas would improve the outside validity and broaden the linkages evaluated. Thirdly, the research uses quantitative approaches to examine variable relationships, but it may not reflect the whole intricacy of the processes. A complementary qualitative study might illuminate how FD, FDI, and REs affect ES. The analysis controls for CSD and uses sophisticated panel data methodologies. However, unknown variables may affect the results. Future research may use auxiliary variable techniques to handle variability and improve causal findings. FD, FDI, and ES metrics are also examined. Future studies might use other metrics and aspects of these variables to comprehend their effects better. Finally, the present research addresses direct factors, although complicated connections among components may have non-linear impacts. Non-linear interactions and threshold impacts might illuminate important points beyond where connections shift considerably in future studies. This investigation improves the comprehension of FD, FDI, NRs, and ES but has several drawbacks. Resolving these constraints and conducting further research will assist us in understanding this crucial topic and make policy choices and responses more effective.

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