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Green Growth or Economic Gain? Assessing Environmental Efficiency Using Data Envelopment Analysis: Case of Africa

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ABSTRACT

In the African context, achieving sustainable development while fostering economic growth and environmental conservation presents a formidable challenge. This article employs Data Envelopment Analysis (DEA) to assess the environmental efficiency of 34 African countries from 2013 to 2022. Using key economic indicators such as Foreign Direct Investment (FDI), Logistics Performance Index (LPI), and Gross Domestic Product (GDP) relative to CO_2 emissions, the study evaluates the ability of African nations to optimize economic output while minimizing environmental impact. The analysis reveals significant heterogeneity in environmental efficiency levels among countries, with some demonstrating high efficiency, while others exhibit room for improvement. Factors such as FDI, LPI, and GDP play pivotal roles in shaping environmental outcomes, highlighting the need for sustainable investment practices and infrastructure development. Peer comparison and output slack analysis provide further insights, identifying opportunities for enhancing efficiency and promoting sustainable growth. Case studies of South Africa, Mali, and Zambia underscore varying degrees of environmental efficiency and offer valuable lessons for sustainable development across the continent. Overall, the findings contribute to a deeper understanding of environmental efficiency in Africa and provide a roadmap for policymakers to pursue greener and more inclusive development trajectories.

Keywords: Green Growth, Economic Gain, Environmental Efficiency
JEL Classifications: E00, L91, Q5, B23, C01, C10

1. INTRODUCTION

In the African context, achieving sustainable development is a complex endeavor that requires a delicate balance between economic growth and environmental preservation. African nations are confronted with the challenge of promoting economic development while addressing the adverse impacts of CO_2 emissions and environmental degradation, particularly in response to climate change. The lack of appropriate policies to anticipate climate change-related emergencies exacerbates the situation. Additionally, reliance on natural resources and the increasing urbanization of the continent contribute to environmental pollution, while renewable energies, technological advancements, and structural transition offer means to mitigate environmental pollutants. It is essential for African countries to prioritize sustainable development and implement policies that promote environmental sustainability, taking into account the unique challenges they face (Ngang, 2023).

The significance of environmental efficiency in the context of African countries holds a crucial dimension in ensuring sustainable growth (Jinapor et al., 2023). This study delves into the evaluation of environmental efficiency using Data Envelopment Analysis (DEA), focusing on CO_2 emissions and their correlation with major economic indicators such as Foreign Direct Investment (FDI), the Logistics Performance Index (LPI), and Gross Domestic Product (GDP). This assessment of environmental efficiency provides insights into the performance of African countries in terms of sustainable growth and elucidates the factors influencing their environmental footprint.

A comparative analysis of environmental efficiency within African nations reveals crucial data, discernible trends, and significant disparities. This information can enlighten policy decisions and guide transformative actions aimed at promoting more environmentally friendly and inclusive development trajectories. Understanding the drivers of this environmental efficiency, by drawing lessons from successes and failures, serves as a lever for African policymakers and stakeholders to chart a path towards a sustainable and resilient future for the continent. The evolution of financial institutions and the implementation of growth-friendly policies are essential elements in achieving environmental sustainability in Africa (Khalid et al., 2023).

2. LITERATURE REVIEW

In recent years, there has been increasing emphasis on sustainable development in Africa as the continent grapples with the challenge of balancing economic progress and environmental protection. Scholars and policymakers are increasingly recognizing the need to understand the dynamics of environmental efficiency in African countries. This involves finding ways to strike a balance between development aspirations and ecological sustainability (Abdi, 2013).

The current state of environmental governance in African countries is influenced by various challenges, including limited resources, weak institutions, and a lack of political will to prioritize environmental protection (Evivie and Evivie, 2023). However, there are also opportunities for improvement, such as greater collaboration between international and governmental institutions, the development of more effective policies and initiatives, and increased investment in environmental protection and sustainable development.

African countries face unique challenges in their pursuit of sustainable growth, given the region's vulnerability to the impacts of climate change and the need to address urgent socio-economic needs. The literature on environmental efficiency in Africa reflects a nuanced understanding of the complex interaction between economic, social, and environmental factors. Studies have highlighted the challenges associated with achieving sustainable development in Africa, including the need to balance growth and ecological sustainability (Ugwu et al., 2023).

Furthermore, it has been demonstrated that the adoption of green energy technologies significantly reduces carbon and particle emissions in some of the most polluted African countries (Wu et al., 2023). The dynamic environmental efficiency of African countries is low, indicating room for improvement, and afforestation and renewable energy consumption have been identified as key factors in combating environmental degradation (Amowine, 2023). However, it has been found that the development of financial institutions in Africa increases carbon emissions, highlighting the need for growth-supportive policies that prioritize environmental sustainability (Chen et al., 2023). The literature acknowledges the importance of considering the complex interactions between economic, social, and environmental factors to achieve sustainable growth in Africa.

Studies have highlighted the importance of using Data Envelopment Analysis (DEA) to assess the environmental performance of countries and identify best practices. DEA is a non-parametric method that measures the relative efficiency of decision-making units (DMUs) by comparing their inputs and outputs. It has been successfully applied in various contexts, including sustainability research, efficiency analysis, and the evaluation of industry and country performance. DEA can provide insights into the factors influencing environmental efficiency and guide policy interventions.

Table 1 : Environmental efficiency analysis of African countries

Country	CRS Efficiency	VRS Efficiency	Scale Efficiency	Scale Type
Angola	0.095	0.111	0.848	IRS
Benin	0.054	0.093	0.580	IRS
Burundi	0.843	1.000	0.843	IRS
Burkina Faso	0.073	0.089	0.826	IRS
Botswana	0.194	0.201	0.968	IRS
Cabo Verde	0.054	0.067	0.812	IRS
Cote d'Ivoire	0.145	0.235	0.616	IRS
Cameroon	0.014	0.179	0.079	IRS
Congo, Dem. Rep.	0.164	0.209	0.786	IRS
Congo, Rep.	0.144	0.299	0.480	DRS
Algeria	0.038	0.068	0.553	IRS
Egypt, Arab Rep.	0.057	0.133	0.430	IRS
Gabon	0.060	0.067	0.888	IRS
Gambia, The	0.105	0.120	0.882	IRS
Guinea	0.127	0.157	0.807	IRS
Guinea-Bissau	0.209	0.278	0.753	IRS
Kenya	0.188	0.214	0.876	IRS
Liberia	0.093	0.319	0.291	IRS
Mali	1.000	1.000	1.000	-
Mauritania	0.019	0.099	0.195	IRS
Mauritius	0.026	0.084	0.312	IRS
Malawi	0.090	0.111	0.811	IRS
Mozambique	0.182	0.369	0.494	IRS
Niger	0.091	0.098	0.920	IRS
Nigeria	0.308	1.000	0.308	DRS
Rwanda	0.089	0.097	0.920	IRS
Senegal	0.270	0.537	0.502	IRS
South Africa	1.000	1.000	1.000	-
South Sudan	0.105	0.118	0.893	IRS
Seychelles	0.040	0.730	0.054	IRS
Togo	0.175	0.179	0.972	IRS
Tunisia	0.124	0.151	0.826	IRS
Uganda	0.072	0.076	0.949	IRS
Zambia	1.000	1.000	1.000	-

Research conducted by Avilés-Sacoto et al. (2021) utilized DEA to assess the environmental performance of different states in Mexico and identify top performers and practices. Similarly, Sotiroski et al. (2023) applied DEA to measure the efficiency of EU countries in achieving sustainable development goals. Therefore, leveraging DEA can contribute to evaluating the environmental efficiency of Nigerian industries and informing policy interventions aimed at improving performance (Iheanachor, 2021).

Foreign direct investment (FDI) plays a significant role in shaping environmental outcomes in Africa. The impact of FDI on the environment varies depending on factors such as technology transfer, regulatory frameworks, and resource governance. Several studies have examined this relationship. Wu et al. (2023) found

Table 2: Country and output slack results

Country	FDI Output Slack	LPI Output Slack	GDP Output Slack	Comments
Angola	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Benin	-38.299	17.598	0.926	Potential to increase FDI, slight increase in LPI, already aligned with GDP.
Burundi	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Burkina Faso	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Botswana	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Cabo Verde	0.000	0.866	0.032	Potential to increase LPI, minimal room for improvement in FDI and GDP.
Cote d'Ivoire	0.000	23.569	1.571	Significant potential to increase LPI, modest opportunity for FDI and GDP growth.
Cameroon	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Congo, Dem. Rep.	0.000	11.807	0.590	Room for increasing LPI and GDP, minimal opportunity for FDI growth.
Congo, Rep.	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Algeria	0.000	22.922	1.433	Significant potential to increase LPI, need to reduce FDI and GDP.
Egypt, Arab Rep.	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Gabon	1699238.616	0.000	0.000	Significant potential for FDI growth, already aligned with LPI and GDP.
Gambia, The	0.000	1.954	0.072	Modest potential to increase LPI and GDP, no room for FDI growth.
Guinea	-9.921	5.998	0.240	Need to reduce FDI, potential to increase LPI and GDP.
Guinea-Bissau	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Kenya	-481.616	46.590	11.647	Need to reduce FDI, significant potential to increase LPI and GDP.
Liberia	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Mali	-1272.133	51.018	25.509	Need to reduce FDI, significant potential to increase LPI and GDP.
Mauritania	-295.370	42.859	7.143	Need to reduce FDI, significant potential to increase LPI and GDP.
Mauritius	0.000	0.858	0.047	Modest potential to increase LPI and GDP, no room for FDI growth.
Malawi	0.000	33.811	0.000	Significant potential to increase LPI, minimal room for improvement in FDI and GDP.
Mozambique	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Niger	1586891.184	0.000	0.000	Significant potential for FDI growth, already aligned with LPI and GDP.
Nigeria	0.000	27.785	0.000	Significant potential to increase LPI, no room for FDI growth.
Rwanda	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Senegal	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
South Africa	-2320.723	53.850	53.850	Need to reduce FDI, significant potential to increase LPI and GDP.
South Sudan	0.000	0.239	0.013	Modest potential to increase LPI and GDP, no room for FDI growth.
Seychelles	8467010.806	0.000	0.000	Significant potential for FDI growth, already aligned with LPI and GDP.
Togo	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.
Tunisia	0.000	0.239	0.013	Modest potential to increase LPI and GDP, no room for FDI growth.
Uganda	8467010.806	0.000	0.000	Significant potential for FDI growth, already aligned with LPI and GDP.
Zambia	0.000	0.000	0.000	No output slack, already aligned with CO_2 emissions constraints.

that FDI had a significant promotional effect on eco-efficiency in China, especially in the eastern region. Jakada et al., (2023) revealed that the interaction between FDI and information and communication technologies (ICT) led to an increase in CO_2 emissions, thus deteriorating environmental quality in African economies. Ahmad et al. (2023) found that FDI had a significant negative impact on the ecological footprint of lower-middle-income countries. Karangwa and Su (2023) emphasized that the overall sustainable effect of FDI in Africa was statistically negligible, with environmental degradation being the main variable influencing overall development. Melega (2022) supported the theory of "pollution havens," indicating that countries with relaxed environmental regulations attract more FDI. Kara et al.'s study in 2023 focused on South Africa, highlighting the need for sustainable investment practices to mitigate negative environmental impacts.

It has been demonstrated that efficient supply chains, as assessed by the Logistics Performance Index (LPI), play a crucial role in reducing carbon emissions and improving overall environmental performance (Sova and Tudor, 2022). The relationship between logistics performance and environmental sustainability has been explored in various contexts, including African countries (Maurya et al., 2023) and emerging economies (Bimha and Bimha, 2023). Studies have shown that higher logistics performance, as measured by the LPI, is associated with a decrease in CO_2 emissions (Wan et al., 2022). Additionally, it has been demonstrated that green innovation and the use of renewable energies have a positive impact on environmental quality. Economic globalization has also been shown to contribute to improved environmental performance (Decampos et al., 2023).

Gross Domestic Product (GDP) remains a central indicator of economic development in Africa, but its relationship with environmental sustainability is complex. Analyses based on DEA have revealed the possibility of decoupling economic growth from environmental degradation through more efficient resource use and cleaner production technologies. However, persistent challenges exist in translating economic gains into tangible environmental benefits, highlighting the need for integrated policy approaches (Abdullahi and Yu, 2023).

The literature on environmental efficiency in Africa provides valuable insights into the opportunities and challenges associated with sustainable development on the continent. Researchers have utilized tools such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis to understand the factors

Table 3: Peer comparison and weight allocation for efficiency assessment

Country	Peers	Peer Weights
Angola (1)	28, 19, 3	0.015, 0.077, 0.908
Benin (2)	28, 3	0.007, 0.993
Burundi (3)	3	1.000
Burkina Faso (4)	28, 19, 3	0.006, 0.036, 0.957
Botswana (5)	28, 19, 3	0.007, 0.767, 0.226
Cabo Verde (6)	28, 3	0.002, 0.998
Cameroon (8)	28, 3	0.043, 0.957
Congo, Dem. Rep. (9)	28, 3	0.075, 0.925
Congo, Rep. (10)	28, 25, 19	0.022, 0.309, 0.668
Algeria (11)	28, 3	0.019, 0.981
Egypt, Arab Rep. (12)	28, 3	0.019, 0.981
Gabon (13)	28, 19, 3	0.020, 0.247, 0.733
Gambia, The (14)	19, 3	0.189, 0.811
Guinea (15)	28, 3	0.001, 0.999
Guinea-Bissau (16)	28, 3	0.000, 1.000
Kenya (17)	28, 19, 3	0.027, 0.149, 0.825
Liberia (18)	28, 3	0.025, 0.975
Mali (19)	19	1.000
Mauritania (20)	28, 19, 3	0.018, 0.000, 0.982
Mauritius (21)	28, 3	0.020, 0.980
Malawi (22)	28, 3	0.003, 0.997
Mozambique (23)	28, 3	0.039, 0.961
Niger (24)	28, 19, 3	0.008, 0.472, 0.519
Nigeria (25)	25	1.000
Rwanda (26)	19, 3	0.405, 0.595
Senegal (27)	28, 3	0.022, 0.978
South Africa (28)	-	1.000
South Sudan (29)	19, 3, 28	0.299, 0.700, 0.001
Seychelles (30)	3, 28	0.997, 0.003
Togo (31)	28, 19, 3	0.015, 0.779, 0.206
Tunisia (32)	28, 3	0.014, 0.986
Uganda (33)	19, 3	0.595, 0.405
Zambia (34)	34	1.000

influencing environmental performance and identify pathways towards greener and more inclusive growth (Staniszewski and Matuszczak, 2023). Studies have highlighted the importance of factors such as ownership structure, political stability, geographical location, economic freedom, and participation in global alliances in enhancing the efficiency and sustainability of airlines (Martini et al., 2023). Additionally, the development of financial institutions and growth-supportive policies proves essential in achieving environmental sustainability in Africa (Chen et al., 2023).

3. DATA AND METHODOLOGY

The data used in this study were collected from the World Bank from 2013 to 2022 and cover 34 African countries. These countries were selected based on data availability and represent a diverse range of economic and environmental contexts across the continent. The dataset gives a thorough assessment of each nation's performance by including important environmental and economic metrics.

The variables included in our analysis are as follows:

FDI (Foreign Direct Investment): This variable represents the amount of foreign investment flowing into each country, measured in a common currency (e.g., USD).

CO_2 EM (CO_2 Emissions): CO_2 emissions are a critical environmental indicator, reflecting the amount of carbon dioxide released into the atmosphere as a result of human activities such as industrial production, transportation, and energy generation (Mardani et al., 2019).

LPI (Logistics Performance Index): The Logistics Performance Index assesses the efficiency of logistics and supply chain management within each country, encompassing factors such as infrastructure, customs procedures, and timeliness of deliveries.

GDP (Gross Domestic Product): GDP serves as a measure of the economic output generated within a country's borders over a specified period, providing insights into its overall economic performance.

To assess the environmental efficiency of African countries, we employ Data Envelopment Analysis (DEA), a non-parametric method widely used for evaluating the relative efficiency of decision-making units (DMUs) such as countries, firms, or regions (Camioto and Pulita, 2022). In our analysis, we treat CO_2 emissions as the primary input variable, representing the environmental impact of economic activities. Our outputs include FDI, LPI, and GDP, which serve as proxies for economic development and infrastructure quality.

We adopt an input-oriented Data Envelopment Analysis (DEA) model to assess the environmental efficiency of African countries. In this model, CO_2 emissions serve as the input, and the aim is to minimize these emissions while maintaining the levels of Logistics Performance Index (LPI), Gross Domestic Product (GDP), and Foreign Direct Investment (FDI). The input-oriented DEA approach allows us to evaluate how efficiently African countries are utilizing their CO_2 emissions to achieve economic outputs and logistics performance while minimizing environmental impact. This method enables a comparative assessment of countries in terms of their ability to reduce CO_2 emissions without compromising economic development and logistics efficiency. Input-oriented DEA models will be constructed to evaluate the environmental efficiency of each African country. The efficiency scores obtained from the DEA analysis will indicate the extent to which countries are minimizing CO_2 emissions while maintaining constant levels of LPI, GDP, and FDI.

4. RESULTS

4.1. Efficiency Assessment

4.1.1. Efficiency scores (CRS and VRS)

High Efficiency: Countries with CRS and VRS efficiency scores close to 1 (or 100%) are considered highly efficient in minimizing CO_2 emissions while achieving economic and logistics outputs effectively like Zambia, South Africa and Mali.

Moderate Efficiency: Countries with efficiency scores ranging between 0.7 and 0.9 demonstrate moderate efficiency. While they are somewhat efficient in minimizing CO_2 emissions, there may still be room for improvement like Burundi and Seychelles.

Low Efficiency: Countries with efficiency scores below 0.7 exhibit lower efficiency levels, indicating significant room for improvement in minimizing CO_2 emissions while maintaining economic and logistics outputs. Examples include Cameroon, Liberia, and Mauritania.

4.1.2. Scale efficiency

Countries with scale efficiency scores close to 1 are operating efficiently at their current scale, minimizing CO_2 emissions input while maximizing economic and logistics outputs. Examples include Zambia, South Africa and Mali. Burundi, Kenya, and Niger. Countries with scale efficiency scores below 1 may have potential inefficiencies in scale utilization, operating either below or above the optimal scale in minimizing CO_2 emissions input.

4.1.3. Scale type

Increasing Returns to Scale (IRS): Countries experiencing increasing efficiency with scale in minimizing CO_2 emissions input may benefit from economies of scale or improved resource utilization. Examples include Burundi, Botswana, and Kenya.

Decreasing Returns to Scale (DRS): Countries experiencing decreasing efficiency with scale may face resource constraints or diminishing returns in minimizing CO_2 emissions input. Examples include Congo, Rep. and Nigeria.

Countries operating at an optimal scale are achieving the most efficient level of CO_2 emissions reduction given their available resources and technology. Examples include Mali, Zambia and South Africa.

A mean value of 0.213 for CRS efficiency, 0.309 for VRS efficiency, and 0.690 for scale efficiency across all countries indicates the overall environmental efficiency performance in the dataset. This values signify that CRS on average, the countries in the dataset are able to achieve about 21.3% of the maximum potential efficiency when considering constant returns to scale. This means that, on average, countries are using about 21.3% of the CO_2 emissions to produce the same level of economic and logistics outputs as the most efficient countries.

The average variable returns to scale efficiency of 30.9% suggests that when allowing for variable returns to scale, countries are able to achieve about 30.9% of the maximum potential efficiency. This takes into account the possibility that some countries may operate at different scales of production.

Scale Efficiency (0.690): The average scale efficiency of 69.0% indicates that, on average, countries are operating at about 69.0% of the optimal scale in terms of minimizing CO_2 emissions while achieving economic and logistics outputs. This suggests that there may be opportunities for improvement in scale utilization across the dataset (Table 1).

4.2. Country and Output Slack Analysis

A positive value indicates that the country can increase its output (FDI, LPI, or GDP) by the amount specified without needing to increase CO_2 emissions. A negative value suggests that the country may need to reduce its output (FDI, LPI, or GDP) to maintain a constant level of CO_2 emissions. Positive values suggest areas where countries may have underutilized resources or untapped potential for increasing FDI, LPI, or GDP without additional environmental impact. Negative values indicate areas where countries may need to adjust their operations to reduce FDI, LPI, or GDP to maintain a constant level of CO_2 emissions.

The mean output slack values provide an average across all countries for each output (FDI, LPI, and GDP). For example, the mean output slack for Output 1 (FDI) is approximately 345,550.663, indicating that, on average, countries could potentially increase their FDI by this amount without increasing CO_2 emissions.

Similarly, the mean output slack for Output 2 (LPI) is approximately 10.051, suggesting that, on average, countries could increase their Logistics Performance Index by this amount without increasing CO_2 emissions (Table 2).

4.3. Peers Comparison

The peer comparison and weight allocation offer valuable understandings into the efficiency assessment of each country within the dataset. Angola, for instance, demonstrates a pronounced dependence on peers 28 and 19, implying a significant influence from specific counterparts in its efficiency evaluation. On the other hand, Benin exhibits a dominant reliance on peer 3, suggesting a strong comparative relationship with this particular country. Burundi's reliance on peer 3 reflects a singular focus, indicating a concentrated benchmark for efficiency assessment. Burkina Faso, meanwhile, depends largely on peers 28 and 19, signaling a substantial comparative influence from these counterparts. Botswana displays a balanced reliance on peers 28, 19, and 3, suggesting a diverse set of benchmarks for efficiency evaluation. In contrast, Cabo Verde is heavily influenced by peer 3, with minimal influence from peer 28, implying a concentrated comparative context. Cote d'Ivoire shows a significant reliance on peers 28 and 3, indicating a strong comparative relationship with these countries. Cameroon is primarily influenced by peers 28 and 3, suggesting a focused benchmark for efficiency evaluation. Congo, Dem. Rep., on the other hand, relies heavily on peer 3, with a lesser influence from peer 28, implying a concentrated comparative context. Finally, Congo, Rep., displays a singular reliance on peer 3, indicating a focused benchmark for efficiency assessment (Table 3).

The peer count analysis reveals interesting patterns among the countries. While some countries have numerous peers, indicating similarity or commonality in their characteristics or performance, others stand out as unique entities within the dataset. For instance, Algeria emerges as a significant peer for many countries, suggesting shared attributes or comparable conditions. On the other hand, Mali appears to have the highest number of peers, highlighting its distinctiveness or strong relationships within the context of the analysis. Additionally, South Africa stands out as a singular entity, indicating its unique position or role within the dataset. The peer count analysis provides visions into the comparative relationships and associations among the countries under consideration.

5. DISCUSSION

The debate around Data Envelopment Analysis (DEA)-based environmental efficiency assessments of African nations provides insightful information on the intricate dynamics of sustainable development on the continent. Leveraging a multidimensional approach that incorporates economic indicators such as Foreign Direct Investment (FDI), Logistics Performance Index (LPI), and Gross Domestic Product (GDP) alongside environmental metrics like CO_2 emissions, the study sheds light on the varying degrees of efficiency and the factors influencing environmental performance across African nations. One key finding of the analysis is the considerable heterogeneity in environmental efficiency levels among African countries. This aligns with existing literature (Amowine et al., 2021; Moutinho and Madaleno, 2021) highlighting the potential for African countries to achieve sustainable growth through improved resource utilization and cleaner production technologies (Bahizire et al., 2022).

Also this research undertakes an investigation into the potential insights that can be gleaned from the top performers in African environmental efficiency, namely Mali, South Africa, and Zambia. The objective is to analyze their respective strategies and policies, with the aim of informing and inspiring broader efforts towards enhanced environmental efficiency across the continent. Our analysis centers on key thematic areas deemed crucial for achieving environmental sustainability, encompassing renewable energy, energy efficiency, land management, and the circular economy. For instance, a scrutiny of specific renewable energy sources prioritized by each country, along with pertinent policies such as South Africa's REIPPPP program, as analyzed by (Müller and Claar, 2021) promises valuable insights. Furthermore, an examination of policies and practices pertaining to land management, including Mali's potential for afforestation programs emerges as imperative for fostering sustainable land management practices (Grovermann et al., 2023). Additionally, discussions on strategies for promoting a circular economy hold considerable promise in this regard (Androniceanu et al., 2021). The incorporation of case studies such as South Africa's REIPPPP, Zambia's National Biomass Strategy, and Mali's ASERMAL further serves to illustrate successful implementation within these thematic domains.

The implications of the environmental efficiency assessment of South Africa, Mali, and Zambia extend beyond their individual performance to broader implications for sustainable development in Africa. The exemplary performance of South Africa in achieving high levels of environmental efficiency while maintaining robust economic and logistical outputs serves as a beacon of hope for other African nations (Boadu and Otoo, 2024). South Africa's success demonstrates that it is possible to achieve green growth and sustainable development, even in the context of a rapidly industrializing economy (Boadu and Otoo, 2024). Policymakers across the continent can draw inspiration from South Africa's experience and prioritize investments in clean energy, sustainable infrastructure, and green technologies to drive economic prosperity without compromising environmental integrity.

Mali's optimal balance between economic development and environmental sustainability offers valuable lessons for resource-constrained countries in Africa (Ugwu et al., 2023). Mali's ability to achieve maximum efficiency scores in both CRS and VRS efficiency despite its challenges highlights the importance of innovative approaches to sustainable development. By focusing on improving logistics efficiency, enhancing agricultural productivity, and promoting renewable energy, Mali can further strengthen its position as a leader in sustainable development and attract investment in key sectors that benefit both people and the planet.

Zambia's success in optimizing resource utilization to minimize CO_2 emissions while maximizing economic and logistical outputs underscores the importance of integrated approaches to sustainable development (Jiying et al., 2023). Zambia's efficient scale utilization indicates that it has achieved a harmonious equilibrium between economic growth and environmental conservation (Karangwa and Su, 2023). By prioritizing policies that promote responsible resource management, sustainable agriculture, and renewable energy, Zambia can continue to serve as a model for sustainable development in the region and inspire other African countries to follow suit.

The experiences of South Africa, Mali, and Zambia highlight the importance of holistic and integrated approaches to sustainable development that prioritize environmental conservation, social equity, and economic prosperity (Avilés-Sacoto et al., 2021). By embracing green growth strategies and leveraging their unique strengths and resources, African countries can unlock new opportunities for inclusive development, poverty alleviation, and environmental stewardship, ultimately paving the way for a more sustainable and resilient future for the continent.

Moreover, the identification and analysis of enabling factors, encompassing supportive frameworks and technological advancements, assume significance in comprehending the underlying mechanisms driving environmental efficiency initiatives (Borgi et al., 2023). Nonetheless, it is imperative to underscore the importance of knowledge sharing and adaptation, as emphasized by scholars, given the inherent diversity of contexts and challenges encountered across African nations (Amowine et al., 2021). Hence, a nuanced approach tailored to the specific circumstances of each nation is deemed essential for ensuring the efficacy of environmental efficiency endeavors. Through a comprehensive analysis of the top performers, coupled with efforts aimed at fostering knowledge exchange and adaptation, this study endeavors to contribute to the advancement of environmental efficiency across Africa, thereby facilitating progress towards a more sustainable future.

While examining the top performers in African environmental efficiency yields valuable insights, understanding the reasons behind low scores in other countries is equally imperative (Pais-Magalhães et al., 2021). This comprehension is vital for crafting targeted interventions and support mechanisms aimed at propelling these nations towards a more sustainable trajectory. Several factors potentially contribute to their low efficiency, including a heavy reliance on fossil fuels (Ugwu et al., 2023), limited access to clean energy infrastructure (Wu et al., 2023), insufficient financial resources (Chen et al., 2023), and weak institutional capacity (Matuszak et al., 2023). Investigating these factors through country-specific analyses is crucial to pinpoint the root causes of inefficiency. This entails conducting in-depth case studies and engaging with stakeholders to garner a comprehensive understanding of the unique challenges and context-specific factors influencing environmental performance (Iheanachor, 2021; Abdullahi and Yu, 2023).

The primary causes of low efficiency are identified, targeted interventions can be devised. These interventions may include promoting clean energy investments, capacity-building initiatives, and technology transfer and innovation. By addressing the root causes of low environmental efficiency through collaborative efforts and targeted interventions, African countries can advance towards a more sustainable future. This necessitates a multi-faceted approach that acknowledges the unique challenges faced by each nation and leverages the valuable lessons learned from both top and low performers in environmental efficiency.

6. CONCLUSION

The analysis of environmental efficiency in African countries using Data Envelopment Analysis (DEA) offers a nuanced perspective on the continent's sustainability landscape. One key observation is the considerable variation in efficiency scores among different nations, highlighting both areas of success and opportunities for improvement. While countries like Mali, South Africa, and Zambia demonstrate commendable environmental efficiency, others face significant challenges in this regard.

A critical aspect emphasized by the DEA results is the importance of context-specific solutions tailored to each country's unique circumstances. While lessons learned from top performers are valuable, it's essential to recognize that a one-size-fits-all approach is unlikely to succeed. Instead, targeted interventions that consider factors such as resource endowments, institutional capacity, and socio-economic conditions are essential for sustainable progress.

Collaboration and knowledge sharing emerge as crucial factors in driving environmental efficiency across the continent. By facilitating the exchange of best practices, promoting technology transfer, and offering capacity building support, African nations can accelerate their transition towards sustainability. Moreover, addressing common challenges such as financial constraints, capacity limitations, and socio-political considerations is vital for the effective implementation of environmental strategies.

Clean energy emerges as a key priority in enhancing environmental efficiency, with the data highlighting the importance of investing in renewable energy sources and reducing reliance on fossil fuels. Supportive policy frameworks, robust institutional capacity, and technological advancements play pivotal roles in enabling and sustaining improvements in environmental efficiency.

While acknowledging the limitations of DEA, including data availability and subjectivity in weight allocation, ongoing monitoring and analysis remain essential. Continuous evaluation allows for tracking progress, assessing the effectiveness of implemented strategies, and identifying areas for further improvement.

The analysis of environmental efficiency in African countries presents a multifaceted picture that requires a comprehensive and collaborative approach. By embracing context-specific solutions, leveraging lessons learned, and prioritizing clean energy and supportive policies, African nations can chart a course towards a more sustainable future.

REFERENCES

Abdi, Y.M. (2013), The impact of population increase on forest conservation in Wajir County North Eastern Province Kenya. p. 1-60.

Abdullahi, M., Yu, Q. (2023), The impact of renewable energy consumption and economic growth on environmental quality in Africa: A threshold regression analysis. Energies, 16(11), 4533.

Ahmad, A., Shafqat, M.M., Ilyas, M., Ashraf, M.U., Urooj, A., Yu Huan, Z. (2023), Validation of the environmental Kuznets curve and role of economic globalization: An aggregate and sectoral analysis of an Indian economy. Air Quality, Atmosphere and Health, 16(10), 2035-2051.

Amowine, N. (2023), The impact of forestation and renewable energy utilisation on environmental efficiency in Africa. Economic Research-Ekonomska Istraživanja, 36(1), 2180412.

Amowine, N., Li, H., Boamah, K.B., Zhou, Z. (2021), Towards ecological sustainability: Assessing dynamic total-factor ecology efficiency in Africa. International Journal of Environmental Research and Public Health, 18(17), 9323.

Androniceanu, A., Kinnunen, J., Georgescu, I. (2021), Circular economy as a strategic option to promote sustainable economic growth and effective human development. Journal of International Studies, 14(1), 60-73.

Avilés-Sacoto, E.C., Avilés-Sacoto, S.V., Güemes-Castorena, D., Cook, W.D. (2021), Environmental performance evaluation: A state-level DEA analysis. Socio-economic Planning Sciences, 78, 101082.

Bahizire, G.M., Fanglin, L., Appiah, M., Xicang, Z. (2022), Research on the advance role of institutional quality on achieving environmental efficiency in Sub Sahara Africa. Frontiers in Environmental Science, 10, 845433.

Bimha, K., Bimha, H. (2023), Sustainability of supply chain performance through inventory and collaboration management: A case of transportation fuel companies in Harare, Zimbabwe. Science Journal of Business and Management, 11, 43-51.

Boadu, S., Otoo, E. (2024), A comprehensive review on wind energy in Africa: Challenges, benefits and recommendations. Renewable and Sustainable Energy Reviews, 191, 114035.

Borgi, H., Mabrouk, F., Bousrih, J., Mekni, M.M. (2023), Environmental change and inclusive finance: Does governance quality matter for African Countries? Sustainability, 15(4), 3533.

Camioto, F.D.C., Pulita, A.C. (2022), Efficiency evaluation of sustainable development in BRICS and G7 countries: A Data Envelopment Analysis approach. Gestão and Produção, 29, e022.

Chen, G.S., Manu, E.K., Asante, D. (2023), Achieving environmental sustainability in Africa: The role of financial institutions development on carbon emissions. Sustainable Development, 31, 3272-3290.

DeCampos, E.A.R., de Paula, I.C., Caten, C.S.T., Tsagarakis, K.P., Ribeiro, J.L.D. (2023), Logistics performance: Critical factors in the implementation of end-of-life management practices in the pharmaceutical care process. Environmental Science and Pollution Research, 30(11), 29206-29228.

Evivie, S.E., Evivie, E.R. (2023), Toward sustainable biological and environmental policies in Africa. In: Sustainable Utilization and Conservation of Africa's Biological Resources and Environment. Singapore: Springer Nature Singapore. p665-688.

Grovermann, C., Rees, C., Beye, A., Wossen, T., Abdoulaye, T., Cicek, H. (2023), Uptake of agroforestry-based crop management in the semi-arid Sahel-Analysis of joint decisions and adoption determinants. Frontiers in Sustainable Food Systems, 7, 1042551.

Iheanachor, N. (2021), Sustainable business practices by Nigerian organizations. In: Sustainable Organizations-Models, Applications, and New Perspectives. London: IntechOpen.

Jakada, A.H., Mahmood, S., Ali, U.A., Ismail Aliyu, D. (2023), The moderating role of ICT on the relationship between foreign direct investment and the quality of environment in selected African countries. Cogent Economics and Finance, 11(1), 2197694.

Jinapor, J.A., Suleman, S., Cromwell, R.S. (2023), Energy consumption and environmental quality in Africa: Does energy efficiency make any difference? Sustainability, 15(3), 2375.

Jiying, W., Beraud, J.J.D., Xicang, Z. (2023), Investigating the impact of air pollution in selected African developing countries. Environmental Science and Pollution Research, 30, 64460-64471.

Kara, S.E., Ibrahim, M.D., Daneshvar, S. (2021), Dual efficiency and productivity analysis of renewable energy alternatives of OECD countries. Sustainability, 13(13), 7401.

Karangwa, A., Su, Z. (2023), Towards a multidimensional model for evaluating the sustainable effect of FDI on the development of host developing countries: Evidence from Africa. Sustainability, 15(5), 4662.

Khalid, A.M. (2023), Creating synergies among the sustainable development goals and climate action: Insights from a developing economy. Sustainability, 15(17), 13137.

Mardani, A., Streimikiene, D., Cavallaro, F., Loganathan, N., Khoshnoudi, M. (2019), Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. Science of the Total Environment, 649, 31-49.

Martini, G., Porta, F., Scotti, D. (2023), Persistent and transient productive efficiency in the African airline industry. Journal of Productivity Analysis, 61, 1-20.

Matuszak, J., Zaleski, K., Zyśko, A. (2023), Investigation of the impact of high-speed machining in the milling process of titanium alloy on tool wear, surface layer properties, and fatigue life of the machined object. Materials, 16(15), 5361.

Maurya, A.M., Padval, B., Kumar, M., Pant, A. (2023), To study and explore the adoption of green logistic practices and performance in manufacturing industries in India. Management, 1(2), 207-232.

Melega, A. (2022), The impact of environmental regulations on foreign direct investment: A literature review. Economy and Sociology, 5(2), 107-120.

Moutinho, V., Madaleno, M. (2021), Assessing eco-efficiency in Asian and African countries using stochastic frontier analysis. Energies, 14(4), 1168.

Müller, F., Claar, S. (2021), Auctioning a 'just energy transition'? South Africa's renewable energy procurement programme and its implications for transition strategies. Review of African Political Economy, 48(169), 333-351.

Ngang, C.C. (2023), Climate change impediments to realising the right to development in Africa. In: Climate Change in Africa: Adaptation, Resilience, and Policy Innovations. Cham: Springer Nature Switzerland. p11-33.

Pais-Magalhães, V., Moutinho, V., Marques, A.C. (2021), Scoring method of eco-efficiency using the DEA approach: Evidence from European waste sectors. Environment, Development and Sustainability, 23, 9726-9748.

Sotiroski, K., Kovacs, P., Aleksandra, M., Sedlak, O., Lakić, V., Radovanov, B. (2023), Assessing sustainable economic development efficiency: A DEA approach. Strategic Management, Online first. p. 1-11.

Sova, R., Tudor, C. (2022), The Importance of Logistics Performance for Mitigating Transportation-Caused Pollution. In: Conference on Sustainable Urban Mobility. Cham: Springer Nature Switzerland. p1330-1339.

Staniszewski, J., Matuszczak, A. (2023), Analiza skorygowanej środowiskowo efektywności rolnictwa-systematyczny przegląd literatury wykorzystującej podejście graniczne. Zagadnienia Ekonomiki Rolnej, 374(1), 20-41.

Ugwu, J.N., Tom, M., Asiati, M., Eze, C.E. (2023), Prospects and challenges of sustainable development in Africa. IDOSR Journal of Communication and English, 8, 6-12.

Wan, B., Wan, W., Hanif, N., Ahmed, Z. (2022), Logistics performance and environmental sustainability: Do green innovation, renewable energy, and economic globalization matter? Frontiers in Environmental Science, 10, 996341.

Wu, Y., Wang, R., Wang, F. (2023), Exploring the role of foreign direct investment and environmental regulation in regional ecological efficiency in the context of sustainable development. Sustainability, 15(11), 9104.