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What abates environmental efficiency in African economies? Exploring the influence of infrastructure, industrialization, and innovation

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ABSTRACT

The study investigates the impact of infrastructure, industrialization, and innovation in improving environmental efficiency in Africa toward addressing the pressing needs for environmental sustainability in the region. The study employed both Data Envelopment Analysis (DEA) and Driscoll & Kraay methods to data collected for 19 African countries from 2000 to 2019. The results show a negative and significant relationship between infrastructure, industrialization, and innovation and the environmental efficiency in selected countries. Furthermore, our findings indicate that growth and energy demand have both positive and negative effects on these relationships. This paper has important policy implications, and we conclude that policies aiming at the development of both infrastructure and industry should consider the use of green technology to ensure sustainable development and environmental protection.

1. Introduction

Climate change is a global issue, and while many developing African economies are not the main contributors to the climate crisis, these countries will undoubtedly be among the first to be affected by the effects of climate change (Neto et al., 2018). Substantial efforts have been made over the last 20 years to examine environmental efficiency challenges in the African context (Bahizire et al., 2022a, 2022b). Large amounts of energy consumption, infrastructure, and industrialization are inextricably linked to the expansion of the African economy, and the negative impact on the environment has become increasingly apparent (Appiah et al., 2022a). As a result, environmental efficiency issues in Africa requires attention from academic scholars which motivates this paper. To date, it is widely acknowledged that African countries are becoming increasingly concerned about environmental sustainability (Naeem and Karim, 2021). They explicitly recommended clean and renewable energy uses and sources, which have since become a road map for high-quality development in a variety of industries (Gu and Zhou, 2020). However, the African countries' efforts on environmental issues have yet to yield major dividends. As a result, the government of the African countries needs to make considerably more effort to increase environmental efficiency.

Increased energy consumption from industry and infrastructural development has put a strain on energy and the environment (Sun and Razzaq, 2022). The purpose of climate change sustainable development is to increase environmental efficiency and reduce pollutant emissions. Environmental efficiency is affected by population expansion, energy consumption, economic growth, and institutions as an indication of environmental performance and a guide to practice (Appiah et al., 2021; Bahizire et al., 2022a, 2022b; Karim and Naeem, 2021, 2022). However, there is a lack of knowledge on the factors that influence environmental efficiency. Institutions, innovation, infrastructure, and industrialization all have an impact on environmental efficiency, whether directly or indirectly (Bian et al., 2019; Hua et al., 2018).

Africa is one of the continents that has committed to new and ambitious goals to achieve net-zero by 2050 or earlier. Infrastructure development and industrialization, which account for around 40 % of the world's energy consumption and nearly 35 % of its GHG emissions, are essential to the transition to a net-zero future (Dogan et al., 2022; Dwivedi et al., 2022). To reach net-zero goals, significant improvements in the built environment's environmental efficiency are therefore required. Numerous international leaders will gather at the 2021 United

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Nations (UN) Climate Change Conference (COP26), which will be held in Glasgow, United Kingdom, to discuss the serious effects of global warming (COP26, 2021). This event offered chances to advance toward net zero targets and more ambitious global climate goals by utilizing the next generation of environmental efficiency in the built environment. With regard to innovative programs to lower overall costs of mitigating carbon emissions in the built environment while furthering social development, boosting energy security and quality of life, and creating jobs, it presents successful examples from the commercial and public sectors (Birol, 2021).

By limiting global temperature increases to 1.5 degrees Celsius over pre-industrial levels, the conference unveiled commitments for consistent progress toward the Paris Agreement and UN Framework Convention on Climate Change (COP26, 2021). The Intergovernmental Panel on Climate Change (IPCC) noted in its 2018 report that for there to continue to be "high confidence" that temperature increases will be kept to manageable levels, global emissions must be at net zero by at least 2050 (Clemens et al., 2020). Governments and businesses are increasingly relying on technology advances to reach net zero emission targets because the shift to net zero demands considerable changes at the societal and industrial levels (Li et al., 2022; Shahbaz et al., 2020). While many of the seemingly insurmountable societal concerns related to climate change have the potential to be solved via digital technologies (Dash and Paul, 2021), some of the recent technological innovation such as cryptocurrencies are getting heavily criticized for their negative environmental impacts (e.g., Corbet et al., 2021; Naeem and Karim, 2021). The World Economic Forum (WEF) and PwC jointly wrote the report Harnessing Technology for the Global Goals, which highlights the important role that digital technology can play in strengthening human capacity to achieve net zero and improving resilience to natural disasters linked to global warming (Choi and Park, 2022). According to the WEF report, digital technology can automate operations in manufacturing, agriculture, and other industries and help them run much more efficiently (Martínez-Caro et al., 2020).

In the previous two decades, Africa's economy has experienced phenomenal growth. In the world, the continent's gross domestic product (GDP) is ranked fifth, and its GDP per capita is eighth (Appiah et al., 2022b). However, the continent's economy is struggling due to issues including excessive resource usage, rising population, and rising CO_2 emissions (Gyamfi et al., 2022). Therefore, CO_2 emissions and population growth (POP) are crucial issues in Africa since they are related to climate change. In 2021, the continent's CO_2 emissions totaled 36.3 billion tons, ranking third globally and second among emerging nations (Appiah et al., 2021). The majority of the continent's linked greenhouse gases (GHG) emissions come from the energy, land-use change and forestry (LUCF), and agricultural sectors in Africa. The African continent also has the top-ranking economy in terms of natural resource abundance as of 2018, however it imports 20 out of 90 inorganic commodities (Katoka and Dostal, 2022; Zallé, 2019). African CO2 emissions, energy use, and natural resources provide a unique opportunity to learn more about the factors affecting the environment on the continent (Avom et al., 2022). Around the world, environmental protection has become a hot concern for academics and decision-makers. In light of these circumstances, it is, therefore, crucial to investigate how some of these factors relate to the environment in the context of Africa. Due to its overabundance of natural resources, the African continent has recently witnessed the development of environmental protection technology as well as an expansion in infrastructure and industry.

The works on eco-efficiency have grown, yet there is little or no indication to back infrastructure, industrial growth, and innovation playing a dominant role in Africa's quest for eco-efficiency. As a result, important components that could spark a pattern shift in Africa's eco-efficiency have been overlooked. No study positions African nations on the mark and emphasizes this scenario, according to the literature search on environmental efficiency. The aim of doing research involving African countries is on the horizon. As a result, the goal of this research is to address a knowledge vacuum by looking at the impact of infrastructure, industrialization, and innovation on environmental efficiency. The countries south of the Sahara Desert are often referred to as 'Sub-Saharan Africa' in the existing literature, however, to our best knowledge, this term is no longer considered to be politically correct (e.g. Banna et al., 2022). Hence, in this paper we focus on 19 African countries, which are chosen as the research object for the following reasons: economic development, infrastructure development, and industrialization, as well as the achievement of the sustainable development goal (SDGs), all of which are conducive to expanding economic co-operative connections (Karim et al., 2022b,c,d; Naeem et al., 2022a, 2022b).

This research contributes to the existing literature in several ways. According to the authors' knowledge, no prior research has looked into the impact of the dynamic nexus of infrastructure, industrialization, and innovation on environmental efficiency in African countries. Furthermore, this research estimates the two functions linked to environmental efficiency in a single study, allowing for the estimation of efficiency scores and examining some variable effects on it. Second, the existing literature substituted carbon emissions for the environment, which are often utilized by scholars due to their exclusive character. As a result, environmental efficiency was chosen as a metric for measuring ecological performance in the current study. This is because environmental efficiency reveals the impact of human actions on the environment in terms of GDP, carbon emissions, capital, labour, and energy (Gozgor et al., 2020; Bahizire et al., 2022a, 2022b); and it is thought to be a more inclusive substitute for environmental sustainability. The paper provides policymakers/governments with a more comprehensive understanding of the nexus between infrastructure, industrialization, and innovation, as well as environmental efficiency in countries, transitioning from agriculture, adding to the large body of literature offering policy recommendation to achieve the Sustainable Development Goals (Sinha et al., 2021). Third, to the best of the author's knowledge, this is the first study to look at the impact of infrastructure, industrialization, and innovation on environmental efficiency in 19 emerging African countries, which has never been done before. Finally, for empirical analysis, our study used robust estimators (Driscoll and Kraay (DK) and Panel-Corrected Standard Errors (PCSE) techniques), which improved the reliability and efficiency of our environmental implications' findings. Finally, this paper provides the empirical evidence about the relationship between economic growth and environmental efficiency, contributing to the literature on economic complexity and carbon emission nexus (Can and Gozgor, 2017; Gozgor et al., 2018).

The study's following portions are organized as follows: The literature on the impact of infrastructure, industrialization, and innovation on environmental efficiency is briefly reviewed in Section 2. Section 3 provides a methodological framework for the data description and model specification; Section 4 summarizes the empirical findings and gives a discussion; and finally, Section 5 provides the conclusion and policy implications.

2. Literature review and hypotheses development

Various empirical investigations have established the dynamic link between infrastructure, industry, and innovation on environmental efficiency. The previous literature is divided into three sections in this study: (i) the infrastructure-environmental efficiency nexus; (ii) the industrialization-environmental efficiency nexus; and (iii) the innovation-environmental efficiency nexus. We explore this in-depth below:

2.1. Innovation and environmental efficiency nexus

Adoption and development of innovation are recognized as one of the most important approaches to addressing low environmental efficiency (Sun and Razzaq, 2022). To tackle the environmental difficulties that confront countries, innovation can motivate businesses to develop and utilize sophisticated technologies, and equipment, and increase resource utilization efficiency. Several types of research have been conducted on the innovation-environmental efficiency nexus. Green technological innovation, according to Yasmeen et al. (2020), can help to boost predicted output. As a result, green technology innovation is an important means of increasing ecological efficiency. The technological progress of capital-intensive enterprises contributes significantly more to corporate eco-efficiency than that of labour-intensive enterprises at the high end of the distribution of corporate eco-efficiency; however, the difference in this contribution is not obvious at the low end of the distribution (Adedoyin et al., 2022). Quanhui and Haiyan (2019) discovered that technology advancement follows a "U" shaped environmental Kuznets curve. Before 2010, they claimed, technological advancement had lowered ecological efficiency.

Following 2010, technical advancements continued to improve environmental efficiency. Keliang et al. (2016) calculated the industrial environmental technology gap using the common technology rate. The study's findings revealed that industrial ecological efficiency and environmental technology differed greatly. Chen and Lei (2018) discovered that technological innovation could help to cut carbon emissions and address environmental sustainability concerns. Green innovation and cleaner production, according to Zameer et al. (2020), can play a key role in environmental sustainability. Energy innovations, according to Shahbaz et al. (2018), can play a key role in improving environmental quality. In another study, Ling Guo et al. (2017) and Miao et al. (2018) found that technological innovation has a strong positive driving influence on the resource utilization efficiency of strategic developing industries, with a steady-state growth tendency overall.

According to Miao et al. (2018), green technology introduction funds and green new product development funds have a considerable favourable impact on natural resource use efficiency. However, other academics argue that technological innovation has a negligible impact on the efficiency with which industrial green resources are utilized. Zhao et al. (2014) argue that technological innovation has a squeezing impact on businesses, preventing them from improving resource usage efficiency. Internal R&D expenditure had a negative effect on ecological efficiency, according to Hongjuan and Chenghao (2016), who used the Tobit model to examine the impact of internal R&D expenditure on ecological efficiency. This could be due to a lack of expertise in the fields of innovation and pollution control. Therefore, we propose the following research hypothesis:

Hypothesis 1 (H1). Innovation improves the environmental efficiency of African countries.

2.2. Industry and environmental efficiency nexus

With the amount of production and energy consumption, the environmental efficiency of industry varies substantially between industrialized and developing countries (Bahizire et al., 2022a, 2022b). The proportion of the industrial structure may alter, resulting in a change in environmental quality. This results in a shift in energy demand and consumption intensity, which has an impact on both industry and the environment's development. There has been a lot of research done on the relationship between industrialization and environmental progress. The proportion of industrial structure has a significant bearing on eco-efficiency, according to (Sun et al., 2020). From this perspective, an industry with a high number of secondary sectors is more likely to consume more resources, which has a stifling effect on environmental efficiency. The aforesaid point of view was also supported by an empirical investigation by Bahizire et al. (2022a, 2022b) stating that the proportion of this industrial structure is thought to have an unavoidable impact on environmental efficiency. The findings of Song et al. (2018) and Qin et al. (2020) studies are consistent with the previous research conclusions.

Alternatively, Anser et al. (2020) investigate why most businesses have high energy consumption and emissions and use the DDF model to examine data from 21 nations, finding that including and excluding undesired output has a major impact on efficiency levels. Cariola et al. (2021) found that rapid industrialization creates an inefficient environment, which has resulted in a slew of environmental challenges including depletion of energy resources, pollution, and environmental deterioration (An et al., 2020; Goli, 2020). According to a study by He (2019) different types of industry have varying effects on the environment. They proposed the hypothesis of factor endowments. According to the study, energy-intensive companies produce significantly more pollution than other sectors, implying that an increase in revenue in these industries will result in significantly more pollution than in other industries Shi et al. (2022) feel that actively pursuing industrial restructuring and technological innovation is a smart strategy to solve the environmental problem while growing the economy, but that environmental protection is essential.

Because the amount of industrialization has a detrimental impact on environmental efficiency, countries that are particularly affected should focus on improving their industrial structure and developing a green economy. This conclusion is supported by several studies that show that increased industrialization leads to increased emissions and thus environmental degradation see, for example, (Karim et al., 2020c). Based on the above assertions, the following is expected:

Hypothesis 2 (H2). The greater the share of industrial structure the lower the scale of environmental efficiency of African countries.

2.3. Infrastructure and environmental efficiency nexus

As people have become more aware of environmental issues, some studies have been conducted to examine the relationship between infrastructure and environmental efficiency. Infrastructure has the greatest impact on eco-efficiency through changes in public perception, behaviour, and technology advancement. People's knowledge of environmental protection will increase as infrastructure improves (Lin and Chen, 2020; Song et al., 2016; Karim et al., 2022a, 2022d; Naeem et al., 2021). According to a recent study, Guo et al. (2019) technical advancement and industrialization will have a pulling effect on economic development, resulting in a rebound in energy consumption and, as a result, a decrease in eco-efficiency. Simultaneously, environmental awareness will play a role in infrastructure, enabling for improved implementation of environmental protection policies. Kong and Liu (2021) and Zhu et al. (2020) argue that upgrading infrastructure and living standards can reduce energy use and improve environmental efficiency.

According to this research, the growth of social infrastructure, innovation, and technological progress are typically fostered, with technological progress reducing the impact on resources and the environment. Maslow's hierarchy of needs theory argues that humans must first meet their bodily requirements before moving on to higher levels of psychological demands (Wang and Chen, 2020). As a result, at the outset of infrastructure, people will continue to engage in production and living activities to satisfy their material needs. However, once the infrastructure is created to a given scale, it can drive total demand to be several times greater than the investment amount, stimulating economic development, enhancing resource use efficiency, and rising pollution levels.

Hypothesis 3 (H3). The lower the level of eco-efficiency in African countries, the larger the proportion of infrastructure development.

3. Data, model & methodology

Due to the relatively limited data on some African countries, we selected 19 African countries as the research focus, and the study period is from 2000 to 2019. The data on innovation comes from the Global Economy website, while the data of AIDI from AfDB, industrialization, energy and growth are obtained from the World Bank database see Table 1. Table 2 shows the descriptive statistics for the aforementioned variables. Among all variables, the maximum values are much larger than the minimum values, indicating the emergence of huge heterogeneities across countries in Africa.

3.1. Model

Founded on the validity of the variables used in this study, the least square panel regression analysis was used to account for the dataset's panel structure. Because it adequately controls for endogeneity, serial correlation, and heteroscedasticity, the estimating technique is regarded as superior to other methods. In this study, the empirical technique is based on the estimation of a simple equation connecting infrastructure, industrialization, innovation, energy usage and growth in a panel data environment while adjusting for other exogenous factors. The studies of (Bahizire et al., 2022a, 2022b) and (Razzaq et al., 2021) were used to develop the approximated equation used in this investigation. As a result, the following is the baseline model for this analysis:

$$\mathrm{EE}_{it} = \beta_0 + \beta_1 \mathrm{AIDI}_{it} + \beta_2 \mathrm{IND}_{it} + \beta_3 \mathrm{INN}_{it} + \beta_4 \mathrm{ENE}_{it} + \beta_5 \mathrm{GR}_{it} + \varepsilon_{it} \quad (1)$$

where EE refers to how efficiently the built environment fosters the efficient use of natural resources—land, energy, and water—as well as waste re-use and/or recovery. The infrastructure vector, represented by AIDI, is used to express the basic physical and organizational structures and facilities required for the operation of a community or business. The term “industrialization” refers to the process by which an economy shifts from being predominantly agricultural to the production of goods specified by IND. The selected African countries' innovation is represented through INN. Finally, macroeconomic factors such as ENE (energy use) and GR (growth rate) are monitored to see if they have an impact on environmental efficiency. These variables are consistent with past research (Appiah et al., 2021; Karim et al., 2020a, b; Bahizire et al., 2022a, 2022b). The $_I$ and $_t$ recommend that each efficiency is identified at certain times.

3.2. Methodology

The analysis is conducted in two stages. First, a non-parametric frontier analysis is implemented to estimate efficiency scores. Second, econometric methods are applied to analyse the role of infrastructure, industry, and innovation on eco-efficiency.

3.2.1. Malmquist productivity index model

The Malmquist (MM) index, that is founded on the Data Envelopment Analysis (DEA) (Färe et al., 1994). They broke down technical efficiency into the following components: Fare broke down the technical efficiency in the following, given the criterion of constant returns to scale and elements with high disposability.

Table 1
Variable description.

Variable	Abbreviations	Unit	Year	Source
Environmental Efficiency	EE	Efficiency Scores calculated by the use of DEA method	2000–2019	Input and output data sourced from PWT
Infrastructure	AIDI	Index	2000–2019	AfDB
Energy Use	ENE	Kilotonne	2000–2019	World Bank (WDI)
Growth	GR	Percentage	2000–2019	World Bank (WDI)
Industrialization	IND	Percentage	2000–2019	World Bank (WDI)
Innovation	INN	Percentage	2000–2019	Global Economy web

Note: The data on innovation comes from the Global Economy website, while the data of AIDI from AfDB, industrialization, energy and growth are obtained from the World Bank database.

Table 2
Pre-diagnostic results.

Diagnostic Test	Findings
CSD test of Pesaran	−0.609
Panel Hettest	12.40***
Slope Homogeneity	−1.188
Modified Wald test (x2)	1773.46***
VIF	1.06

Notes: ***, **, * signifies 1,5, and 10 % significance level.

$$\mathrm{F^t}_i = (y^t, x^t/c,s) = s^t{}_i(y^t, x^t/s)\cdot \mathrm{CN^t}_i(y^t, x^t/v)\cdot \mathrm{F^t}(y^t, x^t/v,w) \quad (2)$$

where $F^t(y^t,x^t/v,w)$ represents pure technical efficiency, $s_i^t(y^t,x^t/s)$ represents scale efficiency, $CN_i^t(y^t,x^t/v)$ represents strong disposability elements, and $F^t(y^t,x^t/v,w)$ represents pure technical efficiency. Technical efficiency of the highest kind function of input distance $D_i^t = (Y^t,X^t)$ multiplied by $F_i^t = (y^t,x^t/c,s)$ equals one.

The input distance function can be thought of as the compression fraction of a certain location (y^t,x^t) compressing to ideal input. When$D^t_i = (y^t,x^t) = 1$, (y^t,x^t) is at its most efficient, i.e. when technic is at its most efficient. $D_i^t = (y^t,x^t) > 1$ denotes (y^t,x^t)'s represents the departure of from the frontier, at which point technic is rendered useless. If we use time t + 1 to place t, the distance function will be $\mathrm{D}_i^{t+1} = (y^{t+1}, x^{t+1})$. The Malmquist index can be used to express input-oriented TFP, according to (Caves et al., 1982a, 1982b).

$$\mathrm{M}_i^t = \frac{D^t{}_i(y^t, x^t)}{D^t{}_i(y^t\overline{1}, x^t\overline{1})} \quad (3)$$

From time t to time t + 1, the prior index shows the DMU's technical modifications in the time t technical system. On the time t + 1 technical state, the technical change index of the DMU from time t to time t + 1 is easily visible.

$$M_i{}^{t+}1 = \frac{D^t{}_i(y^t, x^t)}{D_i{}^{t+}1(y^{t+}1, x^{t+}1)} \quad (4)$$

(Färe et al., 1994) employed two geometric averages of the Malmquist index to export the Malmquist index:

$M_i = \left[\frac{D_i{}^{t+}1(y^{t+}1,x^{t+}1)}{D_i{}^{t+}1(y^t,x^t)}\cdot\frac{D^t{}_i(y^{t+}1,x^{t+}1)}{D^t{}_i(y^t,x^t)}\right]^{1/2}$ (5)where $\mathrm{D_i}^{t+}1(y^{t+}1, x^{t+}1)$ is the new technical efficiency below the t + 1 technical form, and $\mathrm{D^t}_i(y^t$, xis the recent technical efficiency below the t + 1 technical form at time t. $\mathrm{D^t}_i(y^{t+}1, x^{t+}1)$ is the new technical efficiency on the t technical state, while $\mathrm{D^t}_i(y^t, x^t)$ is the technical efficiency on the t technical form at time t + 1. Productivity grows when the result of the formula is greater than one. In addition, productivity is falling.

3.2.2. Driscoll and Kraay's method

The core specification depicts the interplay between innovation, infrastructure, industrialization, and environmental efficiency. The application of the Driscoll & Kraay estimating approach allows these results to be realized. Ordinary least squares (OLS) estimation of the above model will result in erroneous results (Dodoo et al., 2020). This estimator ignores cross-sectional dependence (CSD) and may cause results to be faulty (Gyamfi et al., 2022). This is because, if at all feasible, the correlation of regression errors over time is ignored, showing evidence of contradictory results (Hoechle, 2006).

Because of the nature and type of data used in this study, heteroscedasticity can be found in the dataset. As a result, the study used the Driscoll and Kraay (1998) method which is very appropriate. Driscoll and Kraay (1998) propose a nonparametric covariance matrix estimator that generates heteroskedasticity and autocorrelation-consistent standard errors that are resistant to many types of spatial and temporal dependency. Again, in both balanced and unbalanced panels, the estimator can produce unbiased coefficients. As a result, it can successfully manage missing values as well (Hoechle, 2006). The necessity of using the Driscoll and Kraay (1998) approach is determined by a pre-diagnostic test. The pre-diagnostic analysis demonstrates that the dataset has heteroscedasticity, no cross-sectional dependency, absence of slope homogeneity, and no multicollinearity, as shown in Table 2.

The characteristics of variables used to model the effects of infrastructure, innovation, and industrialization on environmental efficiency in Africa are summarized in Table 3. The average environmental efficiency, as measured by DEA, is 1.0082, according to the findings. Infrastructure (AIDI) was 12.6300 % on average at the regional level, with a minimum of 2.9187 % and a maximum of 24.7161 %, with a Std. Dev. of 5.4044 %. According to the independent variables, IND was 25.8991 % on average, with a minimum and highest value of 14.97901 and 61.74200, respectively. The Std. Dev. rate was also 9.0686 %. Growth (GR) and Energy (ENE) recorded averages of 2.6496 % and 8.2927 kt, respectively. The maximum and minimum analyses are 18.0660 %, 23.35810kt, −18.4911 %, and 2.54893kt, respectively. According to statistics on innovation, on average, the selected countries invest 1.7372 % of their GDP in research and development, with a minimum and maximum of 3.2184 and 0.8759, respectively.

The correlation coefficients between the variables is shown in Table 4. The correlation analysis found a mixed association between environmental efficiency and the indicators, indicating that environmental efficiency, infrastructure, growth, and industrialization all have a favourable relationship. This association shows that infrastructure, expansion, and industrialization in Africa may have a favourable impact on environmental efficiency. The chart also indicated a negative relationship between environmental efficiency, energy, and innovation.

4. Empirical Results and Discussion

Table 5 also shows the relationships between the input variables (labor, capital, and energy) and the outcomes (GDP & CO2). The conclusion shows a significant and positive relationship between energy and labor, GDP and capital, and GDP and CO2 growth. The results suggest a negative and significant correlation between capital and labor, CO2 and labor, and energy and CO2. In conclusion, the majority of the study's variables are shown to be positively and significantly correlated with one another, meaning that any increase in one variable would cause the other variables to rise because they are all moving in the same direction.

Table 6 presents the efficiency scores for each of the selected countries. The greatest value of environmental efficiency for African nations was 2.422 and the smallest value was 0.6162; thus, the value of environmental efficiency in the selected African countries ranged between 0.6162 and 2.422. Over the last ten years, Mauritius, Namibia, Kenya, Niger and Tanzania have been at the forefront of environmental efficiency, implying that environmental efficiency in these regions has improved through collaboration. Nigeria, Cote D'Voire, and B. Faso all had low environmental efficiencies, indicating that they used more energy and degraded the environment. Cote D'Voire and B. Faso was cut off from the effective frontier of environmental efficiency between 2010 and 2019 and 2000–2008 respectively. The environmental efficiency in these countries has continued to deteriorate, and as a result, the coordination of growth and environmental development has deteriorated.

Table 3
Variable statistics.

	EE	AIDI	ENE	GR	IND	INN
Mean	1.0082	12.6300	8.2927	2.6496	25.8990	1.7372
Median	0.9940	12.0694	6.9391	3.2010	24.2014	1.6700
Maximum	2.4220	24.7161	23.3581	18.0660	61.7420	3.2184
Minimum	0.6180	2.9187	2.5489	−18.4911	14.9790	0.8759
Std. Dev.	0.2138	5.4044	4.8296	3.8688	9.0681	0.5232

Notes: Statistics is significant at 1 % significance level.

Table 7 displays the empirical result of the relationship between environmental efficiency and the main components of SDG 9, namely industrialization, infrastructure, and innovation. The study uses the DK technique of estimation to investigate the research's findings and test the hypotheses, while the PCSE model is used to provide the robustness check's results. Infrastructure evidence has a negative contributing influence on environmental efficiency in Africa, according to the findings. In effect, the findings reveal that a 1 % increase in infrastructure results in a.0002 % reduction in environmental efficiency.

Increase in infrastructure serve as a key contributor to economic growth but its over reliance and neglect of the environment becomes a problem. This result is attributed to the destruction of the ecosystem as a result of increase in infrastructure. Mining, oil, and gas installations can also be considered as contributory factors to economic growth but are seen as harmful infrastructure. At worst, these facilities run the potential of catastrophes that might endanger both people and wildlife and severely harm ecosystems. At best, they continue to harm local ecosystems and populations, pollute the air and water, and exacerbate climate change. The results reveal that the hypothesis mentioned above, that the lower the level of environmental efficiency in African countries, the higher the fraction of infrastructure development, is fully supported. The findings of this study are consistent with those of (Guo et al., 2019). This study confirm that technological progress and industrialization will have a pulling effect on economic development, increasing energy consumption and, as a result, a decrease in eco-efficiency and that the scale of infrastructure development will drive total demand and pollution levels. This finding, however, contradicts the findings of (Saidur and Mahlia, 2011; Zhu et al., 2020), which show that infrastructure has a major impact on environmental efficiency. The authors of this study, which focused on industrialized countries, found that infrastructure growth is mostly based on the introduction of contemporary technology that has no negative environmental consequences. As can be seen, African countries do not use current technology in their effort to expand infrastructure, and as a result, environmental deterioration is always a result. These studies emphasize the need of advancing modern technology and materials for infrastructure development, which contributes to environmental conservation and improvement (Naeem et al., 2022a, 2022b).

The results reported in Table 7 show the outcome of the third hypothesis that was tested. The findings contradict the idea that innovation enhances countries' environmental efficiency in Africa. According to these data, there is a negative proportionate link between innovation and environmental efficiency. This conclusion implies that African countries' levels of innovation investment do not enhance environmental efficiency and that greater investment is required. The continued growth of technology is necessary for the survival of growth. Furthermore, technology can have a significant impact on our future, as history has demonstrated. But we also need to take into account how technology affects the environment negatively. Based on the findings, it can be concluded that green technology innovation's promotion effect on ecological efficiency in African nations is currently low and has to be improved. This negative association relates to the over utilization resources extracted from the environment without any proper protection measures. Example the production of renewable energy sources involves the usage of raw materials from the environment. Most innovative ways are presents negative effects on the environment in the long run. This finding is consistent with prior research on the link between innovation and environmental efficiency (Dongyang et al., 2018; Xiaohong and Shi, 2013). However, according to, Dongyang et al. (2018) the impact of technological transition is not obvious, and the contribution of technical development to corporate eco-efficiency is not uniform in its distribution intervals (Xiaohong and Shi, 2013; Karim et al., 2022a, 2022d).

The study focused on the effects of industrialization on

Table 4
Variable correlations.

	EE	AIDI	ENE	GR	IND	INN
EE	1.0000					
AIDI	0.0081	1.0000				
ENE	−0.0648	0.0608	1.0000			
GR	0.1009	0.0074	−0.0009	1.0000		
IND	0.0385	0.1443*	−0.2216**	−0.2089*	1.0000	
INN	−0.0310	−0.0471	0.0085	0.01178	−0.1126	1.0000

Notes: ***, **, * signifies 1,5,10 % significance level.

Table 5
Input & output variable correlations.

	LAB	CAP	ENE	GDP	CO_2
LAB	1.0000				
CAP	−0.0890*	1.0000			
ENE	0.0890*	−0.0231	1.0000		
GDP	−0.0650	0.9133***	−0.0412	1.0000	
CO_2	−0.1293***	0.6686***	−0.1323***	0.5236***	1.0000

NB: ***, **, * signifies 1,5,10 % significance level.

environmental efficiency to prove the third hypothesis. Industrialization has a negative and considerable influence on environmental efficiency, according to the findings. The coefficients of the industrialization variable are negative after gradually adding control variables, and they are significant at the 1 % level. As a result, industrialization will reduce environmental efficiency. Similarly, the findings show that increasing output has no impact on environmental efficiency. Possible reasons include: whether it is an administratively mandated environmental regulatory instrument or a market-driven tool, industries should be required to reduce emissions. Imposing pollutant discharge taxes and trading pollutant discharge rights will stifle industry R&D, which will be counterproductive to energy efficiency initiatives. The likely reason, according to (Sun et al., 2020) and (Falavigna et al., 2015), is that while the rise of the second industry has beneficial benefits to the economy through increasing outputs, it also has negative effects on environmental efficiency since pollution is produced.

The results demonstrate a trend for growth and energy effects on environmental efficiency when compared to the other variables. Growth in African economies is favourable and highly tied to environmental efficiency, according to the data. This shows that higher returns on investment could encourage more investments in ecologically friendly materials, hence boosting environmental sustainability. Similarly, the findings imply that in African nations, the growth rate is similarly important for environmental sustainability. A study by, (Guo et al., 2021; Wang et al., 2018) validates this result, claiming that as long as companies and industries follow environmental rules and regulations, environmental preservation will be included in the manufacturing process (Naz et al., 2022; Alawi et al., 2022; Anwer et al., 2022). Increased energy use in African countries is diminishing environmental efficiency, according to the findings. The rate of environmental efficiency increases when the amount of energy used increases by a percentage. The non-use of renewable energy sources for commercial and domestic consumption is the cause of the above. From a policy standpoint, the study suggests that measures that promote energy efficiency while also enhancing environmental efficiency can help achieve environmental sustainability. Pollution mitigation rules and regulations should also be followed by policymakers and businesses. Businesses can invest in R&D to help reduce pollution in the same way that governments stimulate corporate growth and development.

The Panel-Corrected Standard Errors (PCSE) approach was used in the study to assess its robustness. Its use includes fixing the "small N" issue that both time series and cross-sectional analysis experience (Podestà, 2002). Once more, using a multivariate analysis, this method enables examining the effects of many predictors on the level and change in the dependent variable (Schmidt, 1997). By using this strategy, it is permissible to inquire about "variables" that are difficult to investigate in straightforward cross-sectional or time-series data (Hicks, 1991, 1994). The ability to capture not only the variation of what emerges via time or space, but also the variation of these two dimensions concurrently, is a third argument in favor of pooled TSCS analysis. This is due to the fact that a pooled model is tested for all nations over time rather than evaluating a cross-section model for all countries at once or a time series model for one country using time series data (Pennings et al., 2005). When the coefficients are consistent and robust in terms of their signs and magnitudes, the initial research estimator, DK, is acknowledged, implying robustness. As demonstrated in Table 8, all of the PCSE estimator's coefficients produced results that were identical to those anticipated by the DK, suggesting a high level of resilience. The findings show that a unit increase in infrastructure, industrialization and innovation reduces environmental efficiency by.0002, −0.0014, and − 0.0096 %, respectively, demonstrating that more work needs to be done on the materials used for infrastructure and industrialization to help improve environmental efficiency while also investing in R&D to find innovative solutions to prevent environmental degradation.

The findings above show the robustness of the estimation achieved by using the Tobit method. As can be observed, both positive and negative relations are shown by the robustness check's results. The conclusion holds that energy use and infrastructure growth compromise environmental efficiency. It can be seen that a rise in energy consumption and infrastructure development results in a − 0.000227 and − 0.0126847 reduction in environmental efficiency, respectively. The results of energy use support those presented in the primary regression models; see (Table 7). The growth coefficient, derived from the same regression estimations, is positive and significant, supporting the findings of the primary estimators. Thus, growth improves environmental efficiency.

5. Conclusion

This study empirically examined the roles of infrastructure, industrialization and innovation in improving environmental efficiency in Africa toward addressing the pressing needs for environmental quality for the region. Using a sample of 19 African countries, we discovered that infrastructure, industrialization and innovation has a negative and significant influence on environmental efficiency in Africa. However, only growth rate directly positively impacted African countries' environmental efficiency.

Furthermore, the study has substantial implications for African countries' governments and administrations in terms of research policy. The findings provide several valuable generalizations that have important policy consequences. Policymakers should promote the use of contemporary technologies to improve environmental efficiency since innovation exhibited a negative link with environmental efficiency, the adoption of renewable energy sources over non-renewable energy sources, and increasing sustainable industrial production through long-term policy measures can be implemented.

In African countries, the promotion of greener energy usage in the industrial sector requires modern technology and government funding. The results above call for establishment of small power plants and biogas

Table 6
Efficiency scores.

CT	2000	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	1	0.99	0.86	0.93	1	1.102	0.991	0.923	0.827	1.151	0.622	1.846	1	0.836	0.92	0.87	1.56	0.84	1.03
2	0.7968	1.6709	1.2415	1.29	0.6952	1.073	1.034	0.931	0.981	1.062	0.747	1.256	1.098	0.909	0.8355	1.0082	0.997	0.998	0.988
3	1.2167	1.1097	1.2192	1.1273	1.0771	1.079	0.978	0.929	1.1	0.945	0.915	0.947	1.17	1.044	0.8628	0.9940	0.996	1.005	0.992
4	0.8846	1.8658	1.0515	1.493	1.1827	1.087	1	1	1	0.988	0.915	1.087	1.019	0.912	1.7372	1.6700	0.998	1	0.989
5	0.8130	0.8018	1	0.7672	0.8780	1.303	1	0.972	0.786	1.308	1	1	1	0.994	0.7536	0.7471	1	0.998	0.985
6	0.9678	0.6258	0.8706	0.8386	0.6162	1.065	1.024	0.962	0.809	0.912	1.407	0.997	1.002	1.001	0.6329	0.7299	1	0.998	0.987
7	0.7719	0.6910	0.6687	0.9054	1.4713	0.996	1.004	1	0.979	0.693	1.077	1.369	0.993	0.97	0.9314	0.8906	0.8906	0.996	0.992
8	0.8736	0.9028	0.6387	0.8774	1.6527	1.094	0.986	0.811	1.245	0.78	0.961	0.639	2.098	0.987	0.6568	0.9034	0.9465	0.7128	0.997
9	0.7291	0.7493	0.7732	0.7473	0.6952	1.01	1.023	0.925	1.082	0.92	0.923	0.621	0.804	2.422	1.0072	0.9151	0.9068	0.8337	1.0771
10	1.0126	1.4312	1.5534	1.4153	1.6305	0.979	1.014	1.007	1	1	0.967	0.633	0.848	1.12	1.5782	1.2167	1.0570	1.2002	1.1272
11	1.3091	0.6899	0.7009	0.9097	0.7085	1	0.984	1.016	0.979	0.974	0.96	0.851	0.815	0.942	1.6609	1.501	0.7475	1.0126	1.3091
12	1.008	0.994	0.98	0.90	0.84	0.955	1.178	0.998	0.929	1.069	0.92	0.817	1.065	0.839	0.618	1.737	1.670	0.876	0.8158
13	0.83	0.79	0.98	0.90	0.80	0.932	0.776	1.517	0.96	0.952	1.094	0.78	1.075	0.924	0.97	0.87	0.88	0.71	0.63
14	0.9718	0.7848	0.9422	0.7019	0.9228	0.903	0.853	1.298	1	0.942	1.061	0.945	0.916	0.881	0.6938	1.14	1.08	1.05	1.29
15	0.6938	1	0.8996	1	1.52	1.012	1.021	1.067	0.618	1.624	1.017	1.045	0.941	0.863	0.9063	1	0.7019	1	0.8719
16	1	1	1	1	0.9051	0.871	1.164	0.988	0.799	1.332	1	0.905	1.105	0.843	0.9273	0.9273	0.9314	0.7848	0.9265
17	0.81	0.80	1	1	0.94	0.944	0.836	1.261	0.903	1.089	0.971	1.053	0.982	0.917	1	0.93	0.91	0.72	1
18	1	0.98	0.93	0.87	1	0.987	0.902	0.998	1.117	0.937	1.033	1.041	1	0.976	1	0.83	0.74	1	1
19	0.97	1	1	0.90	0.89	1	0.774	1.253	1.031	0.745	1.343	1	1	1	1	0.79	0.68	1	0.93

Notes: Where 1–19 denotes countries: (1) Botswana; (2) Gabon; (3) Mauritius; (4) Namibia; (5) South Africa; (6) Sudan; (7) Nigeria; (8) Cote D'Ivoire; (9) Cameroon; (10) Kenya; (11) Togo; (12) Zimbabwe; (13) Burkina Faso; (14) Mozambique; (15) Niger; (16) Guinea; (17) Rwanda; (18) Senegal; (19) Tanzania.

Table 7
DK & PCSE results.

	Driscoll and Kraay		PCSE	
	Coef	z-Stats	Coef	z-Stats
AIDI	−0.0002	−0.12	−0.0006	0.09
ENE	−0.0024	2.13*	−0.0018	2.26**
GR	0.0061	3.01**	0.0074	1.74*
IND	−0.0097	1.74*	−0.0014	0.62
INN	−0.0108	3.01***	−0.0096	−0.49
Cons	0.8076	6.35***	1.0008	21.87***

Note: ***, **, * signifies 1,5, and 10 % significance level.

Table 8
Robustness test, Tobit model.

	Tobit Regression	
	Coef	t-Stats
AIDI	−0.0126847	−2.49**
ENE	−0.000227	−2.00**
GR	0.0157579	2.83**
IND	0.0009149	0.64
INN	0.0096888	0.675
Cons	1.000752	14.10***

NB: ***, **, * signifies 1,5,10 % significance level.

plants, dominated by solar, hydro, and wind, to address the issue of electricity and high energy demand, and to reduce reliance on non-renewable energy sources by both construction and industrial firms in this region should be encouraged. During this period, these countries' central governments should improve the feed-in tariff to encourage the use of renewable energy in construction and production. Furthermore, these countries should devise creative ways to make the most of their access to finance and investment to assist the construction and manufacturing of facilities as well as the development of cleaner energy infrastructure. African economies should also strengthen infrastructural cooperation, such as technology and experience management, both outside and inside the area. Furthermore, the administrations of African countries' should assist in increasing domestic investment in research and development, which would help to address the ecological efficiency level.

This study's empirical evidence points to a negative association between infrastructure, industrialization, and innovation as it relates to environmental efficiency. This result demonstrates that fossil fuels account for a significant share of the energy mix in both infrastructure and industrial development. The findings of this study suggest that African economies should increase their investment in cleaner and renewable electrical infrastructures, focusing more on eco-friendly projects in the promotion of renewable energy sources to increase their production potential, increase energy security, and produce higher electrical competencies, and reduce pollution levels. Furthermore, empirical evidence about the relationship between growth and environmental efficiency is given. To improve expansion, energy-efficient equipment and cleaner energy sources are long-term undertakings that require support from financial sources. Strong and established financial markets, institutions, and financial structures are beneficial to the advancement of these initiatives, as they can lower energy demand and so mitigate the negative impact on environmental quality.

CRediT authorship contribution statement

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Data collection and analysis; discussion of the results.
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Conceptualization; literature review; producing first draft.
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Conceptualisation; writing; editing and formatting.

Data availability

Data will be made available on request.

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