

Africa Countries' Energy Efficiency: Evidence from a Directional Distance Function Approach

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Abstract

Energy is recognized as the backbone of economic development while at the same time it is the most contributor to global warming. This paper aims to assess energy-efficiency of a sample of African countries over the period from 1971 to 2014. Through a directional distance function approach, we estimated both the energy efficiency and the environmental energy efficiency scores in the sample. The results showed that ignoring the undesirable output, i.e. dioxide carbon emissions associated with environmental degradation, overestimates countries' energy inefficiency. Besides, from a non-parametric approach, we shed light on the sensitivity of countries environmental energy efficiency to the income level. Our findings confirmed the sensitivity of environmental-energy efficiency to the Kuznets curve hypothesis. In particular, countries with high-level income are the most environmental-energy efficient in the sample over the period of study. The paper ends with some policy implications and some research perspectives.

Keywords

Energy, Environmental Efficiency, Directional Distance Function, Africa

1. Introduction

The debate among economists on energy efficiency originated after the 1973 oil crisis when the energy security of importing countries was threatened due to the oil embargo proclaimed by the world's major oil producers. Thus, an important concern of the public authorities is to find appropriate strategies to satisfy the energy demand which is still growing at high rates. The recent increases in global energy demand of 1.9% in 2017 and 2.3% in 2018 which is the biggest increase of the last three decades confirmed the need for countries to worry about their

energy security (IEA, 2018). The pioneering work of Lovins and Bethe (1977) will then distinguish three fundamental paths to achieve the energy goal of countries. First, one could increase energy production through fossil fuel sources, such as petroleum, coal, uranium. Second, countries could look for improving the rational use of available energy resources, i.e. their energy efficiency which could be defined in economics as the less use of energy for performing the maximum amount of desirable output. Recent studies in developing countries, as well as industrialized countries, found that the greater the energy efficiency is, the lower the energy demand issues are. Agyarko et al. (2020) and Van Buskirk et al. (2007) indicated that households' appliance subsidy policies electricity sector reforms, institutional quality could be used for improving countries energy efficiency.

Finally, countries could mix their energy sources by increasing the share of renewable energies, and many studies found evidence of such a hypothesis (Chang, 2020; Nieto et al., 2020; Ozoegwu & Akpan, 2021). According to these authors, increasing the share of renewable energies, such as solar, wind, biomass energies, in the countries' energy mix has significant impacts on their energy efficiency. However, with the global warming concerns, the concept of energy efficiency has moved from a purely economic concept to an economic and environmental concept. Hence, one could talk about "Eco-Energy Efficiency" or "Environmental-energy Efficiency" or "Energy and Environmental Efficiency" (EEE) for taking into account pollution issues in the energy efficiency measurement.

In order to shed light on the understanding of countries' energy efficiency, scholars have performed many studies which can be classified into generations. The first generation of studies was initially interested in examining the energy efficiency of countries around the world under the pure economic orientation of the concept of energy efficiency (Cantore, Cali, & Velde, 2016; Rajbhandari & Zhang, 2018). Throughout single input (energy) as well as multi-outputs (energy, capital, and labour) production functions, these authors tried to evaluate and explained the main drivers of countries' energy efficiency. They generally concluded that countries can improve their energy use without increasing the amount of input.

A second generation is refining the concept of energy efficiency by taking into account the environmental dimension (Djordjević & Krmac, 2019; Robaina-Alves, Moutinhob, & Macedoc, 2015). For instance, Djordjević and Krmac (2019) examined the environmental energy efficiency of the European countries' transport sector using the non-radial Data Envelopment Analysis (DEA) model. Their findings support that the road sub-sector is the most environmental energy efficient. Robaina-Alves et al. (2015) also used a stochastic frontier model to evaluate the energy and environmental efficiency of European countries during 2000-2011. Their results showed that countries are environmentally energy efficient after the implementation of the Kyoto Protocol in 2005. In the second generation of works, instead of a single output production function, they used a multi-output production function in which an undesirable output measured by pollution is taken into account. They revealed significant differences between energy efficiency and environmental energy efficiency scores.

This paper contributes to existing literature on energy efficiency in Africa, especially that of the environmental-energy efficiency area by investigating the environmental-energy efficiency of African countries. The novelty of this paper is twofold. First, we use the directional distance function approach to estimate both energy inefficiency and environmental-energy efficiency scores by taking into account countries' specific effects over a long period of 44 years. Second, the paper finds out the economic impact of environmental-energy efficiency in Africa through a non-parametric approach. Finally, our results are expected to contribute to a better understanding of how policy-makers could improve the economic and environmental use of energy in Africa.

The rest of the paper is organized as follow. The second section presents the methodology and data sources. The empirical results and the analysis are presented in the third section. Finally, we conclude with some policy implications in the last section.

2. Environmental Energy Efficiency in Africa

Studies on energy efficiency including the environmental pillar in Africa are scarce and very recent apart from those of Ohene-Asare et al. (2020) and Tachega et al. (2021). Indeed, Ohene-Asare et al. (2020) assessed the environmental energy efficiency of a sample of African countries during the period 1980-2011. Through a Slack Based Model (SBM) under variable return to scales, they found that countries can improve their energy efficiency by 35% while significant differences in environmental energy efficiency are recorded across regions. Recently, Tachega et al. (2021) assessed both energy efficiency and environmental energy efficiency of 14 oil-producing countries in Africa during the period 2010-2017 using a DEA slack-based model. They used capital, population, crude oil, natural gas, and electricity as inputs and GDP and CO₂ emissions as respectively desirable and undesirable output. Their findings revealed that not take into account CO₂ emissions overestimate countries' energy efficiency. Amovine et al. (2019) also investigated the energy efficiency improvement of 25 African countries through a dynamic data envelopment analysis slack-based model from 2006-2014. They concluded that the energy efficiency within the sample is low during the period of analysis. However, their study failed to consider the environmental issue.

Yet the issue of environmental energy efficiency is of great importance to African countries for several reasons. First, the continent experienced moderate rates of economic growth these last two decades. From 2000-2014 Africa recorded an average economic growth of 5% even though this performance fell smoothly to 3.1% during the period 2015-2019 (Osman, 2020). However, these three phenomena are reputed to be responsible for high energy demand. Second, Africa's energy demand increased by 2.4% per annum during the last decade against a world average of 1.6% (BP, 2020) while 45% of its primary energy con-

sumption comes from biomass and 39% is based on hydrocarbons. Yet, biomass energy sources are the most pollutant energies (IEA, 2019). Third, the continent's energy intensity which is the energy used for producing one unit of gross domestic product (GDP) remains the highest in the world, i.e. 0.25 kilogram of oil equivalents per five dollars, far higher than that of other developing regions of the world. For example, countries in Asia have an energy intensity score of 0.22 kilogram of oil equivalents per five dollars, and those in Latin America have a score of 0.14 kilogram of oil equivalents per five dollars (UNSD, 2010).

Furthermore, according to IEA (2019), African countries still have high energy intensity scores. For instance, the energy intensity of sub Saharan Africa was about 7.3 megajoules per dollar US in 2016 while the world average is about 5.1 megajoules per dollar US. Hence, African countries need to have better control of their energy use to ensure sustainable growth. Indeed, it's argued in the so-called "Africa Case" scenario that progress in energy efficiency contributes to limiting the increase in the total primary energy demand to 50% by 2040 despite the size of the African economy would be four times larger than today. Consequently, facing this high energy intensity which leads to increase energy waste in the Africa region has great socioeconomic consequences (IEA, 2019). Yet, according to this latter source, nearly half of Africans, i.e. 600 million people do not have access to electricity in 2018 and about 80% of Sub-Saharan African households and firms experience frequent power cuts.

Although the work of Ohene-Asare et al. (2020) and that of Tachega et al. (2021) had the merit of evaluating the energy efficiency of some African countries by taking into account the environmental dimension, they overlooked exploring the role of the level of income in the examination of the environmental-energy efficiency of African countries. Yet, there is a theoretical argument in favour of the consideration of the countries' income levels. Indeed, the environmental Kuznets curve hypothesis posits that there is a nonlinear relationship between the environmental quality and countries' income level. According to this theory, countries are polluting at the early stages of their economic development while their preferences for environmental quality increase when reaching a threshold of income per capita. Many studies found empirical evidence of the environmental Kuznets curve hypothesis in developed countries (Blampied, 2020; Rodil-Marzábal & Campos-Romero, 2021) as well as in developing countries (Amowine et al., 2019; Tachega et al., 2021).

Overall, there is a lack of empirical proof on environmental energy efficiency and its drivers in Africa. This paper contributes to fill this gap through a long series of data.

3. Methodology

In order to estimate countries' energy efficiency, we use the directional distance function approach. The advantage of this approach is that it allows estimating separately efficiency when desirable is considered and when both desirable and undesirable outputs are included without any transformation of undesirable outputs.

3.1. Directional Distance Function without Undesirable Outputs

Let the gross domestic product (GDP) creation within a joint production framework of desirable outputs. Let suppose N Decision Makers Units (DMUs) with $x = (x_1, x_2, x_3) \in \mathbb{R}^3_+$ inputs and $y_d \in \mathbb{R}_+$ desirable outputs. In this paper, the vector of inputs $x = (x_1, x_2, x_3)$ which encompasses capital, labour, and energy consumption is transformed to produce a desirable output y_d designing by GDP. Then, the production technology can be described as follows in Equation (1):

$$T = \{ (x_1, x_2, x_3, y_d) : (x_1, x_2, x_3) \text{ can produce } (y_d) \}$$
(1)

In Equation (1), T describes all input-output combinations that are technologically feasible.

We can define the Pyatt (1972) output distance function to represent the technology T as follows in Equation (2):

$$D(x_1, x_2, x_3, y_d) = \inf \left\{ \theta : \left((x_1, x_2, x_3, y_d) / \theta \right) \in T \right\}$$

$$\tag{2}$$

In Equation (2), the producer aims to expand the GDP production *ceteris paribus.* However, it is possible to expand the desirable output and reduce simultaneously the inputs used by the same proportion under the directional output distance function framework. Hence, following Chung, Färe and Grosskopf (1997), we define the directional output distance function instead of the Shephard's output distance function as follows in Equation (3):

$$\vec{D}(x_1, x_2, x_3, y_d; g_{x_1}, g_{x_2}, g_{x_3}, g_{y_d}) = \sup \left\{ \beta: (x_1, x_2, x_3, y_d) + \beta(g_{x_1}, g_{x_2}, g_{x_3}, g_{y_d}) \in T \right\}$$
(3)

In Equation (3), \vec{D} denotes the directional technology distance function, $g = (g_{x_1}, g_{x_2}, g_{x_3}, g_{y_d})$ is a non-zero directional vector through the input-output combination will be scaled. $g_{x_1} \in \mathbb{R}^+$, $g_{x_2} \in \mathbb{R}^+$, $g_{x_3} \in \mathbb{R}^+$, $g_{y_d} \in \mathbb{R}^+$. As Färe, Grosskopf and Weber (2004), we set the observed input-output direction as follows in Equation (5):

$$g = (-x_1, -x_2, -x_3, y_d)$$
(4)

The direction g states that GDP is increased and capital, labour, and energy consumption are decreased at the same proportion.

The vector $\beta = (\beta_{x_1}, \beta_{x_2}, \beta_{x_3}, \beta_{y_d}) \ge 0$ denotes the scaling factors. The distance \vec{D} indicates how far the input-output combination must be projected along the direction g to reach the efficient technology frontier T. Thus, \vec{D} measures the technical inefficiency which takes values in the interval $[0; +\infty]$. A value of \vec{D} equal to zero indicates that the observed DMU is located on the frontier of the best performance. Then the DMU is fully efficient. A higher di-

rectional distance function (DDF) score indicates that the DMU is at a distance from being efficient, i.e. the observed DMU is more inefficient.

When setting the directional vector to g as specified in Equation (4), the Equation (3) becomes as follows in Equation (5):

$$D(x_1, x_2, x_3, y_d; -x_1, -x_2, -x_3, y_d) = \sup \left\{ \beta : (x_1, x_2, x_3, y_d) + \beta (-x_1, -x_2, -x_3, y_d) \in T \right\}$$
(5)

Equation (5) shows that DMUs seek to simultaneously increase GDP and get a maximum contraction in the capital, labour, and the energy consumption used by the proportion β . The value of $\vec{D}(.)$ can be obtained by solving the following linear programming problem as presented in Equation (6):

$$\vec{D}(x_1, x_2, x_3, y_d; -g_{x_1}, -g_{x_2}, -g_{x_3}, g_{y_d}) = \max \beta$$
(6)

In Equation (6), λ_i denotes the intensity level at which countries form convex combinations of capital, labour, and energy consumption into GDP. Regarding the length of the time-space of our data, Equation (6) is estimated under variable return to scale (VRS). We also estimate an output-oriented directional distance function as suggested in the empirical literature (Bampatsou et al., 2013; Wang et al., 2013). Indeed, countries have better controls of their output than inputs such as energy. Besides, this assumption is confirmed as the conditions of isotonicity are meet, indicating that an increase in inputs (capital, labour, and energy) leads to an increase in countries' outputs (GDP). All inputs are positively correlated to outputs at a 1% level of significance (Table A1 and Table A2 in Appendix).

3.2. Directional Distance Function with Undesirable Outputs

In order to know whether there are some biases by estimating countries' energy efficiencies without considering the pollution issue, we also evaluate energy efficiency by including countries CO₂ emissions. By doing that, we estimate the environmental energy efficiency. Generally, two approaches are used for incorporating the undesirable (bad) outputs in the evaluation of efficiency (Scheel, 2001). The first approach is called the indirect approach that transforms the bad output before including it as good (normal) output in the production function. Gomes and Lins (2008) used this approach to evaluating the energy efficiency of a sample of developed and developing countries. The second approach proceeds directly by including the undesirable output in the production function without any transformation then impose the assumptions that undesirable outputs are weakly disposable and the strong disposability of desirable outputs. Many studies applied this approach for assessing countries' energy efficiency (Wang et al., 2013; Tavana et al., 2021).

We use the direct approach as it avoids potential errors in the transformation of bad outputs through the directional distance functions. This method is an additive of inefficiency measure by setting a given direction and is suitable when we face non-negative inputs or outputs (Chambers et al., 1996).

In presence of the undesirable output y_u measured by the CO₂ emissions, the multiple input-output production technologies defined in Equation (1) becomes as follows:

$$T = \{ (x_1, x_2, x_3, y_d, y_u) : (x_1, x_2, x_3) \text{ can produce } (y_d, y_u) \}$$
(7)

In Equation (7), T describes all input-output combinations that are technologically feasible. Thus, the output set is assumed to have the following properties (Chambers et al., 1996):

1) The assumption of null-jointness is presented in Equation (7.1) as follows:

Suppose
$$(x_1, x_2, x_3, y_d, y_u) \in T$$
 and $y_u = 0$, then $y_d = 0$ (7.1)

The assumption of null-jointness implies that the production of a positive amount of desirable output (GDP) must be accompanied by some amount of undesirable one (CO_2 emissions).

2) The assumption that undesirable outputs are weakly disposable is presented in Equation (7.2):

If
$$(x_1, x_2, x_3, y_d, y_u) \in T$$
 and $0 \le \delta \le 1$, then $(x_1, x_2, x_3, \delta y_d, \delta y_u) \in T$ (7.2)

The assumption *of* weak disposability states that a reduction in CO_2 emissions (undesirable output) is feasible only if GDP (good output) is proportionally reduced, given a fixed level of inputs.

3) The assumption of strong disposability of desirable outputs states that:

$$\left(x_1, x_2, x_3, y_d, y_u\right) \in T \text{ and } y_d^0 \le y_d \Longrightarrow \left(x_1, x_2, x_3, y_d^0, y_u\right) \in T$$

$$(7.3)$$

The strong disposability of desirable outputs states that needed outputs can be contracted without reducing the undesirable outputs. Hence, desirable and undesirable outputs are treated asymmetrically in terms of their disposal in the technology process.

Subsequently, the directional output distance function with undesirable output is defined as follows in Equation (8):

$$D(x_{1}, x_{2}, x_{3}, y_{d}, y_{u}; g_{x_{1}}, g_{x_{2}}, g_{x_{3}}, g_{y_{d}}, g_{y_{u}}) = \sup \left\{ \beta : (x_{1}, x_{2}, x_{3}, y_{d}, y_{u}) + \beta (g_{x_{1}}, g_{x_{2}}, g_{x_{3}}, g_{y_{d}}, g_{y_{u}}) \in T \right\}$$
(8)

In Equation (8), the directional vector is set as follows in Equation (9):

$$g = (-x_1, -x_2, -x_3, y_d, -y_u)$$
(9)

The direction g in Equation (9) indicates that the producer aims to expand the GDP production on the one hand, and reduce the CO₂ emissions, and all inputs are used proportionally and simultaneously as much as is feasible.

Finally, in order to know whether energy efficiency scores estimated from both DDF with CO_2 emissions and without CO_2 emissions are statistically different, we then performing the Wilcoxon matched-pairs signed-rank test. In both cases of energy efficiency and environmental energy efficiency, we use the non-parametric

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DEA approach. This latter has been widely used in the assessment of efficiency in various fields. Its main advantage is it does not require any functional form of production technology. Hence, we avoid the risk of misspecification of the production process.

3.3. Sampling and Data Sources

In this study, we use balanced panel data obtained from a sample of 21 African countries during the period 1971-2014. Countries included in the sample are Algeria, Benin, Cameroon, Congo, Egypt, Gabon, Ghana, Kenya, Mauritius, Morocco, Nigeria, Cote d'Ivoire, Congo Republic, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Zambia, and Zimbabwe. The main criteria of countries' inclusion in the sample refer to the availability of data during the period of the study. Referring to the literature on the estimation of energy efficiency at the country-level, we use three inputs i.e. capital, labour and energy used by each country to produce the GDP as the desirable output and CO₂ emissions as the bad output. The capital variable is measured by the gross fixed formation capital in millers of dollars US constant 2017. Energy consumption in millers of kWh is used as a proxy of the energy used in the economy. CO_2 emissions are used to capturing the amount of undesirable output in terms of kilotons. We limited the measure of the bad output to CO₂ emissions among Nitrous oxide (N₂O), Methane (CH₄) because they have been identified in the literature to be the main cause of global warming (IPCC, 2015). Gross domestic product is measured in miller of dollars US constant 2017. All data used in this paper are gained from the World Development Indicators website (http://www.wdi.org/). Details on data sources are presented in Table 1. In this table, the Gross fixed capital formation is used as a measure of capital. It is expressed in billion dollars. The number of workers in thousands of workers is used as a proxy of labour in the production

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Variable	Indicator	Nature	Unit	Source
Capital	Gross fixed capital formation	Input	Billions of US dollar, constant 2010	World Bank
Labour	Number of workers in the country	Input	thousand workers	World Bank
Energy	Energy used	Input	Kiloton	World Bank
GDP		Desirable output	Billions of US dollar, constant 2010	World Bank
CO2	Carbon emissions	Undesirable output	Tons	World Bank

function. The energy consumption in the kiloton is used for measuring energy used. The gross domestic product in billion dollars constant is used to measure countries total desirable output while the pollution is captured by the Carbon emissions. All data used come from the worldwide data indicators maintained by the World Bank Group.

4. Empirical Results and Discussion

4.1. Descriptive Statistics

Results in **Table 2** show that the average GDP in the sample during the period of the analysis is about 97.625 million dollars with a high standard deviation, implying there is a heterogeneity in the income distribution across countries in the sample due likely to the population-size effect. The smallest country in terms of economic performance recorded an average GDP of 2.679 million dollars, while the highest country has an average GDP of 982.725 million dollars. This heterogeneity is also recorded at all those variables namely capital, labour, energy consumption, and CO_2 emissions. For instance, the average CO_2 emission in the sample is 30,015.076 kilotons with a standard deviation of about 74,257.213 which is greater than the mean of this variable.

4.2. Energy and Eco-Energy Efficiency Scores

In this section, we present the results of both the model that takes into account the undesirable output as specify in Equation (8) and that of the model that does not include the undesirable output (Equation (9)). The model without the undesirable output (model 1) is estimated by using the capital, labour and energy consumption as inputs while the single output used is the countries' GDP. Apart from these inputs and output, the model that takes into account the undesirable output (model 2) includes a second output which is the CO_2 emissions. The results of the directional output distance function estimation based on a DEA approach of both two models (**Table 3**) indicate an average energy inefficiency of 5.91 (model 1) while the eco-energy inefficiency is about 0.33 (model 2). These results show that countries tend to be more inefficient when the CO_2 emissions are not taken into account in the evaluation of the energy efficiency performance.

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP	1028	97.625	156.716	2.679	982.725
CO_2	1056	30,015.076	74,257.214	102.676	503,112.4
Labour	1056	23,167,263	25,816,914	600,613	1.764e+08
Capital	1056	10.827	17.546	0.046	112.882
Energy	1054	635.8	523.656	180.701	3129.079

Table 2. Descriptive statist	ics
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Country	Inefficiency	Eco-Inefficiency
Algeria	10.6044	0.0911
Benin	0.9171	0.6357
Cameroon	3.0649	0.3666
DRC	1.3632	0.1271
Congo	0.4651	0.1538
RCI	3.0435	0.3802
Egypt	5.4430	0.1030
Gabon	0.6556	0.0768
Ghana	4.2595	0.4991
Kenya	5.1226	0.3805
Mauritius	0.3888	0.1823
Morocco	19.8536	0.3081
Nigeria	21.6223	0.2364
Senegal	1.2217	0.7007
South Africa	19.6231	0.1316
Sudan	5.2416	0.0580
Tanzania	7.7128	0.3545
Togo	0.2602	0.5829
Tunisia	7.3425	0.3115
Zambia	4.0881	0.4727
Zimbabwe	1.9466	0.9465
Minimum	0.2602	0.0580
Geometric mean	3.0073	0.2592
Maximum	5.9162	0.3380

Table 3. Countries' energy and environmental-energy inefficiencies.

From the results reported in **Table 3**, the countries' ranking indicates that Togo, Mauritius, Congo, Gabon, and Benin are the best eco-energy efficient countries, i.e. when we do not take into account the undesirable output. However, when considering the model that takes into account the CO_2 emissions, the ranking changes and Sudan, Gabon, Algeria, Egypt, and DRC become the best Eco-energy efficient countries. It can be noticed that the ranking has changed with the inclusion of CO_2 emissions, and only Gabon still been in the top five best eco-energy efficient countries. Furthermore, the rank of Gabon has shift from the fourth position in model 1 (energy efficient) to the second-best eco-energy efficiency when taking into account the CO_2 emissions. Hence, the shift in the ranking from model 1 to model 2 could be due to the inclusion of the CO_2 emissions in model 2.

To confirm whether or not that difference is driven by the inclusion of the CO_2 emissions, we run a nonparametric test imposed by the rejection of the null hypothesis of normality of the distributions through the Shapiro-Wilk test for

normality (**Table 4**, rows 1 and 2). A one-sided Wilcoxon matched-pairs signedrank test (**Table 4**, row 3) supports the rejection of the null hypothesis at a 1% level of significance, implying that there is a significant difference between the inefficiency scores estimated from model 1 and model 2. In particular, the model that does not take into account the pollution issues in the evaluation of energy efficiency underestimates the energy efficiency scores. Our results are in line with previous findings that found countries with a high level of CO_2 emissions are less eco-energy efficient than those who have low environmental impact production behavior (Tachega et al., 2021; Bampatsou et al., 2013; Wang et al., 2013). Other findings outside the energy area also confirmed that efficiency models that ignore undesirable outputs tend to overestimate the inefficiency scores (Almanza et al., 2018; Liu et al., 2020). Therefore, in that follows, we interpret only the results obtained from model 2.

Results of model 2 show that the average eco-energy inefficiency score in the sample is about 0.33 during the period of analysis. Our results are in line with those of (Ohene-Asare et al., 2020) who found an average eco-energy efficiency of about 0.35 by using a slacks based model (SBM). In regard to the mean values of inputs and outputs reported in **Table 2**, our findings imply that countries in the sample have the potential to improve on average their GDP by 32.216 billion of dollars US while reducing the amount of labor and capital used by respectively 7,645,197 of labor force and 3.573 billion dollars US and reducing on average 9904.975 tons of CO_2 emission. These results suggest that African countries have to invest more in energy-saving potential. Especially, key economic sectors such as buildings, transports, residential sectors in cities, including energy-using products are identified as energy-saving sources in Africa (Koskimäki, 2012).

As our model that estimates energy efficiency with undesirable output is standardized for allowing countries to produce the maximum amount of GDP when minimising CO_2 emissions and inputs used, that implies if countries aim

Row	Alternative Hypothesis	Test	Statistics	p-value	Decision
01	The distribution of the Inefficiency scores from model 1 is normal.	Shapiro-Wilk test	0.698	0.000	${\rm H_0}^{\star}$ rejected
02	The distribution of the Inefficiency scores from model 2 is normal.		0.934	0.000	H ₀ rejected
03	Inefficiency scores from model 1 are greater than those from model 2.	Wilcoxon matched-pairs signed-rank test	393,127	0.000	H ₀ rejected
04	Inefficiency scores from income group 1 are greater than those from group 2	Mann Whitney test	134,793	0.000	H ₀ rejected

Table 4. Hypothesis tests.

*H₀ is the null hypothesis.

to reduce the environmental impacts of their energy consumption, they become more efficient. These results could be explained explained by the fact that most African countries have a scanty industrialised sector which is the most pollutant economic sector. Besides, one could argue that environmental energy policies have the potential to compel countries to improve their production process through their technology used and the choice for less pollutant energy sources.

4.3. Trend Analysis on the Energy Efficiency

Figure 1 shows the growth of both energy inefficiency and eco-energy inefficiency during the period of analysis. From the left side of **Figure 1**, it can be seen that the energy inefficiency in the sample has increased on average overall periods, while the eco-energy inefficiency has decreased during the same period.

Furthermore, even though both energy inefficiency and eco-energy inefficiency in the sample have been unbalanced over time, it can be noticed that the instability in model 1 has been greater than that of model 2, supporting the view that environmental issues are matter in energy consumption. Especially, green energy policies have the potential to secure strong energy efficiency in the long term. One explanation of the improvement of African eco-energy efficiency could be that since the united nations conference on the environment, of Stockholm in 1972, African countries have ratified many international conventions and protocols agreements for the reduction on global warming such as the united nations framework convention on climate change in 1992, the Kyoto protocol in 1997, the 21st conference of the parties in 2016.

4.4. Income Level and Environmental-Energy Efficiency

In this paragraph, we wonder if the eco-energy efficiency varies with the level of



Figure 1. Inefficiency and eco-energy inefficiency trend.

development. To know that, nonparametric tests have been used. We first split the sample into two groups according to their level of development. The choice of grouping the sample into two relies on the goal to have a sufficient number of observations in each sub-group. We used the gross domestic product per capita based on purchasing power parity (PPP) in international dollars constant 2010 in 2014 to measure the countries' level of development. The countries that GDP per capita is lower than 3996 dollars US are said to be low-income countries (Group L) and those that GDP per capita is greater or equal to 3996 dollars US are classified in Group H, and called high-income countries¹. We then run a nonparametric test, namely the Mann whitey' test.

The results reported in Table 4, row 4 strongly support the hypothesis that the eco-energy efficiency of the high-level income countries is greater than that of the low-level income countries at a 1% level of significance. Our results are consistent with the theoretical assumptions, especially those of the environmental Kuznets curve hypothesis. Our results are also in line with some empirical evidence in Africa (Güngör et al., 2021; Liu et al., 2020). Indeed, Güngör et al. (2021) tested the environmental Kuznets curve with structural breaks and confirmed that the higher is the income level, the better the environmental quality is in South Africa during the period 1996-2016. (Liu et al., 2020) investigated the nexus between income distribution and environmental pollution using a sample of 33 countries during the period 2000-2016. They confirmed a nonlinear effect of income inequality on energy efficiency within the sample while industrialization harms countries' energy efficiency. Thus, our results could be explained by the fact that the higher is the income level, the greater are resources available to invest in innovation, green energy; and the greater are the population preferences for environmental quality. Furthermore, most of the low-income countries face a lack of access to energy; especially electricity, so that their energy supply is not able to satisfy the demand.

5. Conclusion and Policy Implications

Energy security, fossil fuels' price uncertainties, and the global warming concern have increased the need for countries to control their energy use. For that, energy efficiency has become one of the key instruments to evaluating energy policies which shifted into environmental energy efficiency regarding the importance of green gas emissions in industrialized countries as well as in some developing countries. This study aims to fill gaps in the literature of energy efficiency measurement by focusing on African countries. Especially, we evaluated the energy efficiency by including the environmental pillar which seems to be less investigated in the Africa region. Within a framework of a nonparametric directional output distance function with undesirable output (Chung et al., 1997) under the variable return to scales assumption (VRS), we showed that neglecting

¹The Group L includes Benin, Cameroon, DRC, Congo, RCI, Egypt, Ghana, Kenya, Morocco, Nigeria, Senegal, Sudan, Tanzania, Togo, Zambia, and Zimbabwe. The Group H encompasses Algeria, Gabon, Mauritius, South Africa, and Tunisia.

the dioxide carbon emissions in the estimation of energy efficiency leads to overestimating countries' energy inefficiency. Besides, non-parametric tests are used to find out the role of the level of income in countries' environmental energy efficiency. Our results revealed that there are significant disparities in environmental energy efficiency across income level groups. Thus, high-income level countries are more environmentally energy-efficient than those with low-income levels. This funding confirmed the environmental Kuznets curve hypothesis within the sample. Hence, energy policies should be implemented for improving countries energy savings in Africa, in particular in those with low-income levels. Future researches that investigate the divers of African countries' eco-energy efficiency should take into account the income level disparities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

 Table A1. Inefficiency and eco-inefficiency scores, and growth rates.

Year	Inefficiency	Growth rate	Eco-Inefficiency	Growth rate
1971	3.1932	-	0.4562	-
1972	3.1787	-0.4530	0.4633	1.5503
1973	3.9358	23.8170	0.4717	1.8036
1974	4.1580	5.6470	0.4593	-2.6287
1975	4,6838	12.6460	0.4502	-1.9805
1975	5.0073	6 9059	0.4054	_9 9398
1970	5.0075	8 5702	0.4047	-0.1724
1977	5.4304	4.5924	0.4047	-0.1724
1978	5.1875	-4.5824	0.3826	-5.4010
1979	5.2859	1.9010	0.4091	0.9221
1980	6.0024	13.5547	0.4236	3.5361
1981	6.//36	12.84/2	0.4067	-3.9/91
1982	6.2890	-7.1538	0.4108	1.0051
1983	5.6998	-9.3686	0.4003	-2.5485
1984	4.8286	-15.2858	0.3548	-11.3676
1985	4.5453	-5.8670	0.3461	-2.4670
1986	4.0666	-10.5300	0.3375	-2.4658
1987	3.7221	-8.4730	0.3224	-4.4897
1988	3.8821	4.2993	0.3078	-4.5116
1989	4.1675	7.3505	0.3120	1.3663
1990	4.5573	9.3548	0.3147	0.8401
1991	4.4996	-1.2664	0.2991	-4.9523
1992	4.1666	-7.4000	0.3249	8.6245
1993	4.0596	-2.5689	0.3334	2.6242
1994	4.2844	5.5378	0.3261	-2.1879
1995	4.5879	7.0846	0.3360	3.0498
1996	4.9243	7.3317	0.3269	-2.7322
1997	5.2538	6.6901	0.3320	1.5597
1998	6.0975	16.0607	0.3186	-4.0366
1999	5.5966	-8.2160	0.3075	-3.4806
2000	5.5530	-0.7792	0.3156	2.6366
2001	5.2401	-5.6346	0.3008	-4.6961
2002	5.4714	4.4138	0.3042	1.1293
2003	5.8894	7.6402	0.2925	-3.8220
2004	7.4530	26.5493	0.2904	-0.7227
2005	8.6309	15.8042	0.2925	0.7078
2006	9.4916	9.9729	0.2856	-2.3479
2007	9.1288	-3.8228	0.2754	-3.5676
2008	9.7719	7.0447	0.2608	-5.2953
2009	9.8649	0.9517	0.2491	-4.4997
2010	9.8809	0.1623	0.2633	5.7099
2011	9.6991	-1.8394	0.2568	-2.4627
2012	9.4972	-2.0816	0.2508	-2.3387
2013	8.6582	-8.8346	0.2477	-1.2335
2014	8.0112	-7.4730	0.2450	-1.1167
Min	3.1787	-15.2858	0.2450	-11.3676
Mean	5.9162	2.5699	0.3380	-1.3590
Max	9.8809	26.5493	0.4717	8.6245
Variance	4.1869	87.1046	0.0043	15.5115

Outputs/Inputs	Capital	Labour	Energy
GDP	0.885 (0.000)	0.778 (0.000)	0.401 (0.000)
CO_2	0.796 (0.000)	0.419 (0.000)	0.715 (0.000)

Table A2. Pairwise correlation between inputs and outputs.

Note: Values in brackets indicate the P-values.