ASK Publishers

ISSN: 3049-7159

Research Article

Journal of Business and Econometrics Studies

Implications of Economic Complexity for Renewable Energy Consumption and Sustainable Development: Evidence from Sub-Saharan Africa

Nguena Chistian Lambert[1], Zephania Nji Fogwe[2] and Awemu Jonah Wayih[3*]

[1]*Department of Economics, Faculty of Economics and Management, University of Dschang, Cameroon*
[2]*Department of Geography, Faculty of Arts, University of Bamenda, Cameroon*
[3]*Department of Economics, Faculty of Economics and Management Sciences, University of Bamenda, Cameroon*

[*]Corresponding author
Awemu Jonah Wayih, Department of Economics, Faculty of Economics and Management Sciences, University of Bamenda, Cameroon.

Received: November 23, 2024; **Accepted:** December 05, 2024; **Published:** December 10, 2024

ABSTRACT
This study investigates how economic complexity mediates the effect of Renewable Energy Consumption on Sustainable Development in Sub-Saharan Africa for the period 1990 to 2021 and using data for 32 countries. It considered the enhancing effect of renewable energy consumption on sustainable development, and assessed the extent to which economic complexity mediates the effect of renewable energy consumption on sustainable development in Sub-Saharan Africa. For this purpose, the study employed the ARDL Pooled Mean Group estimation technique for the baseline estimations, while the FGLS, PCSEs and Driscol Kraay estimations for robustness checks. The findings of the study reveal that renewable energy consumption significantly enhances sustainable development. The findings equally reveal that economic complexity significantly mediates the enhancing effect of renewable energy consumption on sustainable to the extent that of the total effect of an increase in renewable energy consumption on sustainable development, about 45.75% is transmitted indirectly through economic complexity. The policy inferences from these findings are that the increased and deliberate improvement and use of renewable energy sources would contribute enormously in reducing the ecological damages arising from development, thereby enhancing as sustainability. Moreover, the measures to boost renewable energy use need to be accompanied by rigorous measures to promote the increased production and exportation of more technologically sophisticated products by Sub-Saharan African countries.

Keywords: ARDL, Economic Complexity, Renewable Energy Consumption, Sub-Saharan Africa, Sustainable Development

Introduction

Countries across the world are highly dependent on the consumption of energy for generation of electricity, fuel being the most widely consumed source. Data and statistics show a timid increment in the consumption of renewable energy sources for power generation over the years relative to nonrenewable sources [1]. This confirms the fact that despite the limited natural resources of planet earth, humans still dare to exploit and use its resources as if they are limitless with natural consequences being the increasing rates of environmental degradation and global warming the world is facing [2].

Economic complexity, which refers to the structural changes existing in the production structure as it moves towards more technological and knowledge-based production processes, has become an important consideration in the ongoing climate change global discourse. Given the consensus among climate change experts that climate change is the consequence of environmental degradation, it is important to understand how environmental degradation is influenced by economic complexity in order to design effective climate change mitigation policies [3]. Existing literature alludes to the fact that economic complexity and environmental degradation are interdependent of each other [4-9]. The environment is believed to degrade when income or economic growth rises and since economic complexity explains and predicts cross-country variations in income and economic growth trajectories, economic complexity may have significant implications for environmental degradation [10]. Some scientists hold that the exportation of highly sophisticated products is associated with increased energy consumption, which unavoidably escalates energy intensity and environmental pollution [11]. It could be observed generally that increased complexity levels indicate that the level of the country's

Citation: Nguena Chistian Lambert, Zephania Nji Fogwe, Awemu Jonah Wayih. Implications of Economic Complexity for Renewable Energy Consumption and Sustainable Development: Evidence from Sub-Saharan Africa. J Bus Econo Stud. 2024. 1(6): 1-9. DOI: doi.org/10.61440/JBES.2024.v1.43

productive capacity corresponds to higher energy requirements given that complex products need to be manufactured in very energy-intensive industrial bases, which may adversely impact the environment [12].

Renewable energy contributes enormously to both the volume and composition of exports across countries of the world as seen in the increased investment in, and use of various renewable energy sources by countries. However, despite her rich renewable energy resources, many African countries, especially in Sub Sahara, only consume a small portion of these evidently because of limited technological abilities in these countries to diversify their energy sources [13-15]. The mediocre management of their natural resources and energy sources has engendered poor performance of the Sub-Saharan African economies, as testified by the Environmental Performance Index ranking three Sub-Saharan African countries (Mali, Lesotho and Somalia) among the five most environmental unfriendly nations of the world [16]. It is also true that the national income of most Sub-Saharan African countries is increasing to some extent, arguably because of the average use of renewable energy sources and increasing complexity of their economies. However, their competitiveness has been dropping as per the Global Competitiveness Report published by World Economic Forum that ranked most of the Sub-Saharan African Economies in the bottom quarter [17]. What accounts for such a disadvantage position despite the enormous potentials and numerous policies in place that should render the economies more productive and diversified? The quest to enhance economic complexity and improve diversification may have exposed most of these Sub-Saharan African countries to poor environmental quality, which puts a question mark on the sustainability of their development. This study undertakes an empirical examination of the effect of renewable energy consumption on sustainable development and sizes up the contribution of economic complexity in the said effect.

The rest of the paper is organized as follow: The second section focus on the literature review; the third section present the methodology; the fourth section highlight the empirical findings; and the fifth section lies on the conclusion and policy recommendations.

Literature Review

This study draws some theoretical foundations on which it is based. One is a blend of Savacool's and the Grossman & Krueger's theories, which posit that adoption of cleaner technologies fosters sustainable economic development by reducing dependence on fossil fuels [18,19]. The others are Barbier's green growth theory and the Environmental Kuznets Curve Theory [20,21], which inspire the study to examine the effect of economic complexity on sustainable development.

Increased renewable consumption kindles the demand for renewable energy technologies, the result being technological advancements and economies of scale. These advancements foster industrial innovation and diversification, thereby contributing to a country's economic complexity [22]. Increased demand for natural resources, on the other hand, exerts so much pressure on the environment, giving rise to environmental issues such as climate change, soil degradation, pollution, and biodiversity loss [14]. The level of economic growth is an important catalyst of environmental deterioration to the extent that the environmental and ecological cost of economic progress has particularly become a serious source of worry [23].

Grossman and Krueger were the first to examine the inverted U-shaped connection between numerous environmental degradation indices and economic development [19]. They were able to demonstrate that as the level of development increases, there is an initial rise in the degradation of the environment but beyond a specific limit, environmental deterioration reduces with increased economic growth. According to Neagu, as an economy's complexity increases, so does product diversity, and more output contributes to higher emissions and higher ecological footprint [11]. Yet, economic complexity can have a beneficial impact on the quality of the environment since it involves research and development activities as well as the ability to promote eco-friendly goods and clean technology. Studies reveal that countries exporting complex (high productivity) products, enjoy better health outcomes, compared with those exporting low productivity products. Additionally, some evidence exists that ECI contributes to health improvements through consolidation employment opportunities. Other studies reveal that countries producing (and exporting) sophisticated high-value products, tend to enjoy more dependable economic growth, which renders them relatively wealthier, with less income inequality [24].

The first segment of empirical literature reviews literature on the effect of renewable energy consumption on sustainable development and the second looks at literature on how economic complexity mediates the effect of renewable energy consumption on sustainable development.

The contribution of renewable energy consumption to sustainable development has become very crucial on two counts: first, the many challenges faced in universal struggles to attain the sustainable development agenda, the main one being the tenacious increase in environmental degradation; second, the multidimensional role played by renewable energy as an essential tool for the reduction of greenhouse gas emissions and the mitigation climate change [24]. While Ojong contended that renewable energy use could enhance energy security, sustainable economic development, and economic growth, and Ojong argued that it plays a major role in tackling energy poverty, Nchofoung et al. posited that it counteracts negative shocks, especially in the agricultural sector [26-28]. Taner argued that renewable energy consumption has a positive effect on sustainable development in the long term as opposed to non-renewable energy consumption that has a negative effect [29]. Aboul-Atta & Rashed reported an inverse correlation between renewable energy consumption and Sustainable Development Index and identified a set of sustainable development indicators that serve as determinants of renewable energy consumption [30].

Regarding the mediating role of economic complexity in the relationship between renewable energy consumption and sustainable development Boleti et al contended that Economic complexity could either support or hinder sustainable development in the renewable energy sector, depending on various factors [31]. Nguyen et al. posited that the promotion of economic complexity could be an effective strategy for promoting renewable energy adoption and sustainable development through the mitigation of carbon emissions [32]. Lorente et al, Buhari et al and Leitão et al showed that both renewable energy and economic complexity enhance sustainable biodiversity by mitigating environmental degradation problems and climate change [33,35]. On their part, Montiel-Hernandez contended that renewable energy consumption supports or contributes to sustainable development only by positively influencing economic complexity [36].

This paper has the objectives to examine the effect of renewable energy consumption on sustainable development in SSA and the mediating role of economic complexity in this effect. To do so, the study uses data for 29 countries in Sub-Saharan Africa for a 32 years period from 1990 to 2021. These objectives are of crucial importance in this era when global concerns are strongly animated by the United Nations' Sustainable Development Goals (SDGs) at the centre of which is the aspect of renewable energy adoption and use. While the seventh goal (SDG 7) has as aim to ensure access to affordable, reliable, sustainable and modern energy for all, there is need for concerted effort to precipitate the hitherto slow transition from fossil fuels to renewable energy [37].

To our knowledge, some studies that are closest to this issue are those of Abdi and Mbiankeu & Kaguendo [38-39]. The former examined the impact of Economic complexity and Renewable energy consumption on Carbondioxide emissions in 41 countries of SSA between 1999 and 2018 while the latter examined how the relationship between economic complexity and inclusive growth is moderated by renewable energy consumption and biomass energy consumption in 22 SSA countries from 2000 to 2017. This current study assesses the influence of renewable energy and economic complexity on different Ecological Footprint aspects and Human Development aspects to capture the implications of Energy use policy and economic diversification among these nations, on the environment and the betterment of the livelihood of the citizens. In addition, it projects the need for policymakers to accord some substantial attention on economic complexity as it has implications for the sustainability of the development process. The study is based on the hypotheses that renewable energy consumption significantly enhances sustainable development in Sub-Saharan Africa and that economic complexity is a mediating channel through which renewable energy consumption affects Sustainable development in Sub-Saharan Africa.

Methodology

Data Sources

The study is based on a sample of 29 countries out of the 49 countries identified to belong to SSA, covering a period of 32 years from 1990 to 2021 inclusive [40]. The data for renewable energy consumption were obtained from the World Development Indicators database (World Bank). Those for economic complexity were sourced from the database of The Observatory of Economic Complexity and those for indicators of sustainable development, as well as other variables, were obtained from varied source including the Human Development Indicators database (UNDP), World Development Indicators, Global Materials Flow database and the Worldwide Governance Indicators (World Bank).

Variables Used

The main dependent variable in this study is sustainable development (SD) which is captured or measured using the sustainable development index (SDI) that was constructed through the principal components analysis.

The first independent variable of interest is renewable energy consumption, which is measured as a percentage of total final energy consumption. Renewable energy consumption has been found to contribute positively to several SDGs, including clean energy access, climate action, and economic growth and to have statistically significant positive effect on sustainable development in the long run [29]. As such, it is expected that the effect of renewable energy consumption of sustainable development would be a positive or enhancing one.

The second independent variable is economic complexity measured through the economic complexity index (ECI), with values ranging from -3.9 to 2.5. Higher values signify a higher ranking for the countries as concerns the production and exportation of technologically sophisticated products [10]. Aluko et al. posited that economic complexity mitigates environmental degradation while Penny & Alexander argued that higher ranked countries are more likely to have higher environmental patenting rates, lower CO_2 emissions, and rigorous environmental policies [41,42]. Therefore, economic complexity is expected to produce a positive effect on sustainable development.

The control variables include GDP per capita measured as a percentage growth per year; trade openness which is measured as trade share percentage of GDP; inflation; population growth rate; credit to private sector and Foreign Direct Investment [43-47].

Model Specification and Regression Methods

The effect of renewable energy consumption on sustainable development is quantified by modelling sustainable development in country i in year t (measured by sustainable development index of that country -$SDIndex_{i,t}$) as a function of renewable energy consumption ($REC_{i,t}$), and other correlates as shown in equation 1.

$$SDIndex_{i.t}=\alpha_0+\alpha_1\, REC_{i.t}+a'\,X_{i.t}+\epsilon_{it} \qquad (1)$$

where $SDIndex_{i,t}$ is the sustainable development index for country i in year t; $REC_{i.t}$ is the renewable energy consumption score for country i in year t; $X_{i.t}$ is a vector of other correlates that are susceptible to have an effect on sustainable development, namely, income as measured by GDP per capita, trade openness, inflation, credit to private sector, population, foreign direct investment and governance; ϵ_{it} on its part is the idiosyncratic error term.

To examine whether economic complexity mediates the effect of renewable energy consumption and sustainable development in SSA, we followed Baron and Kenny's step-wise regression approach, while taking into consideration the critique and adjustments proposed by Zhao, Lynch, and Chen [48,49]. Baron and Kenny suggested a procedure for testing for mediation effect that consists in a series of steps [48]. The first step consists in conducting a regression analysis with the independent variable predicting the outcome variable while controlling for other covariates (equation (1)), using the ARDL-PMG technique.

In the second step, we perform a regression with the independent variable predicting the mediator while controlling for other covariates (equation (2)), using the Panel Dynamic OLS (DOLS) technique.

$$EC_{i.t}=\beta_0+\beta_1 REC_{i.t}++b'X_{i.t}+\epsilon_{it} \quad (2)$$

The third step consists in performing a regression with the mediator predicting the outcome variable while controlling for other covariates (equation (3)), using the ARDL-PMG technique.

$$SDIndex_{i.t}=\delta_0+\delta_1 EC_{i.t}+d'X_{i.t}+\epsilon_{it} \quad (3)$$

Step four consists in regressing the outcome variable on both the predictor and the mediator, while controlling for other covariates (equation (4)), done using the ARDL-PMG technique.

$$SDIndex_{i.t}=\lambda_0+\lambda_1 REC_{i.t}+\lambda_2 EC_{i.t}+\gamma' X_{i.t}+\epsilon_{it} \quad (4)$$

It should be noted that for mediation to be possible, the coefficients α_1, β_1 and δ_1 in equations 1, 2 and 3 have to be statistically significant. Then in step 4, we would conclude that some form of mediation is present if λ_2 the coefficient of the mediator remains significant in the equation. If this happens and the predictor is no longer statistically significant, then we conclude that there is full mediation. But if both the predictor and the mediator remain statistically significant, then we conclude that partial mediation is taking place. In the latter case, we calculate the indirect effect and test its significance by following Sobel whose approach to calculating the indirect effect consists in simply multiplying the coefficient of the mediator in equation (4) with by the coefficient of the predictor [50]. That is,

$$indirect\ effect=(\lambda_2)(\alpha_1) \quad (5)$$

The pooled-mean group (PMG) estimator which was proposed by Pesaran et al. as a panel autoregressive distributed lag (panel ARDL) estimator was used to estimate the long run effect of renewable energy consumption on sustainable development [51]. This is because it helps to examine both the long-run effects and the short-run relationships among the variables. The PMG estimator also helps to investigate the speed of adjustment and whether or not cointegration exists among the series in the model. Being a dynamic estimation technique, it accounts for cross-sectional dependence and integration of different orders, as were the cases with the data used in thus study. The PMG estimator is based on the maximum likelihood and the autoregressive distributed lag procedure. This estimator constraints the long-run coefficients to be the same across panels but allows the short-run coefficients (with the speed of adjustment), the intercepts and error variances to vary across the panels. If the long-run homogeneity restrictions are correct, then the PMG outperforms the mean group (MG) estimator because the MG estimator allows the long-run coefficients to differ across panels.

The Panel DOLS is applied in step 2 because it accounts for endogeneity bias that could arise from a two-way causality between REC and EC, accounts for serial correlation and works well even in small samples. The panel DOLS approach takes care of serial correlation, heteroskedasticity and endogeneity by adding the lags and leads of the independent variables.

For robustness, a second set of estimators was employed in this study to investigate the effect of renewable energy consumption on sustainable development. They are the feasible generalised least squares – FGLS; regression with panel-corrected standard errors – PCSE; and regression with Driscoll-Kraay standard errors - DKSE [52-55]. These static estimators, which account for heteroskedasticity, serial correlation and cross-sectional dependence, are useful in estimating relationships among variables that are stationary at level or integrated of the same order, and where the errors might be heteroskedastic, serially correlated or cross-sectional correlated. The FGLS and PCSE estimators are only valid if the number of time periods is greater than the number of cross-sections while DKSE is valid regardless. In addition, the PCSE estimator performs better in small samples than the FGLS estimator.

To formalize these approaches, we rewrite the renewable energy consumption model in matrix form as follows:

$$Y=X\beta+U \quad (6)$$

Here, $Y=(y_1',\ldots,y_T')'$ is the $NT\times 1$ vector of the dependent variable y_{it} where each y_t is an $N\times 1$ vector. In similar fashion, $X=(x_1',\ldots,x_T')'$ is a matrix of the independent variables x_{it}. $U=((u_1',\ldots,u_T')'$ is the vector of residuals u_{it}, where each u_t is an $N\times 1$ vector. Panel heteroscedasticity means that the error variance is constant within each cross-sectional unit, but varies from one cross-section to another. That is, $E(u_{it}^2)=E(u_{is}^2)=\sigma_i$, but $E(u_{it}^2)\neq E(u_{jt}^2)$. Cross sectional dependence or contemporaneous correlation among errors implies that $E(u_{it}\ u_{jt})=E(u_{is}\ u_{js})=\sigma_{ij}\neq 0$ while serial correlation implies that the errors are correlated across time.

The FGLS estimator for β following Bai, Choi and Liao is then stated as:

$$\hat{\beta}_{FGLS}=[X'^{\hat{\Omega}-1} X]^{-1} X' \hat{\Omega}^{-1} Y \quad (7)$$

The PCSE estimate of the panel corrected covariance matrix of β is thus given as:

$$PCSE_{Var(\hat{\beta})}=(X'X)^{-1} X'(\hat{\Omega})X(X'X)^{-1} \quad (8)$$

where $\hat{\Omega}=(E'E)/T \oplus I_t$. The operator $\oplus$ is the Kroenecker product operator, and I_t is an identity matrix of size T.

$$DriscollKraay_{Var(\hat{\beta})}=(X'X)^{-1} \hat{S}_T (X'X)^{-1} \quad (9)$$

In equation (9), $\hat{S}_T$ is defined following Newey and West [56] as:

$$\hat{S}_T=\hat{\Omega}_0+\sum_{j=1}^{m(T)} \omega(j,m)[\hat{\Omega}_j+\hat{\Omega}_j'] \quad (10)$$

where $m(T)$ represents the lag length up to which the residuals may be correlated and $\omega(j,m)=1-j/[m(T)+1]$ represents the Barlette weights that ensure that the matrix is positive semi-definite.

Empirical Findings

The reporting of findings begins with a display of the descriptive statistics (Tables 1 and 2), followed by the condensed results of the baseline dynamic regressions of the four models (Table 3).

Subsequently, robustness is checked using Fully Generalised Least Squares, Panels Corrected Standard Errors (PCSEs) and Driscoll-Kraay standard errors (Table 4).

Table 1: Descriptive Statistics of variables used in the study

Variables	Obs	Mean	Std. Dev.	Min	Max
Id (country)	928	15	8.4	1	29
year	928	2005.5	9.2	1990	2021
income group	928	1.8	.7	1	3
region	928	2.5	1.4	1	4
REC	928	70.2	23.3	8.4	98.3
ECI	928	-.8	.7	-3.9	2.5
SDI	928	42.3	21	0	100
GDPpc growth	928	1	4.8	-31.3	18.1
Trade Open (gdp)	928	76.5	68.7	3.7	951.3
FDI	928	3.5	7.7	-26.6	103.3
Inflation	928	66.3	915.4	-27	26765.9
INVEST (gdp)	928	22.5	10.1	0	79.4
POP growth	928	2.5	.8	-1.9	7.9
CPS (gdp)	928	21.3	24	.5	142.4
Governance	928	-.7	.6	-2.3	2.2

Source: Authors' computation

Table 2: Descriptive statistics for variables used in constructing the Sustainable Development Index

Variables	Obs	Mean	Std. Dev.	Min	Max
Income index	928	.5	.1	.2	.8
Life Expect index	928	.6	.1	.3	.9
Pollution (air)	928	33.5	12.9	14.3	77.1
Areas protected	928	14.6	9.8	0	41.3
GHG total	928	50696.7	92964.6	740	566989.9
Education index	928	.4	.1	.1	.7

Source: Authors' computation

Table 3: Baseline regression results on Economic Complexity as a mediator on the effect of Renewable Energy Consumption on Sustainable Development.

Variables	Step 1 (SDI) ARDL (PMG)	Step 2 (EC) DOLS	Step 3 (SDI) ARDL (PMG)	Step 4 (SDI) ARDL (PMG)
Long Run Equation				
REC	0.399706*** (0.083015)	0.006062*** (0.002066)	/	0.246826*** (0.033713)
EC	/	/	0.178052*** (0.032848)	0.112725*** (0.025916)
GDPPC	0.404938*** (0.136120)	/	0.026781 (0.036839)	-0.006234 (0.030830)
TRADE	0.172227*** (0.034232)	0.000807* (0.000456)	0.045992*** (0.006850)	0.009595 (0.007847)
INFLATION	-0.003185*** (0.000966)	/	-0.000276* (0.000147)	-6.01E-05 (6.02E-05)
POP	-31.45063*** (2.488729)	/	2.122270*** (0.432318)	9.784293*** (0.584528)
CPS	1.165540*** (0.117242)	-0.003707** (0.001614)	-0.059601* (0.031799)	-0.146705*** (0.039122)
FDI	-0.225743** (0.090696)	0.002884 (0.002819)	0.056075*** (0.007510)	-0.024192 0.033589
INVEST_GDP	/	0.000143 (0.001615)	/	/
GOVERNANCE	5.700740** (2.634079)	0.188038*** (0.043167)	-0.139617 (0.835565)	-3.830527*** (0.651781)
R-squared	/	0.889575	/	/
Adjusted R-squared	/	0.701287	/	/
S.E. of regression	/	0.332274	/	/

Long-run variance	/	0.073107	/	/
COINTEQ01	-0.011303*** (0.002713)	/	-0.043283*** (0.007301)	-0.074542*** (0.014186)
C	0.963343*** (0.252070)	/	0.506869 (0.321611)	-1.417660*** (0.423168)

Source: Authors' computation Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4: Robustness check results for economic complexity mediating the effect of renewable energy consumption on sustainable development, using the FGLS, PCSEs and Driscoll-Kraay Corrected Errors estimations.

(SDI)	ARDL (PMG) (Baseline regression)	FGLS	PCSEs	DRISCOLL/ KRAAY
REC	0.246826*** (0.033713)	.1848253*** (.002619)	.033826* (4.86)	.500721*** (.0675515)
EC	0.112725*** (0.025916)	.1101548*** (.0153626)	.2122647 (.3763417)	.6793845 (1.380467)
GDPPC	-0.006234 (0.030830)	.0067331*** .0006858	.0074563 (.0261717)	.2406346 (.2338857)
Trade	0.009595 (0.007847)	-.0127811*** (.0003658)	-.0152175** (.0064177)	-.0252563 (.0165497)
Inflation	-6.01E-05 (6.02E-05)	-3.53e-07 (2.28e-06)	-2.31e-06 (.0000515)	-.0012542** (.0005769)
Population	9.784293*** (0.584528)	1.106024*** (.0221407)	1.097052*** (.404634)	1.926441 (1.548536)
CPS	-0.146705*** (0.039122)	.0492424*** (.0016143)	.0646349*** (.0234848)	.0444377 (.0271167)
FDI	-0.024192 0.033589	-.0013494 (.0008548)	-.0014387 (.0117126)	.2558942*** (.0667874)
Governance	-3.830527*** (0.651781)	.3861528*** (.0361533)	.2616777 (.6400285)	-7.262119*** (.737895)
Constant	/	41.79363*** (.5106057)	39.70578*** (5.603673)	17.97836* (8.829038)

Source: Authors' computation Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5: Supplementary robustness check results for economic complexity mediating the effect of renewable energy consumption on sustainable development, using the ARDL-PMG on the individual components used in constructing the Sustainable Development Index.

REGRESSORS (Model 4)	COMPONENTS OF SDI						
	Income	Life Exp	Air Pollution	Protected Areas	GHGs	Material Footprint	CO_2
REC	0.00120*** (0.000309)	0.00292*** (0.000396)	-0.1897*** (0.032219)	0.11354*** (0.029000)	-1924.9*** (417.5491)	0.09499*** (0.007056)	-129.9295** (63.88410)
EC	0.00130*** (0.000383)	-0.0023*** (0.000509)	0.059862* (0.035281)	0.05469*** (0.013425)	486.7204** (228.2602)	-0.0421*** (0.008108)	204.0497*** (57.01089)
Trade Open	0.00020*** (4.79E-05)	0.00114*** (0.000164)	-0.011524 (0.009731)	-0.1190*** (0.022274)	-102.2264 (80.37816)	0.004836* (0.002825)	42.13565*** (10.88838)
Inflation	-2.26E-06 (1.40E-06)	-7.78E-1** (3.84E-06)	0.000165 (0.000205)	0.07895*** (0.017153)	2352.44*** (445.4351)	-0.0005*** (0.000134)	38.42025 (24.48263)
Population	0.02881*** (0.005074)	-0.1413*** (0.010622)	5.41674*** (0.623657)	1.21239*** (0.334845)	6800.874** (3361.460)	0.69480*** (0.152574)	3966.498*** (1058.341)
CPS	0.00857*** (0.000587)	0.00525*** (0.000491)	0.20799*** (0.036290)	0.08345*** (0.011814)	1515.56*** (386.0323)	0.02413*** (0.006712)	671.1178*** (158.6768)

FDI	9.79E-05 (0.000180)	-0.000747* (0.000401)	-0.2636*** (0.039520)	-0.080824* (0.047156)	-155.6404 (275.7005)	-0.001901 (0.010685)	-33.64865* (20.07970)
Governance	-0.0899*** (0.012352)	0.04481*** (0.012686)	-1.7479*** (0.724001)	0.97515*** (0.157503)	87781.7*** (10107.84)	0.52942*** (0.144010)	8415.119*** (2351.204)
COINTEQ01	-0.09527** (0.044875)	-0.0119*** (-0.01194)	-0.2334*** (0.051239)	-0.02369** (0.010795)	-0.3429*** (0.058348)	-0.4220*** (0.069093)	-0.4220*** (0.069093)

Source: Authors' computation Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The results (Table 3) indicate that the level relationships tested in steps 1, 2 and 3 do exist, namely, the renewable energy consumption significantly enhances sustainable development and significantly increases the complexity of the economies of Sub-Saharan Africa, while Economic Complexity also significantly enhances sustainable development. The tenability of these results was verified at two levels: first as reflected on Table 3 using alternative estimations like FGLS, PCSEs and Driscoll-Kraay estimations; then an ARDL-PMG estimation of the effects of REC and EC on the individual components used in constructing the sustainable development index (Table 5). Despite some minority deviations from apriori expectations, the robustness results generally reinforced the baseline results. The positive effect of renewable energy consumption on sustainable development is consistent with Grossman & Krueger's theory of environmental innovation and technological change innovation, and with Sovacool's theory of energy democracy [18,19]. It is also consistent with a number of previous findings like those of Lohani et al, Ojong and Aboul-Atta & Rashed [21,26,30].

The positive effect of renewable energy consumption on sustainable development is, however, not a given because of issues surrounding the consumption of renewable energy in Sub-Saharan Africa. It is incumbent to identify and resolve certain issues that impede the effective development and use of renewable energy. Political and institutional governance are an obstacle to the consumption of renewable energy in Sub-Saharan Africa and power outages abound because of very low exploitation of potentialities, the use of weak technologies, insufficient funding, and inadequacy of policies in that field [57,58].

The Dynamic OLS estimates on Table 3 indicate that renewable energy consumption increases the complexity level of economies of Sub-Saharan Africa. The result matches the a priori expectations of this study and other findings like those of Duan et al and Wang et al who found that renewable energy consumption positively influences economic complexity [59,60].

The step 3 results reported on Table 3 reveal that economic complexity contributes to promote sustainable development very significantly. This aligns with the apriori expectation of this study, which itself was motivated by existing theories such as the green growth theory of Barbier [20]. The results are also relevant when we consider the analysis of the Environmental Kuznets Curve at higher levels of income [21]. The result is also consistent with the findings of other previous studies such as those of Yaprakli & Özden and Aluko et al. [41,62].

It is noted that the models on steps 1 to 3 are globally significant since the cointegration equation statistic for steps 1 and 3 are statistically significant at 1%, while the R-squared adjusted for step 2 is also very good. We verify the indirect effect of the mediator by considering the coefficients of the predictor and the mediator as reported in the step 4 result. After the introduction of the mediator (economic complexity) into the model, both the mediator and the predictor (renewable energy consumption) retain their respective significance in explaining the outcome variable (sustainable development), which implies the existence of partial mediation. The total effect of renewable energy consumption on sustainable development is 0.247, of which 0.134 is transmitted directly and 0.113 is transmitted indirectly through economic complexity.

Moreover, the test the significance of the partial mediation role which economic complexity plays on the effect of renewable energy consumption on sustainable development, we followed Sobel who proposed an approach to calculating the indirect effect which consists in simply multiplying the coefficient of the mediator by the coefficient of the predictor [50]. This was done using the Sobel Calculator and the partial mediation effect was found to be significant at 10% level.

Conclusions and Policy Implications

The study looked at the implications of renewable energy consumption on economic complexity and sustainable development based on data for 29 countries of Sub-Saharan Africa for the period 1990-2021. Evidence is established of the enhancing effect of renewable energy consumption on sustainable development. The enormous issues with sustainability in the region can be accounted for by the inadequate adoption and use of renewable energy sources as compared to non-renewable energy sources. So, by augmenting the development and consumption of renewable energy sources, the influence of such energy sources for the attainment of the Sustainable Development Goals, will be reinforced through the pertinent role they play in the production sectors of every economy. This study also establishes the evidence that renewable energy consumption can play a very essential and strategic role in boosting economic complexity, but more importantly, economic complexity matters a lot when the effect of renewable energy consumption on sustainable development is being considered.

The study recommends a reinforcement of the development and use of renewable energy sources as a pivotal strategy for the attainment of sustainable development goals. The goals may be varied in number and dimensions, but the effective attainment of almost all them relies much on renewable energy consumption. This concerns particularly those related to climate action and ecological life, affordable and clean energy, poverty and hunger reduction, quality education, good health, clean water and sanitation, decent work and economic growth, industry and infrastructure, responsible production and consumption. Complementarily, strategies should be put in place to boost the complexity of the economies of Sub-Saharan Africa. Such strategies include good governance, relevant education, knowledge intensification, promotion of industrial and infrastructural development to cater for the transformation (sophistication) of products before exportation, the subsidisation of production activities that significantly add value to output and increased investment in research and development (R&D) which is very vital because diversification and the exporting of high-technology products require innovation. Based in the sustained positive effect that Trade openness has on sustainable development, it is recommended that measures should be taken to enhance the international trade relations that SSA countries have with other countries.

References

1. IEA. Share of modern renewable energy in total final energy consumption by sector, 2017-2023. IEA. 2023.
2. Harvey JA, Kévin T, Rieta G, Robin H, Mariana A, et al. Scientists' Warning on Climate Change and Insects. Ecological Monographs. 2023. 93: e1553.
3. Romero JP, Gramkow C. Economic complexity and greenhouse gas emissions. World Development. 2021. 139: 105317.
4. Abbasi F. Riaz K. CO2 emissions and financial development in an emerging economy: An augmented VAR approach. Energy Policy. 2016. 90, 102-114.
5. Balsalobre-Lorente D, Ibáñez-Luzón L, Usman M, Shahbaz M. The Environmental Kuznets Curve, Based on the Economic Complexity, and the Pollution Have Hypothesis in PHGS Countries. Renew. Energ. 2021.
6. Caglar AE, Zafar MW, Bekun FV, Mert M. Determinants of CO2 emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity. Sustainable Energy Technologies and Assessments. 2022. 51: 101907.
7. Majeed MT, Mazhar M, Samreen I, Tauqir A. Economic complexities and environmental degradation: Evidence from OECD countries. Environment, Development and Sustainability. 2021. 24: 5846-5866.
8. You W, Zhang Y, Lee CC. The dynamic impact of economic growth and economic complexity on CO2 emissions: An advanced panel data estimation. Economic Analysis and Policy. 2022. 73: 112-128.
9. Zheng F, Zhou X, Rahat B. Rubbaniy G. Carbon neutrality target for leading exporting countries: On the role of economic complexity index and renewable energy electricity. Journal of Environmental Management. 2021. 299: 113558.
10. Hidalgo CA. Economic complexity theory and applications. Nature Reviews Physics. 2021. 3: 92-113.
11. Neagu O. Economic Complexity and Ecological Footprint: Evidence from the Most Complex Economies in the World. Sustainability. 2020. 12: 9031.
12. Kazemzadeh E, Fuinhas JA, Shirazi M. Does economic complexity increase energy intensity? Energy Efficiency. 2023. 16: 29.
13. Warsame AA, Sheik-Ali IA, Jama OM, Hassan AA. Barre GM. Assessing the effects of climate change and political instability on sorghum production: Empirical evidence from Somalia, Journal of Cleaner Production. 2022. 360: 131893.
14. Adebayo TS, Kirikkaleli D. Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools, Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development, Springer. 2021. 23: 16057-16082.
15. Su SW, Liu F, Stefea P, Umar M. Does technology innovation help to achieve carbon neutrality? Economic Analysis and Policy. 2023. 78: 1-14.
16. Wendling ZA, Emerson JW, Esty DC, Levy MA, de Sherbinin A. Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. 2018.
17. WEF. The global Competitiveness report 2015-2016. World Economic Forum Geneva. 2015.
18. Savacool BK. Energy injustice and Nordic electric mobility: inequality, elitism, and externalities in qualitative expert perceptions of electrification of vehicle-to-grid (V2G) transport (Ecological Economics, in press). 2019.
19. Grossman GM, Krueger A. Environmental Impacts of the North American Free Trade Agreement. National Bureau of Economic Research Working Paper 3914. 1991.
20. Barbier E. The Policy Challenge for green economy and Sustainable Development. Natural Resources Forum. 2011. 35. 233-245.
21. Nahman A, Antrobus G. The Environmental Kuznets Curve: A Literature Survey. South African Journal of Economics. 2005. 73: 105-120.
22. Caldarola B, Mazzilli D, Napolitano L, Patelli A, Sbardella A. Economic complexity and the sustainability transition: A review of data, methods, and literature. Cornell University - arXiv. 2023.
23. Ozturk I. Acravci A. Energy consumption, CO2 emissions, economic growth, and foreign trade relationship in Cyprus and Malta. Energy Sources, Part B: Economics, Planning, and Policy. 2016. 11: 321-327.
24. Lee JW, Lee H. Human Capital and Income Inequality. ADBI Working Paper 810. Tokyo: Asian Development Bank Institute. 2018.
25. Lohani SP, Gurung P, Gautam B, Kafle U, Fulford D, et al. Status, prospects, and implications of renewable energy for achieving sustainable development goals in Nepal. Sustainable Development. 2022.
26. Ojong N. Fostering human wellbeing in Africa through solar home systems: A systematic and a critical review. Sustainability. 2022. 14: 8382.
27. Ojong N. The rise of solar home systems in sub-Saharan Africa: Examining gender, class, and sustainability. Energy Research & Social Science. 2021. 75: 102011.
28. Nchofoung TN, Asongu SA, Njamen Kengdo AA, Achuo ED. Linear and non-linear effects of infrastructures on inclusive human development in Africa. African Development Review. 2022. 34: 81-96.
29. Taner G. Renewable energy consumption and sustainable development in high-income countries, International Journal of Sustainable Development & World Ecology. 2021. 28: 376-385.
30. Abdoul-Atta TAL, Rashed RH. Analyzing the relationship between sustainable development indicators and renewable energy consumption. J Eng Appl Sci. 2021. 68: 45.

31. Boleti E, Garas A, Kyriakou A, Lapatinas A. Economic Complexity and Environmental Performance: Evidence from a World Sample. Environmental Modeling & Assessment. 2021. 26.
32. Neagu O. The Link between Economic Complexity and Carbon Emissions in the European Union Countries: A Model Based on the Environmental Kuznets Curve (EKC) Approach. Sustainability. 2019. 11: 4753.
33. Lorente DB, Foday J, Ahmed S, Turgut T. Renewable energy, economic complexity and biodiversity risk: New insights from China. Environmental and Sustainability Indicators. 2023. 18: 100244.
34. Buhari Doğan, Oana M Driha, Daniel Balsalobre Lorente, Umer Shahzad. The mitigating effects of economic complexity and renewable energy on carbon emissions in developed countries. Sustainable Development, John Wiley & Sons, Ltd. 2021. 29: 1-12.
35. Leitão, Nuno Carlos, Daniel Balsalobre-Lorente, José María Cantos-Cantos. The Impact of Renewable Energy and Economic Complexity on Carbon Emissions in BRICS Countries under the EKC Scheme. Energies. 2021. 16: 4908.
36. Montiel-Hernández MG, Pérez-Hernández CC, Salazar-Hernández BC. The Intrinsic Links of Economic Complexity with Sustainability Dimensions: A Systematic Review and Agenda for Future Research. Sustainability. 2024. 16: 391.
37. Hosseini SE. Transition Away from Fossil Fuels toward Renewables: Lessons from Russia-Ukraine Crisis. Future Energy. 2022. 1: 2-5.
38. Abdi A. Toward a sustainable development in sub-Saharan Africa: do economic complexity and renewable energy improve environmental quality? Environmental Science and Pollution Research. 2023. 30. 1-17.
39. Mbiankeu NS. Kaguendo U. Moving Towards Shared Prosperity: Examining the Linkage between Economic Complexity, Renewable Energy and Inclusive Growth in Africa. SSRN Electronic Journal. 2023.
40. UN. Political definition of 'Major regions', according to the UN. 2010
41. Aluko O, Opoku E, Acheampong A. Economic complexity and environmental degradation: Evidence from OECD countries. Business Strategy and the Environment. 2022. 10.
42. Penny M, Alexander T. Economic complexity and the green economy, Research Policy. 2022. 51: 103948.
43. Tadele A. Review on Effect of Inflation on Economic Growth in Ethiopia. American Journal of Applied Statistics and Economics (AJASE). 2023. 2.
44. Agenda 21. United Nations Conference on Environment & Development Rio de Janerio, Brazil. sustainabledevelopment.un.org. 1992.
45. ICPD. Programme of Action adopted at the International Conference on Population and Development Cairo. 20th Anniversary Edition. 1994. 5-13.
46. Diallo AK, Masih M. CO2 Emissions and Financial Development: Evidence from the United Arab Emirates Based on an ARDL Approach; MPRA Paper. University Library of Munich: Munich, Germany. 2017. 82054
47. Izadi J, Madirimov B. Effect of foreign direct investment on sustainable development goals? Evidence from Eurasian countries. Journal of Sustainable Finance & Investment. 2023. 1-20.
48. Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology. 1986. 51: 1173-1182.
49. Zhao X, Lynch JG Jr, Chen Q. Reconsidering Baron and Kenny: Myths and truths about mediation analysis. Journal of Consumer Research. 2010. 37: 197-206.
50. Sobel ME. Asymptotic intervals for indirect effects in structural equations models. In S. Leinhart (Ed), San Francisco: Jossey-Bass. Sociological methodology. 1982. 290-312.
51. Pesaran MH, Shin Y, Smith RP. Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. Journal of the American Statistical Association. 1999. 94: 621-634.
52. Parks RW. Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated. Journal of the American Statistical Association. 1967. 62: 500-509.
53. Kmenta J. Elements of econometrics (2nd Ed.). New York: Macmillian. 1986.
54. Beck N. Katz JN. What To Do (and Not to Do) with Times-Series–Cross-Section Data in Comparative Politics. American Political Science Review. 1995. 89: 634-647.
55. Driscoll JC, Kraay AC. Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. The Review of Economics and Statistics. 1998. 80: 549-560.
56. Newey WK, West KD. A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. Econometrica. 1987. 55: 703-708.
57. Asongu S, Odhiambo NM. Governance and renewable energy consumption in sub-Saharan Africa, AGDI Working Paper, No. WP/21/030, African Governance and Development Institute (AGDI), Yaoundé. 2021.
58. Agoundedemba M, Kim CK, Kim HG. Energy Status in Africa: Challenges, Progress and Sustainable Pathways. Energies. 2023. 16: 7708.
59. Duan H, Zhou S, Jiang K, Bertram C, Harmsen M, et al. Assessing China's efforts to pursue the 1.5°C warming limit. In Science (New York, NY). 2021. 372: 378-385.
60. Wang X, Chen G, Afshan S, Abraham AA, Abbas S. Transition towards sustainable energy: The role of economic complexity, financial liberalization and natural resources management in China. Resources Policy. 2023. 83. 103631.
61. Yaprakli S, Ozden E. The Effect of Sustainable Development on Economic Complexity in OECD Countries. International and Multidisciplinary. Journal of Social Sciences. 2021. 10: 51-80.