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Determinants of Renewable Energy Consumption in Africa: Evidence from System GMM

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Abstract: The adoption of renewable energy remains Sub-Saharan Africa's best option to achieve sustainable growth and mitigate climate change. The essence of this study is to examine the factors that determine the adoption of renewable energy adoption in Africa by employing the System Generalized Methods-Of-Moment (GMM) to analyze data sourced from 1990 to 2019 on some selected African economies. The study examined the tripartite role of the economic, environmental, and socio-political factors on renewable energy adoption in Africa and noted that a positive relationship exists between economic and renewable energy adoption, supporting the validity of the feedback hypothesis. Hence, a policy that supports simultaneous growth of the economy and renewable energy could be adopted. The results further show that environmental factors such as carbon emission and ecological footprint negatively impact renewable energy (RE) adoption in Sub-Saharan African economies. The impact of socio-political factors is, at best mixed; for instance, the result of urbanization is positive and significant, suggesting that urbanization helps in the quick adoption of renewable energy in the studied economies, while the results of corruption show otherwise. To account for single-country dynamics, the study employed the full PMG and noted that the pollution haven hypothesis holds for a number of African economies. The results offer some policy implications.

Keywords: renewable energy; climate change; carbon emission; economic growth; Africa

1. Introduction

Top on the agenda of global policymakers is defining and designing suitable energy, economic, and environmental policies that can mitigate increasing global carbon dioxide emissions (CO_2) [1–5]. This is premised on the fact that increasing CO_2 emission negatively impacts human wellbeing and health and poses a threat to handing over a secure and sustainable environment to the future generation [6,7]. Achieving sustainable environmental policies capable of reducing CO_2 emissions requires a comprehensive and robust understanding of its causes [8–13]. Extant literature suggests that to keep humanity and prevent negative alteration of man's state; concerted efforts must be taken to reduce and mitigate the impact of greenhouse gas (GHG) emissions and keep the average global temperature at the pre-industrial state of less than 2° C (IPCC 2007, Kyoto Protocol 1997) [4,14–16].

Evidence such as continuous occurrences of super droughts, wildfires, and hurricanes, among others that suggest the intensification of extreme weather events and natural disasters occurring in higher numbers or frequencies as well as magnitude across the globe call for urgent attention from governmental and non-governmental organizations, bilateral and multilateral institutions, to mitigate climate change/CO_2 to avert global disaster [4,5,17,18]. Several actions and policies have been canvassed by various international institutions to curb the negative impact of CO_2 emissions over the years [19–21]. Some of these policies often center on improving energy efficiency, conserving energy, and designing energy strategies [22]. The main drivers of these policies are reducing the high levels of CO_2 emission from intense nonrenewable energy sources and reducing the high percentage of nonrenewable energy in the total energy component (nonrenewable accounts for more than

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80% of the global total energy components). At the center of these two policies is the need to increase the world component of renewable energy in the global energy mix.

Over the past decades, advocacy has identified renewable energy (RE) sources as reliable alternative sources of energy to conventional fossil energy sources such as crude oil, coal, and natural gas, stressing that they have some added advantages of being environmental-friendly, readily available, among others [23]. As noted by [22], there is a rapid decline in the generation cost of renewable energy. There has been strong advocacy for its usage by international organizations such as the 1997 Kyoto Protocol, the 2016 Paris agreement (COP21), the International Energy Agency, and the United Nations, just to mention a few, as it is environmentally friendly and possess the ability to mitigate climate change, produces either no or minimal global warming emissions [24,25]. Essentially, RE promotes economic growth in a number of ways. (i.) RE technologies support the diversification of the energy mix and support energy security via the provision of a reliable, vast supply of renewable energy necessary to achieve sustainable economic growth. (ii.) RE advances both social and environmental benefits as it reduces the amount of CO_2 emission into the environment, hence reducing the cost of addressing environmental pollution. (iii.) Developing RE sources assist economies in becoming self-reliant for energy and avoiding energy shortages arising from external shocks. (iv.) RE creates job opportunities, among others. It is also worth noting that the continuous shocks or upsurge in oil prices and prices of other fossil fuels against the continuous fall in RE technologies are incentives to shifts towards RE sources adoption [26].

Despite the strength of RE as a source of energy, its universal adoption has been relatively slow. For instance, 80% of the world's energy mix is still comprised of nonrenewable energy. This will have a negative effect on the effort to switch toward a green and sustainable energy system. Hence there is a need to explore the drivers of the deployment of RE to know what factors maximize the achievement of sustainable energy. According to [27], factors that can influence the adaption of RE can be classified into nine strands: political, institutional, economic, social, environmental, regulatory, technical, technological, and logistics.

Extant literature on the determinants of RE adoption is multi-dimensional, focusing on energy indicators, environmental factors, explanatory variables, regions and countries, time periods, econometric models, and estimation techniques [27]; for instance, [8,28–31]. In terms of the methodology adopted, ref. [32] canvassed for strong modeling techniques, ref. [33] employed panel data estimation techniques, ref. [34] employed panel autoregressive distributed lag (P-ARDL), and ref. [35] employed bootstrap ARDL, among others. A closer look at most of the extant studies suggests that though Africa has a huge reserve of renewable energy, few studies have been conducted on the possibility of switching toward the adoption of renewable energy. There are few appreciable studies on the determinants of drivers of RE adoption on the continent. This, among others, is the essence of the current study.

A major factor in mitigating increased emission rates is adopting RE in the production and consumption life. RE is healthy for public health, the environment, and the economy; hence, focusing on adopting RE is key to achieving environmentally sustainable economic growth. RE, among others, helps in diversifying the energy mix, increases energy security as it provides a reliable, vast, and renewable supply of energy needed for sustainable growth, and reduces environmental costs owing to addressing issues related to CO_2 emissions. Specifically, RE can be influenced by three main constructs: economic, environmental, and socio-political factors [36–38]. The impact of economic growth on RE adoption could be explained by the influence of macroeconomic variables such as real gross domestic product (RGDP), foreign direct investment (FDI), financial development (FD), and trade openness (TRD), among others. Similar to every source of energy, four possibilities exist in explaining the linkages between economic growth and RE. They are RE-leading, economic growth following hypothesis; economic growth leading, RE following hypothesis; feedback hypothesis where a bilateral relationship exists between RE and economic growth; the fourth possibility is the neutrality hypothesis, where no causality exists between economic growth and RE [20,39,40].

The impact of environmental factors on RE adoption is essentially influenced by two models: the environmental Kuznets hypothesis (EKC); and the pollutant haven models. The EKC noted that a U-shape relationship exists between economic growth and environmental pollution. The theory simply described a non-linear relationship between growth and environmental degradation. The pollutant haven model stressed that the existence of legislation to punish the deployment of environmentally harmful energy sources would motivate the adoption of RE [41–43].

The socio-political strands focus on the ability of governance structure, government policies, and urbanization, among others, to influence the adoption of RE [44–46]. Urbanization as a socioeconomic factor impacts energy consumption and environmental condition as it may induce the enlargement of energy-intensive industries such as steel and concrete, the power industry, and the transport sector, thereby provoking upward shocks to the environment [47]. Another dimension to the contributions of urbanization to energy consumption and the environment suggests that urbanization might improve the environmental quality, provided man is willing to be environmentally conscious and friendly. As important as these constructs are to the adoption of RE, few studies have accounted for them in RE adoption works. For instance, refs. [1,2] did not account for the impact of socio-political factors, and [48–51] only focused on environmental factors. Refs. [52–54] focused on both economic and environment but did not address socio-political factors. The crux of the current study is to calibrate these constructs to discuss RE adoption with a focus on Africa.

Several factors induced our motivation on Africa (as of 2017, African CO_2 emission was 4% of global CO_2 emissions. It grew at an average of 4.6% yr^{-1} over the period 1990–2017 against the global rate of 12.2% yr^{-1}); for instance, extant studies and reports have noted the deteriorating nature of the environmental space in Africa over the last few decades [55,56]. Air pollution and CO_2 emissions account for environmental degradation in the region more than other types of pollution, such as water or land pollution. The region is reported to have one of the most prolonged CO_2 emission growth rates in the world, with more than a 123% growth rate between 1979 and 2017, surpassing the global average of 60% [57,58]. With the current trend in CO_2 emission growth rate, Africa will, by the year 2030, have a 30% CO_2 emission growth rate.

The essence of this study is to investigate the nexus between RE and economic growth, the environment, and socio-political factors by employing a System Generalized Methods-Of-Moment (GMM) model. Our choice of system GMM was influenced by its many advantages over alternative estimation techniques, such as the difference GMM. For instance, system GMM has three clear-cut advantages: (i.) It is useful in reducing endogeneity bias; (ii.) it reduces time-varying measurement error bias; (iii.) it reduces weak instrument error bias [20,59,60]. The system GMM helps address the issues related to endogeneity resulting from the inclusion of other potential endogenous explanatory variables, as well as other possibilities of measurement errors owing to the use of cross-country data displaying high persistence [61–65]. The study intends to ask the following research questions: (i) What drives renewable energy adoption in Africa? (ii) To what extent do macroeconomic variables impact renewable energy adoption in Africa? (iii) Do environmental factors impact renewable energy adoption in Africa? (iv) What is the role of socio-political factors in renewable energy adoption in Africa?

Our study's novel contribution to literature is four-fold. First, to the best of our knowledge, we are among the first studies to examine the drivers of RE consumption in Africa. Africa, as a growing economy, is in dire need of energy and is simultaneously faced with the need to have a safe environment given the alarming rate of CO_2 emission of 123%, surpassing the global average of 60%. Therefore, Africa needs to switch from traditional fossil fuel-dominated energy sources to clean and safer RE sources; hence the need to understand the drivers of RE adoption for appropriate policy adjustment. Secondly, we account for the role of macroeconomic variables, environmental constructs, and socio-political factors in the nexus between energy, economics, and the environment. Thirdly, we employed novel and appropriate estimation techniques, the system GMM which is useful in reducing endogeneity bias, time-varying measurement error bias, and weak instrument error bias, and reducing measurement errors owing to the adoption of cross-country data. Fourthly, we offer some policy implications.

Our study will provide insights into at least six Sustainable Development Goals (SDGs): SDG 7- affordable and clean energy; SDG 8- economic growth; SDG 11- sustainable cities and communities; SDG 12- responsible consumption and production; SDG13- climate action; and SDG 17- partnership for the goal with trade offering leadership.

The remainder of this study is as follows: Section 2 presents the literature review; Section 3 presents the materials and estimation techniques; Section 4 deals with the presentation and discussion of results, while Section 5 concludes the paper.

2. Literature Review

The theoretical note that governs this study is threefold: cointegration (economic growth-related), environmental, and impact. The cointegration (economic growth) strands are further divided into four hypotheses that explain the possibility of causality between RE and economic growth. These hypotheses are energy-leading growth following hypothesis, which states that it is the demand for energy that spurs economic growth; hence, conservative measures to conserve the environment will have negative consequences on economic growth. The second leg of this strand is the economic growth-leading following hypothesis that suggests that it is growth that drives energy demand. The third strand is the feedback hypothesis which states that a bilateral relationship exists between economic growth and energy consumption. The fourth hypothesis is the neutrality hypothesis which suggests that no causality exists between economic growth and energy consumption. Hence, any policy introduced to manipulate either of the two will have little or no effect on the other [20,66,67].

The discussion of the extant literature on the impact of macroeconomic variables on energy behavior remains inconclusive; for instance, ref. [2] examined the dynamic effect of nonrenewable energy, renewable energy, economic growth, and foreign direct investment on the environment based on data sourced from the year 2000 to 2015 for some selected African economies. The study employed panel ARDL that calibrates the pooled mean group, mean group, and dynamic fixed effect estimator to examine the validity of both the environmental Kuznets curve and/or pollution haven hypothesis. The result attained shows that while a negative and significant relationship exists between renewable energy and CO_2 emissions, the relationship between CO_2 and other explanatory variables is positive and significant, both in the short and long runs, except for FDI, which is positive only in the long run. The study noted that EKC does not hold for the studied economy; as a result, it tilts towards the pollution haven hypothesis. This suggests that African economies are less concerned about their environment but place a high premium on growth. A major difference between ref. [2] and the current study is the fact that whereas the former does not discuss socio-political factors, the latter calibrated it into their model; the current study accounts for single-country analysis.

For some selected 55 economies, ref. [68] employed a two-system GMM procedure to examine the nexus between financial development and renewable energy adoption based on data sourced from 2005 to 2014. The study noted that a positive and significant relationship exists between financial development and renewable energy for high-income economies though the relationship is insignificant for low-income economies. The study noted that sophisticated financing is key to achieving RE in the studied economies. The study also noted that the impact of trade openness and carbon emission are statistically insignificant for the economies studied, suggesting that trade has no impact on RE adoption. The results from the impact of carbon emission on RE adoption are intriguing, especially for high-income economies. The authors concluded that the EKC model is valid for the studied economies.

In a related development, ref. [69] noted that financial development is key to achieving the adoption of RE in China. The study emphasized the role of green financing and a green reputation in achieving the deployment of renewable energy that will support growth. The study employed several econometric techniques to analyze both micro and macro data on the Chinese economy from 2015 to 2020. The study identified oil price volatility and geopolitical risk as key obstacles to adopting RE in China. In a related development, ref. [70] noted that financial development is key to achieving RE consumption in Africa based on the study estimation of the generated method of moments (GMM) and quantitative regression (QR) in analyzing data sourced from 2004 to 2014. The study noted that financial inequality is a major setback to progress in RE consumption in Africa.

Ref. [71] noted that financial development, agriculture, and economic growth are key to the adoption of RE in Africa, while corruption and bad governance negatively affects Africa's adoption of RE. The study analyzed case studies, research articles, policy briefs, and project reports across and beyond Africa. It noted that for Africa to achieve the SGDs, the operations of Power Africa, Sustainable Energy for All (SE4ALL) initiative, concerted efforts must be put in place to address corruption on the continent.

Ref. [72] noted that FDI negatively impacts the environment on the one hand and RE consumption on the other hand for China based on the results obtained on the deployment of systems GMM, random effect, and fixed effect on the annual date from 2011 to 2016. The study noted that the pollution haven hypothesis is valid for the study economy.

Ref. [73] noted that RE and nonrenewable energy (N-RE) are key determinants of FDI inflows. Trade, tourism, and market size play positive but less significant roles in attracting FDI for the BRICS, stressing that a negative relationship exists between FDI and inflation rate. Ref. [74] noted that RE has a neutral effect on FDI. Instead, the institutional environment and land availability are the core factors that stimulate FDI. Ref. [75] noted that a long-run relationship exists between FDI, RE, and economic growth for some selected nine countries identified in the Climate Change Performance Index 2018 report

Ref. [76] estimation of data from G-C economies based on data sourced from 1978 to 2014 shows that capital market expansion and trade openness are the leading drivers of CO_2 emission. The results further noted that CO_2 is respectively related to RE adoption (see also ref. [77]. Their results tilt toward the pollution haven hypothesis

In agriculture, ref. [78] shows that a long-run relationship exists between agricultural land expansion and CO_2 emission in Peru though RE improves environmental quality by reducing CO_2 emission. Ref. [79] noted that a positive relationship exists between agriculture and RE, but no such relationship is found to exist between agriculture and CO_2 for the economies of the US, Canada, China, and Poland. Ref. [80] noted that a bidirectional relationship exists between energy and agriculture for the EU. Ref. [81] noted that agriculture, RE, trade, and globalization negatively impact CO_2 emissions in Turkey. The study tilts toward the pollution haven hypothesis for Turkey.

The theoretical note from the environmental strands can be classified into two main types: The Environmental Kuznets Curve and the pollution haven hypotheses. The EKC opined that the relationship between economic growth and environmental pollution is in the form of an inverted U-shaped, such that at the early stage of a nation's economic growth, environmental pollution deepens, and after reaching a certain threshold level, environmental pollution begins to decline. The proponents of this hypothesis are of the view that at the initial stage of development, economies are concerned with achieving economic growth with less concern for protecting the environment, but with time and advancement in economic growth comes a surge in environmental pollution, and attention begins to shift towards achieving clean energy [41,42,82,83].

A variety of these models has been canvassed in the literature focusing on CO_2 emissions as indicators of environmental pollution [42,84]. Some have calibrated the ecological footprint [49,85]. Recent studies have calibrated macroeconomic and finance-related variables to the studies on EKC [86]. The discussion on the relevance of EKC is continuous and yet to be concluded.

The pollution haven hypothesis (PHH) is the view that multinational companies that engage in rigorous pollution fields prefer to move to developing countries with fewer environmental/ecological protection laws. The reverse of the pollution haven hypothesis is the pollution halo hypothesis, which states that FDI could induce a downward trend in CO_2 emission, hence promoting energy-efficient technology usage that revolved around sustainability methods. Accordingly, it is believed that FDI can positively impact the ecosystem of an economy in three channels: scale effect (economic size), technical effect (improved technology), and structural effect (improvement in manufacturing design). The interaction of these effects will improve growth and reduce CO_2 emissions. The proponent of this hypothesis has identified FDI and yawning for development as the key drivers of CO_2 emissions in developing economies [7,42,47]. Closeness to colonial masters by former colonies and globalization, among others, are the reasons that account for the movement of multinational firms with toxic production outlets to less developing economies [72].

The studies on the impact of ecological footprints suggest that a functional relationship exists between the ecological footprint and several variables. For instance, ref. [86] noted that financial debt and renewable energy help reduce environmental degradation and that financial debt, RE, and NRE positively impact the growth of the 15 highest emitting economies. Ref. [86] noted that economic growth and national resources advance the ecological footprint and that human capital in the current state cannot mitigate environmental deterioration. Though RE does decrease ecological footprint, the study established the existence of feedback causality between human capital, urbanization, and ecological footprint. Ref. [31] noted that RE decreases ecological footprint in the long run in Turkey and that a bi-directional relationship exists between RE and economic growth and ecological footprint.

The theoretical note on impact assessment focuses on the role of governance and other socio-political factors in shaping the choice of energy usage to achieve carbon neutrality. The proponents of this thought believe that climate change is a global public issue and requires effective climate governance to address it [87–90]. As noted by ref. [91], energy governance is key to decoupling carbon emissions as it is vital to promoting RE adoption. For a sample of 36 emerging economies, ref. [92] observed that good governance especially economic and institutional governance is key to mitigating CO_2 emission and progressive adoption of RE. Ref. [93] designed a novel, holistic analytical approach to examine energy access governance for the Southern African economies of Uganda and Zambia by employing three data collection methods: qualitative document analysis, semi-structured stakeholder interviews, and closed surveys. The study noted that the rule of law, transparency standards, accountability, and inclusiveness are key to accessing RE for the studied economies. The study also noted that competing regulatory frameworks distort access to RE. Ref. [90] cautioned on the danger of monopolized power in designing and implementing RE for the economies of Nepal and Indonesia. The authors noted that RE designed in the studied economies was bedeviled with the inability to carry the major stakeholders along in its design and running.

Ref. [94] calibrated the role of corruption perception and political governance in energy consumption-economic growth nexus for a team of 49 economies using a dynamic data environment analysis model based on data sourced from 2007 to 2016. The study noted that political governance proxied by political stability, bureaucratic quality, personal safety and security of private property, and legal and regulatory frameworks positively impact energy consumption.

Ref. [89] employed machine learning techniques to analyze the impact of green governance on renewable energy consumption in India and noted that governance structure influences the adoption of energy choices. The study further noted that the taxonomy of green governance proxy by global governance, adaptive governance, climate governance, ecological governance, self-governance, energy governance, and information technology governance are related and work on the same objectives by pursuing different activities.

For Switzerland, ref. [95] examined the role of public awareness and governance structure in the effective transition from nonrenewable energy consumption to renewable energy sources. The study noted that public awareness and good governance are crucial to the effective transition and adoption of RE (see also ref. [88]. Ref. [96] explored the role of both internal and external governance structures in the adoption of renewable energy for some selected 1027 firms spread across 47 economies/regions. The study noted that internal governance structure tends to have a negative influence on RE adoption as it often induces a declining influence on RE, whereas external governance has a negative impact.

In Brazil, ref. [97] employed quantitative measures to access the nexus between water, energy, food, and land as it affects the adoption of biofuels emanating from sugarcane. The study concluded that each of these factors is key to achieving sustainable/green energy adoption in the studied economy. A study by ref. [97] was further expanded by ref. [98], who calibrated the role of geopolitics in adopting RE in Mexico. The study employed an external multi-regional input-output model (EMRIO) that calibrates import dependence and governance quality into the RE adoption framework for the Mexican economy. The study noted that better governance is key to the successful adoption and implementation of RE in the studied economy.

Ref. [50] noted that for governance structure and effectiveness to influence the adoption of RE positively, there is a need to have a holistic view of the consequences of RE adoption by calibrating natural resources extortion into the equation. The study argued that evidence abounds to show that the transition from a fossil-dominated system towards RE will have negative consequences on metal by more than a fraction of 7 by 2050 when compared with the 2015 levels, especially in economies with weak, poor, and failing resource governance up to between 32 and 40%.

Ref. [99] noted that political interference in environmental management, poor or lack of effective implementation, and lack of political independence of environmental agencies, which increases the risk of consumption, are the main factors militating against the adoption of RE in Brazil (see also ref. [100]).

A critical look at the literature reviewed here suggests that little or no study has been conducted on the determinants of renewable energy consumption in Africa, and their findings are inconclusive. This is what the current study aims to do, and by extension, calibrate the role of environmental factors, economic growth, and socio-political factors to study RE adoption in Africa.

3. Materials and Methods

The section presents the data-generating set and sources. It also presents the methodology employed and the justification for employing it.

3.1. Data

The data for the current study were sourced from several reputable global data outlets. For instance, we obtained data on macroeconomic variables, including real gross domestic product (RGDP), foreign direct investment (FDI), financial development (FD), trade (TRD), and government spending (GOVT) from the World Development Indicators (various issues). The data on the inflation rate (INF) was sourced from the United Nations Statistics (UN Data). We sourced data on agricultural output (AGRIC) from the Economic Research Service of the US Department of Agriculture (USDA). Data on environmental factors proxy by CO_2 emission (thousand kt) and ecological footprint were sourced from the BP Statistical Review of the World Energy (various issues). To account for the impact of socio-political factors, we calibrated the impact of governance effectiveness (GOVE) and urbanization (URB) into our model. Data on these variables were sourced from the World Development Indicators (various issues). We also account for the impact of the life expectancy index, education index, and corruption perception index as part of our socio-political factors in shaping the adoption of RE. Data on the education index (EI) and life expectancy index (LEI) were sourced from the United Nations Development Program (UNDP) development reports (various issues). Meanwhile, data on the corruption perception index (COR) was sourced from the Transparency International database. To address issues relating to heteroscedasticity, we standardized our variables by obtaining their natural log forms. Data on renewable energy were sourced from the International Energy Agency database (various issues).

A Priori Expectations

Theoretically, we expect a positive relationship between RE and each RGDP, financial development, trade openness, agricultural output, and FDI. A negative relationship is expected to exist between RE and inflation. On environmental variables, we expect an inverse relationship between RE and $CO_{2.}$ On socio-political constructs, we expect that a positive relationship should exist between government effectiveness and RE. The relationship between RE and urbanization could be either positive (if the people are en vironmentally conscious) or negative if smart cities and the environment are neglected. The relationship between RE and other variables could be either way.

3.2. Methodology

The essence of the current study is to examine the determinant of RE adoption in some selected African economies. The study explored the neoclassical production function employed by [20,26,101] to develop the model for the study as stated below:

$$RE_{it} = \alpha_1 RE_{it-1} + \beta_1 W_{it} + \beta_2 X_{it} + \beta_3 Z_{it} + \delta_t + \varnothing_i + \varepsilon_{it} \quad (1)$$

where RE_{it} is the renewable energy consumption per capita, W is the proxy of all macroeconomic variables that can influence renewable energy consumption, X is the proxy of all environmental factors that can influence renewable energy consumption, Z is the proxy of all socio-political factors that can influence renewable energy consumption, α *and* β are the coefficients of the model, $\varnothing_i$ is the time-invariant country effects, δ_t is the unobservable time effects, ε is the residual term, t is the time period. The GMM estimation techniques proposed by Arellano and Bond for our model, as stated in Equation (2), are as follows:

$$E(y_{it-s} - \Delta u_{it}) = 0 \; for \; t = 3, \ldots\ldots .T \; and \; 2 \leq T \quad (2)$$

Here, y_{it-s} is the suitable lags of the dependent variables. The implication is that the second and further lags of the dependent variables are employed as an instrument for the residual of Equation (1) in differences. As noted by refs. [20,59,102], the estimator of Equation (2) is prone to a huge small sample bias, given the fact that the number of periods is small, with the dependent variables presenting a high degree of persistence. To address this, our study employed the system GMM model as suggested by refs. [40,101,103]. The model is as follows

$$E(\Delta d_{it-s} - (\delta_i - u_{it})) = 0 \; for \; t = 3, \ldots\ldots .T \quad (3)$$

It becomes unattractive and inappropriate to employ the ordinary least squares (OLS), fixed effects, or random effects because of the presence of lagged endogenous variable $y, \; t-1$ in Equation (1), given that y_{it} is correlated with δ_i and it induces upward biases, which is inconsistent with the OLS assumption of independence of the error term from the regressors [101,104–107]. To address this problem, the extant literature on dynamic panel models employed the Arellano and Bond GMM estimation model that employs an internal mechanism to explore the correlation between $y, \; t-1.$ and δ_i. The GMM techniques remove $\varnothing_i$ in short dynamic panels such as Equation (1) by differencing it first. To obtain a relatively consistent estimator, we employed lagged values of the levels of the independent variables as the predetermined variables [26,108]. In specific, when $\varnothing_i$ (I = 1,2, ..., n) are serially uncorrelated, then the second and higher-order lags of the independent variables are valid instruments. Extant literature has shown that a major problem of the [104] GMM model is that it produces poor instruments for the regressors when the regressors display persistence over time. To overcome this challenge, Arellano and Bond 1995, developed a system GMM that can estimate two sets of equations: (i) A set of levels that employ lags of the regressors in first differences as instruments; (ii) a set of equations in first differences that employs lags of the regressors in level as instruments. From the narrative, it can be deduced that the system GMM is superior and appropriate for our model when compared with the difference GMM in at least three areas. (i.) It reduces endogeneity bias. (ii.) It reduces time-varying measurement error bias. (iii.) It reduces weak instrument error bias.

The current study employed the system GMM to address the endogeneity in the data generating set that could occur as a result of including $y,\ t-1$, an indication that RE consumption and many of the other regressors may be jointly determined by the growth rate of the GDP, as well as the possibility of measurement errors that could occur because of employing cross country data that displays high persistence. To examine the validity of the orthogonality assumption of system GMM, we employed the Hansen test of over-identification and the Arellano and Bond tests for second-order and higher-order several correlations $AR(2)$ test, given that system GMM techniques rely on internal instruments. The study adopted the [109] small sample correction of the standard errors for all the two-step system analyses, as suggested by ref. [110]. Some of the variables in some of the studied economies are heterogeneous; hence, we employed a full PMG method for the short-run nexus following [111–113].

4. Results and Discussion

We present the results of the current study in two parts. The first part focuses on the nexus between RE, economic growth, environmental factors, and socio-political factors in the selected African economies, based on system GMM estimation techniques. The second is our analysis focused on the country-specific output of these relationships in each studied economy.

4.1. System GMM Estimates

We present the descriptive analysis results of the relationship between the variables explored in Table 1. The results suggest that FDI has the lowest mean, while corruption has the highest mean value. The result, as presented by standard deviation, suggests that corruption has the highest standard deviation, while RGDP has the lowest standard deviation.

Table 1. Descriptive statistic.

Variables	Descriptive Analysis				Normality Analysis (Natural Log-Form)			
	Mean	**Max.**	**Min.**	**SD**	**Skewness**	**Kurtosis**	**Jarque-Bera**	**Probability**
InRE	1655.98	2368.77	1032.67	367.09	−0.98	2.04	4.77	0.06
InRGDP	0.59	0.88	0.04	0.51	−0.34	3.19	0.72	0.67
InFDI	46.44	64.07	34.57	5.12	0.55	2.04	3.53	0.16
InFD	1438.78	1968.09	1011.11	214.09	−0.56	3.05	478	0.07
InTRD	1.65	2.32	1.33	0.34	0.13	1.45	3.02	0.24
InGOVSD	2.86	5.01	1.18	0.44	0.04	1.63	2.16	0.25
InINF	2.11	5.11	1.15	0.24	0.03	1.43	2.13	0.15
InAGR	11.98	2.07	12.67	7.09	0.71	2.02	4.74	0.04
InC02	12.59	2.88	4.04	0.41	0.23	3.29	0.73	0.47
ECL	43.41	62.01	32.53	5.23	0.51	2.14	3.23	0.36
GOVE	1.78	1.99	1.21	4.49	0.36	3.11	112	0.05
InURB	1.62	2.12	1.31	0.31	0.14	1.15	3.01	0.21
LEI	2.11	3.11	1.12	0.14	0.15	1.03	2.13	0.23
EI	15.18	24.7	2.27	2.04	0.18	1.04	4.01	0.05
COR	0.44	0.14	0.14	0.31	0.31	3.14	0.32	0.17

Source: Author's computation 2023.

We present the results of the impact of our independent variables on the dependent variable (RE) in Table 2. From the results, as shown in columns (1–5), the results of the OLS, fixed effects, baseline system GMM, and alternative system estimates are presented respectively for robustness purposes. As earlier noted, OLS estimation of Equation (1) induces upward bias for the lagged per RE, while fixed effects induce a downward bias. Empirically, a valid estimate is expected to lie between the OLS and fixed effects [20,60,65,110]. Our results, as presented in column 3 of Table 2, suggests that the two-step system GMM coefficient on the lagged RE is −1.582, and it is between the upward-biased OLS estimates of

−1.143 and downward-biased fixed effect estimates of 5.446. The results also suggests that our estimation is negative and highly significant. This suggests the existence of conditional convergence across the selected African economies studied (See also [111]).

Table 2. Baseline system GMM results.

Dep. Variable: *RE*	**[1] OLS**	**[2] Fixed Effect**	**[3] SYSGMM1**	**[4] SYSGMM2**	**[5] SYSGMM3**
InRE	1.644	1.754	2.671	2.601	1.908
	[0.012]	[0.051]	[0.132]	[0.102]	[0.014]
InRGDP	0.169	0.167	0.176	0.164	0.161
	[0.012]	[0.004]	[0.004]	[0.006]	[0.023]
InFDI	0.015	0.017	0.019	0.014	0.298
	[0.015]	[0.051]	[0.002]	[0.004]	[0.013]
InFD	0.042	0.029	0.027	0.074	0.043
	[0.071]	[0.052]	[0.025]	[0.062]	[0.016]
InTRD	0.056	0.058	0.061	0.059	0.058
	[0.051]	[0.051]	[0.005]	[0.015]	[0.016]
InGOVSD	0.171	0.166	0.158	0.158	0.155
	[0.007]	[0.005]	[0.004]	[0.013]	[0.026]
InINF	0.152	0.144	0.132	0.112	0.111
	[0.042]	[0.007]	[0.007]	[0.007]	[0.035]
InAGR	0.162	0.122	0.133	0.144	0.151
	[0.005]	[0.041]	[0.008]	[0.007]	[0.027]
InC02	0.111	0.124	0.129	0.131	0.078
	[0.023]	[0.042]	[0.016]	[0.035]	[0.043]
ECL	0.155	0.142	0.151	0.102	0.098
	[0.007]	[0.034]	[0.015]	[0.006]	[0.045]
GOVE	0.169	0.152	0.158	0.158	0.156
	[0.014]	[0.034]	[0.021]	[0.031]	[0.044]
InURB	0.168	0.157	0.172	0.156	0.117
	[0.008]	[0.007]	[0.021]	[0.126]	[0.034]
LEI	0.177	0.163	0.164	0.161	0.111
	[0.021]	[0.043]	[0.013]	[0.114]	[0.036]
EI	0.198	0.187	0.211	0.201	0.188
	[0.035]	[0.036]	[0.019]	[0.119]	[0.026]
COR	0.188	0.177	0.199	0.177	0.167
	[0.015]	[0.016]	[0.016]	[0.114]	[0.015]
Intercept	11.066 ***	32.044			
	[3.544]	[7.633]			
AR(2)test			−2.544	−1.432	−1.435
			[0.105]	[0.113]	[0.109]
Hansen test			33.014	32.189	66.712
			[1.000]	[1.000]	[1.000]

Note: standard errors are reported in []; *** represent 1%. Source: Author's computation 2023.

In column [3] of Table 2, we present the results of the impact of economic growth on RE for the selected economies based on the two-step system GMM. We obtained an estimate of 0.1015 with a 1% level of significance. This suggests that economic growth promotes RE adoption in the selected economies. We validated our results by testing for over-identification restrictions and second-order serial correlation based on $AR(2)$ test and the Hansen test. The ρ-value result of the $AR(2)$ at 0.104 rules out the possibility of second or higher-order serial correlation in the residuals. The results of the Hansen test for over-identification further validated the instruments employed.

A look at the results of other explanatory variates suggests that our results are in line with relevant economic theory and existing empirical findings. For instance, the coefficients of financial development are positive and significant, suggesting that financial development aids the consumption of renewable energy. This supports the finding of [26,69]. The results from each agriculture and trade openness are positive and significant, suggesting that each of them positively supports RE adoption [71]. The results from trade suggest that trade policies such as market liberalization that supports international trade advance the adoption of RE in Africa and, by extension, advance economic growth in the region (see ref. [112]). The result on agriculture suggests that agriculture significantly aids RE adoption in the studied economies and is in line with the findings of [79,81]. As expected, the results on the relationship between RE adoption and inflation are negative and significant. This suggests that with rising inflation, peoples' adoption of RE will be slow as the purchasing power ability of the people is eroded. Our result is in line with the findings of [113].

Our results are mixed for the other explanatory constructs (environmental and socio-political). For instance, while the results from CO_2 emission and ecological footprints are negative and significant, the result from urbanization is positive and significant. This suggests that as these economies get urbanized, the adoption of RE is embraced. This also connotes that, on average, men in these economies are environmentally conscious and friendly. Our results support the findings of [86] for the BRICS economies. The result of CO_2 emission suggests that CO_2 has an inverse relationship with RE in the studied economies (see also ref. [31]). On the socio-political factors, our results also show that governance structure has a positive and significant relationship with RE adoption, suggesting that with a good governance structure, more people will embrace the adoption of RE. The results agree with the findings of [89,92–94] but contradict [71] submission for sub-Saharan African economies.

4.2. Single-Country Estimates Results

Beyond panel estimation, we provide a single-country estimation in our model to account for the heterogeneous behavior of some variables in some of the selected African economies. Hence, our study followed [111–113] to employ a full PMG test for short-run nexus. Before we employed a full PMG model, we conducted unit root tests using In-Pesaran-Shin (IPS), Levin-Lin-Chu (LLC), and cross-sectional augmented Dickey-Fuller test. Our results suggest that none of the variables in the model is found to be $I(2)$). Results are available upon demand. We employed both the Pedroni test and the Westerlund test to conduct a cointegration estimate. The results show that the long-run estimates across all countries are stronger. Results are available upon demand. The result of the full PMG estimate showing country-specific estimate is presented in Table 3. From the results, it can be deduced that the impact of RGDP on RE is positive and significant for Nigeria, Ghana, Kenya, Ethiopia, Morocco, and South Africa, though a negative and significant relationship is noted for Algeria and DR Congo. The results of other macroeconomic variables are similar. For instance, a positive relationship exists between financial development and RE in Nigeria, South Africa, Ghana, and Kenya. The result also shows that foreign direct investment positively impacts renewable energy in Nigeria, Ghana, and South Africa. Trade openness supports RE adoption in Ghana, SA, Kenya, and Nigeria. The inflation rate negatively impacts RE for all the economies studied. On environmental factors, both CO_2 and ecological footprint has a negative and significant impact on RE for Angola, Tanzania, Ivory Coast, Nigeria, Ethiopia, Kenya, and DR Congo. Socio-political factors exhibit some level of positive impact on RE adoption. For instance, urbanization impacts RE adoption positively in South Africa, Nigeria, Ghana, Kenya, Ethiopia, and Angola. Life expectancy and education index impact RE positively and significantly for economies such as Nigeria, South Africa, Tanzania, Kenya, Angola, Ethiopia, and Egypt. The result for corruption index offers mixed results. For instance, it was reported that a negative relationship exists between corruption and RE adoption in Nigeria, Kenya, Ivory Coast, DR Congo, Egypt, and South Africa. Overall examination of our results suggests that most of the studied economies exhibit interacting trends in the adoption of RE.

Table 3. Country-specific full short-run PMG estimates.

Countries	Variables	Coefficients	Countries	Variables	Coefficients
Nigeria	ECT	0.147 *** (0.027)	Egypt	ECT	0.162 *** (0.023)
	InRGDP	0.063 *** (0.047)		InRGDP	0.043 *** (0.044)
	InFDI	0.042 ** (0.052)		InFDI	0.032 *** (0.053)
	InFD	0.201 * (0.054)		InFD	0.211 * (0.034)
	InTRD	0.0032 *** (0.017)		InTRD	0.0043 *** (0.014)
	InGOVSD	0.0116 *** (0.036)		InGOVSD	0.0115 *** (0.033)
	InINF	−0.017 *** (0.027)		InINF	−0.014 *** (0.024)
	InAGR	0.033 *** (0.047)		InAGR	0.023 *** (0.023)
	InC02	−0.012 ** (0.027)		InC02	−0.011 ** (0.024)
	ECL	−0.031 * (0.046)		ECL	−0.021 * (0.043)
	GOVE	0.0158 *** (0.019)		GOVE	0.0128 *** (0.014)
	InURB	−0.019 ** (0.21)		InURB	0.0101 ** (0.011)
	LEI	0.014 *** (0.011)		LEI.	0.013 *** (0.012)
	EI	013 *** (0.003)		EI	0.014 *** (0.006)
	COR	−0.012 ** (0.012)		COR	−0.042 ** (0.013)
South Africa	ECT	0.011 * (0.024)	Algeria	ECT	0.014 * (0.021)
	InRGDP	0.032 *** (0.017)		InRGDP	−0.034 *** (0.013)
	InFDI	0.118 *** (0.036)		InFDI	0.114 *** (0.033)
	InFD	0.107 *** (0.017)		InFD	0.104 *** (0.013)
	InTRD	0.013 *** (0.017)		InTRD	0.014 *** (0.015)
	InGOVSD	0.012 ** (0.017)		InGOVSD	−0.013 ** (0.018)
	InINF	−0.031 * (0.042)		InINF	−0.033 * (0.045)
	InAGR	0.018 *** (0.013)		InAGR	0.015 *** (0.014)
	InC02	−0.109 *** (0.21)		InC02	0.106 *** (0.021)
	ECL	0.0113 *** (0.002)		ECL	0.0115 *** (0.006)
	GOVE	0.013 *** (0.017)		GOVE	0.015 *** (0.014)
	InURB	0.112 ** (0.012)		InURB	0.115 ** (0.014)
	LEI	0.016 * (0.051)		LEI	0.017 * (0.031)
	EI	0.027 *** (0.014)		EI	0.023 *** (0.016)
	COR	−0.111 *** (0.006)		COR	−0.117 *** (0.016)
Kenya	ECT	0.117 *** (0.012)	Morocco	ECT	0.114 *** (0.016)
	InRGDP	0.05 *** (0.041)		InRGDP	0.04 *** (0.021)
	InFDI	0.012 ** (0.021)		InFDI	0.011 ** (0.011)
	InFD	0.011 *(0.041)		InFD	0.021 * (0.011)
	InTRD	0.011 *** (0.019)		InTRD	0.013 *** (0.014)
	InGOVSD	0.119 *** (0.21)		InGOVSD	0.114 *** (0.021)
	InINF	−0.015 *** (0.025)		InINF	−0.014 *** (0.022)
	InAGR	0.13 *** (0.004)		InAGR	0.14 *** (0.004)
	InC02	−0.12 ** (0.012)		InC02	−0.14 ** (0.016)
	ECL	0.012 * (0.014)		ECL	0.015 *** (0.016)
	GOVE	0.012 *** (0.013)		GOVE	0.012 *** (0.016)
	InURB	0.111 *** (0.012)		InURB	0.113 *** (0.015)
	LEI.	0.101 *** (0.02		LEI	0.102 *** (0.031)
	EI.	0.013 *** (041)		EI	0.014 *** (0.051)
	COR	−0.014 ** (0.021)		COR	0.015 *** (0.041)

Table 3. *Cont.*

Countries	Variables	Coefficients	Countries	Variables	Coefficients
Ghana	InRGDP	0.113 *** (0.019)		InRGDP	0.015 ** (0.041)
	InFDI.	001 *** (0.001)		InFDI	0.015 * (0.031)
	InFD	0.012(0.002)		InFD	0.014 *** (0.014)
	InTRD	0.102 *** (0.011)		InTRD	0.114 *** (0.021)
	InGOVSD	0.013 *** (0.011)		InGOVSD	0.013 *** (0.024)
	InINF	0.112 ** (0.072)		InINF	0.015 *** (0.006)
	InAGR	0.011 * (0.001)		InAGR	0.012 ** (0.016)
	InC02	0.023 *** (0.017)		InC02	0.042 ** (0.014)
	ECL	0.016 *** (0.031)		ECL	0.016 *** (0.017)
	GOVE.	0.017 *** (0.021)		GOVE	0.114 *** (0.015)
	InURB	0.053 *** (0.04)		InURB	0.104 *** (0.051)
	LEI	0.012 ** (0.022)		LEI	0.014 *** (0.051)
	EI	0.012 * (0.041)		EI	0.013 *** (0.023)
	COR	0.0118 *** (0.019)		COR	0.005 *** (0.031)
Ethiopia	ECT	0.019 *** (0.021)	Tanzania	ECT	0.015 *** (0.021)
	InRGDP	0.02 * (0.014)		InRGDP	0.014 ** (0.021)
	InFDI	0.011 *** (0.017)		InFDI	0.013 *** (0.014)
	InFD	0.113 *** (0.026)		InFD	0.116 *** (0.21)
	InTRD	0.101 *** (0.011)		InTRD	0.017 *** (0.021)
	InGOVSD	0.013 *** (0.012)		InGOVSD	0.16 *** (0.004)
	InINF	0.014 ** (0.014)		InINF	0.111 ** (0.012)
	InAGR	0.032 * (0.043)		InAGR	0.014 ** (0.014)
	InC02	0.015 *** (0.012)		InC02	0.017 *** (0.014)
	ECL	0.105 *** (0.021)		ECL	0.114 *** (0.013)
	GOVE	0.0115 *** (0.006)		GOVE	0.0011 *** (0.021)
	InURB	0.016 *** (0.012)		InURB.	0.014 *** (0.044)
	LEI	022 ** (0.015)		LEI	0.013 *** (0.021)
	EI	0.017 * (0.052)		EI	0.06 *** (0.051)
	COR	0.024 *** (0.018)		COR	0.015 *** (0.051)
Ivory Coast	ECT	0.113 *** (0.006)	DR Congo	ECT	0.012 * (0.042)
	InRGDP	0.031 * (0.014)		InRGDP	−0.013 *** (0.014)
	InFDI	0.011 *** (0.013)		InFDI	0.114 *** (0.021)
	InFD	0.113 *** (0.032)		InFD	0.013 *** (0.024)
	InTRD	0.107 *** (0.014)		InTRD	0.13 *** (0.004)
	InGOVSD	0.013 *** (0.014)		InGOVSD	0.012 *** (0.012)
	InINF	−0.012 ** (0.017)		InINF	−0.012 ** (0.014)
	InAGR	0.031 * (0.022)		InAGR	0.015 *** (0.015)
	InC02	−0.015 *** (0.014)		InC02	−0.114 *** (0.013)
	ECL	0.105 *** (0.021)		ECL	0.103 *** (0.041)
	GOVE	0.0113 *** (0.002)		GOVE	0.015 *** (0.061)
	InURB	0.013 *** (0.011)		InURB	0.013 ** (0.051)
	LEI	0.112 *** (0.012)		LEI	0.112 *** (0.005)
	EI	0.014 *** (0.031)		EI	0.111 *** (0.014)
	COR	−0.022 *** (0.013)		COR	−0.033 *** (0.014)

Source: Author's computation 2023. Note: *, **, *** represent 10%, 5%, 1% significant level respectively.

5. Conclusions

Decarbonization of the energy sector is at the front burner of the 21st-century energy adoption policy among economies across the world. This is essential to achieving the global quest for sustainable growth via renewable energy that helps in mitigating climate change [10]. A good understanding of the drivers of RE adoption is key to achieving success in RE growth which is essential to attaining sustainable growth. As noted earlier, four macroeconomic-energy possibilities exist in the literature on the link between economic growth and energy. They are the energy-led growth-following hypothesis, growth-led energy-following hypothesis, feedback/bi-directional hypothesis, and neutrality/indifference hypothesis, with each of these possibilities offering unique implications for policy modeling. Beyond macroeconomic variables, environmental factors (such as CO_2 emission and ecological footprint) and socio-political factors (education, life expectancy, and urbanization) often determine the adoption of RE. This paper contributes to the literature by employing appropriate estimation techniques—system GMM and full PMG—to examine the factors that influence the deployment of RE in the African sub-region based on data sourced from 1980 to 2019. Our choice of the system GMM was driven by the possibility that RE adoption and other control variables employed in our model could be jointly determined. The system GMM employed can deal with endogeneity-related issues. It can address the susceptibility of data to measurement error among other things. Validating the orthogonality assumptions in the system GMM, the study employed the Hansen test of over-identification, the Arellano and Bond (2000) test of second-order serial correlation, and the small sample correction of the standard errors.

The results of our estimation techniques and the results from a series of robust tests reveal that the relationship between RE and economic growth in the studied economies is positive and significant, suggesting that RE promotes economic growth on the one hand and economic growth promotes RE adoption on the studied economies, supporting the validity of feedback hypothesis in the studied economies. Hence, policies that support RE adoption should be advanced. A look at other explanatory variables suggests that a positive relationship exists between financial development, foreign direct investment, trade, governance, urbanization, and life expectancy that stimulates RE adoption.

This suggests that for these economies to achieve sustainable growth powered by RE, policymakers need to implement policies that will promote financial development, enhance trade, promote urbanization, and promote education and governance structure. The results of the nexus between inflation and each economic growth and RE adoption are negative, suggesting that policymakers should lower the inflation rate to promote economic growth influenced by RE adoption.

The second strand of our analysis focused on country-specific estimates. From the results, it can be deduced that the results obtained in country-specific estimation are not too far from the ones obtained at the aggregate level. For instance, the connection between RE and economic growth is positive and significant for the economies of SA, Nigeria, and Kenya, suggesting the possibility of a feedback hypothesis.

Though this study has advanced literature by examining the drivers of RE adoption from the point of economic, environmental, and socio-political views, there is a need for further empirical analysis on the subject to further enhance the knowledge of this nexus. Hence, we suggest that further study could examine the impact of RE on total energy adoption in Africa. Different estimation techniques can also be employed.

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Data Availability Statement: We obtained data on macroeconomic variables, including real gross domestic product (RGDP), foreign direct investment (FDI), financial development (FD), trade (TRD), and government spending (GOVT) from the World Development Indicators (various issues). The data on the inflation rate (INF) was sourced from the United Nations Statistics (UN Data). We sourced data on agricultural output (AGRIC) from the Economic Research Service of the US Department of Agriculture (USDA). Data on environmental factors proxy by CO2 emission (thousand kt) and ecological footprint were sourced from the BP Statistical Review of the World Energy (various issues). To account for the impact of socio-political factors, we calibrated the impact of governance effectiveness (GOVE) and urbanization (URB) into our model. Data on these variables were sourced from the World Development Indicators (various issues). We also account for the impact of the life expectancy index, education index, and corruption perception index as part of our socio-political factors in shaping the adoption of RE. Data on the education index (EI) and life expectancy index (LEI) were sourced from the United Nations Development Program (UNDP) development reports (various issues). Meanwhile, data on the corruption perception index (COR) was sourced from the Transparency International database. To address issues relating to heteroscedasticity, we standardized our variables by obtaining their natural log forms. Data on renewable energy were sourced from the International Energy Agency database (various issues).

Conflicts of Interest: The author declares no conflict of interest.

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