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A Cost–Benefit Analyses of Investment in Electricity Supply in Sub-Saharan Africa

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ABSTRACT

The real benefit of electricity consumption (EC) to the economies of Sub-Saharan African (SSA) countries is not well understood since many studies ignore the cost component. Consequently, the push for increased investment in electricity supply has received little serious attention. This study, therefore, presents a method for conducting a cost–benefit analysis (CBA) to argue for or against making significant investment in electricity supply. The benefit of electricity supply to an economy is determined through an autoregressive distributed lag (ARDL) model, whereas the cost is determined through a look-back generation expansion planning (GEP) model. This leads to the computation of a benefit–cost ratio (BCR) that can serve as a justification for or against increasing investment in electricity supply. The proposed CBA method when applied to countries in Sub-Saharan Africa over the period from 2000 to 2019 reveals a BCR ranging from a low of 7 for Ghana to a high of over 108 for Chad. Intuitively, a dollar spent on increasing electricity supply is worth around 7 dollars to the economy of Ghana and over 108 dollars to that of Chad. The CBA result indicates the immense economic benefit yet to be tapped by SSA countries through investments aimed at increasing electricity supply.

1 | Introduction

Data indicates that about 675 million people in the world were living in the dark as of 2021, and that four out of five of them were in Sub-Saharan Africa [1–3]. Available World Bank data indicates that among regions in the world, Sub-Saharan Africa (SSA) consumed the least electricity (505.4 kWh per capita) within the period from 2000 to 2014. In contrast, the second least consuming region, East Asia and Pacific (excluding high-income countries), consumed 1860.9 kWh per capita of electricity, which was three times more than that of the SSA. Within the same period from 2000 to 2014, the SSA region had the second worst average gross domestic product (GDP) per capita (US\$1287.5). In

contrast, the average GDP per capita (US\$2987.4) of East Asia and Pacific (excluding high income countries) was more than twice that of the SSA [3]. These statistics give a hint that perhaps electricity consumption (EC) influences economic growth in some regions of the world.

Many studies have examined the relationship between EC and economic output, and depending on the country under study, finds a bi, uni, or no directional causality between them. Further, studies such as for instance IEA [4], Chirwa and Odhiambo [5], Dey and Tareque [6], Pueyo and Maestre [7], Best and Burke [8], Twerefou et al. [9], Wolde-Rufael [10], confirm that EC has a positive impact on economic output in many developing

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countries, and that shortage of electricity is undesirable for their economies. In fact, it is reported that African countries lose 2%–4% of their annual GDP to energy-sector bottlenecks and electricity shortages [11]. If so, why do countries in the SSA, with less electricity access rates and inadequate electricity supply (for those even with access), fail year-on-year to make substantial investment to increase electricity supply? Perhaps the true benefit of investment in electricity supply is not clearly understood or quantified.

Admittedly, while many studies have been conducted on the impact of EC on economic output, these studies usually stop short of estimating the cost incurred in providing the amount of electricity needed to achieve such an impact. In other words, the direction of study to date have prioritized estimating the benefit of EC to the economy to the neglect of the cost incurred thereof. Thus, one of the contributions of this research is to extend the electricity-economic growth nexus to include accounting for cost.

There are good reasons for also paying attention to the cost incurred in supplying the amount of electricity needed to achieve the touted economic growth. This is because some studies attribute the low electricity access rate in the SSA mainly to lack of financial resources [12–14]. This presents a conundrum where, on the one hand studies, acclaim that EC in some SSA countries increases economic growth, yet on the other hand, such countries cannot seem to find the financial resources to invest in increasing electricity supply to benefit from the purported economic growth. Indeed, this should not happen if truly the benefit of EC outweighs the cost involved. Thus, a plausible and perhaps justifiable reason for the low electricity access rates in the SSA could be just obliviousness or that improving electricity access rate is of low priority to governments in the SSA region. In that sense, something must be done to awaken or better inform governments in the SSA region to the need to increase investment in electricity supply.

One approach is to highlight the size of the opportunity lost due to failure to invest in electricity supply. This therefore underscores the objective of this research, which is to develop a cost–benefit analysis (CBA) framework for analyzing investment in electricity supply in countries yet to attain substantial electricity access rates. The objective is not to conduct a full welfare-based CBA but rather to estimate and compare supply-side electricity costs as an input into broader policy discussions. A CBA is a proven technique for determining the worthiness of an investment and therefore can be used to argue for increasing investment in electricity supply. In particular, a CBA has the tendency to alert SSA countries on the scale of the opportunity lost due to inaction in finding the necessary financing to ensure an adequate supply of electricity.

However, accurately estimating the cost incurred in providing the amount of electricity needed to bring about the anticipated economic benefit is not trivial. Such estimation involves choosing from several alternative generation plants to minimize the total cost of electricity generation. This study estimates the cost of electricity supply using a proposed look-back generation expansion planning (GEP) model.

Though some CBA studies related to electricity supply in the SSA exist, they all differ from the topic of this research. For example,

Quak [15] carried out a CBA of lighting and electricity services for off-grid communities in the SSA region. Martinez, Oliver, and Trowbridge [16] also carried out a CBA of off-grid solar investments in East Africa. Du Preez, Beukes, and van Dyk [17] also conducted a CBA of concentrator photovoltaic technology use in South Africa. These studies, however, were not focused on the country level. A literature search indicates that this is perhaps the first study to extend the energy consumption-economic growth nexus study to the context of CBA.

This research contributes to the growing literature on electricity policy, planning, and analysis in developing countries by providing a mechanism to assess and compare the cost and benefit of increasing electricity supply. The proposed CBA approach is unique in the sense that it can be used not only to assess the past but the future as well. In particular, the developed GEP model offers a way to estimate the total cost of electricity generated in the past or envisioned in the future, thereby allowing for the calculation of a CBA, whether in the past or into the future. This study also contributes to practice by offering governments in developing countries, especially those in the SSA, the ability to determine whether it is necessary to source for loans or offer incentives to private investors to attract them into the electricity sector. Conceptually, this study, through the lens of a CBA, provides a level of understanding into whether the laid-back approach to investment in electricity supply in SSA countries is justified given the opportunity for increased economic output as a result.

The rest of the paper is organized as follows. Section 2 presents a brief literature review, followed by the model for determining the benefit–cost ratio (BCR) for a desired increase in electricity supply in Section 3. This is followed by an application of the model to determine the BCR of Sub-Saharan African (SSA) countries. Section 5 presents the analysis of the BCR results, and Section 6 concludes.

2 | Literature Review

Both the EC-economic growth nexus and the cost of electricity supply in the SSA have received attention in the literature over the last two decades. This section summarizes the findings of previous studies.

2.1 | EC-Economic Growth Nexus

In general, the relationship between EC and economic growth of a country is assumed to follow one of four hypothetical angles. The growth hypothesis posits that EC drives economic growth and that efforts should be put in place to increase electricity supply [18]. Several studies have found the existence of the growth hypothesis in some SSA countries. Chirwa and Odhiambo [5] found that EC positively influences economic growth in South Africa but negatively in Kenya in the long run. A study by Gyimah et al. [19] found that renewable electricity positively influences economic growth in Ghana. Furthermore, Abdullahi and Sieng [20] examined the impact of investment in energy infrastructure on economic growth in 10 SSA countries and found that countries with reliable electricity supply experience higher GDP growth rates. Likewise, a study by Adams, Klobodu, and Apio [21] on 30 SSA countries finds that

EC has a significant positive effect on economic growth. Furthermore, Zerbo [22] reported the existence of the growth hypothesis in Gabon, Kenya and Nigeria.

On the other hand, the conservation hypothesis posits that economic growth drives higher EC, for this reason there should be less concern that energy conservation policies could hinder economic growth. A study by Nyasha, Gwenthure, and Odhiambo [23] found that economic growth positively influences energy consumption in Ethiopia in the short and long runs. Zerbo [22] also found the existence of the conservation hypothesis in Sudan and Zambia. Other studies involving countries from the SSA that also find the presence of the conservation hypothesis include Asongu, El Montasser, and Toumi [24] and Farhani [25].

The feedback hypothesis also assumes that both EC and economic growth influence each other [26]. Studies concerning SSA countries that have found the existence of the feedback hypothesis include Adams, Klobodu and Opoku [27] who used panel data of 16 SSA countries for the period 1971–2013, Zerbo [22] concerning Cameroon, Ouédraogo [28] concerning Burkina Faso. and the seminal work of Wolde-Rufael [10].

Finally, the neutrality hypothesis assumes no causal relationship exists; thus, energy policies hardly play a significant role in achieving economic growth [9]. Studies pointing to the neutrality hypothesis in some SSA countries include Bah and Azam [29] who used data from 1971 to 2012 for South Africa and found no causality between EC and economic growth, and Zerbo [22] who found the existence of the neutrality hypothesis in Benin, Cote d'Ivoire, Congo, Ghana, Senegal, South Africa, and Togo.

The focus of this research is on the growth and feedback hypothesis in SSA countries where EC is considered to positively influence economic growth, suggesting the need for increased investment in electricity supply. This research argues that studies that find such positive influence should be expanded to include the estimation of the cost to supply the amount of electricity needed to cause such positive change. Such an extension would enable policymakers to better understand how the cost of a proposed investment in electricity supply compares to the benefit thereof.

2.2 | Cost of Electricity Supply in the SSA

The cost of electricity supply is generally considered high in developing countries, particularly in the SSA region. Many SSA countries rely on fossil fuel-based power plants, including diesel generators, leading to high generation costs [30, 31]. The high cost is also partly due to poor supply quality and poor transmission and distribution systems that lead to high system losses [32, 33]. The size of the economies in the SSA also does not promote economies of scale [34] in electricity generation. In addition, grid extension, particularly to rural areas, is very costly [35]. Given the high cost of electricity generation in the SSA region, a CBA is necessary for an intended investment since it is possible that the cost could be significant when compared to the anticipated benefit. A CBA would give the true scale of the benefit to be accrued from a proposed investment aimed at increasing electricity supply, which could serve as an impetus to governments in SSA countries, especially when the scale is truly significant.

3 | Methodology

The methods used in this research to estimate the benefit to the economy due to increased EC, and the cost of supplying the said electricity is presented next.

3.1 | Impact of EC on Economic Output

There is a well-established literature on the estimation of the impact of EC on economic output and vice versa. In general, such studies seek to examine whether there is a long-run relationship between economic output and EC through a cointegration analysis [27]. This study follows largely the approach in Chirwa and Odhiambo [5], and in addition to EC, include other economic indicators as control variables in the estimation. The GDP in gross (current US dollars) of a country is taken as an indicator of economic output and therefore the dependent variable, whereas EC (MWh) of a country is taken as the main independent variable. The study also adds gross fixed capital formation (denoted GFCF, in current US dollars), foreign direct investment (denoted FDI, in net inflows, and in current US dollars), inflation (measured by consumer price index's annual growth rate and denoted as INF), and percentage of Primary School Enrollment (denoted as PSE) as control variables. The PSE variable is meant to be a proxy for labor of which many SSA countries had insufficient data available. This study uses the conventional measure of GDP and incorporates the social cost of electricity supply by including environmentally related costs within the cost-minimization framework presented in Equations (5)–(8), which implies that both the private cost (capital cost, operation and maintenance cost, fuel cost, etc.) and social cost (i.e., cost of carbon emissions) of electricity supply are accounted for in the cost minimization framework.

Thus, the study regards GDP as a function of the independent variables as given in Equation (1) of which their long-run relationship with GDP is sought through a cointegration test.

$$GDP = f(EC, GFCF, FDI, INF, PSE). \quad (1)$$

The above will give the estimates of the marginal effect of EC on GDP to help quantify the aggregate benefit from EC to the economy. To estimate Equation (1), it is important to determine there is such a long-term relation as presented above and to do that, it is important to test for cointegration. Several techniques for performing cointegration tests exist, including the vector error correction model (VECM), and the autoregressive distributed lag (ARDL) model. The VECM is a cointegrated VAR model and is widely used for cointegration tests if all variables (including the dependent variable) are stationary at first difference. The VECM provides both long- and short-run relationships. The ARDL model is also a popular model of choice, especially when some variables are stationary at level and some at first difference. The ARDL method is also the model of choice for relatively small samples. This research employed ARDL for the case study involving SSA countries, given the obvious advantage, especially when some countries had missing data for some time periods.

Following Chirwa and Odhiambo [5], the ARDL($p, q, q, \dots, q$) model is as specified in Equation (2).

$$\begin{aligned} \ln \text{GDP}_{it} = & \delta_{i0} + \sum_{j=1}^p \beta_{1,ij} \ln \text{GDP}_{i,t-j} + \sum_{j=0}^q \beta_{2,ij} \ln \text{EC}_{i,t-j} \\ & + \sum_{j=0}^q \beta_{3,ij} \ln \text{FDI}_{i,t-j} + \sum_{j=0}^q \beta_{4,ij} \ln \text{GFCF}_{i,t-j} + \sum_{j=0}^q \beta_{5,ij} \ln \text{INF}_{i,t-j} \\ & + \sum_{j=0}^q \beta_{6,ij} \ln \text{PSE}_{i,t-j} + \varepsilon_{it}, \end{aligned} \quad (2)$$

where t , j , and i respectfully represent time, lag, and country, and the variables in log form.

The coefficient δ_{i0} represents the fixed effect of the panel ARDL model, which is either a constant, trend, or both. On the other hand, the $\beta_{1,ij}$ is the coefficient for the lagged dependent variable, whereas $\beta_{2,ij}, \dots, \beta_{6,ij}$ are the coefficients for the lagged regressors. Also, ε_{it} is a stationary cointegrating error component. The term ε_{it} , can be thought of as short-term deviations from the long-run equilibrium.

The panel error correction representation of Equation (2) is given in Equation (3) as follows:

$$\begin{aligned} \Delta \ln \text{GDP}_{it} = & \delta_{i0} + \sum_{j=1}^p \beta_{1,ij} \Delta \ln \text{GDP}_{i,t-j} + \sum_{j=0}^q \beta_{2,ij} \Delta \ln \text{EC}_{i,t-j} \\ & + \sum_{j=0}^q \beta_{3,ij} \Delta \ln \text{FDI}_{i,t-j} + \sum_{j=0}^q \beta_{4,ij} \Delta \ln \text{GFCF}_{i,t-j} + \sum_{j=0}^q \beta_{5,ij} \Delta \ln \text{INF}_{i,t-j} \\ & + \sum_{j=0}^q \beta_{6,ij} \Delta \ln \text{PSE}_{i,t-j} + \alpha_{1,ij} \ln \text{GDP}_{i,t-1} + \alpha_{2,ij} \ln \text{EC}_{i,t-1} \\ & + \alpha_{3,ij} \ln \text{FDI}_{i,t-1} + \alpha_{4,ij} \ln \text{GFCF}_{i,t-1} + \alpha_{5,ij} \ln \text{INF}_{i,t-1} \\ & + \alpha_{6,ij} \ln \text{PSE}_{i,t-1} + \varepsilon_{it} \end{aligned} \quad (3)$$

The parameters $\beta_{1,ij}, \dots, \beta_{6,ij}$ are considered the short-run coefficients while $\alpha_{1,ij}, \dots, \alpha_{6,ij}$ are the long-run coefficients.

The long-run coefficient $\alpha_{2,ij}$, is of high interest to this research. When using Equation (3), $\alpha_{2,ij}$ is interpreted as the percentage increase in GDP due to a 1% increase in EC, ceteris paribus. The value of $\alpha_{2,ij}$ is thus used to determine the economic benefit as a result of an increase in EC.

A key assumption in cointegration analysis is that the variables are stationary. This assumption is necessary to avoid spurious test results [36]. Therefore, a unit root test is first performed on all the variables to establish their stationarity before carrying out the cointegration test. In addition, the unit root test accounts for a structural breaks using the Perron unit root breakpoint test since the data spans a period of 40 years. Failure to account for structural break in the data creates the risk of falsely accepting the null hypothesis that a unit root exists when in fact the data is a stationary process but with a structural break [36]. In some cases, Granger causality might otherwise be proclaimed to not exist due to a failure to account for structural break in the data. Most importantly, disregarding such breaks when in fact present may bias regression results [37]. After a cointegration test, diagnostic tests such as an autocorrelation test and a heteroskedasticity test are then conducted to ascertain the robustness of the model generated.

3.2 | Cost of Electricity Supply

The cost incurred producing the required electricity to boost economic output can be broken down into (1) generation capacity investment cost, (2) fixed maintenance and operation cost, (3) variable operation cost (including fuel cost), (4) emissions cost to account for environmental cost, and (5) transmission and distribution cost. Ordinarily, determining the cost of electricity supply should be straightforward. However, this is not trivial as first thought because there are several generation plants to choose from, some with cheaper investment cost but expensive operation cost and vice versa. Also, since different generation plants have different lifespans, the generation investment cost must be treated with care in order not to disadvantage one over another.

Depending on the planning horizon, it is possible to select a combination of generators which together minimizes the total cost incurred. Such a problem is best solved as a GEP problem, which enables the selection of appropriate generation plants given demand and technical constraints to minimize cost of electricity supply [38, 39]. It must be emphasized that this study looks at what happened or could have happened in the past based on past data. As such, to determine the cost of electricity consumed from the past to a desired time T , a look-back GEP model is employed which enables the mimicking of optimal behavior in a selected period of time to meet electricity demand. The look-back GEP model is cast in the form of a mixed integer linear program (MILP) in order to accommodate both integer and non-integer variables of the problem.

The resulting MILP–GEP model is presented in Equations (4)–(8). Equation (4) captures the future value of the total cost of electricity provision, where C_{it}^c is the capacity charge (in annualized form) and $\ln C_{it}^f$ is the fixed operating and maintenance cost that is charged to the available capacity W_{it} of generator type $i = 1, 2, \dots, I$ in period $t = 1, 2, \dots, T$. Also, a unit of power from generator i in period t is charged C_{it}^v to cover fuel and variable operating cost, and $P_{i,t}^{\text{CO}_2}$ as emissions cost to account for environmental cost. The parameters TC and DC are, respectively, the transmission and distribution costs of an electric power generated and are assumed constant for every MWh of power generated (as is the practice, for instance, in Ghana [40]). The transmission and distribution costs in the objective function are designed to also indirectly account for investment in new transmission and distribution lines. The model assumes a nonprofit-seeking centralized system operator so that there is no propensity to make profit. Note that capacity and fixed charges are applied on existing generation capacity I_{it} as well.

The electricity demanded in any period denoted D_t is to be met by supply from the various generation plants in that period, each producing an amount of Y_{it} . This is captured by Equation (5). On the other hand, Equation (6) captures the idea that production from a generator type i at any time must respect its rated capacity W_{it} , and capacity factor represented by A_i over the production cycle H_t . The model assumes the same capacity factor for all generator type i , whether new (i.e., generators bought within the period of analysis and represented by Z_{it}) or existing (i.e., generators existing prior to the beginning of the period of analysis and represented by I_{it}). Generation capacity available, both from new and total (i.e., new plus existing and represented by W_{it}) are

tracked with Equations (7a) and (7b), respectively. The model is concluded with the nonnegativity constraints of Equation (8).

$$\text{Minimize } V = \sum_{t=1}^T \left[\sum_{i=1}^I (C_{it}^c + C_{it}^f) W_{it} + \sum_{i=1}^I (C_{it}^v + P_{it}^{\text{CO}_2} + \text{TC} + \text{DC}) Y_{it} \right] (1+r)^{T-t}, \quad (4)$$

$$\sum_{i=1}^I Y_{it} = D_t, \quad \forall t, \quad (5)$$

$$Y_{it} \leq H_t A_i W_{it}, \quad \forall i, \forall t, \quad (6)$$

$$Z_{it} = Z_{it-1} + W_i^{\max} G_{it-\Delta i}, \quad \forall i, \forall t, \quad (7a)$$

$$W_{it} = I_i + Z_{it}, \quad \forall i, \forall t, \quad (7b)$$

$$G_{it}, Z_{it}, W_{it}, Y_{it} \geq 0, G_{it} \text{ integer}, \quad \forall i, \forall t. \quad (8)$$

In general, if V , the total cost of electricity generation is less than its contribution to economic output, then it is worth attempting to increase investment in electricity supply. To determine the cost attributed to an increase in EC, the GEP model is run with and without an increase in demand. The difference between the two costs is then taken as the estimate for the cost incurred to meet the additional demand. Formally, let V_1 and V_2 be the total cost incurred to provide electricity without and with an additional increase. The total cost incurred to serve the additional increase in electricity within a certain period is then $V_2 - V_1$.

3.3 | CBA of Increasing Electricity Supply

Results from Sections 3.1 and 3.2 form the basis for the calculation of the BCR of an increase in EC as represented in

Equation (9). Since the analysis looks at what happened in the past, the numerator is the net future value of the change in GDP (denoted by ΔGDP_t) recorded in a past time t due to an increase in EC.

$$\text{BCR} = \frac{\text{Total change in GDP}}{\text{Total cost incurred}} = \frac{\sum_{t=1}^T (\Delta \text{GDP}_t) (1+r)^{T-t}}{V_2 - V_1}. \quad (9)$$

The BCR of Equation (9) gives the dollar-valued contribution to economic output per dollar spent. A BCR greater than 1 indicates that an investment to increase electricity supply is worthwhile.

4 | Empirical Results

This section employs the BCR model developed in the previous section to the countries in Sub-Saharan Africa. Figure 1 shows the electricity access rates for SSA countries in the West African region to put into perspective the need for increased investment in electricity supply in the SSA. It can be seen that no country in this SSA region had a 100% electricity access rate as of 2021. Countries such as Niger, Burkina Faso, Sierra Leone, and Liberia had less than 30% of the population with access to electricity. Nigeria, one of the largest economies in Africa [3] had more than 40% of its people without access to electricity. With an average electricity access rate of 51.3% of the population [3], all 16 countries in West Africa have room to improve electricity access rates and therefore electricity supply, making them a prime example to apply the proposed BCR model. However, while it is obvious that electricity supply in the SSA should be ramped up, it is often not clear whether the investment required to increase electricity supply is worthwhile as far as the economy is concerned. The BCR values for these countries should shed



FIGURE 1 | Electricity access rate of West African countries in 2021 [3].

light in judging the action and inaction of governments in these countries towards investment to increase electricity supply.

4.1 | Relationship Between EC and Economic Output

4.1.1 | Data

The data for estimating the relationship between EC and economic output of SSA countries were sourced primarily from the World Development Indicators website [3], the U.S. Energy Information Administration (EIA), as well as independent data bodies such as countryeconomy.com [41] and Our World in Data. Data on GDP (in gross, and current US\$), EC GWh, GFCF (current US\$), FDI (current US\$), inflation, and PSE (as a percentage of population) over a 40-year period from 1980 to 2019 were used in the analysis.

Figure 2a,b provide time-series plots between the two main variables of interest (i.e., GDP and EC) for countries in West Africa. Except for Liberia and Sierra Leone, there appears to be a strong positive correlation between GDP and EC for most of the countries within the 40-year period. For instance, the correlation coefficient between GDP and EC is 0.90 for Nigeria, and 0.99 for Ivory Coast. The plots for Liberia and Sierra Leone show virtually no correlation, perhaps because of the wars experienced by these countries during the period of analysis. In view of this, Liberia and Sierra Leone were dropped from the subsequent analysis, as are any SSA countries that exhibit such behavior.

4.1.2 | Unit Root Test Results

Table A1 in the appendix provides a list of the variables used in performing the ARDL model for the SSA countries grouped into regions. For credible results, a country is included in the analysis only if it has sufficient data for at least three independent variables. This led to the exclusion of Angola, Equatorial Guinea, and the Democratic Republic of Congo. Also, except for the Gambia, all the countries had a structural break in the dependent variable GDP when testing for breakpoints. Therefore, a unit root test with structural break was conducted for the variables for all the remaining countries to ensure they are either stationary at $I(0)$ or $I(1)$. Table A2 in the appendix gives the Perron unit root breakpoint test that accounts for structural breaks in the data. The results indicate a structural break in virtually all the variables for all the countries. The result from Table A2 also affirms the use of the ARDL model as some variables are stationary at $I(0)$ and others at $I(1)$. The p -values for the independent variable PSE for Ivory Coast and Niger in Table A2 suggest it is nonstationary at both $I(0)$ and $I(1)$, though it was stationary at $I(1)$ when the unit root test was conducted without structural break. Nevertheless, to facilitate a comparison of findings across countries, PSE was included in the ARDL model for Ivory Coast and Niger.

4.1.3 | Cointegration Test

The result of the cointegration test using the ARDL model for the SSA countries grouped into regions is presented in Table 1. The dependent variable is GDP. Note that the variables GDP, EC, FDI, and GFCF are in natural logarithmic form, whereas INF and PSE are in percentage form and need not be transformed into logarithmic form. Also, a dummy variable was included in the

ARDL model for all the countries except The Gambia since a structural break was detected in their respective dependent variables. It can be seen from the last column of Table 1 that the null hypothesis of no long-run relationship between the dependent variable and the independent variables is rejected for all qualified countries. The existence of long-term causality is supported by the error-correction term, which is negatively and statistically significant for all countries. Overall, the speed of adjustment of any disequilibrium towards a long-run equilibrium state within a 1-year-range from 10.3% to 88.0%. Only Burundi had a negative long-run coefficient (-0.044%) indicating an inverse relationship between the GDP and EC in the long run. For the rest of the countries, the long-run coefficient ranged from as low as 0.0817% increase in GDP for Congo Republic to as high as 1.575% increase in GDP for Sao Tome and Principe for a 1% increase in electricity supply. A positive long-run coefficient suggests that in the long run, an increase in EC leads to an increase in economic output.

To conclude the cointegration test, a diagnostic test for autocorrelation and homoskedasticity was performed to ensure that the residuals are serially uncorrelated and homoscedastic for all countries.

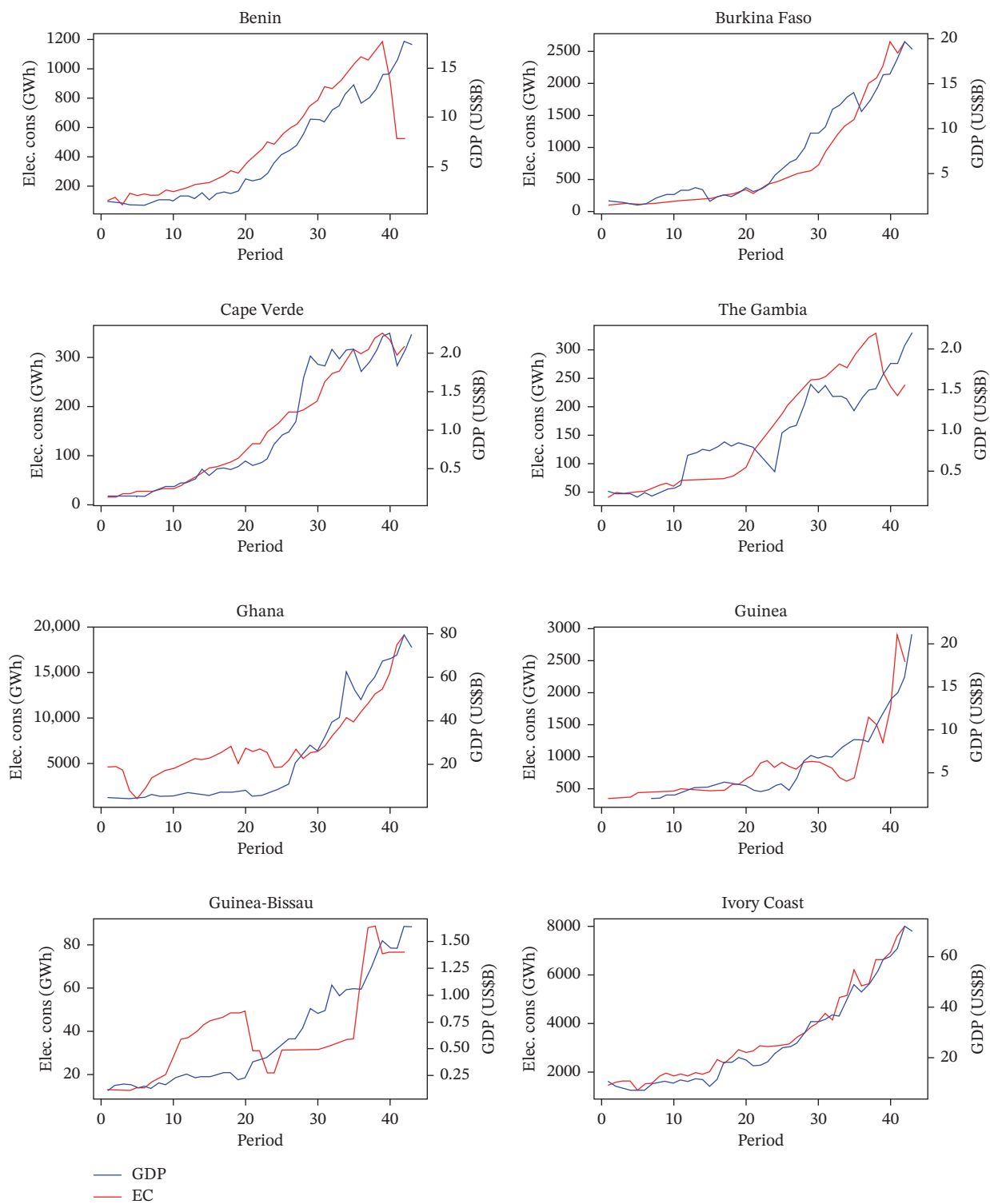
4.1.4 | Granger Causality Test

Theoretically, a CBA is desirable if EC is found to Granger cause GDP. A Granger causality test was thus conducted to examine the direction of the long-run relationship between GDP and EC for the SSA countries. As an example, Table 2 presents the Granger causality test results for the West African countries. In all, Benin, Ivory Coast, Mauritania, Niger, and Senegal had a unidirectional causality that runs from EC to GDP. Ghana and Mali had a unidirectional causality that runs from GDP to EC. Nigeria had a bidirectional causality between GDP and EC. The result did not indicate any causality between GDP and EC for Burkina Faso, Cape Verde, The Gambia, Guinea, Guinea Bissau, and Togo. Even though the Granger causality test did not suggest a causality running from EC to GDP for most of the countries, Ventosa-Santaulària and Vera-Valdés [43] proved that if the data has a structural break, then correct inference cannot be drawn from the Granger causality test since the test may identify nonexistent causal relationships even when the data is differenced. In line with this, a CBA was conducted for a country if a long-run relationship was established through the cointegration test, irrespective of whether EC granger causes GDP. This assumption was extended to the countries in the other SSA regions.

4.2 | Cost of Electricity Supply

4.2.1 | Data

The main data for running the look-back GEP model of Equations (4)–(8) can be found in the appendix. Data on electricity generation from 2000 to 2019 for the countries was obtained from the World Bank's World Development Indicators, and countryeconomy.com, whereas data on installed generation capacity in year 2000 (broken down into various technologies in Table A3 in the appendix) was obtained from the U.S. EIA. Also, necessary parameters on candidate generators can be found in Table A4 in the appendix. For a realistic electricity supply cost, data on electricity generation is used in place of EC in the GEP model since



(a)

FIGURE 2 | (Continued)

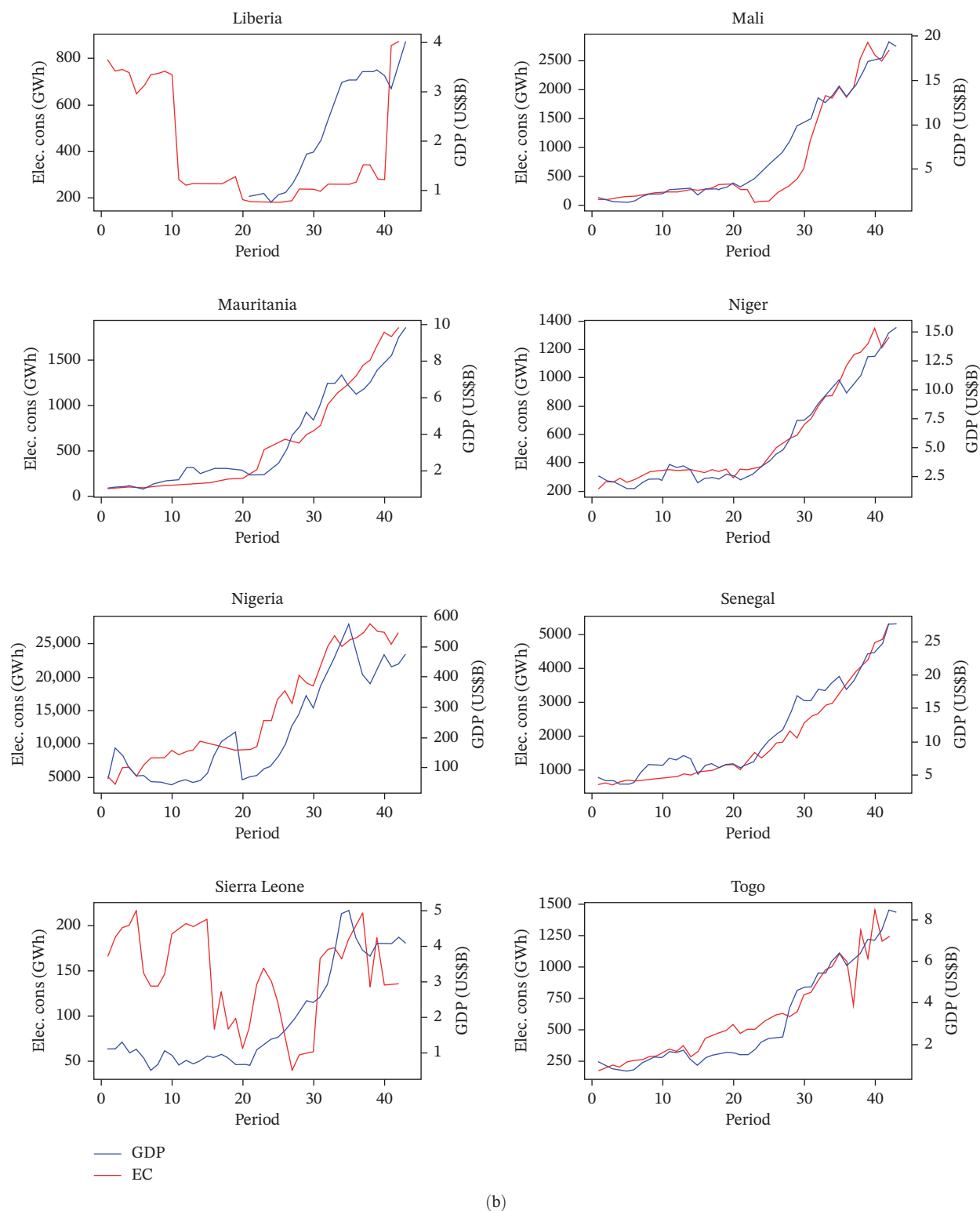


FIGURE 2 | (a) Time series plots of economic output (GDP) and electricity consumption (EC) for Benin, Burkina Faso, Cape Verde, The Gambia, Ghana, Guinea, Guinea-Bissau, and Ivory Coast from 1980 to 2021. (b) Time series plots of economic output (GDP) and electricity consumption for Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo from 1980 to 2021.

consumption does not include losses which must also be accounted for in the supply cost. The GEP analysis is carried out over a 20-year period from 2000–2019.

Starting with the installed capacity in the year 2000, the GEP model attempts to mimic how a country met its electricity demand over the 20-year period by buying new generators. The

type and size of new generators were determined based on a country's generation capacity accumulation over the 20-year period. The generators considered were mainly hydropower, combined or open-cycle gas turbines, coal (especially for Southern African countries), solar, wind, and biomass, though very few countries used these last three generators. Hydropower plant was used in place of geothermal primarily for Kenya, the only country

TABLE 1 | Tests for cointegration using the ARDL approach.

Region	Country	F-statistic	Long-run coefficient	EC term CointEq (−1)	Adjusted R-squared	Cointegration
West	Benin	4.417*	0.349	−0.536	0.793	Yes
	Burkina Faso	14.119*	0.265	−0.622	0.815	Yes
	Cape Verde	5.261*	0.54	−0.411	0.501	Yes
	The Gambia	4.766*	0.232	−0.462	0.746	Yes
	Ghana	4.210*	0.247	−0.566	0.461	Yes
	Guinea	11.260*	0.309	−0.702	0.8	Yes
	Guinea-Bissau	8.806*	0.184	−0.631	0.856	Yes
	Ivory Coast	3.547**	0.541	−0.273	0.852	Yes
	Mali	6.863*	0.182	−0.825	0.883	Yes
	Mauritania	4.047*	0.375	−0.32	0.479	Yes
	Niger	5.890*	0.516	−0.676	0.759	Yes
	Nigeria	9.319*	0.452	−0.75	0.893	Yes
	Senegal	6.420*	0.603	−0.88	0.958	Yes
	Togo	12.702*	0.387	−0.804	0.763	Yes
Central	Cameroon	7.188*	0.322	−0.716	0.692	Yes
	Central African Rep.	9.678*	0.563	−0.539	0.589	Yes
	Chad	3.145**	0.283	−0.353	0.504	Yes
	Congo Rep.	10.487*	0.0817	−2.2	0.936	Yes
	Gabon	7.013*	0.465	−0.328	0.904	Yes
	Sao Tome and Principe	3.863**	1.575	−0.463	0.772	Yes
Eastern	Burundi	3.534*	−0.044	−0.662	0.753	Yes
	Ethiopia	2.341***	0.17	−0.62	0.788	Yes
	Kenya	7.800*	0.897	−0.4511	0.956	Yes
	Madagascar	8.498*	0.111	−0.312	0.895	Yes
	Malawi	5.556*	1.156	−0.649	0.762	Yes
	Mauritius	9.683*	0.457	−0.57	0.965	Yes
	Mozambique	5.020*	0.517	−0.488	0.582	Yes
	Tanzania	6.274*	0.544	−0.295	0.78	Yes
	Uganda	3.711**	0.131	−0.384	0.863	Yes
	Zambia	4.023*	0.888	−0.505	0.629	Yes
	Zimbabwe	1.318+	0.885	−0.466	0.575	Yes
Southern	Botswana	5.673*	0.23	−0.76	0.903	Yes
	Lesotho	7.954*	0.245	−0.427	0.759	Yes
	Namibia	8.362*	0.273	−0.49	0.742	Yes
	Eswatini	6.295*	0.498	−0.451	0.6	Yes
	South Africa	2.337***	0.636	−0.277	0.889	Yes

Note: *, **, and *** denote significance at 1%, 5%, and 10%, respectively. The F-statistic is tabulated in line with Pesaran et al. [42].

in the SSA which generate substantial electricity from geothermal since both plants have similar cost overall. The cost parameters in Table A4 were based on the projected values for 2024

issued in the 2022 edition of the Cost and Performance Characteristics of New Generating Technologies by the U.S. EIA. The capital cost was assumed to decrease by 0.5% per year to reflect

TABLE 2 | Granger no causality test result.

Country	From EC → GDP <i>p</i> -Value	From GDP → EC <i>p</i> -Value	Direction of causality
Benin	0.010	0.534	EC → GDP
Burkina Faso	0.136	0.527	—
Cape Verde	0.090	0.405	—
The Gambia	0.326	0.681	—
Ghana	0.853	0.008	GDP → EC
Guinea	0.069	0.090	—
Guinea-Bissau	0.715	0.343	—
Ivory Coast	0.002	0.165	EC → GDP
Mali	0.377	0.034	GDP → EC
Mauritania	0.013	0.633	EC → GDP
Niger	0.020	0.261	EC → GDP
Nigeria	0.001	0.325	EC ↔ GDP
Senegal	0.018	0.694	EC → GDP
Togo	0.141	0.265	—

advances in technology, whereas fixed O&M costs were assumed to increase by 0.1% per year to reflect the rising cost of living. Note that distribution and transmission costs were considered in the model so that investment cost in new transmission and distribution lines need not be explicitly accounted for in the model. A transmission charge of US\$8.22/MWh and a distribution charge of US\$18/MWh based on estimates in PURC (2023) were applied to the model. Based on information captured in Section 4.2.1, the estimated total cost of the electricity supplied between the period 2000–2019 for the selected SSA countries is presented Table 3.

4.3 | BCR of Electricity Supply

Though the cointegration analysis was carried out over a 40-year period, the CBA was carried out over a 20-year period between 2000 and 2019 due to lack of data and the need for accuracy in the estimation of electricity supply cost. However, since the structural break was accounted for in the estimation of the long-run coefficients, the coefficients should adequately reflect events within the 20 years period. Instead of a cost–benefit ratio, the study preferred the BCR for the CBA since it is easier to interpret if the ratio is more than unity. The study adopted the discount rate of 6% in line with das Neves, Bolle, and De Nocker [46], and 12% in line with GridCo [47] for the CBA analysis. The calculations for both the costs and benefits were done using the same discount rate.

To obtain the BCRs, the increase in GDP due to a 1% increase in annual electricity supply within the 20-year period was first computed using the long-run coefficients from Table 1. These coefficients are the percentage increase in GDP for a 1% increase in electricity supply, *ceteris paribus*. Thus, for instance, it is expected that a 1% increase in electricity supply in 2019 for Nigeria would have increased the recorded 2019 GDP of US

\$474.52 billion by 0.452% (i.e., US\$2.145 billion) when all other factors that contribute to GDP are kept constant. Following this approach, the total estimated increase in GDP from a 1% increase in annual electricity supply for the selected countries can be found in Table 3 under the column Change in GDP. The change in GDP value for each country is the net future value of the recorded increase in annual GDP from 2000 to 2019 assuming an interest rate of 6% per year.

The cost incurred for supplying an additional 1% of electricity was obtained by subtracting the cost of supplying the actual electricity recorded between 2000 and 2019 (Table 3) from the cost when this actual electricity supplied is increased by 1%. The net future values of the change in cost of electricity supply from 2000 to 2019 for the selected countries are presented under the column change in elect. cost in Table 3.

The BCR values are obtained using Equation (9) and can be found under the BCR column in Table 3. Specifically, a BCR value is the ratio of the corresponding value under the “Change in GDP” column to the value in the “Change in Elect. Cost” column.

5 | Discussion

The BCR values in Table 3 encapsulate the objectives of this research. They represent the overall value for money of a proposed investment aimed at increasing electricity supply for each country. In general, the proposed investment is worth the money if the BCR is greater than 1 (i.e., the benefit is greater than the cost), and the higher the BCR, the better the investment. The BCR can also be interpreted to mean the expected benefit for every \$1 invested. For example, the BCR for Benin is 36.33 within the period 2000 and 2019. This implies that for Benin, on average, the benefit in GDP due to a 1% increase in electricity supply is

TABLE 3 | Cost of electricity supply (US\$ Billion), benefit in GDP (US\$ Billion), and benefit–cost ratio due to a 1% increase in electricity supply at 6% discount rate for 36 Sub-Saharan African countries from 2000 to 2019.

Region	Country	Actual electricity supply Elect. Cost	1% increase in electricity supply		
			Change in elect. cost	Change in GDP	BCR
West	Benin	2.567	0.029	1.050	36.33
	Burkina Faso	2.574	0.030	0.803	27.14
	Cape Verde	1.179	0.011	0.271	23.81
	The Gambia	0.878	0.009	0.096	11.15
	Ghana	22.202	0.364	2.433	6.68
	Guinea	2.162	0.036	0.657	18.01
	Guinea Bissau	0.168	0.002	0.051	31.87
	Ivory Coast	16.200	0.248	6.184	24.92
	Mali	4.730	0.052	0.579	11.13
	Mauritania	2.465	0.027	0.587	21.89
	Niger	2.687	0.026	1.195	46.57
	Nigeria	61.843	0.918	44.466	48.44
	Senegal	10.440	0.111	2.973	26.81
	Togo	1.737	0.025	0.530	21.62
Central	Cameroon	11.139	0.201	2.777	13.847
	Central African Rep.	0.350	0.006	0.330	56.778
	Chad	0.693	0.007	0.764	107.536
	Congo Rep.	3.000	0.038	0.270	7.054
	Gabon	4.503	0.067	1.926	28.703
	Sao Tome and Principe	0.229	0.002	0.102	43.612
East	Burundi	0.189	0.003	−0.026	−10.36
	Ethiopia	16.353	0.212	1.838	8.67
	Kenya	17.588	0.257	12.343	47.95
	Madagascar	3.858	0.055	0.347	6.32
	Malawi	3.875	0.068	3.100	45.40
	Mauritius	7.857	0.095	1.448	15.26
	Mozambique	12.679	0.284	2.025	7.13
	Tanzania	9.569	0.152	5.592	36.72
	Uganda	6.147	0.117	0.815	6.97
	Zambia	18.661	0.420	4.575	10.89
	Zimbabwe	20.410	0.269	3.787	14.08
Southern	Botswana	12.022	0.122	0.890	7.268
	Lesotho	1.516	0.021	0.153	7.375
	Namibia	10.396	0.125	0.830	6.641
	Eswatini	4.937	0.059	0.587	9.879
	South Africa	726.217	7.459	68.096	9.130

TABLE 4 | Cost of electricity supply (in US\$ Billion), benefit in GDP (in US\$ Billion), and benefit–cost ratio due to a 1% increase in electricity supply at 12% discount rate for 36 Sub-Saharan African countries from 2000 to 2019.

Region	Country	Actual electricity supply Elect. cost	1% increase in electricity supply		
			Change in elect. cost	Change in GDP	BCR
West	Benin	4.481	0.051	1.813	35.64
	Burkina Faso	4.174	0.049	1.35	27.55
	Cape Verde	2.065	0.020	0.467	23.64
	The Gambia	1.585	0.015	0.173	11.43
	Ghana	37.679	0.662	3.743	5.65
	Guinea	3.884	0.068	1.117	16.54
	Guinea Bissau	0.300	0.003	0.088	30.26
	Ivory Coast	28.488	0.443	10.758	24.31
	Mali	7.113	0.081	0.97	11.95
	Mauritania	4.011	0.045	0.991	22.21
	Niger	4.598	0.044	1.993	45.66
	Nigeria	109.592	1.694	72.999	43.10
	Senegal	18.305	0.197	5.17	26.20
	Togo	2.899	0.043	0.891	20.58
Central	Cameroon	18.321	0.359	4.836	13.470
	Central African Rep.	0.638	0.011	0.594	54.494
	Chad	1.172	0.012	1.269	104.377
	Congo Rep.	3.994	0.054	0.451	8.326
	Gabon	7.956	0.121	3.349	27.687
	Sao Tome and Principe	0.374	0.004	0.172	42.958
Eastern	Burundi	0.305	0.004	−0.044	−11.89
	Ethiopia	23.764	0.326	2.795	8.57
	Kenya	29.789	0.462	19.688	42.64
	Madagascar	6.573	0.096	0.612	6.36
	Malawi	6.889	0.126	5.436	43.12
	Mauritius	14.355	0.172	2.535	14.72
	Mozambique	20.815	0.447	3.572	7.98
	Tanzania	15.191	0.261	9.371	35.90
	Uganda	10.394	0.198	1.321	6.66
	Zambia	31.314	0.773	7.445	9.63
	Zimbabwe	39.199	0.519	6.109	11.78
Southern	Botswana	22.134	0.220	1.572	7.146
	Lesotho	2.465	0.035	0.271	7.697
	Namibia	18.522	0.223	1.439	6.447
	Eswatini	9.601	0.118	1.042	8.865
	South Africa	1386.323	14.251	121.088	8.497

roughly 36 times as much as the cost incurred in providing the 1% extra electricity. In other words, a dollar spent on increasing electricity supply is worth 36 dollars to the economy of Benin. Put differently, the BCR represents the size of the opportunity let go in comparison to the price to pay to access the opportunity. All the SSA countries except for Burundi had a BCR greater than 1, signifying the need to increase investment to improve electricity access in the region.

Overall, Madagascar, Namibia, Ghana, Uganda, Congo Republic, Mozambique, Botswana, and Lesotho had the least BCR of roughly 7, whereas Chad had the largest BCR of 108. The BCR value for Chad appears quite large, but this is expected for a country with an electricity access rate of 11% as of 2022. For such an energy-starved country, the high BCR value reveals what the country is missing from lack of electricity supply. Since electricity is a key factor of production, the high BCR reflects the many economic opportunities that are inaccessible to the populace due to inadequate power supply.

In general, the higher the electricity access rate of a country, the lower the BCR and vice versa. This does not mean that there are fewer opportunities for increasing electricity access for those with already high electricity access rates, but that a greater part of the opportunities that come with increasing electricity supply have been realized. Similarly, countries with lower electricity access rates but higher BCR values point to significant opportunities yet to be tapped by these countries. Among SSA regions, the Southern African region has on average the highest electricity access rate and lowest BCR. On the other hand, the Central African region has on average the lowest electricity access rate and the highest BCR. However, note that for countries with relatively good electricity access rates the BCR could also be influenced by efficiency in the use of electricity. For example, Ivory Coast and Ghana appear closely matched in terms of electricity access, population size, and GDP, yet the BCR of Ivory Coast is almost four times that of Ghana. In fact, Ivory Coast uses less electricity (8746 GWh in 2023) compared to Ghana (19,534 GWh in 2023).

The BCR value for Nigeria is not surprising given that it is the country with the smallest electricity access rate among the top 5 largest economies of Africa. Its BCR value of 48 translates to a net benefit of roughly US\$1.18 billion annually for a 1% increase in electricity supply and signifies the immense potential yet to be tapped by Nigeria. A World Bank report indicates that Nigeria loses roughly US\$29 billion annually due to a shortage of electricity supply [48].

The only country with a negative BCR is Burundi. While this is unusual, it could mean that there is little economic use for electricity to the extent that the cost of electricity supply cannot be fully recovered and, in fact, is a drain on the country's finances.

5.1 | Robustness of the BCR Values

Long-term BCR values are considered very sensitive to the discount rate used. For this reason, the BCR values were also calculated using a higher rate of 12% to judge their robustness. Table 4 gives BCR values for an interest rate of 12% per year for both cost and benefit for all selected SSA countries under a 1% increment in electricity supply. As can be seen, the differences in the values

compared to those obtained at a 6% discount rate in Table 3 are almost insignificant and affirm the stability of the BCR values. Also, though not presented in this study due to space, the BCR values at a 6% and 12% discount rates for the 2.5% and 5% increment of electricity supply under a direct proportionality assumption for long-run coefficients in Table 1 are similar to those obtained in Tables 3 and 4, further confirming the robustness of the CBA technique employed in this study.

6 | Conclusion and Recommendations

This study performed a CBA of increasing electricity supply in SSA countries. The benefit accruing to the economy due to the increase in electricity supply was estimated through an ARDL model. Electricity generation and supply cost were estimated through a look-up GEP model. Except Burundi, the long-run coefficients of the ARDL model output for the remaining 35 countries included in the study suggest that in the long run, an increase in EC leads to an increase in economic output in these countries. Overall, the research finds that there is little justification for the low level of access to electricity supply in the SSA.

The BCRs from the CBA of investments aimed at increasing electricity supply in the SSA suggest that in the long run, such an endeavor is worthwhile and that huge opportunities are let go by SSA countries each year. The benefit-cost ratio values for the SSA countries ranged from a low of 7 for Ghana to a high of 108 for Chad, indicating a high return for every dollar invested to increase electricity supply in the SSA. This implies that countries in the SSA region stand to gain from increasing electricity supply. It is therefore imperative that governments in this region prioritize investments in acquiring more generation capacity, expanding the national grid, and improving electricity distribution infrastructure to ensure an adequate supply of electricity. Given the high level of BCR values, governments in the SSA should be bold to seek loans from both domestic and international lending institutions to increase the supply of electricity. The African Development Bank, the World Bank, and the International Monetary Fund, who are the major lending institutions in the SSA, must also prioritize the provision of energy-related loans to SSA countries to speed up the expansion of the electricity supply infrastructure in the SSA.

This research contributes to the literature on EC and economic growth. It helps quantify the size of the benefit to a country's economy in comparison to the investment required in electricity supply to attain such a benefit. A shortcoming of this research is that some of the countries had no data for some years for some of the variables, leading to the exclusion of such variables in the estimation of the relationship between EC and GDP. Also, the analysis did not consider the environmentally related cost of GDP, which could potentially result in underestimating the cost part of the CBA. Nevertheless, the BCRs give a rough estimate of the untapped opportunities of increasing electricity supply in the SSA region. Future research could take into consideration the cost of securing loans to pursue the untapped opportunities emanating from improving electricity supply to these electricity-starved countries.

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Conflicts of Interest

The authors declares no conflicts of interest

Data Availability Statement

The data that support the findings of this study are available in World Development Indicators at <https://databank.worldbank.org/source/world-development-indicators>, Reference Number 7011578. These data were derived from the following resources available in the public domain World Development Indicators, <https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=CI>; Countryeconomy, <https://countryeconomy.com/energy-and-environment/electricity-generation>; Energy Information Administration, https://www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf; Energy Information Administration, <https://www.eia.gov/international/overview/country/>.

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Appendix

TABLE A1 | Variables used in the ARDL model for the cointegration test for the SSA countries.

Region	Country	Independent Variables						
		lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE	Dummy
West	Benin	✓	✓	✓	is	✓	✓	✓
	Burkina Faso	✓	✓	✓	✓	✓	✓	✓
	Cape Verde	✓	✓	✓	✓	nd	✓	✓
	The Gambia	✓	✓	✓	✓	✓	✓	x
	Ghana	✓	✓	✓	✓	✓	✓	✓
	Guinea	✓	✓	✓	is	✓	✓	✓
	Guinea Bissau	✓	✓	✓	✓	✓	is	✓
	Ivory Coast	✓	✓	✓	✓	✓	✓	✓
	Mali	✓	✓	✓	✓	✓	✓	✓
	Mauritania	✓	✓	✓	✓	✓	✓	✓
	Niger	✓	✓	✓	✓	✓	✓	✓
	Nigeria	✓	✓	✓	✓	✓	✓	✓
	Senegal	✓	✓	✓	✓	✓	✓	✓
	Togo	✓	✓	is	✓	✓	✓	✓
Central	Angola	—	—	—	—	—	—	—
	Cameroon	✓	✓	✓	✓	✓	✓	✓
	Central African Rep.	✓	✓	is	✓	✓	is	✓
	Chad	✓	✓	is	is	✓	✓	✓

(Continues)

TABLE A1 | (Continued)

Region	Country	Independent Variables						
		lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE	Dummy
Eastern	Congo Rep.	✓	✓	✓	is	✓	✓	✓
	Gabon	✓	✓	✓	✓	✓	is	✓
	Sao Tome and Principe	✓	✓	✓	✓	nd	✓	✓
	Burundi	✓	✓	✓	✓	✓	✓	✓
	Ethiopia	✓	✓	is	✓	is	✓	✓
	Kenya	✓	✓	✓	✓	✓	✓	✓
	Madagascar	✓	✓	✓	✓	✓	✓	✓
	Malawi	✓	✓	✓	✓	nd	✓	✓
	Mauritius	✓	✓	✓	✓	✓	✓	✓
	Mozambique	✓	✓	✓	is	nd	✓	✓
Southern	Tanzania	✓	✓	✓	✓	✓	✓	✓
	Uganda	✓	✓	✓	is	✓	✓	✓
	Zambia	✓	✓	✓	is	is	✓	✓
	Zimbabwe	✓	✓	✓	is	✓	✓	✓
	Botswana	✓	✓	✓	✓	✓	✓	✓
	Lesotho	✓	✓	✓	✓	is	✓	✓
	Namibia	✓	✓	✓	is	✓	✓	✓
	Eswatini	✓	✓	✓	✓	is	✓	✓
	South Africa	✓	✓	is	✓	✓	✓	✓

Note: ✓, variable included in the analysis; is, Insufficient data; nd, no data available.

TABLE A2 | p-Values of the Perron unit root breakpoint test on the variables of analysis.

Region	Country	Model with only constant term (level form)						Model with only constant term (first difference)					
		lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE	lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE
West Africa	Benin	0.9	0.87	0.66	x	0.97	0.04	<0.01	<0.01	<0.01	x	<0.01	<0.01
	Burkina Faso	0.31	>0.99	0.01	<0.01	0.43	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.98
	Cape Verde	0.92	0.07	0.04	0.01	x	0.17	<0.01	<0.01	<0.01	<0.01	x	<0.01
	The Gambia	0.62	<0.01	0.55	<0.01	0.56	0.89	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Ghana	> = 0.50	0.64	0.72	<0.01	0.87	0.56	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Guinea	0.98	0.89	0.12	<0.01	0.46	0.57	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Guinea-Bissau	0.52	0.8	0.04	<0.01	0.39	x	<0.01	<0.01	<0.01	<0.01	<0.01	x
	Ivory Coast	>0.99	>0.99	0.56	<0.01	>0.99	0.9	<0.01	<0.01	<0.01	<0.01	<0.01	0.14
	Mali	0.1	<0.01	<0.01	<0.01	0.04	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.38
	Mauritania	0.6	0.23	<0.01	<0.01	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Niger	0.98	0.43	0.08	<0.01	0.42	0.65	<0.01	<0.01	<0.01	<0.01	<0.01	0.2
	Nigeria	0.65	<0.01	<0.01	<0.01	0.15	0.22	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
	Senegal	0.03	>0.99	0.84	<0.01	>0.99	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Togo	0.95	0.95	x	<0.01	0.71	0.48	<0.01	<0.01	x	<0.01	<0.01	<0.01

(Continues)

TABLE A2 | (Continued)

Region	Country	Model with only constant term (level form)						Model with only constant term (first difference)					
		lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE	lnGDP	lnEC	lnFDI	INF	lnGFCF	PSE
Central	Cameroon	>= 0.50	0.492	131	0	0.9	0.508	<0.01	0	0	0	0	0
	Central African Rep.	>= 0.10	0.51	1	0.001	0.338	0.975	<0.01	0	0.027	0	0	0.023
	Congo Rep.	<0.05	0.929	0.773	0.001	0.727	0.425	<0.01	0	0.001	0	0	0
	Chad	>= 0.10	0.712	0.11	0	0.291	0.489	<0.025	0.002	0.001	0	0.001	0
	Gabon	>= 0.10	0.919	0.001	0	0.727	0.006	<0.01	0	0	0	0	0
	Sao Tome and Principe	>= 0.50	0.91	0.344	0.037	x	0.851	<0.01	0	0	0.000	x	0.196
Eastern	Burundi	>0.10	0.4	0.65	0.997	0.841	0.479	<0.05	0	0	0.001	0	0.018
	Ethiopia	>0.50	0.981	x	0.002	x	0.441	<0.01	0	x	0	x	0.015
	Kenya	>0.50	0.78	0.06	0.012	0.96	0.75	<0.01	0	0	0	0	0
	Madagascar	>= 0.5	0.99	0.461	0.014	0.6	0.81	<0.01	0	0	0	0	0.002
	Malawi	0.92	0.1	0.026	0.01	x	0.71	0.000	0	0	0	x	0
	Mauritius	>= 0.10	0.247	0.252	0	0.81	0.628	<0.01	0.002	0	0	0	0
	Mozambique	<0.10	0.816	0.648	0.021	x	0.882	<0.01	0.001	0	0	x	0.001
	Tanzania	>0.50	0.977	0.73	0.682	0.939	0.464	0.025	0	0.001	0	0	0.022
	Uganda	>= 0.10	0.948	0.001	0.003	0.759	0.409	<0.01	0	0.07	0.000	0	0
	Zambia	<0.10	0.982	0.708	0.332	0.138	0.776	<0.01	0	0	0	0.014	0
Southern	Zimbabwe	<0.01	0.232	0.228	0.272	0.248	0.062	<0.01	0	0	0.001	0	0
	Botswana	<0.025	0.004	0.148	0.085	0.708	0.026	<0.01	0	0	0	0	0.001
	Lesotho++	>= 0.10	0.576	0.002	0	0.084	0.848	<0.01	0	0	0	0.017	0.002
	Namibia++	<0.10	0.619	0.303	0.11	0.716	0.741	<0.01	0	0	0.03	0	0.003
	Eswatini	>= 0.50	0.066	0	0.013	x	0.853	<0.01	0	0	0	x	0.002
	South Africa	>= 0.50	0.004	0.081	0.469	0.752	0.404	<0.01	0.001	0	0	0.001	0

++: Used data from 1990 to 2019.

TABLE A3 | Installed capacity of electricity generation plants for SSA countries in year 2000.

Region	Country	Installed generation capacity in 2000 (MW)							
		Hydro	Geoth	CCGT	OCGT	Biomass	Solar	Wind	Coal
West	Benin	1	—	34	50	—	—	—	—
	Burkina Faso	32	—	40	50	—	—	—	—
	Cape Verde	—	—	—	47	—	—	—	—
	The Gambia	—	—	—	29	—	—	—	—
	Ghana	1072	—	280	300	—	—	—	—
	Guinea	139	—	—	208	—	—	—	—
	Guinea Bissau	—	—	—	21	—	—	—	—
	Ivory Coast	614	—	200	170	—	—	—	—
	Mali	90	—	50	50	—	—	—	—
	Mauritania	82	—	—	63	—	—	—	—
	Niger	—	—	50	95	—	—	—	—
	Nigeria	1967	—	1044	1848	—	—	—	—
	Senegal	—	—	92	200	—	—	—	—
	Togo	67	—	—	25	—	—	—	—
Central	Cameroon	725	—	71	—	—	7.3	—	—
	Central African Rep.	18.8	—	—	21	—	—	—	—
	Chad	—	—	—	29	—	—	—	—
	Congo Rep.	92	—	—	29	—	—	—	—
	Gabon	170.2	—	200	35	—	—	—	—
	Sao Tome and Principe	2.3	—	—	8	—	—	—	—
Eastern	Burundi	43	0	0	12	4	0	0	0
	Ethiopia	378.5	0	160.8	0	21	7.3	0	0
	Kenya	680.6	58	250	79	33.5	—	0.4	—
	Madagascar	105.8	—	80	42	—	—	—	—
	Malawi	221	—	—	21	12	—	—	—
	Mauritius	59.4	—	450	152	51.7	—	—	—
	Mozambique	2177.4	—	150	53	14	—	—	—
	Tanzania	581.3	—	250	—	31.2	—	—	—
	Uganda	261	—	—	4	16	0.2	—	—
	Zambia	1789.9	—	—	50	12.4	—	—	—
	Zimbabwe	668.3	—	—	65	61.5	—	—	1295
Southern	Botswana	0	0	0	0	0	0	0	132
	Lesotho	75.4	0	0	0	0	0	0	0
	Namibia	240	0	16	0	0	1	0	—
	Eswatini	42.8	—	0	63	61	—	—	—
	South Africa	2068	—	—	—	242	—	—	44,055

Source: <https://www.eia.gov/international/data/country>.

TABLE A4 | Assumed parameter values for candidate generation plants.

Generator type	Capacity factor	Variable cost (\$ per MWh)	Capital cost (\$ per KW)	Generator life span (year)	Fixed O&M cost (\$ per MW per year)
Hydropower	50.0%	2.0	3083	60	43,780
Geothermal	50.0%	2.0	3083	60	143,220
CCGT	50.0%	65.8	1201	25	14,760
OCGT	40.5%	98.8	785	25	7330
Biomass	50.0%	51.5	4524	20	131,620
Solar	19.5%	0	1327	20	15,970
Wind	16.5%	9.27	1718	20	27,570
Coal	65%	46.5	4074	35	42,490

Variable cost includes fuel cost.
Source: EIA [44]; IEA [45].