Causal Relationships between Energy Consumption, Economic Growth and CO₂ Emission in Sub-Saharan: Evidence from Dynamic Simultaneous-Equations Models

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Abstract

The purpose of this study is to investigate the interrelationship between energy-CO₂ emission-GDP for Sub-Saharan countries covering the period 2000-2012. To circumvent this issue we use dynamic simultaneous-equation. Our empirical findings show that there is a bidirectional causal relationship between energy consumption and economic growth. The results support also a bidirectional relationship between energy consumption and electricity consumption, but variables reflecting pollution affect negatively electricity consumption. As well the rise in economic growth increases the level of CO₂ emissions and vice versa.

Keywords

GDP, Energy Consumption, CO₂, GMM

1. Introduction

Sub-Saharan Africa accounts for 13% of the world population. Economic growth in these countries has long been lower than other developing countries. Since 2000, Sub-Saharan Africa has experienced rapid economic growth and energy demand has increased to 45%. These countries have a diversity of energy resources unevenly distributed across the continent. During the last decade, nearly 30% of world oil discoveries were in Sub-Saharan Africa and other resources such as gaz; in addition this region has vast untapped renewable energy including hydropower and solar energy. Despite the diversity of its energy resources,

sub-Saharan Africa exploits only the biomass energy accounting for over 30% of the energy consumed in the continent and over 80% for many Sub-Saharan countries. Biomass is the main source of energy for the majority of African households and generates CO_2. We thus focus on the CO_2-energy-economic growth nexus in 35 Sub-Saharan African countries. We study the case of sub-Saharan countries firstly because these countries have huge renewable and non-renewable energy and also because the majority of recent studies focus on developing countries such as country Latin America, Asia and the Middle East.

The relationship between energy consumption, environmental quality and economic growth has attracted the interest of economists and ecologists in recent years. This is not only because energy consumption affects economic activity, but also because it has an effect on the environment, especially in the industrialized countries. Climate change and the increase in temperature degrees have prompted many empirical studies of the link between energy consumption, economic growth and environmental quality since 1970 and 1990 [1] [2] [3] [4] [5]. The results of recent studies have explored both short- and long-term relationships and the direction of causality. The literature has been well documented by multi-country studies and other country-specific studies. Roughly, we can classify recent studies into three lines of research.

The first line examines the relationship between economic growth and energy consumption. Since the energy crises (1973, 1979-1980), the relationship between economic growth and energy consumption has become a topical issue. Many studies found that economic growth and energy consumption can be identified jointly [6] [7].

This relationship postulated that higher economic growth requires more energy. They have confirmed the idea that economic growth can lead to an increase in energy consumption [8] [9] [10] [11] [12].

The second strand focused on the Environmental Kuznet Curve (EKC) hypothesis. The EKC hypothesis supposes an inverted U-shaped curve between environmental quality and economic growth [13]-[19]. This curve describes the evolution of CO_2 level following the evolution of economic growth. The degradation of the environment rises jointly with economic growth and it decreases after a certain threshold. However, a high level of economic growth does not necessarily warrant environmental degradation.

The last strand focuses on the three-way linkages between economic growth-energy consumption-environment. The economic development resulting from the consumption of energy exerts pressure on the environment. The relationship between energy consumption and economic growth on the one hand and between environment and economic growth on the other hand has been the subject of academic. Studies have revealed mixed empirical results [20] [21] [22] [23] [24].

The contribution of this work to the existing literature is to simultaneously examine energy-environment-economic growth nexus. Indeed, all three models explore simultaneously the effect of 1) energy consumption and economic growth

on environmental quality, 2) energy consumption and environmental quality on economic growth, and 3) economic growth and the quality of the environment on energy consumption.

The study is organized as follows: Section 2 explains literature review. Methodology and the econometric specification are presented in Section 3. Section 4 reports and discusses the results and finally Section 5 concludes.

2. Literature Review

The relationship between energy consumption and economic growth, as well as the relationship between economic growth and emissions of pollutants, has been the subject of numerous investigations over the past three decades. There have been three main areas of research in the literature. The first line of research is the relationship between economic growth and energy consumption. The second theme concerned the relationship between economic growth and pollution. The third axis combines the first two axes simultaneously studying the relationship between economic growth, energy consumption and pollution in the same model. Several researches have studied the relationship between CO_2, energy and GDP by integrating the variables of interest, external trade by [17], urban population with [25] and [26], financial development by [27] [28] [29]; and [25]. These researches have yielded conflicting results about the existence and the direction of causality between variables.

[30] studied the relationship between CO_2, GDP, energy consumption and financial development in thirty Sub Saharan African countries, the results showed a bidirectional causal relationship between all variables in the long run, and a positive bidirectional causal relationship between energy consumption and CO_2 in short run. More recently, in the developed countries, [16], investigated the relationship between energy consumption, CO_2 and GDP, using a vector error correction model, he found bidirectional causality between GDP and CO_2, electricity consumption and GDP and a unidirectional causality running from electricity consumption to CO_2 emissions. [17] investigated the causal relationship between CO_2 emission, GDP, energy consumption and foreign trade. The author showed that the granger causality test results revealed the presence of a bidirectional causal relationship between CO_2 emissions and GDP and no relationship between energy consumption and GDP.

2.1. Economic Growth and Energy Consumption

The link economic growth and energy has been widely studied. The lack of consensus in the results of studies of the same country or the same geographical area is therefore related to methodological differences or databases differences taken into account, general, are very diverse and often contradictory. They look different on the existence and direction of causality and their implications for energy policy in the short term and long term. These energy policy implications may significantly depend on the type causality between energy consumption and

the growth rate [31]. For example [1], with annual data between 1947 and 1974, found by the method of Granger and the US growth Granger causes energy. [32] and [33] found same results for the USA, there is a unidirectional causality running from electricity consumption to economic growth. While [34] between 1954-1993 found that the relationship is unidirectional GDP to energy. [35] reported evidence of unidirectional causality from energy consumption to economic growth for different panel countries and with different techniques. [5] found that energy is a driving factor for economic growth for India. On the other hand, some studies found contradictory results; [36] examined the relationship between energy consumption and economic growth in Congo, the results show one-way granger causality runs from economic growth to energy consumption. [37] adopts panel cointegration approach; he found a causal relationship runs from economic growth to energy consumption for 11 oil exporting countries. [38] with annual data between 1961 and 1990 found a bidirectional relationship, energy and GDP influence each other, but [39] found unidirectional causality, energy because GDP between 1970 and 1999. in the G-7, [40], in a study that covered the period from 1960 to 2004, determined the existence of three forms of bond, GDP because the energy in Germany, the energy due GDP in France and the United States and finally energy and GDP influence each other in Italy, Canada, Japan and England. In turn [41] found only one meaning in the G-7, the energy causes the GDP in their study covering the period 1972-2002. They [42] demonstrated the possibility of the evolution of causality in time. Indeed, through their work on the countries of the Commonwealth, they demonstrated that between energy and product, the causal link is unidirectional in the short term, because the energy produced and is bidirectional in the long term. For different geographical areas, the diversity of direction of causation may be due to the characteristics of such countries as the supply of local energy, political and economic history, energy policies implemented, etc. Several studies identify the two-way linkages involve the causality running from economic growth to energy consumption, While [43] found a bidirectional causal relationship between energy consumption and economic growth in the USA. The same result found by [44], he investigates the short and long-term causal effects between energy consumption and economic growth during the period 1968-2002.

[45] studied the case of 49 countries; the results included the four hypotheses; the growth hypothesis for 5 countries, the neutrality hypothesis for 24 countries, the conservation hypothesis for 13 countries, and the feedback hypothesis for 7 countries. Same results in 19 African countries [35] found unidirectional from energy consumption to economic growth hypothesis for 7 countries, conservation hypothesis for 3 countries, feedback hypothesis for two countries and neutrality hypothesis for 5 countries. In a further study [46] examined the relationship between energy consumption and economic growth for 20 African countries, his findings reveal a positive and significant impact of GDP on electricity for 6 countries and negative and significant impact of GDP on energy consump-

tion for two countries, a neutrality hypothesis for 9 countries, a conservation hypothesis for two countries and one growth hypothesis for one country. However, some studies found no relationship between energy consumption and economic growth, [47] show that in short run there is no causality between energy and economic growth for 16 Asian countries. Many studies focus on African countries, some studies examines the relationship between energy consumption and economic growth for single country and other for multiplies countries. [48] [36] and [49] using different econometric techniques; the obtained results validate the feedback hypothesis between electricity and economic growth for Malawi, South Africa and Tunisia respectively.

2.2. Economic Growth and CO_2 Emissions

Environment and economic growth nexus was the subject of several studies, different econometric methodologies; time span of the data and model specification have been employed leading to mixed results. The relationship between environmental pollution and economic growth, in general, was modeled by Environmental Kuznets Curve. The pioneer study of Kuznets in 1955, he claimed for an inverted U-shaped relationship between economic growth and income. In this context, Grossman & Krueger (1991) were the first to test the EKC. They were followed by several other authors, including [2] [50] [51] [52] [53] [54]. However, the findings are diverse and often contradictory and in most cases the EKC is not observed. [55] [56] [57], and [31] have demonstrated in different economies validity of EKC. However, Holtz-Eakin & Selden (1995) find a monotone and positive relationship between economic growth and pollution on the one hand and [51], a form related to "N" reversed, other share. Also, [58] [59] etc., conclude a neutral relationship. [60] investigates the environmental kuznet curve hypothesis over the period 1980-2005 they found unidirectional causality running from GDP to CO_2 emissions in both the short and long run. The same findings by [18] using VECM-based Granger causality. [47] investigated the link between CO_2 emissions and GDP in South Africa their empirical results show causal relationship running from CO_2 emissions to GDP. [6] studied the relationship between economic growth CO_2 emissions, trade and financial development over the period 1990-2011 using simultaneous-equation panel data model, their empirical results show bidirectional causality between CO_2 emissions and economic growth. In another work, [6] using dynamic simultaneous-equation for 54 countries to examine the relationship between CO_2 emissions, economic growth and foreign direct investment, they found unidirectional causality running from CO_2 emissions to economic growth.

2.3. GDP-CO_2 Emissions and Energy Nexus

The third line of research that has emerged, combining the two previous and simultaneously analyzes the relationship between the three variables-growth energy-pollution. Some recent investigations of this approach have been con-

ducted for example by, [22] [25] [40] [61] [62] [63], etc.

[22] studied the causal link between energy consumption, carbon dioxide (CO_2) and income over the period from 1971 to 2006 in India. Their results show the existence of a long-term two-way relationship between energy consumption and CO_2 emissions. However, the relationship is neutral between firstly income and energy consumption, on the other hand between income and CO_2 emissions. [64], in his study of the Middle East and North Africa (MENA) over the period 1980-2008, showed that CO_2 emissions and oil have a long-term relationship with economic growth. However, the results of its estimates have revealed the existence of a short-term two-way relationship between CO_2, oil consumption and economic growth. [65] studied the causal link between CO_2 emissions, GDP and energy consumption covering the period between 1971 and 2009 in six Sub-Saharan countries using ARDL model, their empirical findings reveal a unidirectional granger causality relationships run from GDP and energy consumption to CO_2 emissions and there is no evidence of any bidirectional causality relationship between variables. The following Table 1 presents some studies.

Table 1. Summary of the existing empirical studies relationship between CO_2 emissions, energy consumption and GDP.

Studies	Countries	Methodologies	Results
Halicioglu (2009)	Turkey	Granger causality, ARDL	GDP----En
Zhang & Chang (2009c)	China	Granger causality, VECM	GDP $\rightarrow$ En
Apergis & Payne (2009c)	6 Central American countries	Panel vector error correction model	En $\leftrightarrow$ GDP in the short run
Apergis & Payne (2009b)	11 independent common wealth countries	Panel cointegration error correction model	En $\leftrightarrow$ GDP In the short run
Saboori & al (2012)	Malaysia	EKC hypothesis	$CO_2 \rightarrow$ GDP In the long run
Lotfalipour *et al.* (2010)	Iran	Toda-Yamamoto method	GDP $\rightarrow CO_2$ In the long run
Chang (2008)	China	Multivariate cointegration, vector error correction model	GDP $\leftrightarrow CO_2$ En $\leftrightarrow$ GDP En$\rightarrow CO_2$
Fodha and Zaghdoud (2010)	Tunisia	Granger causality based on ECM	GDP$\rightarrow CO_2$
Ang (2008)	Malaysia	Granger causality	GDP $\leftrightarrow CO_2$
Richmond & Kauffman (2006)	20 developed countries	Cointegration test	En $\rightarrow CO_2$ GDP $\rightarrow CO_2$
Ozturk & Acaravci (2013)	Turkey	Granger causality ARDL cointegration	EC $\neq$ GDP $CO_2 \neq$ GDP
Pao & al (2011)	Russia	Granger causality VECM, cointegration	GDP $\leftrightarrow CO_2$ EC $\leftrightarrow$ GDP EC $\leftrightarrow CO_2$

Notes: GDP, CO_2, En and EC indicate the per capita GDP, per capita carbon dioxide emissions, energy and electricity consumption. $\rightarrow$, $\leftrightarrow$, and $\neq$ indicate the unidirectional causality hypothesis, feedback hypothesis, and neutral hypothesis, respectively.

3. Econometric Method and Data

The objective of our study is to examine the interrelationship between economic growth, energy consumption and CO_2 emissions by using the Cobb-Douglas production function. This extended production function provides a useful framework which helps us to explore the three-way linkages between the three variables. We include labor force and capital as additional factors of production, [26] [47] [53] [66], among others, include energy consumption and CO_2 emissions to study the empirical depends also on energy consumption which is related to CO_2 emissions. According to the literature review, most studies claim that economic growth leads to changes in CO_2 emissions, it has also mentioned that energy consumption is a main cause of carbon emissions. It is therefore worth to examine the interrelationship between GDP, energy consumption and CO_2 emissions by considering them simultaneous them simultaneously in a modeling framework. The Cobb-Douglas production function is as follows:

$$Y_{it} = AEL^{\alpha it} CO2^{\alpha it} e^{\mu it} \tag{1}$$

After logarithmic transformation Equation (1) is written as follows:

$$\ln Y_{it} = \alpha_0 + \alpha_{1i} \ln EL_{it} + \alpha_{2i} \ln CO2_{it} + \mu_{it} \tag{2}$$

where $\alpha_0 = \ln(A)$; $i = 1, \cdots, N$ denotes the country and $t = 1, \cdots, T$ denotes the time period (the period of study is 2000-2012); $\ln Y_{it}$ represents the gross domestic product per capita measured in constant national currency, $\ln EL$ indicates the level of electricity consumption and $\ln CO_2$ represents the CO_2 emissions. A is the level of technology and e is the residual term. We then transform the production function Equation (2), into regression equations to derive the empirical models to examine simultaneously the interactions between GDP, energy consumption and CO_2 emissions. These simultaneous equations are constructed on the basis of theoretical and empirical insights of recent literature; the three-way linkage between these variable are presented in the following three equations:

$$\ln Y_{it} = \alpha_0 + \alpha_{1i} \ln EL_{it} + \alpha_{2i} \ln CO_{2_{it}} + \alpha_{3i} \ln L_{it} + \alpha_{4i} \ln K_{it} \mu_{it} \tag{3}$$

$$\ln EL_{it} = \alpha_0 + \alpha_{1i} \ln Y_{it?} + \alpha_{2i} \ln CO_{2_{it}} + \alpha_{3i} \ln OILP_{it} + \alpha_{4i} \ln CPI_{it} \mu_{it} \tag{4}$$

$$\ln CO_{2_{it}} = \alpha_0 + \alpha_{1i} \ln EL_{it} + \alpha_{2i} \ln Y_{it} + \alpha_{3i} \ln INDVA_{it} + \alpha_{4i} \ln URB_{it} \mu_{it} \tag{5}$$

Equation (3) states that energy consumption and CO_2 emissions and other variables namely labor force and capital can determine economic growth [67], the income of a country could be strongly linked to the consumption of energy and, therefore, as it may be a factor limiting economic growth. [68] found is a factor of economic development in USA, which was confirmed by [5] [26], and [35], Moreover, CO_2 emissions influence the level of economic growth, [52]. The degradation of environment has an impact on economic growth, the decline in environment quality lead to reduce economic activities.

Equation (4) shows the interaction between CO_2 and GDP with electricity consumption, we try to explain how to act the electricity consumption in the

presence of CO_2 and GDP; following the previous studies the generated results are mixed; [49] [62] [65] and [69]. Then we include OIL-PRICE and CPI, [70] [71] [72]. Oil-price has a positive impact on electricity consumption, CPI negatively affects electricity consumption.

Equation (5) examines the determinants of CO_2 emissions. Electricity consumption has a significant impact on the reduction of CO_2 emissions, [40]. Moreover, an increase in income is accompanied by an increase of CO_2 emissions [21] and [73]. Also energy consumption has an impact on CO_2 emissions; it plays a major role to increase CO_2 emissions [17] and [42]. The URB indicates the rate urban population of the total; we include this variable as a factor affecting CO_2 emissions [74] [75], and [76].

3.1. Estimation Procedure

To examine the interrelationship between variables, our models were estimated simultaneously with the generalized method of moment (GMM) using the [77] GMM estimator. The GMM is the most commonly used in models with panel data; this approach uses a set of instrumental variables to solve the problem of endogeneity. It also avoids the estimation bias that may arise from the correlation between the lagged dependent variables and the error terms.

3.2. Data

We use annual data over the period 2000-2012, GDP per capita (constant US$), CO_2 emissions in the metric tons, electricity consumption in KWh per capita, urbanization (the urban population as the share of the population), industrial value-added measure in real per capita, consumer price index is used as energy price index, POL-PRICE is used as the price of substitutable energy price, labor force measured in thousands of workers, and capital. The data sources are taken from the World Development Indicator (WDI (2018), https://data.worldbank.org/). Our study covers the Sub Saharan African countries; we selected 35 countries on the basis of data availability and we present the descriptive statistics.

Table 2 summarizes the descriptive statistics, the mean value, min and max

Table 2. Descriptive statistics.

Variables	Mean	Std-Dev	Min	Max
CO_2	0.6229228	1.516522	0.0037499	10.03407
CPI	81.19431	59.24271	0.0745612	1196.678
INDVA	27.09978	15.32877	3.285216	77.41366
GDP	3.006644	1.283109	2.124373	10.12755
EL	5.596116	3.043646	1.35841	9.45038
GFCF	9.031245	0.6131475	7.363409	10.78616
LABOR	6.519646	0.5499285	5.227686	7.639399
OIL-PRICE	60.01462	26.1791	25.98	99.67
URB	1.504458	0.2016076	0.9162433	1.936348

value and the standard deviation of the variables for the panel. GDP ranges between 2.124 and 10.127 the highest value of GDP (10.127) in Boutswana, EL (9.45) in Uganda and CO_2 emissions (10.034) in South Africa. Then the lowest value of GDP (2.124) is in Burundi, EL (1.358) is in Ethiopia and per capita emissions (.0037) are in Lesotho.

4. Results of Estimates GMM

Values in parenthesis are the estimated p-values. Hansen J-test refers to the overidentification test for the restrictions in GMM estimation. DWH test is the Durbin-Wu-Hausman test for endogeneity. The AR2 test is the Arellano-Bond test for the existence of the second-order autocorrelation in first differences. *, ** and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

Results and Discussions

We begin our results by the unit root test, this test aims to verify the stationary variables to decide which variables should go into the empirical model. Proposed by [78] to test the unit root autoregressive process, the concept of unit root therefore remains indispensable in the analysis of long-term process involving the use of two static series. Recently applied to panel data by [79], the unit root test aims to answer the question of taking into account the heterogeneity of forms based on the assumption of the existence of specific constants the individual to individual fixed effects model seeks to take into account.

Then we present in Table 3 the empirical methods for assessing interactions

Table 3. Estimation results for the entire sample.

| Variables	Model (1)	Model (2)	Model (3)
	CO_2 Coefficient/p-value	EC Coefficient/p-value	GDP Coefficient/p-value
CO_2	-	−10.7383 (0.000)***	2.7883 (0.000)***
INDVA	−0.0060 (0.011)**	-	-
GDP	0.4548 (0.000)***	3.4059 (0.000)***	-
EC	−0.1397 (0.000)***	-	0.2489 (0.000)***
URB	−0.00082 (0.988)	-	-
OILPRICE	-	−0.0051 (0.014)**	-
CPI	-	−0.00006 (0.968)	-
GFCG	-	-	0.1646 (0.010)**
LABOR	-	-	−0.1515 (0.032)**
const	−0.4 (0.000)***	−0.1394 (0.280)	−0.3201(0.000)***
Hansen J-test	21.81 (0.351)	20.96 (0.339)	23.47 (0.266)
DWH test (p-value)	29.425 (0.000)***		16.533 (0.000)***
AR2 test	−1.07 (0.284)	−0.99 (0.323)	−1.68 (0.092)*

between CO_2 emissions, GDP and energy consumption, we use the [77] GMM approach for all countries. Three specifications; each specification corresponds to equation. Equations (3)-(5) are estimated at the same time. The statistical robustness of the model results depends on the validity of the test specifications; mainly test of endogeneity/exogeneity, test of overidentification restrictions and autocorrelation test order 2. (Hansen-J for over-identification, test endogenous Durbin-Wu-Hausman and AR2 Arellano-Bond for the existence of the second order autocorrelation in first differences). The results offer good statistical performance.

The empirical findings of Equation (3) showed that economic growth has a significant positive effect on CO_2 emissions, the coefficient is 0.458, and this indicates that the CO_2 increases by 0.458% when there is an increase of 1% of GDP. Economic growth played an important role to increase CO_2 emissions; the sub-Saharan countries mainly use fossil fuels, which explain the high pollution. Economic growth contributes to environmental degradation, the same results have been found by [17] in Turkey [80] in Brazil. On the other hand, the electricity consumption has a negative and significant effect on CO_2 emissions. CO_2 emissions fell by 0.139% following a 1% increase in electricity consumption; electricity is in favor for the protection of the environment. Urbanization has a negative and insignificant effect on CO_2 emissions that result is the same as that of [64]; the industrial added value coefficient has a negative and significant effect on CO_2 emissions; industrial value added affects very minimum the CO_2 emissions, 1% rise in industrial value added is linked with a 0.006% decrease in CO_2 emissions the same finding as [81] but [82] and [83] found that industrialization lead to a large pollution in Bangladesh.
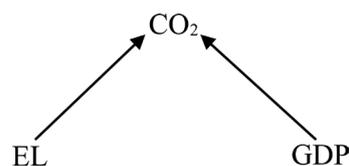

Empirical results about Equation (4) outline the second specification about the effect of GDP and CO_2 emissions on electricity consumption. Economic growth has a positive and significant effect on electricity consumption. One hypothetical relationships defined in literature is verified here. This is the conservation hypothesis, which states that there is a unidirectional causal relationship from growth to energy consumption. This implies that a restrictive energy policy can be implemented without risk of nuisance for growth. The coefficient of GDP is 3.406 indicating that an increase of GDP per capita by 1% leads to increase energy consumption by 3.406%. Regarding the pollutant variable, CO_2 emissions, there is a negative and significant effect running from CO_2 emissions to energy consumption. As expected, the energy has a negative impact on CO_2 emissions; an increase of CO_2 emissions by 1% decreases electricity consumption by 10.738%. Energy from biomass accounts for over 30% of the energy con-

sumed in the continent, and over 80% for many Sub-Saharan countries. Biomass is the main source of energy for the majority of African households and is mainly used for cooking, drying and heating which causes pollution. The coefficient of CPI has a negative and insignificant effect on energy consumption (-0.0051), the negative effect of proxy of energy price is may be due to the facilities is low, lack of infrastructure and renewable energy sectors, adapted to the isolated population of service, remaining very expensive. They [31] [36] [42] [72] find a relationship between CPI and energy consumption in selected African countries.

$$\text{CO}_2 \nearrow \overset{\text{EL}}{} \nwarrow \text{GDP}$$
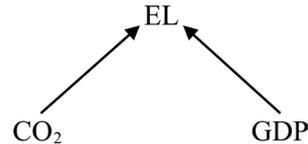
Empirical results pertaining to the Equation (5) show that energy consumption has a significantly positive effect on GDP. The increase in energy consumption by 1% grown per capita GDP by 0.249%; we deduce that the growth hypothesis is verified. The latter assumes that energy plays a critical role in the production process. It is a complementary factor of production to the usual factors such as capital and labor. The level of CO_2 emissions can influence GDP, an increase by 1% in CO_2 emissions increase economic growth by 2.788%. The same results were found by [22]. The coefficient of labor has a negative impact on GDP; this may be due to uneducated, unskilled work, and the brain-drain. Then, a 5% increase in labor decrease GDP by 0.151% [22] [32] [84].

$$\text{EL} \nearrow \overset{\text{GDP}}{} \nwarrow \text{CO}_2$$
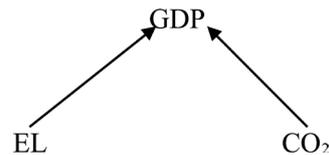
5. Conclusions and Implications

The objective of this study is to determine the causal relationship between energy consumption per capita, GDP per capita and CO_2 emissions per capita in sub-Saharan countries. Variables were taken as control variables. To achieve our goal, we used annual data for 13 years from 2000 to 2012. Several studies have examined this relationship in these countries but no study investigated this interaction via simultaneous equations.

By observing these causal triangles, we see general trends. First, the neutral causal relationships are negligible. Next, among the hypothetical relationships defined in the literature between GDP, energy and CO_2 emissions one of them is checked here. This is the feedback hypothesis that describes a bidirectional relationship between GDP, CO_2 emissions and energy. Our results significantly reject the neo-classical assumption that energy is neutral for growth. The empirical findings show bidirectional causality between energy consumption and economic growth, a high level of energy consumption leads to a high level of eco-

nomic growth and vice versa. The increase in economic growth leads to a high energy demand, which puts pressure on the environment quality.

Our findings present a bidirectional causal relationship between energy and CO_2 emissions and between economic growth and CO_2 emissions. The economic growth increases environmental pollution, but energy consumption conserves the environment. This is due to the massive use of fossil fuels; the economy of sub-Saharan countries is mainly based on biomass. These countries need to improve their energy potential, infrastructure, expand electrification networks and especially use renewable sources for producing electricity.

The massive use of energy with serious environmental consequences gave the current situation of the planet and the degradation of the environment so it became mandatory to take into account the environmental situation, integrating the environment into the economy-energy nexus and find an equilibrium between energy use and conservation of the environment. Environmentalists and scientists have found that renewable energies are the solution to work around this problem.

It is apparent globally that the economic, energy and environmental policies in the sub-Saharan countries will necessarily be implemented jointly to create both growth and to best limit the CO_2 emissions. However, the question remains, can the country consider implementing these public policies, *i.e.* to scale continent?

Conflicts of Interest

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

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