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Renewable energy, CO_2 emissions and economic growth in sub-Saharan Africa: Does institutional quality matter?

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Abstract: Renewable energy appears to be the most optimal alternative to fossil fuel and the widely accepted pathway towards climate change mitigation. However, the costs of adopting renewable energy are high, and it appears the wealth of nations, the stages of economic development and growth and institutional willingness and quality are important in winning this global challenge. However, there is limited information on the interplay of all the factors that are perceived as critical in moving the world towards the use of renewable energy sources to meet most of the domestic and industrial energy needs. This study investigates the inter-temporal causal relationship between institutions, renewable energy, carbon emissions and economic growth for 45 sub-Saharan Africa countries using annual data from 1960 to 2017. We used the generalised method of moment panel vector autoregression (GMM-PVAR) technique to explore the linkages. From a general perspective, the results reveal no causal relationship between institutions and economic growth, but a bidirectional causality exists between economic growth and renewable energy. Our results indicate that economic growth causes carbon emissions, and institutions are more likely to respond to carbon emissions and renewable energy but prompt no causality between carbon emissions and renewable energy. Interestingly, these results differ between countries with different institutional origin. The policy implications are discussed.

Keywords: CO_2 emissions; Economic Growth; GMM-PVAR; Institutional Quality; Renewable Energy; Sub-Saharan Africa

JEL Classification Code: C13; O44; Q43; Q50

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1. Introduction

This study investigates the dynamic causal relationship between institutions, economic growth, renewable energy, and CO_2 emissions for sub-Saharan Africa (SSA). Recently, research on the environment-energy-economic growth nexus has become a hot topic in energy and environmental economics because of its associated policy implications. Climate change continues to be the biggest threat to human and economic development (Acheampong, 2019; Farzanegan et al., 2018; Oh & Lee, 2004; Sethi et al., 2020). Unless immediate action is taken to mitigate its effects of climate change, the overall cost has been approximated to be a permanent 5% loss of global GDP forever[2], but be as much as 20% if a broader range of impacts and risks are considered (Stern, 2007). However, many scholars are drawing attention to the costs of climate change, arguing that about 1% of GDP would need to sacrifice. Sacrificing GDP to that extent could be damaging the current global economic position and slowing down future growth (Apergis & Payne, 2010b, 2014; Bhattacharya et al., 2017; Bhattacharya et al., 2016). To mitigate climate change and global warming, there has been a call to reduce carbon (CO_2) emissions. Thus, there is high and increasing interest in CO_2 emissions mitigation by international organisations and nations (e.g. small island nations in the Pacific region and elsewhere) to control and reduce the adverse impact of climate change and global warming (Jafari et al., 2012; Tamazian, Chousa, & Vadlamannati, 2009).

Despite desperate attempts by international organisations to reduce CO_2 emissions, global emissions are increasing astronomically. The International Energy Agency (IEA) (2018) report indicate that in 2017, global CO_2 emissions increased by 1.4%. Thus, globally, CO_2 emissions rose by 460 million ton (Mt) in absolute terms and reaching an unprecedented high level of 32.5 gigatons (Gt) after a three (3)-year period of stagnation. Climate scientists have been warning the world over the past two to three decades about the need for a sharp reduction in CO_2 emissions to meet the goal of the Paris agreement on climate change (IEA, 2018). The consistent increase in global CO_2 emissions suggests that current efforts by policymakers are insufficient to meet the objectives of the Paris agreement on climate change (IEA, 2018).

It is argued that the greatest offender in the rising level of global CO_2 emissions is fossil fuel consumption (Dong et al., 2018; Jardón, Kuik, & Tol, 2017; Vlachou et al., 1996). Therefore, to reduce CO_2 emissions, replacing fossil fuel energy with an alternative energy source that is clean is critical for sustainable development. Renewable energy has been the most effective and optimal alternative to fossil fuel and widely accepted pathway towards the mitigation of climate change (Apergis & Payne, 2010b, 2010c, 2011, 2014; Bhattacharya et al., 2017; Bhattacharya et al., 2016; Dong et al., 2018; Sadorsky, 2009). Furthermore, the global concerns associated with the rising prices and the volatility of fossil fuel energy supply have made renewable energy the pathway to address climate change and the best strategy to improve energy security, efficiency, and accessibility (Menyah & Wolde-Rufael, 2010). These merits associated with renewable energy have made it received much attention in the sustainable development debate.

Because of climate change, energy security, energy accessibility and energy efficiency awareness, the goal of most economies is to achieve a balance among three critical policy

[2] Tol (2002a, 2002b) argues that the context in which climate change will affect is highly uncertain but very important.

objectives. These critical policy objectives include 1) to achieve energy security by increasing the share of renewable energy sources in the total energy mix, 2) to lower CO_2 emissions by giving priority to renewable energy and discourage the use of fossil fuel energy and, 3) to work towards sustainable economic growth (Bhattacharya et al., 2017; Soytas & Sari, 2006). Balancing these policy objectives in an integrated framework is a challenge to both policymakers and analyst. However, researchers have begun utilising an integrated approach to investigate the dynamic causal relationship between renewable energy, CO_2 emissions and economic growth[3] (for instance, Acheampong, 2018; Apergis et al., 2014; Bélaïd & Youssef, 2017; Ito, 2017; Lu, 2017; Menyah & Wolde-Rufael, 2010; Zeb et al., 2014). Although these studies are relatively few and still at the infant stage, the empirical findings remain contradictory (see Adewuyi & Awodumi, 2017; Ito, 2017; Lu, 2017; Ozcan, Tzeremes, & Tzeremes, 2019). For instance, Arminen and Menegaki (2019) indicate that with the limited studies and the contradictory findings, further research is needed to reconcile or advance knowledge on the dynamic relationship between energy, CO_2 emissions and economic growth. Furthermore, little is known about the dynamic relationship between energy, CO_2 emissions and economic growth in sub-Saharan Africa (Adewuyi & Awodumi, 2017). Additionally, as institutions are found to shape economic growth (Acemoglu, Gallego, & Robinson, 2014; Acemoglu & Johnson, 2005; Acemoglu, Johnson, & Robinson [hereafter AJR], 2005), the environment and energy (Abid, 2016; 2017; Bhattacharya et al., 2017; Omri, 2014; Cadoret & Padovano, 2016; Stern, 2012), it is important to incorporate institutions in the energy- CO_2 emissions-economic growth nexus (Bhattacharya et al., 2017; Arminen et al., 2019).

With these knowledge gaps, this paper extends the limited literature by using an integrated framework approach to investigate the dynamic causal relationship between institutions, economic growth, renewable energy, and CO_2 emissions for 45 SSA countries for the period between 1960-2017. Using the integrated framework to study the causal linkages between institutional quality, energy, economic growth, and CO_2 emissions help to avoid the problem of misspecification and present important policy recommendation (Acheampong, 2018; Ang, 2007, 2008; Soytas et al., 2009; Soytas et al., 2007). In achieving the goal of this study, two important two questions are addressed by this paper. 1) What is the impact and direction of causality between institutional quality, renewable energy, economic growth, and CO_2 emissions in SSA? 2) Do the dynamic causal relationships between institutions- renewable energy-growth- CO_2 emissions differ between countries with different historical/institutional legacies in SSA?

This study is focused on SSA because the region contributes less to global CO_2 emissions but pays/bears the highest cost associated with climate change. While SSA is the minor emitter of CO_2 emissions globally, CO_2 emissions from this region have been rising recently, raising concerns among policymakers (Acheampong, 2019). It is suggested that if pragmatic policy measures are not taken to limit the growth of CO_2 emissions in SSA, it will stymie its economic development. Furthermore, SSA is at the forefront of implementing the Sustainable Energy for All (SEE4ALL) goals, which includes improving energy efficiency, energy accessibility, and increasing the share of clean and renewable energy. The IEA (2014)

[3] See the appendix for the summary of the empirical literature on the renewable energy, carbon emissions and economic growth linkages.

report indicates that only 290 million people out of the entire SSA population of 915 million have access to energy while people without energy have been increasing. The report also suggests that increasing the share of renewable energy in the SSA total energy mix could potentially increase energy accessibility and energy efficiency while mitigating CO_2 emissions. Although SSA is renewable energy-rich region, renewable energy has been a standstill in the region. Economic growth in SSA has been weak, and observation indicates that the region's economic growth has been recovering, thereby increasing its GDP per capita. It is also argued that SSA countries have weak or extractive institutions, which have rendered most of their policies inefficient (AJR, 2003; 2001). Therefore, results that will emanate from this study would help guide policymakers in designing future economic, energy and environmental policies and institutional reforms. These reasons make it prudent to study the dynamic causal relationship between institutions, economic growth, renewable energy, and CO_2 emissions in SSA.

This study makes several distinct contributions to the literature. First, this study augments the economic growth-renewable energy- CO_2 emissions nexus with institutions, and such augmentation prevents variable omission bias. Second, this study utilises the Principal Component Analysis (PCA) to construct a composite measure for institutions using the six governance indicators (voice and accountability, political stability and lack of violence, government effectiveness, regulatory quality, the rule of law and control of corruption). Second, the institutional economics literature argues that the rate of economic growth, renewable energy adoption and the level of CO_2 emissions differ between countries with different institutions (AJR, 2001, 2002; Bhattacharya et al., 2017). Despite this argument, previous studies fail to consider institutional origin or heterogeneities among countries when studying the dynamic linkages between economic growths, energy, and CO_2 emissions. In this regard, this study further conducts sensitivity analysis by disaggregating the full sample into three main sub-samples based on the countries' institutional origin/colonial heritage to examine the variation in our results. Finally, this study employs the recently developed generalised method of moment panel vector autoregression (GMM-PVAR) estimator to investigate the dynamic relationship between institutions, economic growth, renewable energy, and CO_2 emissions. The results from the GMM-PVAR, which is a sophisticated econometric technique, are efficient and robust as it employs the GMM approach to estimate the relationship and test the causality between the variables. This econometric technique prevents endogeneity and further makes its estimates consistent and robust.

2. Brief Literature Review

Institutions are the "rules of the game" of society that constraint and shape human interaction (North, 1989;1990; 1992). In other words, institutions define the incentives and penalties, structure and shape social behaviour, and collective actions and thus, are pre-condition for sustainable development (Alonso & Garcimartín, 2013). The role of institutions in shaping countries' economic development continues to attract the attention of researchers and policymakers. AJR (2005) argues that institutions are a fundamental cause of economic growth since it structures property right protection. Without property rights protection, individuals will not have the incentives to invest in human or physical capital and adopt efficient technologies. Additionally, institutions determine the efficiency of resource allocation and determine transaction cost. Therefore, institutions are the cause of the divergence in development path among countries (AJR, 2001). Evidence from the empirical literature, which uses different econometric techniques and institutions proxies, indicate that institutions shape countries' economic growth (Acemoglu, Johnson, Robinson, & Thaicharoen, 2003; AJR, 2001;2002; Esfahani & Ramírez, 2003; Flachaire et al., 2014; Fosu, 1992; Rodrik, Subramanian, & Trebbi, 2004). The main conclusion from the voluminous empirical literature is that countries with extractive institutions have experienced poor economic growth relative to countries with growth-supporting/efficient institutions.

Some institutional economists argue that institutions are not homogenous among countries and cause economic development divergence among countries. In their scholarly works, North (1989;1992), North, Summerhill and Weingast (2000) and Shirley (2008) argue that countries that were ruled by different European nationals inherited different sets of institutions from their colonial masters. The implication is that countries that inherited different institutions from their colonial masters have experienced different post-colonial economic development. For instance, countries that the British ruled inherited British institutions while French ex-colonies also inherited French institutions; therefore, British and French ex-colonies tend to have a different level of economic growth and institutional quality. This theoretical argument has been supported empirically (Bertocchi & Canova, 2002; Grier, 1999; North, 1989). Consistently, La Porta et al. (2008, p. 286) argue that countries British institutional origin (legal system) support better property right protection, private market outcome, contract enforcement and lower formalism of judicial procedures. In contrast, countries with French German and Scandinavian institutional origin are associated with a heavier hand of government ownership and regulation, less secure of property right and contract enforcement. Therefore, based on the argument by these prominent scholars, we avoid the assumption of homogeneity among our sample.

Although the literature on institutions and economic growth are abundant, limited literature exists on the impact of institutions on the environment and energy (Arminen et al., 2019). Theoretically, Aguirre et al. (2009) and Bhattacharya et al. (2017) contend that institutions that promote property rights protection support voluntary exchange and help governments design and implement sustainable development policies. Thus, the effectiveness of environmental and renewable energy policies depend on the efficacy of institutions without which government policies will not bear the desirable outcome. Omri (2014) further argues that institutions do not influence economic growth only but also shape the efficacy of energy policies. Additionally, better institutions improve energy efficiency and the adoption of renewable energy and result in stringent energy and environmental policies (Cadoret & Padovano, 2016; Fredriksson & Svensson, 2003; Fredriksson, Vollebergh, & Dijkgraaf, 2004; Stern, 2012). Empirically, the results of Abid (2016) indicate that government effectiveness, political stability, control of corruption contribute to CO_2 emissions mitigation while regulatory quality and the rule of law do not limit the rise of CO_2 emissions in SSA. Extending the earlier study, Abid (2017) found that government effectiveness, political stability, control of corruption, regulatory quality and the rule of law limits the growth of CO_2 emissions in the EU, while none of these measures of institutions significantly affects CO_2 emissions in the Middle East and North Africa countries. As institutions shape economic, energy and environmental policies, it is crucial to incorporate institutional variables when analysing the nexus between renewable energy, CO_2 emissions and economic growth to prevent variable omission bias. Therefore, this paper contributes to the limited literature by using an integrated framework approach to investigate the dynamic causal relationship between institutions, economic growth, renewable energy, and CO_2 emissions for 45 SSA countries between 1960-2017.

3. Data and Methodology

3.1 Data

The data for this study extends from 1960-2017 for a panel of 45 countries[4]. Following Rafiq, Bloch, and Salim (2014) and da Silva, Cerqueira, and Ogbe (2018), renewable energy was proxied using renewable electricity output as a share of total electricity output, and this is the share of electricity generated by renewable power plants in total electricity generated by all types of plants. Real GDP per capita was used as the proxy for income/economic growth. Carbon emission (kg) per 2010 US dollars as a percentage of GDP was used to measure CO_2 emissions. These data were obtained from the World Development Indicators (2018). Following Abid (2016, 2017), the study used world governance indicators as indicators for institutions. The world governance indicators capture six (6) main components of governance: voice and accountability, political stability and lack of violence, government effectiveness, regulatory quality, the rule of law, and control of corruption. The governance indicators were sourced from Kaufmann, Kraay, and Mastruzzi (2011). This study used the Principal Component Analysis (PCA) to derive a unified measure of institutional quality (QI). The PCA prevents multi-collinearity among the variables while preserving the data originality as it is (Shahbaz, Shahzad, Ahmad, & Alam, 2016).

Before estimating the empirical model, we conducted four types of panel unit root tests, including the Levin-Lin-Chu (LLC) unit root test (Levin, Lin, & James Chu, 2002), Im-Pesaran-Shin (IPS) unit root test (Im, Pesaran, & Shin, 2003), Augmented Dickey-Fuller (ADF) unit root test (Dickey & Fuller, 1979) and the Philips-Perron (PP) unit root test (Phillips & Perron, 1988). The LLC unit toot tests assume common unit root tests across the cross-section, while the IPS, ADF and the PP assume individual unit root process across the cross-section. The null hypothesis for the LLC is that there is a unit root, while the alternative hypothesis is that there is no unit root. The null hypothesis for IPS, ADF and PP is that all panel contain a unit root, while the alternative hypothesis is that at least one panel is stationary. As presented in Appendix Table A.2, except for the economic growth (lngdpc) and renewable energy (lnrenewout) series, most of the unit tests show that the remaining variables are stationary at levels. However, at the first difference, all the unit root tests indicate that all the variables are stationary.

[4] Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

3.2. Econometric estimation technique

This paper examines the dynamic causality between institutional quality, economic growth, renewable energy, and CO_2 emissions. To achieve this objective and present robust results for informing policy, the current study follows the generalised method of moment panel vector auto-regression (GMM-PVAR)[5] empirical methodology of Abrigo and Love (2015), Acheampong (2018) and Love and Zicchino (2006). Thus, the study estimates the following empirical models:

$$Y_{it} = A_0 + A_{i1}Y_{t-1} + A_{i2}Y_{t-2} + A_{ip}Y_{t-p} + \mu_{it} + e_{it} \qquad (1)$$

Where $i \epsilon\{1,2, \dots\dots\dots, N\}, t \in \{1,2, \dots., T\}$, Y_{it} is a $(1 \times k)$ vector of the endogenous variables - thus institutional quality (QI), economic growth (lngdpc), renewable energy deployment (lnrenewout) and CO_2 dioxide emission ($lnCO_2gdp$); μ_{it} and e_{it} are $(1 \times k)$ vectors of the endogenous variable specific fixed effects and the idiosyncratic errors, respectively. The $A_1, A_2, \dots\dots\dots\dots\dots\dots A_{p-1}$ are the $(K \times K)$ matrices to be estimated. It is assumed that the idiosyncratic errors have the following features: $E[e_{it}] = 0, E[e_{it}\, e'_{it}] = \Omega, E[e_{it}\, e'_{it-K}] = 0$. Thus, the idiosyncratic errors are uncorrelated over time and are normally distributed with zero mean and covariance matrix Σ_{ii} that is of dimension $[NG \times NG]$. The $[NG \times NG]$-matrix A_P for one particular lag p is defined as:

$$A_P = \begin{bmatrix} a^{11}_{p,11} & \cdots & a^{1k}_{p,1j} & \cdots & a^{1G}_{p,1N} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a^{l1}_{p,i1} & \ddots & a^{1k}_{p,ij} & \cdots & a^{lG}_{p,iN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ a^{G1}_{p,N1} & & a^{GK}_{p,Nj} & \cdots & a^{GG}_{p,NN} \end{bmatrix} \qquad (2)$$

The element $a^{lk}_{p,ij}$ is the coefficient of the lag p of the variable k of the country j in the equation of the variable l of country i. Thus, the element $a^{lk}_{p,ij}$ measures the impact of lag p of variable k of country j o variable l of country i.

Eq. (1) could have been estimated using Ordinary Least Squares (OLS) and fixed effect. However, the inclusion of the lagged of the dependent variable within the system equation would correlate with the panel fixed effect resulting in bias and inconsistent estimates of the parameters. In this regard, Baltagi (2008) argues that using the lagged instruments and first differencing are the best strategies to eliminate the individual fixed effect and produce consistent estimates. Following the above argument, this study adopted the Blundell and Bond [hereafter, BB] (1998) system generalised method of moment (GMM) to estimate the above equation. Unlike the Arellano and Bond (1991) GMM approach, the generalized method of moment of BB (1998) utilises the difference of lag of the dependent variable as instruments for equations in levels and also incorporate the lagged levels of the dependent variable as instruments for equations in first differences (see Acheampong, 2018; Čeh Časni, Dumičić and Tica, 2016)). Therefore, to eliminate the country-specific effect from Eq. (1), we estimate Eq. (2), using the first difference (Δ) approach as specified in Eq. (3).

[5] The GMM-PVAR was implemented in STATA using the code developed by Love and Zicchino (2006).

$$\Delta Y_{it} = A_{i1}\Delta Y_{t-1} + A_{i2}\Delta Y_{t-2} + \cdots + A_{ip}\Delta Y_{t-p} + e_{it} \qquad (3)$$

We further follow the standard approach of Hamilton (1994) and Lutkepohl (2005) to estimate the impulse response functions (IRF). The IRF demonstrates the reaction of one variable to a shock to another variable within the system while all other shocks constant (Love & Zicchino, 2006). The IRF could be computed using the infinite vector moving-average as presented in Eq. (4) below, where Φ_i are the parameters of the vector moving-average. Given that the errors e_{it} are contemporaneously correlated, a shock to one variable could eventually be accompanied by shock to other variables. Hence, the IRF should not be interpreted as causality (Abrigo & Love, 2015). In our model, we orthogonalized the errors such that we could isolate the shocks to one of the VAR errors.

$$\Phi_i = \begin{cases} I_k\,, & i = 0 \\ \sum_{j=1}^{i} \Phi_{t-j} A_j\,, & i = 1,2 \end{cases} \qquad (4)$$

According to Sims (1980), variables in the VAR model should have recursive causal ordering based on their degree of exogeneity. For the model identification, we set with the assumption that a current shock to institutions has a contemporaneous effect on economic growth, renewable energy and CO_2 emissions while economic growth, renewable energy and CO_2 emissions impact institutions only with their lags. This justification is plausible since current economic growth, environmental pollution (CO_2 emissions), and renewable energy would not affect current institutions but affect future institutional reforms (institutional quality). Thus, current institutions are influenced by previous economic growth, environmental pollution and renewable energy (see Acheampong, 2018). Therefore, institutions were listed first, followed by economic growth, renewable energy, and CO_2 emissions. In analysing the IRF, one thousand (1000) Monte Carlo replication or simulations were conducted to generate the IRF standard errors.

The forecast error variance could be computed using Eq. (5). Thus, the $h\text{-}step$ ahead of the forecast error is expressed as:

$$Y_{it+h} - E[Y_{it+h}] = \sum_{i=0}^{h-1} |e_{i(t+1-i)}\Phi_i \qquad (5)$$

Where Y_{it+h} is the observed vector at time $t + h$ and $E[Y_{it+h}]$ is the $h\text{-}step$ ahead predicted vector made at time t. Like the IRF, we orthogonalised the shocks using thr matric P to isolate the contribution of each variable to the forecast variance. The orthogonalised shocks $e_{it}P^{-1}$ have a covariance matrix I_K, which allows the direct decomposition of the forecast error variance. In other words, the contribution of variable m to the $h\text{-}step$ ahead of the forecast-error variance of variable n is computed using Eq. (6).

$$\sum_{i=0}^{h-1} \theta_{mn}^2 = \sum_{i=1}^{h-1} (i_n' P \Phi_i i_m)^2 \qquad (6)$$

Where i_s is the s-th column of $\boldsymbol{I_K}$. In practice, the contribution of each variable to the $h\text{-}step$ forecast error variance of variable $\boldsymbol{n}$ is normalised using Eq. (7). Like the IRF, we used one thousand (1000) Monte Carlo simulations to generate the confidence intervals for the forecast error variance.

$$\sum_{i=0}^{h-1} \theta_{.n}^2 = \sum_{i=1}^{h-1} i_n' P \Phi_i' i_n \tag{7}$$

According to Abrigo et al. (2015), Hamilton (1994) and Lutkepohl (2005), the VAR model is stable if all the companion matrix $\overleftarrow{\boldsymbol{A}}$ is strictly less than one or when the all the eigenvalues lie within the unit circle. The companion matrix is given in Eq. (8).

$$\overleftarrow{A} = \begin{bmatrix} A_1 & A_2 & \dots & A_P & A_{P-1} \\ I_k & O_k & \dots & O_k & O_k \\ O_k & I_k & \ddots & O_k & O_k \\ \vdots & \vdots & & \vdots & \vdots \\ O_k & O_k & \cdots & I_k & O_k \end{bmatrix} \tag{8}$$

The stability of the panel vector autoregression (PVAR) is an indication that PVAR has an infinite vector moving average representation, which provides a known interpretation to the estimated IRF and the forecast error variance decomposition (Abrigo et al., 2015). The GMM-PVAR is advantageous in our study since it builds an endogenous system and treats all the variables in an unrestricted way (Love et al., 2006). This feature helps this study account for the dynamic endogenous interactions between institutional quality, economic growth, renewable energy, and CO_2 emissions. Additionally, the GMM-PVAR provides a better understanding of the source of heterogeneities by accounting for cross-sectional dynamic heterogeneities. Given that there exist some variations in institutional quality, economic growth, renewable energy, and CO_2 emissions among countries considered, we identify the dynamic interactions among these variables between countries with different institutional origins. The GMM-PVAR further helps to capture the time variations in the coefficient and the variance of the shocks. Compared to the traditional VAR model, the GMM-PVAR has robust and consistent results by increasing the estimation observations (Acheampong, 2018). The GMM-PVAR also presents robust causality between the variables considered.

4. Empirical Results

4.1. Impulse Response Function

This section reports and discusses the Impulse Response Function (IRF) findings and the 95% confidence interval band that was generated using 1000 Monte Carlo simulations. The empirical results would help guide policymakers in designing future economic, energy and environmental policies as well as institutional reforms. To make the results comparable to the existing literature, we categorise our analysis into six (6) main strands: economic growth-institutions nexus, renewable energy-institutions nexus, CO_2 emissions-institutions nexus, CO_2 emissions-renewable energy nexus and CO_2 emissions-economic growth nexus (see Fig. 1).

From Fig. 1, the IRF results suggest that economic growth reacts positively to a shock in CO_2 emissions. The positive effect of CO_2 emissions on economic growth implies that using stringent environmental policies to control CO_2 emissions could impede economic growth, such that the cost of forgoing economic growth is higher than the cost associated with the abatement of greenhouse gases (Tol & Dowlatabadi, 2001; Tol & Yohe, 2006). Consistent with the theoretical argument of Ricci (2007), when CO_2 emissions are regarded as input in production and a by-product of production, it could boost economic growth. Similarly, it is contended that abating CO_2 emissions will reduce economic growth as there will be an adjustment in industries or limit the growth of high-carbon intensive sectors that contribute significantly to economic growth (see also Acheampong, 2018; Fan, Zhang, & Zhu, 2010; Hsu and Chou, 2000). The results further suggest that a shock to renewable energy reduces economic growth. The implication is that renewable energy has not reached the level to contribute significantly to sub-Saharan Africa economic growth. It is noted that renewable energy accounts for less than 2% of sub-Saharan Africa total energy mix (IEA, 2014), and such a percentage is not sufficient to boost economic growth. Therefore, for renewable energy to contribute significantly to sub-Saharan Africa economic growth, policymakers should invest and tapped the available potential renewable energy resources that are in abundance in the region. As depicted in Fig. 1, the results reveal that a shock to institutions reduces economic growth. This result reflects the extractive/weak institutions of sub-Saharan Africa, which has been inimical to its economic growth.

As indicated in Fig. 1, a shock to economic growth reduces CO_2 emissions. This result confirms Meadows, Randers, and Meadows (1992) argument that economic growth may be necessary to maintain the quality of the environment. The results also suggest that a shock to renewable energy results in a significant reduction in CO_2 emissions. This finding supports the expectation that deploying renewable energy is an effective solution for reducing CO_2 emissions and contributing to climate change mitigation. Existing studies such as Acheampong, Adams, and Boateng (2019) and Adams and Acheampong (2019) indicated that renewable energy contributes to CO_2 emissions mitigation in SSA. Also, the results reveal that shock to institutions reduces CO_2 emissions. As explained earlier, since the effectiveness of renewable energy and environmental policies largely depends on the efficacy of domestic institutions (Bhattacharya et al., 2017), improving the quality of institutions could speed renewable energy expansion and the improvement in environmental quality.

The IRF also indicates that renewable energy reacts negatively to a shock to CO_2 emissions. The negative effect of CO_2 emissions on renewable energy suggests that CO_2 emissions are not compelling sub-Saharan Africa economies to transition towards renewable energy effectively. This result confirms the findings of da Silva et al. (2018) and Marques, Fuinhas and Pires-Manso (2010), which revealed that CO_2 emissions reduce renewable energy in sub-Saharan Africa and Europeans countries, respectively. The results also suggest that renewable energy reacts negatively to a shock in economic growth. The implication is that economic growth hampers the growth of renewable energy. This result reflects sub-Saharan Africa anaemic economic growth. Investment in renewable energy is relatively costly, and the region's poor economic growth cannot provide sufficient income to support the adoption of renewable energy. The results further reveal that shock to institutions increases renewable energy. As explained earlier, since the effectiveness of renewable energy and environmental policies largely depends on the efficacy of domestic institutions (Bhattacharya et al., 2017), improving the quality of institutions could speed renewable energy expansion and the improvement in environmental quality.

It is also observed from Fig. 1 that a shock to economic growth improves institutions. The implication is that implementing structural policies to boost economic growth will improve institutions in sub-Saharan Africa. Also, a shock to renewable energy has an insignificant positive effect on institutional quality. Thus, the need to transition towards renewable energy does not affect institutional reform in sub-Saharan Africa.

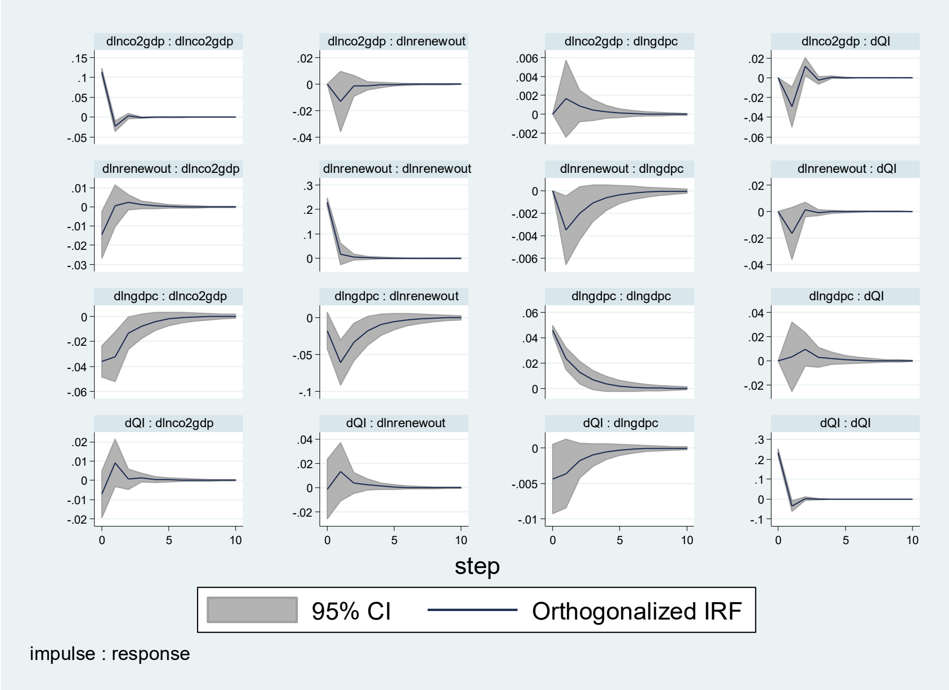

Fig 1: IRF for composite institutions, economic growth, renewable energy and CO_2

4.2. GMM-PVAR Results

To complement the IRF results, Table 1 presents the GMM-PVAR[6] causality results among the variables. On the economic growth estimates, renewable energy exerts a significant negative effect on economic growth. This result could be due to the minimal share of renewable energy in the total energy mix, thereby hampering economic growth. In other words, renewable energy has not reached the level to contribute significantly to economic growth in sub-Saharan Africa. Additionally, the results imply that institutions retard economic growth. The broader context of this result implies that institutions in the region do not function properly, as they are incapable of shaping an actor/agent's behaviour (Alonso & Garcimartín, 2013), thereby exerting a negligible effect on economic growth. The results also indicate that CO_2 emissions exert an insignificant positive effect on economic growth. Thus, CO_2 emission is not a major contributor to economic growth in SSA, and this contradicts the results of Acheampong (2018) and Menyah and Wolde-Rufael (2010), which indicated that carbon emissions contribute to economic growth.

On renewable energy estimates, economic growth significantly reduces renewable energy. This result contradicts previous findings that economic growth increases renewable energy (see da Silva et al., 2018; Lu, 2017; Sadorsky, 2009; Salim & Rafiq, 2012). It is also observed that CO_2 emissions have an insignificant effect on renewable energy. This result contradicts the findings of Apergis and Payne (2014), Sadorsky (2009), Salim and Rafiq (2012) and Lu (2017), which suggest that CO_2 emissions increase renewable energy. The results further reveal that institutions have a negligible positive effect on renewable energy. This result

[6] The GMM-PVAR is not the same as the ordinary system generalised method of moment (System-GMM) (see, Acheampong, 2018).

implies that institutions have not been supportive enough to support the growth of renewable energy in sub-Saharan Africa.

It is obvious from the results that economic growth reduces CO_2 emissions, and the estimated coefficient is 0.864%. This finding depicts that sub-Saharan African has been a minor contributor to global CO_2 emissions due to its relatively low level of economic growth. This observed result is not in line with the findings of Abid (2016), Burnett et al. (2013) and Pal et al. (2017), which reveal that CO_2 emissions increase with economic growth but confirms the results of Kim et al. (2020). However, this result is consistent with Abdouli, Kamoun and Hamdi (2018) and Hailemariam, Dzhumashev and Shahbaz (2019) findings, which indicate that economic growth reduces CO_2 emissions in the long run. Still, the results show that renewable energy mitigates CO_2 emissions such that an increase in renewable energy will reduce CO_2 emissions. This evidence supports the findings of Bhattacharya et al. (2017), Al-Mulali, Ozturk, and Lean (2015) and Dong et al. (2018), which indicate that renewable energy mitigates CO_2 emissions. Institutions are found to exert a weak effect on CO_2 emissions and renewable energy.

Table 1: GMM-PVAR causality main results

Independent variables	***Dependent variables***			
	dQI_t	$dlngdpc_t$	$dlnrenewout_t$	$dlnco2gdp_t$
dQI_{t-1}	-0.160***	-0.005	0.028	0.016
	(0.057)	(0.008)	(0.049)	(0.025)
$dlngdpc_{t-1}$	-0.162	0.519***	-1.384***	-0.864***
	(0.315)	(0.100)	(0.364)	(0.226)
$dlnrenewout_{t-1}$	-0.090**	-0.014**	0.073	-0.009
	(0.044)	(0.007)	(0.095)	(0.025)
$dlnco2gdp_{t-1}$	-0.258***	0.014	-0.116	-0.201***
	(0.089)	(0.018)	(0.101)	(0.059)

Heteroskedasticity-robust standard errors in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Apparently, the results indicate that economic growth significantly worsens institutions in SSA. As argued by Clague et al. (1996) and Eggertsson (1990), higher economic growth is needed to promote the efficiency of domestic institutions. Therefore, the negative effect of economic growth on institutions suggests that economic growth is not enough to improve the efficiency of its domestic institution in SSA. From the empirical results, CO_2 emissions worsen institutions. As explained earlier, CO_2 emissions could result in uneven access to and supply resources, leading to competition and conflict through climate change, thereby deteriorating the quality of institutions (see Hendrix et al., 2007; Reuveny, 2007).

4.3. Sensitivity analysis

From the theoretical perspective as discussed in the literature section, we conduct sensitivity analysis by disaggregate our sample into three main sub-samples based on the countries' institutional origin/colonial heritage (British, French[7] and rest of sub-Saharan Africa (SSA)

[7] The British and French ex-colonies were the countries that were under the rule of British and French respectively before they gained independence. This approach has been used in earlier studies (see Bertocchi and Canova 2002; Lange, Mahoney, and Vom Hau 2006; Lange 2004; Olsson 2009; La Porta et al. 2008).

countries[8]) to comparatively analyse how the results differ. The IRF results for the British ex-colonies, French ex-colonies, and the rest of the SSA countries are presented in Fig. 2, 3 and 4, respectively.

The results indicate that a shock to economic growth reduces CO_2 emissions for the sub-samples. This result suggests that higher economic growth in the sub-samples will contribute to the mitigation of CO_2 emissions. It is also observed that for the British ex-colonies and the rest of SSA countries, a shock to institutions reduces CO_2 emissions while it increases CO_2 emissions in the French ex-colonies. The implication is that institutions in British ex-colonies and the rest of SSA countries are key for mitigating CO_2 emissions, while in the case of French ex-colonies, institutions have been weak in mitigating CO_2 emissions. This result is consistent with Acheampong and Dzator (2020) findings that the role of institutions in mitigating carbon emissions differs between countries with different institutional origin. The results suggest that for the British ex-colonies and the rest of SSA countries, a shock to renewable energy reduces CO_2 emissions while it increases CO_2 emissions in French ex-colonies. Thus, renewable energy in British ex-colonies and the rest of SSA countries plays a significant role in CO2 emission mitigation but not in the French ex-colonies.

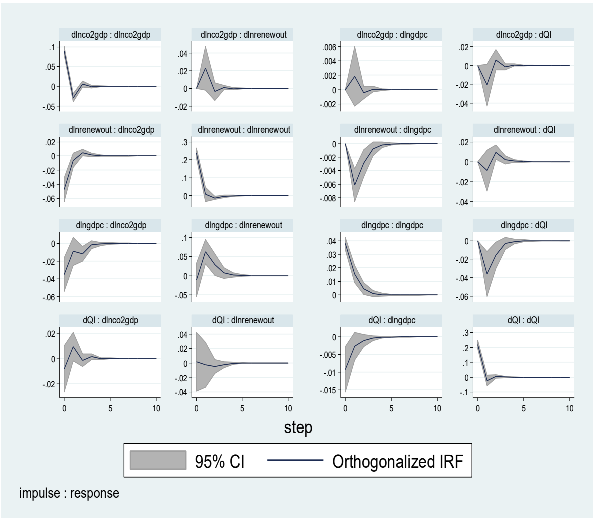

Fig 2: IRF for ex-British colonies.

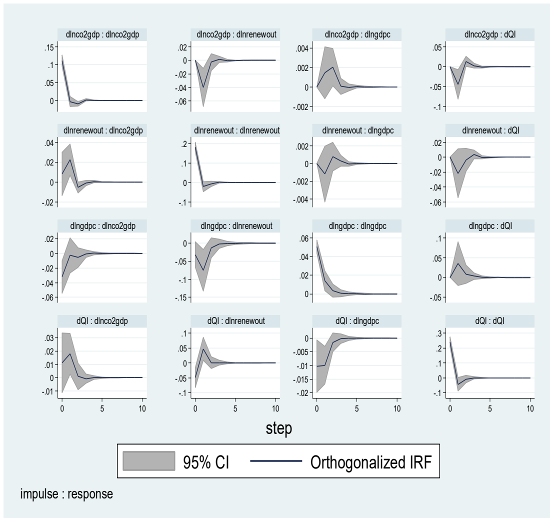

Fig 3: IRF for French ex-colonies.

[8] The rest of the sub-Saharan African countries includes countries that were never colonised, Belgium, Portugal, Spain and Germany ex-colonies. We put all these countries together because with respect to their colonial masters, their sample size was small to warrant further comparative analysis using panel data approach.

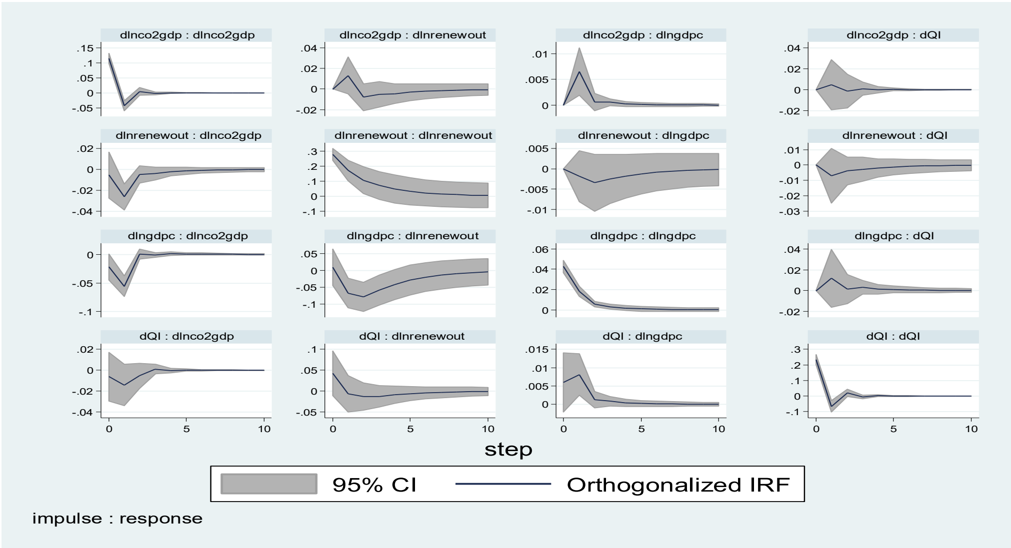

Fig 4: IRF for the rest of SSA countries.

The IRF results also indicate that a shock to CO_2 emissions increases economic growth for the sub-samples. On the other hand, economic growth reacts negatively to a shock to renewable energy for the sub-samples. For the British and French ex-colonies, a shock to institutions reduces economic growth while it increases economic growth in the rest of SSA countries. Besides, for the British ex-colonies and the rest of SSA countries, a positive shock to CO_2 emissions increases renewable energy while reducing renewable energy in the French ex-colonies. Similarly, renewable energy reacts positively to a shock to economic growth in the British ex-colonies while reducing renewable energy in the French ex-colonies and the rest of SSA countries. Also, a shock to institutions increases renewable energy in the British ex-colonies while reducing renewable energy in the French ex-colonies and the rest of SSA countries. For the British ex-colonies, a shock to economic growth worsens institutions in the British ex-colonies while it improves institutions in the French ex-colonies and the rest of SSA countries. For the British ex-colonies and the French ex-colonies, a shock to CO_2 emissions worsens institutions while it improves institutions in the rest of SSA countries. The results also indicate that a shock to renewable energy worsens institutions in the British and French ex-colonies while it improves institutions in the rest of SSA countries. These reported results indicate that the relationship between institutions, economic growth, renewable energy, and CO2 emissions differ between countries with different institutional origins. Therefore, different policy measures are required to reduce CO2 emissions while improving institutions, economic growth, and renewable energy use among the SSA countries.

4.3.1 GMM-PVAR results for the sub-samples

The results shown in Table 2: Panel A gives the estimates for the British ex-colonies, while Panel B and C present the estimates for the French ex-colonies and the rest of SSA countries, respectively. It is apparent from the results that economic growth significantly increases renewable energy in the British ex-colonies (1.904%) while it reduces renewable energy in both French ex-colonies (-1.780%) and the rest of SSA countries (-1.646%). It is argued in the vast literature that the British ex-colonies have experienced higher economic growth relative to other ex-colonies (Bertocchi et al., 2002; Grier, 1999; Lange et al. 2004 North, 1989;1992). The implication of this result is that the relatively higher economic growth in the British ex-colonies supports the adoption of renewable energy. Contrarily, the negative effect of economic growth on renewable energy in the French ex-colonies and the rest of SSA countries manifests a low level of economic growth in these countries. The findings further show that CO_2 emissions increase renewable energy in the British ex-colonies and the rest of SSA colonies, but the impact is only significant in the British ex-colonies. Thus, the continuous increase in CO_2 emissions in the British ex-colonies is a major driver behind the expansion of renewable energy. This finding confirms Sadorsky (2009) findings that the persistent increase in CO_2 emissions remains a major reason behind renewable energy usage. Contrarily, the impact of CO_2 emissions on renewable energy in the French ex-colonies is negative and statistically significant. This result also supports da Silva et al. (2018) results, which revealed that CO_2 emissions reduce renewable energy in some of the sub-Saharan Africa countries. The estimated coefficient of institutions on renewable energy is positive and statistically significant for French ex-colonies (0.118%), while it reduces renewable energy significantly in the rest of SSA countries (0.097%). On the other hand, institutions have a negligible effect on renewable energy in the British ex-colonies.

On CO_2 emissions estimates, economic growth reduces CO_2 emissions significantly in the British ex-colonies (-0.562%) and the rest of SSA (-1.470%) countries while it has a negligible positive impact on CO_2 emissions in the French ex-colonies. It could argue from this result that economic growth in the British ex-colonies and the rest of SSA countries is promoting structural shifts towards information industries and service that are less CO_2 intensive. The results reveal that renewable energy significantly contributes to CO_2 emissions mitigation in the British ex-colonies (-0.091%) and the rest of SSA countries (-0.102%) while it increases CO_2 emissions in the French ex-colonies (0.125). Thus, while renewable energy is reducing CO_2 emissions in the British colonies and the rest of SSA countries, the positive effect of renewable energy on CO_2 emissions in the French ex-colonies indicates the limited share of renewable energy, which make it insufficient to mitigate CO_2 emissions. It is further observed from the results that institutions increase CO_2 emissions significantly in the French ex-colonies. In contrast, institutions exert no effect on CO_2 emissions in the British ex-colonies and the rest of SSA countries. Thus, the relative weak institutions in the French ex-colonies (Lange et al. 2004; North, 1989;1992) are weakening environmental regulation or do not promote the transfer of environmental-friendly technologies, thereby contributing to the rise in CO_2 emissions in these countries.

Table 2: GMM-PVAR causality main results for the sub-samples

	Dependent variables			
Panel A: British ex-colonies				
	dQI_t	$dlngdpc_t$	$dlnrenewout_t$	$dlnco2gdp_t$
dQI_{t-1}	-0.161*	0.006	0.079	0.007
	(0.086)	(0.007)	(0.059)	(0.020)
$dlngdpc_{t-1}$	-1.197***	0.419***	1.904***	-0.562***
	(0.350)	(0.078)	(0.465)	(0.212)
$dlnrenewout_{t-1}$	-0.084	-0.022***	0.079	-0.091***
	(0.052)	(0.006)	(0.087)	(0.020)
$dlnco2gdp_{t-1}$	-0.232*	0.021	0.253*	-0.321***
	(0.129)	(0.024)	(0.138)	(0.057)

Panel B: French ex-colonies

	dQI_t	$dlngdpc_t$	$dlnrenewout_t$	$dlnco2gdp_t$
dQI_{t-1}	-0.167*	-0.031***	0.118**	0.101***
	(0.095)	(0.011)	(0.055)	(0.032)
$dlngdpc_{t-1}$	0.376	0.283**	-1.780***	0.004
	(0.535)	(0.111)	(0.610)	(0.224)
$dlnrenewout_{t-1}$	-0.101	-0.007	-0.102	0.125***
	(0.089)	(0.009)	(0.070)	(0.042)
$dlnco2gdp_{t-1}$	-0.401**	0.013	-0.359***	-0.029
	(0.168)	(0.012)	(0.130)	(0.059)

Panel C: Rest of the SSA countries

	dQI_t	$dlngdpc_t$	$dlnrenewout_t$	$dlnco2gdp_t$
dQI_{t-1}	-0.285***	0.026***	-0.097**	-0.014
	(0.077)	(0.010)	(0.049)	(0.033)
$dlngdpc_{t-1}$	0.303	0.456***	-1.646***	-1.470***
	(0.328)	(0.055)	(0.342)	(0.156)
$dlnrenewout_{t-1}$	-0.024	-0.005	0.618***	-0.102***
	(0.033)	(0.011)	(0.118)	(0.015)
$dlnco2gdp_{t-1}$	0.041	0.057***	0.115	-0.374***
	(0.113)	(0.020)	(0.079)	(0.067)

Heteroskedasticity-robust standard errors in parenthesis. * p < 0.1, ** p <0.05, *** p < 0.01

It is apparent from the estimates that CO_2 emissions have an insignificant positive effect on economic growth in the British and French ex-colonies while significantly increasing economic growth in the rest of SSA countries. Additionally, the results reveal that institutions significantly reduce economic growth for the French ex-colonies (-0.031%) while it increases economic growth in the rest of SSA countries (0.026%) and British ex-colonies (not statistically significant). As argued previously, the implications of these results are that institutions in the French ex-colonies colonies have not supported higher economic growth, supporting the work of (Grier, 1999; Lange et al., 2004; North, 1989;1992). The results suggest that economic growth significantly worsens institutions in the British ex-colonies[9] while it has an insignificant positive effect for French ex-colonies and the rest of SSA countries. The results reveal that renewable energy exerts a negligible effect on institutions for the sub-samples. The results indicate that CO_2 emissions significantly worsen institutions in the British and French ex-colonies while not affecting the rest of SSA countries' institutions.

The results from disaggregated analysis reveal that the speed of renewable energy adoption, economic growth and CO_2 emissions mitigation differs across countries with different institutional origin. These results broadly support the argument that institutional origin is the fundamental source of the disparities in post-colonial economic development between countries with distinct colonial heritage[10].

[9] While this is beyond the scope of this paper, it is likely that economic growth is not supporting human capital development as well as worsening inequality, thereby resulting in poor institutional development.
[10] See also Agbor, 2015; Banerjee & Iyer, 2005; Grier, 1999; Lange et al., 2006; Lange, 2004; North, 1989; and North et al., 2000.

5. Policy Implications

The empirical results have significant ramifications for policy and should be considered in designing and implementing future energy, environmental and economic policies for sub-Saharan Africa countries. Firstly, for renewable energy to significantly contribute to economic growth, mitigate CO2 emissions, and improve institutions, the share of renewable energy in the energy mix should be increased. Given that renewable energy accounts for less than 2% of sub-Saharan Africa energy portfolio, the percentage of renewable energy in the total energy mix should be significantly increased. The abundance of renewable energy resources in sub-Saharan Africa and the budget constraints of governments means that governments should collaborate with the private sector to allocate more resources towards the investment in the renewable energy sector. Furthermore, governments should develop national energy policies with clear goals and incentives for investment in renewable energy, which will increase the share of renewable energy in the energy portfolio. Increasing the share of renewable energy in the energy portfolio will not only boost economic growth and mitigate CO_2 emissions but will also help sub-Saharan Africa to achieve the Sustainable Energy for All (SEE4ALL) goal as well as the Sustainable Development Goal 7 (SDG7).

Secondly, reforming and strengthening the existing institutions in sub-Saharan African countries would allow for a more efficient transition towards the adoption of renewable energy, achieve higher economic performance, and mitigate CO_2 emissions. The effectiveness of economic, environmental and energy policies mostly depend on the efficacy of domestic institutions. Without the development of supportive institutions, the government ability to enforce economic, environmental and energy policies would be largely undermined. Therefore, the implementation of regional and national strategies that promote political stability, control corruption, voice and accountability, government effectiveness, regulatory quality and the rule of law is vital for ensuring environmental sustainability, higher economic growth, and adopting renewable energy technologies. Additionally, promoting institutions that facilitate property right protections is crucial for increasing environmental quality, higher economic performance, and the share of renewable energy in the energy portfolio since property right protection encourages technological innovation.

Finally, given that economic growth promotes institutional quality, policymakers should pursue growth-promoting policies to enhance the efficiency of institutions. Achieving higher economic growth in sub-Saharan Africa requires governments to liberalize their economies and diversify their economies to avoid over-reliance on the primary sector of the economy. The liberalisation of sub-Saharan African economies will not only promote higher economic performance to improve the efficiency of institutions but also supports the transfer of environmentally friendly technologies that will help mitigate CO_2 emissions. These policy recommendations are not only applicable in sub-Saharan Africa countries but also apply to other developing regions/countries with the same economic and institutional structures as sub-Saharan Africa. Future studies could extend our methodology to other regions to provide a further understanding of the dynamics between institutions, energy, economic growth, and CO2 emissions.

6. Conclusions

This paper investigates the dynamic relationships between institutions, renewable energy, CO_2 emissions and economic growth for 45 sub-Saharan Africa countries using annual data from 1960 to 2017. Our results from the GMM-PVAR suggests renewable energy and CO_2 emissions worsen institutions, while economic growth has a negligible effect on institutions. The results also indicate that renewable energy insignificantly reduces CO_2 emissions but significantly reduces economic growth by 0.014%. Similarly, economic growth significantly reduces renewable energy by 1.384% and CO_2 emissions by 0.864%. Furthermore, the results indicate that CO_2 emissions have a negligible effect on economic growth and renewable energy. Interestingly, these results were found to differ between countries with different institutional origin. Post-estimation statistics suggest that these results are stable as the root of the companion matrix shows that all the eigenvalues are less than one, or the eigenvalues lie within the unit circle, suggesting that our models are stable[11]. These empirical results would help guide policymakers in designing future economic, energy and environmental policies as well as institutional reforms in SSA.

APPENDIX

Table A.1.: Summary of the empirical literature on the nexus between energy, carbon emissions and economic growth

Author (s)	Period	Countries	Methodology	Empirical results
Renewable energy, economic growth, and carbon emissions				
Bélaïd and Youssef (2017)	1980-2012	Algeria	ARDL, GRC	**(SR)** RGDP→ NREW **(LR)** RGDP →CO_2 ; REW→CO_2 ; NREW→CO_2
Menyah and Wolde-Rufael (2010)	1960-2007	USA	GRC	NUC→CO_2 ; NUC≠RGDP ; RGDP →REW; REW ≠ CO_2 ; RGDP↔CO_2
Cerdeira Bento and Moutinho (2016)	1960-2011	Italy	ARDL, GRC	RGDP →REW
Boontome et al. (2017)	1971-2013	Thailand	GRC	NREW→CO_2 ; REW ≠ RGDP ; REW ≠ CO_2 ; RGDP≠ CO_2
Lu (2017)	1990-2012	24-Asian countries	VECM	RGDP →CO_2 ; REW ↔ CO_2 ; REW ↔ RGDP
Sebri and Ben-Salha (2014)	1971-2010	BRICS	ARDL, VECM	REW ↔ RGDP ; REW → CO_2 ; CO_2 → RGDP
Apergis and Payne (2014)	1980-2010	7 CA	FMOLS, Regime-Wise GRC	REW ↔ RGDP; REW ↔ CO_2
Total energy consumption, economic growth, and carbon emissions				
Ang (2007)	1960-2000	France	ARDL, VECM	**(SR)** ENER → RGDP **(LR)** RGDP →CO_2; ENER →CO_2
Jahangir Alam et al. (2012)	1972-2006	Bangladesh	ARDL, VECM	**(SR)** ENER → RGDP ; ELEC ≠ RGDP ; ENER →CO_2 ; CO_2 → RGDP **(LR)** ELEC ↔ RGDP ; ENER ↔ CO_2 ; CO_2 → RGDP
Acheampong (2018)	1990-2016	116 countries	GMM-PVAR	ENER → RGDP; RGDP ↔ CO_2 ; ENER ↔ CO_2
Mirza and Kanwal (2017)	1971-2009	Pakistan	ARDL, VECM	RGDP ↔ CO_2 ; ENER ↔ CO_2 ; ENER ↔ RGDP
Soytas and Sari (2009)	1960-2000	Turkey	VAR	CO_2 → ENER ; RGDP≠ CO_2 ; RGDP≠ ENER
Soytas et al. (2007)	1960-2004	USA	VAR	RGDP≠ ENER; CO_2 → ENER; RGDP≠ CO_2
Zhang and Cheng (2009)	1960-2007	China	VAR, VECM	RGDP → ENER; ENER → CO_2 ; RGDP≠ CO_2
Salahuddin and Gow (2014)	1980-2012	GCC	PMG, SUR, GRC	ENER ↔ CO_2 ; RGDP → ENER ; RGDP≠ CO_2
Halicioglu (2009)	1960-2005	Turkey	ARDL	**(SR)** ENER↔ CO_2 ; CO_2 ↔ RGDP ; ENER↔ RGDP **(LR)** ENER →CO_2 ; CO_2 ↔ RGDP ; ENER → RGDP
Al-mulali et al. (2013)	1980-2008	LAC	CCR	ENER↔ CO_2 ; CO_2 ↔ RGDP ; ENER↔ RGDP
Omri (2013)	1990-2011	MENA	System-GMM	ENER↔ RGDP ; ENER →CO_2 ; CO_2 ↔ RGDP

[11] The stability graphs and the forecast error variance results are available upon requests

Apergis and Payne (2010a)	1992-2004	CIS	FMOLS, GRC	**(SR)** ENER → CO_2 ; RGDP→ CO_2 ; ENER↔ RGDP **(LR)** CO_2 ↔ ENER
Apergis and Payne (2009)	1971-2004	CA	FMOLS, GRC	**(SR)** ENER → CO_2 ; RGDP→ CO_2 ; ENER↔ RGDP **(LR)** CO_2 ↔ ENER

SR = Short-run; LR =Long-run; → unidirectional causality; ↔ bidirectional causality; ≠ No causality; RGDP = Economic growth; CO2 = Carbon emissions; NUC= Nuclear energy; REW =Renewable energy; NREW = Non-renewable energy; ENER =Total energy consumption; ELEC =Electricity; FMOLS = Fully modified ordinary least square; GRC =Granger causality; CCR =Conical cointegration regression; ARDL =Autoregressive distributed lag; VAR =Vector autoregression; VECM =Vector error correction model; PMG = Pooled mean group; SUR = Seemingly unrelated regression; GMM-PVAR = Generalised method of moments – panel vector autoregression; CA =Central America; GCC = Gulf Cooperation Council countries; MENA = Middle East and North Africa countries; CIS =Commonwealth Independent States; LAC =Latin America and Caribbean.

Table A.2: Panel unit root test

	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
	Levels				First difference			
lngdpc	0.354	7.933	53.364	79.327	-16.079***	-20.888***	632.588***	1065.87***
lnrenewout	-0.856	-0.667	85.889	87.740	-11.535***	-13.952***	345.697***	576.459***
lnco2gdp	-2.931***	-5.504***	184.644***	253.489***	-15.264***	-27.094***	852.470***	1700.56***
QI	-5.594***	-3.133***	145.466***	176.001***	-11.474***	-10.593***	278.054***	535.070***

Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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