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Carbon Lock-In and Sustainable Development Challenges: Evidence from Sub-Saharan Africa

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ABSTRACT

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This research seeks to investigate the risks of carbon lock-in by examining the potential factors influencing carbon dioxide emissions levels in Sub-Saharan Africa. Given this, we employed a panel Sub-Saharan Africa comprised of 35 countries in the sub-region, from 2000 to 2014 with cross-sectional dependence among variables. We used the Two-step robust System Generalized Method of Moments to estimate the influencing factors of carbon emissions level that create path dependency. The main findings are: (1) income per capita, urbanization, and financial resources contribute to the increase of carbon emissions level in the Sub-Saharan Africa countries, in the short-run; (2) we noticed that in the short-run, the impacts of fossil fuels per capita, energy intensity and total energy consumption are insignificant; (3) in the long-run, income per capita, urbanization and financial resources increase carbon emissions level; (4) from various factors that increase carbon emissions level, these factors form a path dependency that slow the introduction of low-carbon systems, thus, creating carbon lock-in in the Sub-Saharan Africa countries. Considering this, policymakers and governments should ensure the strict compliance of environmental regulations by financial institutions and organizations, promote low-carbon cities during economic transformation, and encourage investments in low-carbon projects. The government should also educate and build awareness on the effects of environmental pollution on population health, provide incentives for energy conservation and promote the use of clean products to avoid future risks of lock-in in the sub-region.

Keywords: Carbon dioxide emissions, Carbon lock-in, Sustainable Development, System Generalized Method of Moments, Sub-Saharan Africa

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I. INTRODUCTION

The emergency of efforts to mitigate environmental pollution and climate change for sustainable development has intensified the risks of carbon lock-in in both international and national communities. With the growing global challenges of greenhouse gas emissions and climate change, it becomes difficult to fulfil energy demand and supply without environmental damages. Fossil fuel systems are the leading emitter of carbon dioxide; as a result, contribute not only to environmental degradation but also to climate change that could put human lives at risk (Appiah, 2017). Lock-in, therefore, arises when infrastructures and technologies that directly or indirectly emit and shape energy demand and supply create a path dependency that slows the introduction of clean energy and low-carbon development. Sub-Saharan African (SSA) countries are facing an energy crisis and growing environmental damages. With over 2% increase in carbon dioxide emissions yearly, the region could have high pressure on achieving sustainable development goals. Thus, the reduction of carbon dioxide emissions has become an emergency. Sub-Saharan Africa is at a crucial point of its economic development, and this could lead to high carbon lock-in. It is, therefore, essential to investigate the potential factors that could influence the level of carbon emissions in Sub-Saharan Africa and estimate future carbon lock-in risks.

Many studies on carbon lock-in have been identified. Most scholars focus on the causes of different lock-in (Buschmann & Oels, 2019) and the analysis on how to avoid high carbon emissions (Mattauch et al., 2015; Wang et al., 2020). They believed that increased carbon emissions are from the manufacturing industry, and energy intensity could help to reduce future emissions, avoiding lock-in. Erickson et al. (2015) assessed carbon lock-in in the global perspective focusing on energy-consuming assets such as buildings, power plants, and industries. They found that carbon lock-in was great in coal power plants, oil-based vehicles, and gas power plants (Erickson et al., 2015). Seto et al. (2016), in their studies, stated that escalating returns mechanisms might create lock-in. They further suggested that technological situation whereby the introduction of alternative technologies in the market aiming to reduce carbon emissions could be the leading cause of carbon lock-in (Seto et al., 2016). Following Seto's viewpoint, Janipour et al., (2020) in their case study believed that the sources of carbon lock-in might be technological incompatibility, sunk costs, and government policy inconsistency in ensuring energy efficiency and solving environmental problems.

Moreover, some Sub-Saharan African countries are carbon-intensive nations. Carbon emissions from fossil fuel combustion in the region have grown by more than 2% yearly. However, the carbon intensity has fallen by 5% yearly due to knowledge Spillover and adoption of foreign environmental technologies, for instance, solar products and green mini-grids have been highly noticeable in the sub-region (World Bank, 2018). Irrespective of the issue of carbon intensity, there is a tendency that urban development leads to lock-in. For instance, in Kenya, Nigeria, South Africa, and other African countries the problems of transportation, electrification, and energy efficiency stimulate potential risks of carbon lock-in as huge investments are tied to carbon-intensive pathways. About 14% of carbon intensity is projected to be covered by carbon capture and sequestration by 2060. According to IEA, there has been a 1% yearly growth of carbon emissions in Africa, with approximately 17% covered by carbon capture and sequestration (IEA, 2017). Although they have policies related to mitigation of climate change at a national level and have ratified international treaties such as Paris Agreement to reduce greenhouse gas emissions, they also support fossil fuel production and consumption (Burton et al., 2020). This support through energy policies could lead to carbon emissions growth than a reduction in the future. In this line, leveraging economic opportunities on renewable energy technology development and investing more to develop mitigation mechanisms in the form of energy-efficient technologies and low carbon energy sources could help in encouraging clean fuel; thus, reduce the risk of lock-in in the sub-region. A report from the World Energy Council using Kaya identity has indicated that human activities on climate determine the level of greenhouse emissions (especially, carbon dioxide emissions) (World Energy Council, 2017). Economic and social challenges faced by Sub-Saharan Africa countries make it complex to focus solely on human actions to estimate carbon emissions. Thus, deconstructing the various factors affecting carbon emissions could illustrate the inter-relationship between political situation, economics, energy sector, and many other factors that could play a vital role in the future sustainability outlook of Sub-Saharan Africa.

Considering determinants of carbon lock-in literature, we have noticed that most of the studies covered carbon dioxide emissions, focusing on the emissions in the energy industry and assessed the intensity of lock-in from a global and national perspective. Studies analyzing the sources of carbon lock-in in a regional perspective are sparse; this poses a gap in previous literature. Consequently, measures to avoid future lock-in suggested in the global perspective may not be applicable in Sub-Saharan Africa or other regions. Besides, in examining the sources of carbon lock-in, researchers usually emphasize on carbon-intensive technologies, thus, stressing more on the global carbon emissions growth to determine path dependency that inhibits the introduction of renewable energy systems. However, with the differences in regional settings and the pace of economic growth, there may be some variations in lock-in risks, which could need in-depth understandings. Based on this; a carbon lock-in scenario could be discussed considering variation in carbon emissions level from social and economic settings.

Since Sub-Saharan Africa is the research focus, we investigate the various factors that influence the level of carbon emissions to depict the risk of carbon lock-in in the sub-region. We further examine regional lock-in risks and provide guidelines aiming to avoid future risks of carbon lock-in in the panel Sub-Saharan Africa. In carrying our analysis, this paper used data from 2000 to 2014 collected from the World Bank Indicators and EDGAR report (Muntean et al. 2018). Before estimating the relationship among variables, we tested for cross-sectional dependency and found cross-sectional dependence among variables. We tested for unit root using CIPS and CADF unit root tests. The findings revealed that all the series except one have unit roots at their level and stationary at their first difference, at 1% and 5% significant level. We estimate factors influencing carbon emissions level using the two-step robust system Generalized Method of Moments (GMM) and the findings indicated that income per capita, urbanization, and financial resources foreign contribute to increasing carbon dioxide emissions level in Sub-Saharan Africa in both short-run and the long run, could lead to high risk of lock-in. For recommendations regarding avoiding future risks of carbon lock-in for sustainable growth, policymakers and government should strengthen environmental regulations and policies, enforce their rigorous compliance by investors, promote low-carbon cites and improve their human development strategies.

This study is structured as follows; in Section 2, we provide a literature review while Section 3 deals with the method, Section 4 is empirical findings and discussions, and Section 5 presents conclusion and policy implications.

II. LITERATURE REVIEW

Introduced by Gregory Unruh (2000), carbon lock-in is built on the concepts of path dependency and increasing returns, and he indicated that industrial economies had been trapped into fossil fuel-based technologies through a process of institution and technology co-evolution driven by carbon lock-in path-dependent or increasing return to scale creating a ‘techno-institutional complex’. Unruh further stated that carbon lock-in condition arises when incumbent technological solutions, which are dominated by carbon fossil fuel technologies, prevent improved technologies (clean technologies) and innovation in the market (Seto et al., 2016). It is then stressed that this condition creates persistent policy and market failures that can impede the diffusion of low carbon-emitting technologies regardless of their apparent economic and environmental advantages (Stein & Levin, 2017). Lock-in arises, therefore, when two externalities are combined, that is, learning spillovers (positive externalities) and the ignorance of the negative effect of carbon-intensive production that triggers climate change (negative externalities). The combination of these externalities prevent the development of the low-carbon sector and delay low-carbon development transition. With learning-by-doing behaviour towards clean technology instead of technical change, the demand for dirty energy can decrease but not zero (Mattauch et al., 2015).

Lock-in scenario is fitting most of the industrialized economies today, as they strive to develop policies to fight against climate change (Unruh, 2002). Majority of fossil fuels (dirty energy) producing countries are leaders in the development of climate policies. It is believed that the economic interest of industrialized nations can go jointly with progressive climate change mitigation actions. However, labour unions and fossil fuel industries overshadow the positive impacts of factors related to good environmental quality (Erickson et al.,2015), thus, explaining the difficulty of countries in taking action in response to climate change. Furthermore, some studies have stated that increasing returns mechanisms could result in technological lock-in described by the difficulty in introducing new technologies to the market (Seto et al., 2016). However, these mechanisms that create path dependency may lead to carbon lock-in (Stein & Levin, 2017). More so, with increasing returns to scale, incumbent industries become more dependent on fossil fuel technologies, which inhibit the development and adoption of clean technologies and restrict low-carbon technology innovation (Yang et al., 2015). However, implementing learning strategies, networks and investment in clean technologies could increase the confidence level over the positive effects of those technologies on the environment and human life, thus, speeding up adaptability (Seto et al., 2016) (Ivanova et al., 2018).

Moreover, high-income countries are the main contributor to the world's environmental pollution, given their economic size and are highly industrialized. They likely have a higher level of fossil fuel consumption and energy use, which produce carbon dioxide (Omri, 2018). From a perspective of Sub-Saharan Africa, according to Asongu, (2017), middle-income countries are more likely to have effective mechanisms of managing carbon dioxide emissions compared to low-income countries. He added that being less industrialized, low-income countries require fewer means to reduce environmental pollution but attract more firms that exploit their weak environmental legislations or regulations to establish factories that use fossil fuels or dirty technologies. As a result, pollution may be higher in the sub-region as the majority of the Sub-Saharan African counties are low-income countries. With consensus regarding reducing the environmental population, rapid population growth has been a typical factor that increases poverty and environmental deterioration (Rashid Khan et al., 2019). Massive population growth may lead to unequal distribution of income, therefore, restricting most of the population from using clean technologies. However, the increased rate of urbanization generally complements low carbon intensity development (Liu et al., 2017). In this same line, Fang et al., (2019) believe that the increase in urbanization rate could lead to the reduction of carbon dioxide emissions per capita. However, there should be other requirements regarding infrastructure construction, energy utilization in urban residential areas. In contrast, Liddle B. (2013) stated that urban density and population size positively increase carbon dioxide emissions. Based on this, we can attempt to note that urbanization could be an essential factor influencing carbon emissions levels.

Though resource-rich countries have significant economic performance that could help to alleviate climate change and poverty, Sub-Saharan Africa is characterized by a high level of economic development. However, the benefits of its development, such as cleantech only reach a minority of citizens (Hogarth et al., 2015), this makes the sub-region being much more vulnerable to climate change catastrophes. Some technology systems such as applications of renewable energies (wind, solar, hydro, geothermal, etc.) and as well as eco-innovations can lessen carbon intensity related to economic activities in cost-effective ways (Perrot & Sanni, 2018). These technologies can help to reduce climate-forcing CO_2 emissions. The speculation is that most industrialized countries have been locked in fossil fuel energy systems by past policies and investment decisions, economic growth associated with energy infrastructure, and the positive feedback effects on increasing returns (Mattauch et al., 2015). Carbon lock-in emerges eventually as economic development and energy in industrialized nations have proceeded (Burton et al., 2020). However, limiting the production of fossil fuels could help to avoid a more excessive supply of fossil fuel, which is associated with carbon lock-in of the political system and energy infrastructures, which make it difficult to move from dirty energy to clean energy (Erickson et al. 2015). Due to the tangible effect of fossil fuels project development versus the diffuse impact of carbon emissions, it should be essential to have climate change mitigation regulations more accessible (Piggot et al., 2017)

The Long-life of physical infrastructure investments, such as buildings, street layouts, land use patterns lock countries in carbon-intensive emissions pathways. Being costly and challenging to replace, these infrastructure investments could likely inhibit the efforts to lessen emissions intensive of a country (Bissoon, 2017). As a result, more environmental problems could be perceived if the initial conditions on investments (environmental regulations compliance) are not fulfilled. Also, slow-changing of assets such as buildings, transport, and electricity infrastructures are predominantly at risk of intensive lock-in pathways (Bertheau et al., 2018). Governments often increase the cost of economic activities that generate greenhouse gas emissions using cap-and-trade or carbon tax systems to limit emissions (Song Y. et al., 2019). Adversely, these systems, when implemented, can lead to high consumption of fossil fuel but generate income that could be used to alleviate poverty and improve economic development. According to Perrot & Sanni (2018), the development of renewable energy has progressively reduced carbon dioxide emissions. However, countries focus more on the impact of the policies instruments such as feed-in tariff schemes and green certificates on emissions than the choice of the instruments. As a result, the government inability to set appropriate policies to reduce emissions could rather worsen the situation, thus, creating lock-in in the future.

It has been seen that, understanding the threat posed by international agreement and climate change and to lower fossil fuels by implementing taxation likely accelerate innovation in the energy sector. This, therefore, leads to the development of sustainable energies that are capable of breaking carbon lock-in (Karlsson, 2012). It is evident that the challenge for sustainable development today is the rapid absorption of dirty energy and the injection of low-carbon technology in the economy and implemented strategic research and development in the system (Saleem H. et al., 2019). Consequently, radical interventions are necessary if all countries need to escape carbon lock-in. As long as there are long-life infrastructures, investment in fossil fuels energy systems, high energy consumption, the existing path dependency would continuously reproduce and reinforce high carbon emissions (Driscoll, 2014). However, carbon lock-in is a persistent mechanism than policy and market barriers to alternatives (Unruh, 2000). Hence, without appropriate legislation, carbon emissions growth is inevitable, and this can put countries at risk of lock-in. They could miss the opportunities for energy saving and reduction of greenhouse gas that could help to reduce the inertia (Zaid et al., 2015).

Carbon lock-in generally involved economic, technological, social, and political efforts to lower carbon emissions; it is, therefore, seen that technical, institutional complex likely reinforce and create a collective lock-in. According to Markusson (2008), carbon capture and storage (CCS) has limited the development of new fossil fuel plants and, in the future, this will reduce the risk of lock-in. On the other side, institutional path dependency, still encourages investments in fossil fuel power generation systems, especially on the supply side. To avoid new lock-ins, more policies and measures are required to ensure that the new infrastructural investments are in line with low-carbon development pathways (Mutanga et al., 2018). These measures should be applied in all the countries with noticeable high risks of carbon lock-in.

With the complexity of analyzing carbon lock-in scenarios, some researchers examined carbon lock-in by exploring how policies impact long-run transformation pathways using capital stock inertia and found that less stringent near-term guidelines consume more cumulative emissions budget in the long-run, which likely the likelihood of exceeding budget, thus urgency of decreasing carbon emissions (Bertram et al., 2015). Also, Chang & Li, (2017) examined the problem related to decoupling lock-in effect in China and found that there is a linkage between economic growth and carbon dioxide emissions through a structural adjustment and suggested that there should be better carbon emissions mitigation policies with more attention on the economy and CO_2 emissions. Besides, Haoqi et al. (2017) explore the lock-in effect of emission when a country adopts some new market-based instruments to manage emissions and found that lock-in effect can cause a kinkpoint to MAC curve due to policies that induce lock-in effect generated by the introduction of carbon emission intensity target regulations that could restricts agents ability to choose emissions abatement. Following previous research, only focus on existing lock-in and the various policies pertaining managing lock-in but not how to avoid lock-in.

However, this study's objective is to examine what causes lock-in, and in doing so, we investigate how the lock-in arises or could arise. We then capitalized on the various factors influencing carbon emissions that could inhibit low-carbon transition considering the 'Techno-Institutional Complex' as prescribe by Unruh. The multiple factors that could drive carbon emissions are examined by Henriques & Borowiecki, (2017) who used the extended Kaya decomposition and found that switching from biomass to fuels with a low level of income per capita contribute to emissions growth in Europe. However, technological change could be the primary offsetting means in the long-run. Fang et al., (2019) compute panel grey incidence level between carbon emissions and influencing factors in China and found that economic growth influences carbon emission through energy intensity, trade openness, and urbanization. Hence, they stated that the increase in income could lead to more energy consumption. As a result, severe environmental damage but urbanization could reduce emissions if there are sustainable infrastructure and responsible energy consumption in the urban areas. In the same line, Liu et al., (2017) explore the driving forces of carbon emissions in China using GTWR and found that urbanization, larger population size, more significant economic development, a larger share of secondary industry, a larger share of coal consumption, higher energy intensity, higher economic openness contribute to higher carbon emissions in China.

Further, Dogan & Seker, (2016) used dynamic ordinary least square estimations to ascertain the determinants of carbon emissions in the European Union and found trade and renewable energy mitigate carbon emissions while non-renewable energy increase emissions. Besides, Dong et al. (2018) used System GMM and

LMDI to examine the driving forces of carbon emissions across countries. They found that income and population growth are the main drivers of escalated CO_2 emissions and suggested that energy efficiency improvement could reduce emissions level; otherwise, there could be more increase in the future.

Given the development of numerous industrial sectors in Sub-Saharan Africa, the risk of carbon lock-in is high since green products to phase out resource-intensive or polluting infrastructures are costly and technically difficult to be implemented or adopted.

III. METHODOLOGY

3.1 Data

In deriving regional factors influencing carbon emissions level, thus creating lock-in, the researchers used a sample of 35 Sub-Saharan African countries as a whole panel, with data collected from the World Bank Development Indicators (WDI, 2019) and EDGAR (Muntean et al., 2018) for the period 2000 to 2014. While the periodicity's choice is due to limitations in data availability, the research scope is built considering data constraints. A sub-Saharan account for 48 countries out of 54 countries in Africa according to the World Bank and UN Development Program. Regarding the study series, many countries in Sub-Saharan have missing data in between time-series and, before 2000 and after 2014. For instance, some countries such as Comoros, Mauritania South Sudan, and many other countries have missing data for some variables such as financial resources and total energy consumption before 2000 and even in the study time scope. Due to the missing data, we restricted our sample to 35 Sub-Saharan Africa countries and the time-period 2000-2014.

More so, Sub-Saharan Africa is a particular region as its emissions level is relatively low compared to the other areas, but pollution is existent in the sub-region (Mensah I.A. et al., 2019). The study focused on Sub-Saharan Africa due to existing market failures due to industrialization on economic development, which contributes to environmental degradation and hinders population health in the sub-region. Further, there are notably incentives such as fossil fuel incentives to boost production and favour economic growth but with no or less consideration on environmental sustainability. Also, Sub-Saharan lack clean technologies and use mostly dirty technologies for businesses and household. This likely slows the adoption of clean technologies, as the investment in existing technologies is enormous and difficult to reverse, thus, creating lock-in.

Table 1 : Selected Sub-Saharan African Countries

Sub-Saharan Africa (sub-): 35 Countries	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Congo Democratic Republic, Congo Republic, Côte d'Ivoire. , Eswatini, Gabon, Gambia (The), Ghana, Guinea, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia

Furthermore, in the investigation the factors that increase the level of carbon emissions, this paper used variables such as carbon dioxide emissions level (CEL), income per capita (IC), urbanization (URB), fossil fuel per capita (FF), financial resources (FR), energy intensity (EI) and total energy consumption. The choice of variables is consistent with numerous studies on carbon lock-in (Buschmann & Oels, 2019) (Wang et al., 2020); environmental unsustainability (Riti et al., 2015); drivers of CO_2 emissions (Dogan & Seker, 2016;

Dong et al., 2018; Qin et al., 2019), and sustainable development (Asongu S., 2018) (Rauf et al., 2018). All the studies above emphasized the factors that influence carbon dioxide emissions, which are macroeconomic factors and others, and the reason for carbon lock-in, as highlighted in the literature. The carbon emissions level (CEL) describes the extent to which carbon lock-in arises, and it is measured using carbon dioxide emissions in metric per tons. The income per capita measures economic development, and it is measured using GDP per capita, which is the primary variable of the study. The income per capita hypothetically has a very strong influence on the level of carbon emissions; thus, could be the main factor favouring lock-in. We used urbanization to express how environmental sustainability could be affected negatively by population migration; it is therefore measured using the ratio of urban population on total population.

Further, fossil fuel per capita was used as contributing to carbon emissions; this refers to CO_2 emissions for the burning of fossil fuels; it is measured in Kton t CO_2/cap/year. In addition, energy intensity is indicative of how energy is utilized in the production of one unit output, the change in technology affecting carbon emissions. It is measured in MJ/2011 USD PPP. Finally, total energy consumption refers to all end-use energy.

Table 2 : Data Indications

Variables	Indications	Sources
Carbon Emissions Level (CEL)	CO2 emissions in metric tons as a proxy	World Development Indicators
Income per capita (IC)	GDP per capita in US$ constant 2010	World Development Indicators
Urbanization (URB)	Urban population (% of the total population)	World Development Indicators
Fossil Fuels per capita (FF)	Fossil CO_2 per capita in t CO2/cap/year	EDGAR
Financial Resources (FR)	Domestic credit to private sectors provided by the financial sector and banks (% of GDP)	World Development Indicators
Energy Intensity (EI)	The ration of energy use to the GDP at purchasing power parity (MJ/2011 USD PPP)	World Development Indicators
Total Energy Consumption (TEC)	All the end-use energy in Tera Joule (TJ)	World Development Indicators

All the independent variables could strengthen carbon lock-in if proper and robust environmental regulations are inexistent in the region. Thus, the logarithmic form of these variables is estimated to reduce variables omission bias. It is worth noting that the increase in income, urbanization, fossil fuel per capita, financial resources, energy intensity, and total energy consumption may lead to high carbon emissions meanwhile financial resources and energy intensity may instead help in reducing CO_2 emissions if environment-related projects are established, and the use of cleaner energy/technology is promoted in Sub-Saharan Africa.

3.2 Estimation Methods

In estimating the high-carbon emitting sources across Sub-Saharan African Countries, we firstly tested for cross-sectional dependency test the assumption that there is the non-existence of cross-section dependence among series that could distort the findings (Hdom, 2019). Secondly, we tested for the presence of unit root using the CIPS and CADF) unit root tests concerning the outcome of cross-sectional dependency test to establish whether there is an existence or not of a unit root within the series. The economic meaning of the existence of unit root in the series is that the variation in one variable will have a permanent impact on other variables (Adu & Denkyirah, 2018). Secondly, we applied the dynamic panel data method in consonant with Armeanu et al., (2017), Olanrewaju et al., (2019) (Dong et al., 2018) studies to investigate whether income per capita, urbanization, fossil fuel per capita, financial resources, energy intensity, and total energy consumption can influence carbon dioxide emissions level in Sub-Saharan Africa. Thus, we used System Generalized Method of Moment (GMM) estimation, proposed by Arellano and Bover (1995) and Blundell and Bond (1998), which combines set of equations in first differences with the appropriate lagged level as instruments. We included all the instruments and the lagged value of carbon dioxide emissions level in our model. The advantage of using this estimation model is that, during the identification process, variables or years being the likely time-invariant influence the impact of the variable (CEL) outcome, since the explanatory variables are suspected to be endogenous but not after the first difference (Omri & Khuong, 2014). Also, the system GMM method is in line with panel data settings in which cross-sectional difference among variables is considered in the regression. Its consistency depends on the assumptions that the error term does not suffer for serial correlation issues and validity of instruments with other moments restrictions (Berk et al., 2018). Besides, the system GMM technique is more efficient than the difference GMM as it restricts the over-identification of instruments and overcomes panel data bias (Asongu, 2017). We finally used Pooled Ordinary Least Squared (POLS) and Fixed Effect (FE) estimations as a robustness check to confirm the validity of dynamic panel data estimation as suggested (Bond, 2002). Instigated by factors that influence carbon emissions level leading to carbon lock-in in Sub-Saharan Africa, we, therefore, estimate the following equation:

$$CEL = f(IC, URB, FF, FR, EI, TEC) \qquad (1)$$

Where CEL represents carbon dioxide emissions level, and it is a function of IC, URB, FF, FR, EI, and TEC, which represent income per capita, urbanization, fossil fuels per capita, financial resources, energy intensity, and total energy consumption respectively.

Since our study deal with panel data, Equation (1), can be rewritten as follows:

$$CEL_{i.t} = \alpha_0 + \alpha_1 IC_{i,t} + \alpha_2\, URB_{i,t} + \alpha_3\, FF_{i,t} + \alpha_4 FR_{i,t} + \alpha_5 EI_{i,t} + \alpha_6 TEC_{i,t} + \varepsilon_{i,t} \qquad (2)$$

Where I denotes the various countries in Sub-Saharan Africa panel with i= 1,…….N where N is 35 countries in Sub-Saharan Africa, thus, t represents the time period. CEL indicates carbon dioxide emissions level defined in metric tons, which is composed of emissions from the combustion of gaseous, liquid, and solid fuels. Hence, IC represents income per capita while FF, while FF is fossil fuel per capita, URB represents urbanization while FR is financial resources. EI denotes energy intensity while TEC is total energy consumption.

Considering our panel data estimation method, we can transform our equation (2) as follows:

$$CEL_{i,t} = \alpha_0 CEL_{i.t-1} + \sum_{j=0}^{k} \beta X'_{i.t} + \gamma_{i,t} + \varepsilon_{i,t'} \qquad (3)$$

i= 1, ……. 35; *t*= 2000, …… 2014

where $CEL_{i.t}$ stands for the country *i*'s carbon dioxide emissions level at time *t*. the parameter to be estimated is α_0. Also, X represents the main explanatory variables utilized to model carbon dioxide emissions level, which include income per capita, urbanization, fossil fuel per capita, financial resources, energy intensity, and total energy consumption. γ and ε indicate the nation-specific effects and the error term, respectively.

IV. EMPIRICAL RESULTS AND DISCUSSION

4.1 Results

4.1.1 Descriptive Analysis

Table 3 depicts descriptive statistics for the variables mentioned above for the Sub-Saharan Africa sample of

35 selected countries from 2000-2014. All the variables were transformed to their natural logarithmic form. The findings reveal that carbon emissions level (CEL) has the lowest average (Mean: -1.370, Standard deviation: 1380) while total energy consumption (TEC) has the highest Mean (11.574) among the variables followed by income per capita (IC) (Mean: 6.741, Standard deviation: 1.069). Besides, the results show that fossil fuel per capita (FF) has the highest standard deviation (1.390) but having the second lower average statistics (-1.291) followed by energy intensity (EI) (Mean:1.913, Standard deviation: 0.590), financial resources (FR) (Mean: 3.212, Standard deviation: 0.899) and urbanization (URB) (Mean: 3.538, Standard deviation: 0.473).

In general, for observed variables to be symmetric or normally distributed, the normal value for skewness should be 'zero' and the kurtosis value should be 'three'. As per skewness and kurtosis values reported in Table 3, we noticed that none of the series follows a normal distribution. Notably, the skewness values for urbanization (URB) and financial resources (FR) are negative, which means the distributions are highly skewed. Whereas, the skewness values for carbon emissions level (CEL), income per capita (IC), fossil fuel per capita (FF), energy intensity (EI), and total energy consumption (TEC) are positive. This, therefore, indicates that the series mentioned above are flattering to the left (URB, FR) and the right (CEL, IC, FF, EI, TEC) compared to the normal distribution, so, the study observations are spread in both positive and negative sides. Also, the kurtosis results show that URB is approximately mesokurtic (kurtosis value approximately the same as the normal distribution) meanwhile the kurtosis results for FR and TEC are leptokurtic (kurtosis value greater than normal distribution). From the results of skewness and kurtosis, we confirmed that none of those mentioned above series satisfies normality conditions and we affirm that the variables are not normally distributed. This is therefore in line with the values of the Jarque-Bera normality test, which attest that the variables are not normally distributed as the p-values of all the series (CEL, IC, URB, FF, FR, EI) except TEC are statistically significant at 1%. This, therefore, implies that the null hypothesis of the normal distribution of variables is rejected.

Table 3 : Descriptive Statistics

Sub-Saharan Africa (SSA): 35 countries							
Variables	***lnCEL***	***lnIC***	***lnURB***	***lnFF***	***lnFR***	***lnEI***	***lnTEC***
Mean	-1.376	6.741	3.538	-1.291	3.212	1.913	11.574
Standard Deviation	1.380	1.069	0.473	1.390	0.899	0.590	1.256
Minimum	-4.058	4.732	2.110	-3.751	-0.061	0.647	8.004
Maximum	2.290	9.287	4.473	2.266	5.474	3.468	14.901
Skewness	0.552	0.629	-0.595	0.578	-0.014	0.478	0.039
Kurtosis	2.887	2.445	2.968	2.641	3.831	2.863	3.380
Probability	0.000	0.000	0.000	0.000	0.001	0.000	0.193
Jarque-Bera	26.923	41.348	30.986	32.025	15.114	20.412	3.294
No. of countries	35	35	35	35	35	35	35
Observation	525	525	525	525	525	525	525

4.1.2 Cross-sectional Dependence (CD) Test

The cross-sectional dependency test results are shown in Table 4 instruct that there is cross-sectional dependency among variables. This implies a rejection of the null hypothesis since the p-values of all the variables are below the significance level (1%, 5%, and 10%). Based on the CD test statistics, the p-values of all the variables in the panel Sub-Saharan Africa (SSA) are statistically significant at 1%. It is therefore relevant to consider CD test before any policy formulation attempt as it helps to have appropriate knowledge about the behaviour of the series among themselves in the sub-region SSA. Also, the CD test result determines the unit test category (first or second-generation) that should be used. Thus, considering our CD test, which confirms cross-section dependency among series, second-generation unit root tests that are CIPS and CADF are appropriate as they provide reliable and accurate findings for our research.

Table 4 : Cross-sectional Dependence (CD) Test

Sub-Saharan Africa (SSA): 35 countries							
Variables	***lnCEL***	***lnIC***	***lnURB***	***lnFF***	***lnFR***	***lnEI***	***lnTEC***
CD-Test	30.606	83.875	70.975	22.92	59.385	18.094	56.112
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

4.1.3 Unit Root Test

We conducted a test of a unit root in all the variables to check the stationarity level of the series. We use two methods of panel unit root test, that is, Pesaran's CIPS and CADF unit root tests and estimations were made with constant and trend to exploit possible hidden features. The CIPS and CADF test results recorded in Table 4 show that, except for urbanization (URB), carbon emissions level (CEL), income per capita (IC), fossil fuel per capita (FF), financial resources (FR), energy intensity (EI) and total energy consumption (TEC) have units at their level and stationary at their respective first difference. This, therefore, implies that CEL, IC, FF, FR, EI, and TEC are integrated at I(1). Considering that the study period is somewhat short and confirming the stationarity of variables from the unit root tests, we can directly perform our model.

Table 4 : Unit Root Test

CIPS			**CADF**		
Variable	**Level (Cons/trend)**	**First Diff.**	**Variable**	**Level(Cons/trend)**	**First Diff.**
lnCEL	-2.221	-3.358***	***lnCEL***	2.111	2.515***
lnIC	-2.693	-3.185***	***lnIC***	2.866	2.581***
lnURB	-1.852	-1.151	***lnURB***	1.908	1.489
lnFF	-2.009	-3.305***	***lnFF***	1.779	2.128**
lnFR	-2.390	-3.382***	***lnFR***	2.530	2.726***

lnEI	-2.292	-3.392***	***lnEI***	2.196	2.541***
lnTEC	-2.355	-3.328***	***lnTEC***	2.355	2.458***

***, **, * indicate 1%, 5% and 10% significance level

4.1.4 System GMM estimations

The results in Table 5 represent the Arellano-Bond dynamic panel two-step System Generalized Method of Moments (GMM) estimation. This estimation is carried out using data of 35 selected Sub-Saharan African (SSA) countries over the period 2000-2014. From the Hansen test, the over-identifying restrictions accept the null hypothesis at 1% and 5% significance level (p-value is greater than 1% and 5%). This, therefore, indicates that there is valid instrumentation in the model as shown in Table 5 in which, the number of the instrument is lesser than the number of groups that is, 34 instruments, which is marginally below 35 the number of groups (selected SSA countries). Besides, the F statistic is significant at 1%, which implies that the instruments used in the model are significant in explaining carbon emissions level (CEL). The Arellano-Bond test result (AR(2)) shows that the error term does not suffer for second-order serial correlation as we accept the null hypothesis of no second-order serial correlation based on the z-value (1.21) which is not statistically significant. The below results, therefore support the validity of the System GMM specification.

Based on our panel estimation, the findings reveal that, in the short run and long run, income per capita (IC), urbanization (URB), and financial resources (FR) have positive and statistically significant impacts on carbon emissions level (CEL). In the short run, a percentage change in IC, URB, and FR is associated with an increase in CEL by 0.166%, 0.178%, and 0.095% respectively, at the 10% significance level. Whereas in the long run, an increase in IC, URB, and FR escalates CEL by 0.586%, 0.627%, and 0.336%, respectively, at the 1% significance level. Consequently, in both the short-run and the long run, CEL exhibits less elasticity to FR than to URB and IC.

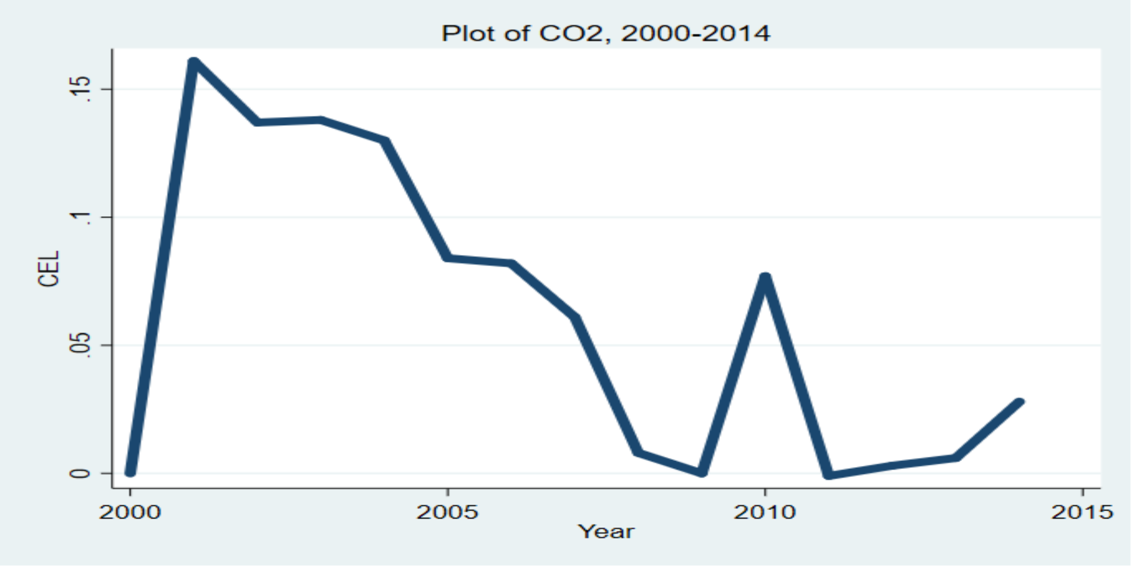
Also, findings reveal that fossil fuel per capita (FF), energy intensity (EI), and total energy consumption have positive and statistically insignificant impacts on CEL. Thus, a percentage increase in FF, EI, and TEC reduces CEL by 0.084%, 0.053%, and 0.022% respectively, but no significant impacts are revealed.

Table 5 : Two-step Robust System GMM Dynamic Panel Data Estimation

Variables	**System GMM Estimation (Std. err.)**	**Long-run GMM Estimation (Std. err.)**
lnCEL (_1)	0.716*** (0.158)	
lnIC	0.166* (0.088)	0.586*** (0.147)
lnURB	0.178* (096)	0.627*** (0.155)
lnFF	0.084 (0.075)	
lnFR	0.095* (0.052)	0.336*** (0.112)
lnEI	0.053 (0.035)	
lnTEC	0.022 (0.019)	

Year Dummies	Yes
No. of Observation	490
F Statistics	1519.20***
Groups/Instruments	35/34
AR (2) (*p value*)	1.21 (0.225)
Hansen Statistic (*p value*)	16.62 (0.083)

***, **, * indicate 1%, 5% and 10% significance level



4.1.5 Robustness Check: Pooled Ordinary Least Squared and Fixed Effect

Invalidating our findings obtained from the system Generalized Method of Moments (GMM), we employed Pooled Ordinary Least Squared (POLS) and Fixed Effect (FE). The results in Table 6 reveal that the coefficient of the lagged carbon emissions level (CEL (_1)) in the POLS estimation is greater than the coefficient of the CEL (_1) in FE estimation. Considering the system GMM estimation results in Table 5, we confirm that the coefficient of the CEL (_1) lies between the coefficient of the CEL (_1) obtained from POLS and FE estimations, that is, FE = 0.577 < system GMM= 0.716 < POLS= 0.930. This, therefore, confirms the validity of results obtained from our system GMM estimator.

Table 6 : Pooled Ordinary Least Squared (POLS) and Fixed Effect (FE)

	Pooled OLS (POLS)	*Fixed Effect (FE)*
Variables	*Coefficient*	*Coefficient*
lnCEL (_1)	***0.930****	***0.577****
lnIC	***0.044****	***0.049***
lnURB	***0.051***	***0.428***
lnFF	***0.017***	***0.154***
lnFR	***0.019***	***0.048***
lnEI	***0.0166***	***0.074***
lnTEC	***0.010***	***0.037***
F-Statistic	***10312.77****	***107.84****

***, **, * indicate 1%, 5% and 10% significance level

4.2 Discussions

The main aim of this paper was to ascertain carbon emissions level from the various factors that favour carbon dioxide emissions in the panel of 35 Sub-Saharan Africa selected countries over the period 2000-2014 to estimate the risk of carbon lock-in the region. In examining the various factors that contribute to an increase in carbon dioxide emissions, we used income growth income per capita (IC), urbanization (URB), fossil fuels per capita (FF), financial resources (FR), energy intensity (EI) and total energy consumption (TEC) as the main series that trigger carbon emissions level. We started our analysis by testing for the panel unit root. Both CIPS and CADF unit root tests revealed that all the variables except one, at their level, have unit root and are stationary at their first difference, at 1% and 5% significance level, thus, integrated at first order (I(1)). It is important to emphasize that, for any regressions models, it is relevant to test for stationarity as it helps in estimating the model. As a result, limit spurious results. This is inconsonant with (Dogan & Seker, 2016) work which employed CIPS and CADF unit root tests for examining the determinants of carbon dioxide emissions in the panel European Union countries.

In estimating our two-step System GMM model, linking carbon dioxide emissions level to its potential contributing factors; our results firstly indicate that the impact of income per capita is positive and statistically significant in Sub-Saharan Africa (SSA). These results imply that income per capita is an important mechanism that impacts the level of carbon emissions in the sub-region, which is large enough to contribute to carbon lock-in in the Sub-Saharan African countries. This rise in carbon emissions level could be to the fact that the various countries in the sub-region are involved in economic activities to boost their economic development that likely produces more emissions (Henriques & Borowiecki, 2017). It is therefore suggested that in the process of economic development, countries should capitalize on the reduction of carbon emissions by using more sustainable and low-emitting resources or energy systems, this is in line with (Qin et al., 2019) who believed that developed nations have high historical emissions and should put more effort to decrease emissions. Besides, Sub-Saharan Africa countries are characterized by more low-income countries than middle-income countries, which are getting involved in industrialization to transform the economy. As a result, the divergence of income per capita in the sub-region has grown widely though at the lower rate. However, the increase in revenue per capita as the economy with the expansion scale could lead to more dirty energy consumption in line with (Fang et al., 2019). It appears that the increase of income in Sub-Saharan African countries depicts insufficient disposable income allocated to develop products and technologies, which are environmentally friendly, this, therefore, inhibits the development of the low-carbon emitting system, thus favouring carbon lock-in in the sub-region (Bertheau et al., 2018).

Further, the impacts of financial resources (FR) is positive and statistically significant in Sub-Saharan Africa (SSA). Financial resources have always been perceived as an essential source of increasing investment in domestic projects but also play a significant role in sustainable development by supporting energy-saving and environment-related projects that could lower carbon emissions (Omri et al., 2015). Despite the fact, financial resources contribute to other aspects of economic growth such as job creation; the development of projects could have an adverse effect on the environment and population health. Our model indicates that the financial resources significantly increased carbon emissions level. It is perceived that Sub-Saharan African countries are mostly engaged in introducing financial resources in their projects but fail to consider their environmental quality that consequently increases their level of carbon emissions in consonant with Huang, et al., (2019) findings revealing that financial development input with weak environmental policies could contribute to environmental degradation. It is therefore evident that financial resources could be used to explain the level of lock-in in Sub-Saharan Africa as suggested Wang et al., (2020) who believed that in the process of economic transformation, countries' investments are tied in extended life span infrastructures that create emissions path dependency. Hence, from our long run estimation, financial resources increase carbon dioxide emissions level, which means that Sub-Saharan Africa could be reluctant to consider the negative impacts of financial resources on environmental problems and climate change.

Consequently, there could be an increase in carbon emissions in the sub-region, this is in line with Burton et al., (2020) work on sustaining lock-in, in which more fossil fuels subsidies are perceived in Africa than support to low-carbon development. To achieve sustainable development, it is vital and even mandatory that Sub-Saharan African countries should cut down economic activities and concentrate more on environmental unsustainability, which is a global issue to tackle. Also, governments should reinforce their ecological regulations and enforce their compliance by all financial institutions, investors and firms to reduce emissions and avoid future lock-in risks in the sub-region.

Moreover, the findings depict that urbanization has a positive and significant effect on carbon dioxide emissions level; thus, urbanization is a potential source of carbon emissions in Sub-Saharan Africa and contributes to lock-in. It is always seen that the high rate of urbanization is linked to the development of major economic sectors in the country with emphasis on the provisions of more sustainable goods and services in the urban areas and population. As a result, Liu et al. (2017) suggested that the rise in urbanization could decrease carbon dioxide emissions. Contrary to what is perceived in other regions and countries, the rate of urbanization in Sub-Saharan Africa is supported by industrialization with high carbon-emitting systems, slowing the introduction of low-carbon systems. The reason behind this is that, with industrial growth, the migration flow from rural to urban areas has escalated the population size in the urban areas, thus rise in demand and supply of products. In this effect, economies of scale in the production systems entail high carbon intensity, which contributes to environmental unsustainability, this aligns with Dong et al. (2018) who found that the rate of urbanization affects the level of carbon emissions at a particular stage of economic development. However, Ivanova et al. (2018) in examining the carbon mitigating factors of consumer lock-in, found that urbanization may reduce emissions if energy-saving technologies are put in place in a high-density area. They went further and suggested that renewable energies and low-carbon heating systems should be implemented to decrease the reliance on fossil fuel-based energy since the urban areas are likely to be vulnerable to carbon dioxide emissions and climate change (Dogan & Seker, 2016). In doing so, countries may avoid future lock-in and promote a sustainable environment.

Considering our findings, it is important to indicate that Sub-Saharan Africa has a high rate of population growth, internal migration to urban areas is high, and most of the countries in the sub-region are between low and middle incomes, which are in the process of their economic development. The sub-region also injects for financial resources to support industrialization and the economy, and to cater to population demand and supply of products. So, they emphasize less on environmental problems. It is therefore plausive that, the concentration on economic activities, high rate of urbanization, and provisions of financial subsidies to promote development, could hinder society, thus, increase environmental degradation. However, to reduce environmental problems, it is important that Sub-Saharan African countries start educating the population about the various environmental risks, provide efficient energy systems and implement low-carbon mitigating measures to mitigate climate change and reduce risks of carbon lock-in in the future.

Further, the results reveal that fossil fuels per capita, energy intensity, and total energy consumption are positive and statistically insignificant on carbons emissions level in Sub-Saharan Africa. The positive and insignificant coefficient of fossil fuels per capita implies that fossil fuel is not an important factor in carbon emissions rise in Sub-Saharan Africa same as energy intensity and total energy consumption. The findings, therefore, suggest that the increase in fossil fuels, energy intensity, and total energy consumption in Sub-Saharan African countries affects carbon dioxide emissions. However, it is insignificant, this contrary to several studies that fossil fuels instead increase carbon emissions significantly (Dogan & Seker, 2016; Henriques & Borowiecki, 2017; Ivanova et al., 2018). It should be noted that, during the transition from high-carbon to a low-carbon economy, fossil fuels CO2, energy intensity and various forms of energy consumption could increase carbon emissions. However, at a certain level of this transition, their effects are insignificant. These insignificant effects on carbon emissions levels in Sub-Saharan Africa could be due to either very low energy consumption or the promotion of sustainability in the transformation process of the sub-region economy.

To reduce the intensity of carbon emissions in Sub-Sahara Africa, governments should implement strong regulations and policies for low carbon development. The overall findings indicate that the high factors contributing to the increase in carbon emissions level in Sub-Saharan Africa are income per capita, urbanization, and financial resources. Meanwhile, fossil fuel per capita, energy intensity, and total energy consumption are not contributing factors to the increase of carbon emission level in Sub-Saharan Africa since their effects are insignificant although positive. Besides, lock-in in carbon arises from economic development through income per capita, high rate of urbanization, and financial resources.

V. CONCLUSION

This paper investigates the potential contributing factors of an increase in carbon emissions level to estimate the level of carbon lock-in in Sub-Saharan Africa. We looked at the impacts of income per capita, urbanization, financial resources, fossil fuels per capita, energy intensity, and total energy consumption on the rise of carbon dioxide emissions level in a panel of 35 Sub-Saharan African (SSA) countries over 2000-2014. We used a two-step robust System Generalized Method of Moments (GMM) with the primary objective to estimate the short-run and long-run effects of income per capita, urbanization, financial resources, fossil fuel per capita, energy intensity, and total energy consumption on carbon emissions level in SSA. We first used the Pesaran cross-section dependency test to examine the behaviours among various series, and we found that there is cross-sectional dependency among the variables. Hence, we applied CIPS and CADF unit root tests and realized that the series are non-stationary at their respective level but stationary at their first difference. Finally, we estimated the short-run and long-run convergence among the variables and carbon emissions level using the two systems robust System GMM in which, the long run estimations were done only for series that were statistically significant in the short-run. The system GMM is advantageous in the sense that it helps in solving endogeneity issues that could arise from the potential correlation between the error term and independent variables. The findings, therefore, indicated that income per capita, urbanization, and financial resources are positive and contribute significantly to the rise of carbon emissions level, in both the short-run and long-run, at 10% and 1% significant level. Meanwhile, fossil fuel per capita, energy intensity, total energy consumption contribute to the increase of carbon emissions level, but this has not been proved significant, in the short-run estimations.

Based on our robust empirical results, we can conclude that the growth in carbon emissions in Sub-Saharan Africa has been due to economic development, high use of financial resources for economic development, and urbanization with no awareness of environmental risks on population health and lack of adequate, sustainable products. Indeed, the environmental problems faced by Sub-Saharan African countries are worsened by their high dependency on financial resources and the high rate of migration from rural to urban areas due to high population growth and less supply. This is because the demands of products especially energy resources, are high in the sub-region with collection concentrated in the urban areas, which are known to be the resource hub of the various countries in Sub-Saharan Africa. As a result, the economic transformation is trapped into high carbon-emitting systems that inhibit low-carbon development, thus creating carbon lock-in.

However, it is of high importance to note that for sustainable development, policies and regulations should also be environmentally orientated, and the process of decarbonization implemented. The policies implications and recommendations are as follows:

Firstly, the significant impact of income per capita on carbon emissions level demonstrates that countries in the sub-region are gradually going through an economic development process but with the use of dirty energy systems. This means the various states in Sub-Sahara Africa do not have enough approach for sustainable development and therefore cap their existing resources. There should be increased cooperation among Sub-Saharan African countries since some countries have more sustainable resources than others does. This will build a sustainability hub in which countries could source resources among themselves to transform their economy as prescribed by sustainable development goals.

Secondly, human activities have always contributed to environmental degradation, and Sub-Saharan Africa cannot be exempted. However, the sub-region records less pollution compared to other regions in the world. The high contribution of urbanization on carbon emissions growth in Sub-Saharan Africa is mainly due to the high demand for products by the population, especially in the cities, and low environmental literacy. In solving urbanization issues in Sub-Saharan Africa, countries should provide regulations incentives for efficient energy use and tax and financial support to individuals and organizations that have clean production systems and the ability to engage in energy conservation projects. Besides, governments should introduce the concept of implement the concept of low-carbon cities, environmental protection, and preservation to reduce carbon emissions level and avoid future lock-in. In doing this, Sub-Saharan Africa countries could preserve their future economic output, control urbanization rate, and anticipate on mitigation measures of future carbon emissions in the sub-region.

Thirdly, a high dependency on financial resources (FR) has led Sub-Saharan Africa (SSA) to increase their level of carbon emissions (CEL). To reduce this negative impact of FR on carbon emissions level in SSA countries, governments and policymakers should strengthen their environmental regulations by setting up a carbon tax policy framework and enforce their strict compliance. Only financial resources for low or no carbon-emitting projects and projects with no impact on climate change should be approved in the sub-region. With Sub-Saharan Africa countries, being mostly low-income countries, any increase in the price of products can likely hinder economic activities to some extent. Following that, the rise of expenditure on high carbon-emitting products and projects could stop product development; thus, the reduction of carbon emissions and limit carbon lock-in levels in the sub-region.

More so, governments should implement regulations and policies that favour the development of environment-related products or green products, promote the use of less emitting technologies irrespective of the income level and environmental protection among countries in the sub-region. This will allow the fast spread of knowledge Spillover and exchange of environmentally friendly technologies among various countries in Sub-Saharan Africa, thus, reducing avoid the risks of lock-in. To ensure sustainable development in the sub-region, there should be cooperation among nations to develop environmentally friendly products and technologies specific to their environment before adopting foreign products. They should come out with a stable policy framework for investment that benefits their environment without putting their population health at risk. Sub-Saharan African countries should make environmental sustainability and population health their priority in their attempt to develop their economy and guarantee sustainable growth.

With numerous studies on factors that influence the carbon emissions growth, different econometric methods have been used; this present research may have some limitations even though the estimation model used is robust enough to provide reliable results. In general, this focus on a panel of Sub-Saharan Africa countries with no consideration of country characteristics. Further, this study focused on factors that trigger carbon emissions level, which could likely be the reason for carbon lock-in but does not investigate the measure to avoid such lock-in. However, for future research, if country-specific and decarbonization measures are considered, it can improve the literature. Therefore, investigating decarbonization for sustainable development could establish linkages about previous empirical findings when other regions or countries are scrutinized.

Regardless of the limitations above, the aim of this present study has been met.

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