Determinants of Environmental Pollution in Sub-Sahara Africa

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Abstract: **This study examined the determinants of environmental pollution in Sub-Sahara Africa. Specifically the study analyze the effect of some economic variables (Energy Consumption, Gross Domestic Product, Population Size, Trade Openness, Domestic Investment, Foreign Direct Investment) on the level of environmental pollution measured in terms of carbon- dioxide emission, Nitrous-oxide emission and methane emission. This study focused on 35 Sub-Saharan African countries, covering a period of 18 years spanning from 2000 to 2017. Data were sourced from World banks' development indicator database. This study made use of panel corrected standard error (PCSE) estimator. Result showed that energy consumption exerts significant positive effect on carbon-dioxide emission (22.40624, $p < 0.05$) and Nitrous oxide emission (12.60901, $p < 0.05$); gross domestic product exerts significant positive effect on Methane emission (0.03616, $p < 0.05$); trade openness exerts significant positive effect on Nitrous-oxide emission (16.58554, $p < 0.05$), and Methane emission (17.3302, $p < 0.05$), but its effect on carbon-dioxide emission is negative and significant (-10.9857, $p < 0.05$); also population size exerts significant positive effect on carbon-dioxide emission (173.7638, $p < 0.05$); Nitrous-oxide emission (265.0668, $p < 0.05$), and methane emission (417.5629, $p < 0.05$). This study thus concluded that environmental pollution in Sub-Sahara Africa is significantly determined by energy consumption, population size, trade openness and gross domestic product among other variables examined in the study. Hence Sub-Sahara African countries should objectively embrace technological diffusion by encouraging mobilization of finance, investment and innovation in low-carbon production processes. Also Environmental regulatory frameworks in SSA should advocate for bold pollution-beating commitments from the industrial sector to regulate pollution associated with production processes**

***Keywords*: Environmental pollution, determinants, Sub- Sahara, Africa**

I. INTRODUCTION

The rise in global environmental pollution is reflected in the rate of greenhouse gas emission, which observably as at 2010 was 20% higher than what was recorded in year 2000. Global emissions of carbon dioxide (CO_2) had trended upwards over time with 2011 emission almost 50 percent above that of 1990 (United Nations, 2014). Depletion of Ozone layer due to rise in environmental pollution in recent time resulted into over-exposure to harmful Ultra-Violet (UV) light from the sun, thus increasing the chances of deadly skin cancer by threefold especially in children (United Nations, 2017; Anand, 2013)

As observed by Coker (2012), discharge of pollutants in terms of materials and energy into water, land, and air, has the capacity to erode the quality of life by causing short-term or long-term detrimental damage on plants, living organism and the ecological system as a whole. Given the deleterious impact of environmental pollution, there has been a rising collaboration on the global scale to abate the booming effects of environmental pollution, in the quest to ensure transformation of prevailing social and economic paradigm into a more sustainable one. The Paris agreement on climate change by community of nations in 2015 reflects a concerted strive on the global front to ease global warming which is often heralded by rising environmental pollution (UNEP, 2015). Despite the shift in focus towards implementation of action for sustainable environment by nations, global warming continue to rise, setting a record of about 1.1 degrees Celsius above the pre-industrial period (United Nations 2017). According to Bakare, Oladejo, Olatunji, and Onuoha (2014), effect of environmental pollution on people especially in developing countries has continued to engender high rate of death and illnesses such as asthma, neurodevelopmental disorders and birth defects in children, as well as heart disease, stroke, and cancer among adults. As reported by Organization for Economic Cooperation and Development [OECD] (2015), rise in environmental pollution resulted in 5.5 million premature deaths globally in 2013, with high rate of respiratory and cardiovascular diseases, which hiked global air pollution-related health care cost from US$ 21 billion in 2005 to US$ 176 billion in 2015.

Observably, emission of greenhouse gases such as carbon-dioxide, nitrous oxide, methane e.t.c has been on the increase in Sub-Sahara Africa region over the years. As reported by World Bank (2017), carbon dioxide emission since year 2000, trended consistently upward in countries like Uganda, Tanzania, Sudan, Senegal, Mozambique, Lesotho, Ethiopia, Djibouti, Chad, Angola, Cameroon, Boswana to mention but few. Statistics also revealed that nitrous oxide emission and methane emission recorded peak values during the last decade for most Sub-Sahara African countries. Specifically, carbon dioxide emission in Uganda rose from 1430.13 kt in 2000 to 5229.142 kt in 2014, in Tanzania, it rose from 2651.24 kt in 2000 to 11562.05 kt in 2014, in Sudan, from 5533.5 kt to15364.7 kt, in Senegal, from 3938.4 kt to 8855.8 kt, in Mozambique, from 1349.5 kt to 8426.8 kt, in Lesotho, from 1851.8 kt to 2467.9 kt, in Ethiopia, from 3549.7 kt to 11598.7 kt, in Djibouti, from 341.0 kt to 722.4 kt, in Chad, from 176.0

kt to 729.7 kt, in Angola, from 9541.5 kt to 34763.2 kt, in Cameroon, from 3432.3 kt to 7003.9 kt, in Boswana, from 3780.7 kt to 7033.3 kt, to mention but few (International Energy Agency [IEA] (2014).

With the burgeoning trend of environmental pollution across nations of the world, various empirical investigations had been conducted in the quest to ascertain factors responsible for such trend. While some studies (Wang, Zhao, and Chen 2017; Usenobong and Godwin, 2012; Lamia, Abdelkuder 2016; Reza, Samira, Ethan and Jack 2017; Daigee, Arwin, Chang-Chin and Ming-Feng 2012; Faiza, Muneeb & Shaista, 2014; Opoku, Amoako & Amankwa, 2014; Managi, Hibiki, and Tsurumi 2008) established that factors like energy consumption, population growth, economic growth, trade openness, urbanization e.t.c exerts positive influence on environmental pollution, other studies like (Ullas & Mahvish, 2012; Selahattin & Ferda 2016; Yunpeng, Huai, Qiuán, Changhui Gang, Yanzheng and Yao 2014; Mobeen and Mushab 2017; Jevan, 2013; Zakir and Nisar 2013; Rahul & Chandi, 2013;) discovered that factors such as trade openness, industries expansion, population and/or economic growth exert negative impact on environmental pollution. However while some of the studies established significant impact of identified factor variables on environmental pollution (see Faiza, Muneeb & Shaista, 2014; Jevan, 2013; Anthony & Achike 2013: Asma, 2015), others found insignificant impact. In addition Studies on the determinants of environmental pollution also, are largely countries specific, with only few studies conducted in the context of a defined region/zone or selected countries of the world (see Keho, 2016; Faiza, Muneeb & Shaista, 2014; Jevan 2013; Olarinde, Martins & Abdulsalam 2014). It thus becomes a knowledge puzzle among scholars as to drawing conclusion on the core determinants of environmental pollution especially across regions of the world due to divergent empirical findings. In specific terms therefore this study investigated

(i) Determinants of environmental pollution in Sub-Sahara African countries?

II. LITERATURE REVIEW

Environmental Pollution

As identified by Aduebe (2013), environmental pollution involved the destruction and deterioration of ecosystem, including the exhaustive and driving away of wildlife from where they are best needed, through overutilization or inadequate use of natural resources. Mostly, people centered attention on satisfaction needed from food, recreation, infrastructural facilities and other desires and wants, at the expense of the environment (Omofomwan and Osa-Edoh, 2008). For instance, increase in the demand for owned-shelter results in deforestation, which has adverse effect on the environment. According to Heidari, Katircioglu and Saeidpour (2015) vegetation that could help in photosynthesis and/or absorb human waste and heat produced in the environment, is increasingly been depleted to meet high demand for house around the world and this alone contribute largely to rise in the trend of environmental pollution.

Environmental pollution can be attributed to emission from energy production and consumption in the environment (Evelyn and Tyav, 2013). According to Zhao, Niu and Zhang (2012), excessive energy consumption tends to expose the environment to the danger of climate change, pollution and unhealthy condition for man. Energy is an engine necessary to drive the development of every economy. Energy provides heat, coolness and light for both firms (including household), fuels for production (food products and capital goods) and transportation of people and goods, as well as promotes communication and technology. In a nut shell, energy serves as aid to other sectors in the country. It enhances industrialization and urbanization through increased productivity, alleviates poverty, effective transportation of goods and services to the most needed units and improved standard of living (Cao, 2003). However, the exploration, extraction and exploitation of energy by individual and industries to inhibit growth process has increased the occurrence of environmental pollution in many countries, especially developed and emerging economies (Usenobong and Godwin, 2012). In the word of Mobeen and Mushab (2017) demand for energy which is on a continuous increase due to expansion in industrial activities (manufacturing products such as plastics, textiles, fertilizers, and petrochemical products) in developing countries, has increase energy consumption, and by extension, the amount of emission in the environment, causing increase in the rate of environmental pollution.

Forms of Environmental Pollution

i. Air pollution

Air pollution is the concentration of substance, that are capable of endangering endanger human health or produce other measured effects on living matter and other materials, in the atmosphere. Sources of air pollution include smoke, dust, heat generation, the burning of solid wastes and industrial processes of air pollutants that produce carbon dioxide, carbon monoxide from incomplete combustion engine and others which consists of hydrocarbons, nitrogen oxides, sulfur dioxide and photochemical oxidants. All these chemical components transit into greenhouse effect, that is, hinder heat in the atmosphere from transmitting into space (Daigee, Arwin, Chang-Chin & Ming-Feng, 2012).

ii. Land pollution

Land pollution is the degradation of the land surface through inappropriate use of the soil by poor agricultural practices, mineral exploitation, industrial waste dumping and indiscriminate disposal of urine waters. Land pollution arises as a result of several activities such as deforestation, excessive exploitation of fuel wood, overgrazing, agricultural activities and industrialization. According to Rahul and Chandi (2013), land pollution are accounted for by overgrazing (35%), agricultural activities (24%), deforestation (30%), excessive exploitation of fuel-wood (7%), and industrialization (4%) on the global level.

iii. Water pollution

Water pollution refers to discharge into ocean waters, chemical, physical or biological material that deteriorates the qualities of the water. The process ranges from simple addition of dissolved or suspended solids to discharge of the most insidious toxic pollutants (such as pesticides, heavy materials and non-degradable bio-accumulative, halogenated, hydrocarbons) which persist and pervade the environment. Much nipanon water are heavily polluted by human face and faucal polluted water that causes cholera. For instance, rain water in Warri metropolis contains a high level of acidity due to the high emission of particulate matters and gases into the urban atmospheric environment.

iv. Noise pollution

` Noise pollution is a composite of sounds generated by human activities ranging from blasting stereo system to the roar of transport vehicles. The most readily measurable physiological effect of noise pollution is damage of hearing, which may be either temporary or permanent and may cause distraction of normal activities or general annoyance.

Determinants of Environmental Pollution

According to He, Zhong, Yin and Wang (2018), sources of environmental pollution can be categorized into two- energy-related factors and socio-economic factors. Environmental pollution arises through the conversion of an energy source to a useful component or through its usage. According to International Energy Agency 2010, energy contributes about 83% of waste in the environment. These sources of energy are then discussed below in relation to their contribution to environmental pollution.

i. Fossil Fuel

Fossil fuel is also referred to as mineral fuels (Bozkurt, 2010). It can be majorly categorized into three- oil, coal and natural gas (Mustapha, 2005). They are source of energy generation that is characterized by hydrocarbon. Fossil fuel can cause air, land or aquatic pollution. From exploration through to usage of oil, there is possibility of oil spillage and gas flaring which can pollute land, air and water resources (Maren, Morgan and Ishaku, 2013).Fossil fuel is used in houses, commercial and industrial sectors, heat production and production of electric power. Fossil fuel is mostly for generating electric power. In electric power generators, the combustion of fossil fuel is transmitted to the turbine as power. While the combustion rotate turbine in the earlier generators, it rotates the gas turbine directly for the new power generators. The combustion of fossil fuel emits carbon dioxide and methane which keeps heat in the atmosphere. This is because emission from fossil fuel combustion hinders the transmission mechanism between atmosphere and space. The sun provides heat and radiation from sunrise to sunset. For natural cycle to be maintained, the heat must be transferred to the space. However, the emission from fossil fuel hinders this process which then increased accumulation of CO_2 component of greenhouse gas (GHG) in the atmosphere and causes changes in climate, mostly resulting in global warming. Thus, fossil fuel contributes to global warming. According to International Energy Agency (2010), greenhouse gas emission is dominated by CO_2 from the oxidation of carbon. And, as established by Bozkurt (2010), CO2 emission is responsible for 50% global warming. Researchers that found evidence on huge contribution of fossil fuel among others are Bozkurt (2010); Usenobong and Godwin, (2012); Abdeen, (2011); Zhao, Niu, and Zhang, (2012); and Mobeen and Mushab(2017).

ii. Thermal energy

The thermoelectric power production is made generally by using coal, petroleum and natural gas fuels. Only 30-40% of the energy produced in thermal power plants can be converted to electric energy. The remaining part is called as “fault energy” and comes from its boiler with radiation or discarded from funnel together with funnel gas. The gases that come out from funnel of thermal power plants and greatly affect the flora are dioxide and azoth oxides. The organ of plants mostly sensitive to such gases is their leaves. Such gases that enter into leaves by means of stomas destroy the structure of chlorophylls in leaves. Damages on plants are seen in three different dimensions. These are acute, chronicle and hidden damages. Plants expose to acute damage die immediately. Though the chronicle damage is not vital, it greatly destroys the quality of plants. The hidden damage occurs in a time. This could lead to any form of environmental pollution- air, water and land use/soil pollution.

iii. Population

Population is a key factor of environmental degradation. The effect of population on environment pollution, are mostly through the use of natural resources. This process is connected to environmental stresses like loss of biodiversity, air and water pollution and increased pressure on arable land (Rajiv, 2016). Population growth requires that resources available such as food, housing, energy etc. keep pace with it. Increase in population essentially increases the demand for food, energy and housing. To meet up with this, available land is cultivated excessively, inorganic fertilizers are applied, forest are cleared for buildings and agricultural practices. Excessive vegetation clearance and pressure on land are likely to lead to soil infertility, soil erosion, losses of nutrients, reduce level of oxygen, climate change and unhealthy condition for man through air and soil pollution.

iv. Transportation

Transportation is a most rapidly growing socio-economic factor that contributes to environmental pollution. Mostly, transportation effects are in form of air pollution. Motor vehicles used fossil fuel for operation. They emits chemical such as carbon dioxide, chlorofluorocarbons, nitrous oxide, and carbon monoxide, which are components of greenhouse gas. Nearly 50 percent of global carbon monoxide, hydrocarbon, and nitrogen oxide emissions from fossil fuel combustion come from gasoline and diesel powered engines (Ndoke and Jimoh, 2006). However, level of traffic determines the level of emission. In developing countries like Mexico City, Bangkok, and Lagos, Nigeria, automotive air pollution is mostly a problem in large cities with high levels of traffic.

v. Industrial activities

The manufacturing technology adopted by most of the industries has placed a heavy load on environment especially through intensive resource and energy use, as is evident in natural resource depletion (fossil fuel, minerals, timber etc.), water, air and land contamination, health hazards and degradation of natural eco-systems. With high proportion fossil fuel as the main source of industrial energy and major air polluting industries such as iron and steel, fertilizers and cement growing, industrial sources have contributed to a relatively high share in air pollution. Large quantities of industrial and hazardous wastes brought about by expansion of chemical based industry have compounded the wastes management problem with serious environmental health implication (Rajiv, 2016).

Theoretical Review

Pollution Haven Theory

The first pollution haven model was developed by Pethig (1976). He considered two countries that are completely identical except that one (North) has a higher pollution tax than the other (South). North's high pollution tax gives it a comparative advantage in the clean good. When trade is liberalized, trade shifts pollution-intensive production to the low-regulation country (South). Copeland and Taylor (1994) showed how pollution havens could develop in poor countries even if all governments were free to choose whatever pollution policy best suited their countries. In the Copeland and Taylor model, countries are completely identical except in income levels. Northern countries are richer than Southern countries. The key assumption is that environmental quality is a normal good as income increases, consumers demand higher environmental quality. If government policy is responsive to consumer demand, then the model predicts that richer countries will have more stringent environmental policy than poorer countries. Consequently, poor countries will have a comparative advantage in pollution-intensive production. When trade is liberalized, North exports clean goods, and South exports pollution-intensive goods: poor countries will become pollution havens. This result is only part of the story. In reality, there are many reasons for trade, and the actual pattern of trade depends on the interaction among all such motives.

Copeland, and Taylor (2001) developed a pollution haven model suitable for empirical testing by allowing for more than one motive for trade. In this model, countries differ in capital abundance as well as in income levels. Suppose that pollution-intensive industry is also capital intensive and that North is capital abundant. North's capital abundance tends to give it a comparative advantage in the pollution-intensive industry, but its stringent pollution policy tends to give it a comparative advantage in the clean industry. If the effects of North's capital abundance on the trade pattern are more important than the cost-increasing effect of its stricter environmental policy, then North will have a comparative advantage in the pollution intensive good and trade liberalization will shift pollution-intensive production from the low income South to the high-income North. In short, theory predicts that pollution policy is but one of many factors that affect trade. Whether or not trade liberalization leads to pollution havens depends on whether the effects of differences in environmental policy on production costs are more or less important than all of the other motives for trade

Empirical Review

Jevan (2017) examined trade liberalization and the environment for NAFTA and US manufacturing. The study specifically analysed the aggregate effects of international trade on the environment. The study collected primary panel data containing information on pollution emissions and other plant characteristics covering the years 1991 to 1998. The study employed descriptive and regression analysis. The study revealed that trade liberalization following NAFTA decreased emissions of particulate matter and sulphur-dioxide from affected plants. Also, the study revealed that decreases in emission levels are primarily driven by changes in the emission intensity of production rather than changes in the level of output produced. Thus, the study concluded that that trade liberalization led to significant reductions of pollutants that affected plants. similar study by Shanty and Firmansyah (2016) investigated analysed the relationships between environmental degradation and trade openness in Indonesia. Specifically, the study assessed the effect of trade liberalization on environmental quality and the existence of environmental Kuznets curve (EKC) in Indonesia. The study used linear, quadratic and cubic equation. The study employed carbon emission, trade liberalization and gross domestic product per capita as variable of interest. The study adopted data covering the period 1976-2014. The study analyzed data using co-integration method. The study revealed that trade liberalization has positive and significant effect on CO_2 emission in the quadratic and cubic equation but insignificant in the linear equation. Also, the study discovered that the quadratic equation confirmed the inverted U-shaped of EKC hypothesis. Thus, the study concluded that there is positive relationship between environmental degradation and trade openness in Indonesia. Another study by Asma (2015) analyzed whether trade liberalization, economic growth, energy consumption are good for the environment. The study specifically examined the dynamic relationship between trade openness, income growth, energy consumption and CO_2 emissions for Pakistan. The study used vector error correction model. The study employed data collected data over the period 1980-2003. The study analyzed data using Johansen-Juselius co-integration test. The study revealed significant long run relationship among the variable. The study discovered that income growth and energy consumption have positive and significant relationship with CO_2 emission while negative long run relationship with CO_2 emission. Thus, the study concluded that income growth and energy consumption have detrimental impacts on environmental quality.

Sepideh (2015) evaluated the effect of trade liberalization on the quality of the environment in both developed and developing countries. The study specifically analysed effect of trade liberalization on the environment pollution based on environmental Kuznets curve hypothesis. The modeled emission (BOD emissions and CO_2 emission) on per capita GDP, its squared term and trade openness (trade liberalization measure). The study employed data collected over the period 1990-2013 for 12 countries. The study analysed data using unit root test and Johansen co-integration test, F-Lymr test, Hausman test, and panel regression analysis. The study discovered long-term equilibrium relationship between BOD and CO_2 emissions; and trade openness has positive effect on emission measures for developed countries, but negative for developing countries. Also, the study revealed that BOD model for developed countries established Kuznets curve but the developing countries do not follow the Kuznets curve whereas CO_2 pollution both developed countries and developing countries confirmed the Kuznets curve. The study recommended that improvements in fuel quality, fuel substitution with less pollution and reduce pollution equipment will reduce CO_2 emissions in the environment.

In china, Jose, Laura and Sandra (2015) investigated whether trade openness reduced pollution. The study specifically assessed environmental consequences of China's integration into the world economy. The study used SO_2 emission as proxy for pollution, while explanatory variables were trade openness rate, log of per capita income, local factor endowment and other that may correlate with city environmental and trade performance. The study employed data collated over the period 2003-2012 for 235 Chinese cities. The study analyzed data using fixed effect and instrumental variable. The study discovered negative and significant effect of trade on emissions. The effect of trade on emissions is larger for processing trade and activities undertaken by foreign firms. Also, the study discovered that the environmental gains from either ordinary trade activities or domestic firms appear much lower. Thus, the study recommended that caution should be taken regarding the future pollution prospects in the context of China's ongoing transition to ordinary trade. Maryam and Mohamad (2016) studied Inter-industrial trade on Iran's air pollution. The study specifically tested pollution haven hypothesis in Iran; and examined both the direct and indirect effect of inter-industrial trade on the environment. The dependent variable was carbon emission while explanatory variables were value added of industry, capital to labour ratio and trade intensity. The study employed data covering the period 1980-2014. The study used fixed and random effect model. The study analyzed data using panel regression. The study discovered that inter-industrial trade has positive impact on the environment. Also, the study showed that pollution haven hypothesis is applicable in Iran.

Hui, Danxiang and Yuling (2017) evaluated foreign trade and pollution. The study specifically analyzed the interrelationship among economic growth, energy use and pollution; and examined the evidence of inverted U-shaped. The study used simultaneous equation model. The variable were GDP per capita, import, exports, capital stock and BOD emission. The study employed data covering the period 1990-2015. The study analyzed data using two stage feasible general least square. The study revealed that interrelationship between the South China economic growth and water pollution is inverted U-shaped EKC. Also, the study revealed that with increase in export ratio or decrease in import ratio, EKC slope will decline. Thus, the study suggested that China needs to direct trade to environmental friendly export or pollution intensive import.

Xu, Benjamin, Simon, Baosheng and Mikael (2015) investigated energy, economy and environment. The study specifically examined the co-integrating relationship between the energy, economy and environment (E3) of China. The study employed discursive method. The study revealed that energy cost for producing fossil energy is increasing and that the energy return on investment (EROI) is declining in China; energy production and consumption have become one of the main reasons for environmental deterioration in China; and China's economic growth has driven and been fuelled by a large energy requirement. Thus, the study concluded that there is relationship between energy, economy and environment of China.

In an attempt to investigate the position of energy consumption as a determinant of environment pollution, quite a number of researches has been conducted in recent time for instance, Reza, Samira, Elham and Jack (2017) evaluated energy consumption and environmental pollution. Specifically, the study investigated the relationship between energy consumption and CO_2 emission for selected developing countries. The study used energy consumption as dependent variable while explanatory variables were carbon emission, urbanization, trade openness, financial development, total population per capita, capital stock and total labour force. The study employed simultaneous equation model. The first modelled energy consumption on Gross domestic product, carbon emission, labour force, capital stock, foreign direct investment and population. The second modelled carbon emission on gross domestic product, urbanization, and trade openness. The study collated data over the period 2000-2011for 22 countries. The study analysed data using Two stage least square. The study showed that that CO2 emission, total labour force, capital stock and population have positive impact on energy consumption per capita. GDP per capita and financial development has no significant impact on energy consumption per capita. Also, the study discovered that energy consumption, GDP per capita and urbanization have significant positive impact on CO_2 emission. Trade openness has no significant impact on CO_2 emission per capita.

Similar study by Lingyun, Zhangqi, Fang and Deqing (2018) examined the impact of energy consumption on air quality in Jiangsu province of China. Specifically, the study analysed effect of energy consumption on air quality with exclusion and inclusion of control variable. The study used industrial structure, energy efficiency and energy consumption structure as control variables, air quality as dependent variable and energy consumption as explanatory variable. The study collated data over the period 2006-2015. The study analyzed data using three stage least square. The study revealed U-shaped relationship between energy consumption on air quality with exclusion and inclusion of control variable. Also, the study revealed that industrial structure, energy efficiency and energy consumption structure have influence on air quality. However, the study identified that the structure and efficiency paths do not have a significant effect on air quality improvement in Jiangsu Province. Therefore, the study recommended that air quality should be improved through effective industrial structure, energy efficiency and energy consumption structure. Also, Suleiman, Suryati, Nornaz and Moukhtar (2018) assessed energy consumption, environmental emissions and economic growth. The study specifically focused on the relationship between of energy consumption, emissions and economic growth. The study regressed gross domestic product (measure of economic growth) on energy consumption, CO_2 emission, fossil fuel consumption, trade openness and foreign direct investment. The study employed data extracted over the period 1960-2014. The study analysed data using descriptive analysis, ADF and PP unit root, ARDL bound test. The study discovered that energy consumption has positive and significant impact on gross domestic product both in the long run and short run. Fossil fuel and foreign direct investment have negative and significant impact on gross domestic product. However, he study identified industrialization process as the cause of GDP which generate more carbon emission. Thus, the study recommended that government should undoubtedly spell out the penalties for polluters and others emitters who refused to reduce the allowed abatement to firms or individuals.

Another study by Lamia and Abdelkoder (2016) examined energy consumption and economic growth lead to environmental degradation. Specifically, the study focused on relationship between economic aggregates and environmental pollution in Asian countries, using annual panel data for the period 1991-2013 for China, India, Thailand, Japan, Malaysia, Singapore, Indonesia, and South Korea. Unit root test, co-integration test, fully modified OLS and panel causality techniques we The study revealed that CO_2 emission has positive relationship with economic growth, trade openness, energy consumptions, capital stock, and urbanization rate. Relationship between economic growth and financial development was negative. Also, the study discovered unidirectional causality running from environmental degradation to energy consumption and economic growth to financial development. Thus, the study recommended that government should promote investment on new resources in the energy sector which are beneficial in terms of CO_2 emissions, as renewable energy.

Wang, Zhao and Chen (2017) assessed population agglomeration, economic growth and environmental degradation. The study specifically focused on determinants of environmental degradation. The study employed the framework of the Human Impact, Population, Affluence and Technology (IPAT) model. The study used population density and growth, GDP per capital and its square value, and industrial share of GDP as explanatory variables. Environmental pollution was measure by industrial sot emission. The study extracted data over the period of 2003-2012 for 290 cities from all 31 provinces of China. The study analyzed data using descriptive and regression analysis. The study revealed that population agglomeration has little or very small impact on environmental degradation, whereas the population size has a positive impact on environmental pollution. Also, the study discovered that relationship between economic growth and pollution depicts inverted U-shaped for China. However, the situation differs for various cities. Thus, the study concluded that EKC hypothesis is applicable for China.

Teklu (2016) analyzed rapid population growth and Environmental degradation in Ethiopia. The study specifically analyzed the effect and relationship between population growth an environmental degradation. The study employed discursive method. The study discovered that high population growth causes increase in number of people below poverty line, increasing population density and pressure on natural resources. Also, study also discovered that the population growth has encouraged rapid growth of energy consumption which has lead to environmental pollution such as air pollution and global warming. Therefore, the study concluded that population growth continually degrade environment.

Bernard and Mandal (2016) examined the impact of trade openness on environmental quality. The study employed GDP, Trade Openness, Energy Consumption, Financial Development, FDI, Urbanization, Political Globalization and Governance as explanatory variables, while carbon-dioxide emission and environmental performance index were used as dependent variable. The study adopted data collated over the period 2002-2012 for 60 emerging and developing countries. The study analyzed data using fixed effect model and generalized method of moment. The study revealed that gross domestic product and trade openness exert positive and significant impact on carbon emission and environmental performance index for fixed effect model. The study also revealed that effect of trade openness was insignificant for GMM. Thus, the study recommended comprehensive economic, financial, institutional, and energy policies for guaranteeing environmental sustainability.

Mkonda and Xinhua (2017) investigated the emerging population increase and its environmental challenges and remedies in Iringa Municipal of Tanzania. The study collected primary data from 200 respondents at the household level through questionnaire and interview was also conducted in the study. The study analyzed data using descriptive analysis. The study indicated that poverty and population increase are the root causes contributing about 90% of environmental degradation. The study also discovered that food and energy requirements, and inadequate awareness on the issues of environmental management were obstacles in the addressing environmental degradation. Deforestation, monoculture, poor waste management, and pollution of heavy metals (especially lead, copper and arsenic) are some of the anthropogenic activities creating environmental degradations in the Iringa municipality. The study then concluded that relationship between man and environment is parasitic and asymmetric. The study recommended that proper agronomic practices and alternative energy sources should be employed to enhance crops yield and environmental goods and services as well.

Doris (2017) analyzed overpopulation and the impact on the environment. The study specifically investigated impact of overpopulation on environment. The study employed discursive method. The study discovered that overpopulation results to urbanization, global warming, increase emission and green-house effect, and scarcity of food. The study recommended that technology may be the only factor that will save the planet from destruction. Technological innovations and devices produce large sets of data that are able to predict what actions should be taken to maintain environmental sustainability and support humanity

Mobeen and Mushab (2017) examined energy consumption to environmental degradation, the growth appetite in SAARC nations. The study specifically analysed the role of energy consumption on environmental degradation. The study analyzed data using panel unit root, co-integration test, fully modified OLS, dynamic OLS and causality test and discovered that GDP and its square have significant negative impact on CO2 emission in emerging markets and EFA panel, but its results are insignificant for the frontier panel. The study also revealed that population growth has nominal but significant impact in EFA markets and insignificant impact in frontier markets and emerging market. The study therefore concluded that there is evidence of inverted U-shaped EKC in the countries. Thus, the study recommended that countries should implement strategies that enforce the use of environmental friendly technologies and operations to enhance the domestic production capacities.

III. METHOD

This study focused on Sub-Sahara Africa, being the region of Africa continent that lies south of the Sahara. It consists of all African countries that are fully or partially located south of the Sahara.

Source: Free World Map (2018)

Model Specification

To ascertain determinants of environmental pollution this study adapted the model used by Somlanare (2015) which focused on the influence of level of education on the growth of carbon-dioxide emission per capita controlled by domestic investment, population growth rate, trade openness, and democratic institution. The baseline model used by Somlanare (2015) is presented equation 3.2

$$\log\left(\frac{e_{i,t}}{e_{i,t-1}}\right) = \beta_1 \log(e_{i,t-1}) + \beta_2 \log(h_{i,t}) + \delta x_{i,t} + \gamma_t + \alpha_i + \varepsilon_{i,t} - - - - - - - 3.2$$

Where:

$e_{i,t}$ is the average quantity of carbon dioxide emissions per capita (in metric tons) in a country i over a period t, $h_{i,t}$ is education, $\varepsilon_{i,t}$ is the error term, γ_t denotes time effects and α_i represents country specific effects, while $x_{i,t}$ is a vector of control variables including domestic investments, population growth rate, trade openness and democratic institutions.

Equation 3.2 was modified by replacing growth of carbon-dioxide emission per capita by absolute emission variables including carbon dioxide ($C0_2$) emission, Nitrous oxide (N_20) emission, and methane (CH_4) emission, thus making a 3x1 vector of dependent variables, while determinant variable such as energy consumption (EC), Gross Domestic Product (GDP), Population size (POS), Trade Openness(TOP), domestic investment (Dinv) and Foreign Direct Investment (FDinv) forms set of independent variables. For simplicity however the model is present in linear form in equation 3.3.

$$Y_{it} = \varphi_0 + \varphi_1 EC_{it} + \varphi_2 GDP_{it} + \varphi_3 POS_{it} + \varphi_4 TOP_{it} + \varphi_5 Dinv_{it} + \varphi_6 FDinv_{it} + \varepsilon_{3t} --3.3$$

Where:

Y_{it} is a 3x1 vector of dependent variables representing environmental pollution (carbon-dioxide emission [kilo ton (kt)], Nitrous-oxide emission [thousand metric tons of CO_2 equivalent], methane emission [kt of CO_2 equivalent]), EC is energy consumption [kg of oil equivalent per capita], GDP is Gross Domestic Product [constant 2010 US$)], POS is Population size [No of persons], TOP is Trade Openness [% of gdp], Dinv is Domestic investment [% of GDP], and FDinv is Foreign Direct Investment [% of GDP], $\varphi_0 \dots\dots\dots.. \varphi_6$ are parameter estimates for the intercept and independent variables identified as factors of environmental pollution model.

Scope of the Study

This study focused on 35 Sub-Saharan African countries, covering a period of 18 years spanning from 2000 to 2017, being an era where collaborative effort was put in place by community of nations to drives home the achievement of millennium development goals that can ensure sustainable economic development across countries of the world. Specifically, this study selected 35 Sub-Sahara African countries reported by the United Nation in 2015, as countries with relatively low human development including Angola, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo (Democratic Republic of the), Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Swaziland, Senegal, Sierra Leone, South Sudan, Sudan, Tanzania (United Republic of), Togo, Uganda, Zimbabwe

Source(s) of data and Method of Data Analysis

Data were sourced from World banks development indicator database. In the quest to attain the objectives in the research work and to provide answers to those research questions raised, the study made use of preliminary techniques of analysis including descriptive and correlation analysis, and panel corrected standard error (PCSE) estimator. Notably, This study estimated the data set first with static panel based estimators including pooled OLS, fixed effect LSDV estimation, random effect estimation, and then test the validity and fitness of the model based on post estimation test such as restricted F-test, Hausman test, Wald test for panel heteroscedasticity, Wooldridge test of autocorrelation, and peseran cross section dependence test. The result reflect for the models estimated that there is presence of both cross-sectional dependence and heteroscedasticity in the models,

To correct for the presence of cross-sectional dependence and panel heteroscedasticity, this study employed panel-corrected standard error (PCSE) estimation. Notably in the literature of panel data estimation, there is a clear cut evidence that one key issue faced by applied researcher is how to handle the problem of cross sectional dependence (Moundigbaye, Rea & Reed, 2018). Basically, there are three general approaches to the issue of cross sectional dependence. The first approach is to model the error-variance covariance matrix in the framework of Seemingly Unrelated Regression (SUR). Here, the common estimator is Feasible Generalized Least Squares (FGLS), where the cross-sectional covariances are typically modeled parametrically. The classic reference is Parks (1967) and the corresponding Data-Generating Process (DGP) is commonly called the Parks model. The second approach is to model the cross-sectional dependencies "spatially" (Anselin, 2013; Baltagi et al., 2013; Elhorst, 2014; Bivand and Piras, 2015). This typically involves modelling the dependencies across units as a function of distance, in either a continuous or binary fashion. While this has the advantage of greatly reducing the number of parameters to be estimated, it comes at the cost of possible misspecification, because misspecification occurs if the nature of the respective cross-sectional dependencies cannot be effectively reduced to a function of distance (Corrado and Fingleton, 2012).

The third approach is to model cross-sectional correlation as a function of time-specific common factors (Pesaran and Smith, 1995; Bai, 2003; Coakley et al., 2006; Pesaran, 2006; Eberhardt et al., 2013; Kapetanios et al., 2011). This approach has proven particularly popular in the macro panel literature (Eberhardt and Teal, 2011). The multi-factor framework for cross-sectional correlation allows one to incorporate a number of other important issues, it also comes at the cost of possible misspecification, because it greatly reduces the number of parameters to be estimated. Despite the existence of more recent alternatives, the Parks model continues to be relevant for applied researchers. However, a major problem with this model is the large number of parameters that need to be estimated. In its general form, with groupwise heteroskedasticity, group-wise specific AR(1) autocorrelation and time-invariant cross-sectional correlation, the classic Parks model has a total of $\left(\frac{N^2+3N}{2}\right)$ unique parameters in the Error Variance-Covariance Matrix (EVCM), where N is the number of cross-sectional units. This causes two problems. First, the FGLS estimator cannot be estimated when the number of time periods, T, is less than N, because the associated EVCM cannot be inverted (Beck and Katz, 1995). Second, even when $T \geq N$, there may be relatively few observations per EVCM parameter, causing the associated elements of the EVCM to be estimated with great imprecision.

As demonstrated by Beck and Katz (1995), this can cause severe underestimation of coefficient standard errors, rendering hypothesis testing useless. To address these problems, Beck and Katz (1995), proposed a modification of the FGLS-Parks estimator called Panel-Corrected Standard Errors (PCSE). PCSE preserves the (Prais-Winsten) weighting of observations for autocorrelation, but uses a sandwich estimator to incorporate cross-sectional dependence when calculating standard errors. The PCSE estimator has proven very popular, as evidenced by over 2000 citations in Web of Science. In addition Beck and Katz (1995) affirmed that PCSE correct for cross sectional dependence alongside heteroscedasticty and produce more accurate result relative to the feasible generalized least square (FGLS) estimator. Hence this study adopt PCSE estimator to correct for the presence of cross sectional dependence and heteroscedasticity in the panel. Notably, results presented in this study captured three models including carbon-dioxide specification, Nitrous-oxide specification and Methane specification.

IV. RESULT

Table 1: Panel-Corrected Standard Errors (PCSE) estimation result ($C0_2$ Specification)

Series: $C0_2$ EC GDP POS TOP DINV FDINV

Variable	Coefficient	Panel Corrected Standard Error	Z-Test stat	Probability
C	10601.29	2032.319	5.22	0.000
EC	22.40624*	1.940176	11.55	0.000
GDP	-0.0013381*	.0208517	-0.06	0.949
POS	173.7638*	46.14126	3.77	0.000
TOP	-10.98571*	3.93685	-2.79	0.005
DINV	3.314145	8.796053	0.38	0.706
FDINV	-0.5944773	6.98748	-0.09	0.932

R-square=0.9848; Wald chi2(5)= 29235.04; Prob> chi2= 0.0000

* Connote significance at 5% level of significant

Source: Author's Computation (2021)

Estimation result presented in Table 1 showed the impact of determinant variables on carbon-dioxide emission after presence of heteroscedasticity and cross sectional dependence has been control. Result showed that energy consumption and population size exert significant positive impact on the level of carbon-dioxide emission with coefficient estimate of 22.40624($p < 0.05$) and 173.7638($p < 0.05$). Domestic investment exerts positive but insignificant impact on carbon-dioxide emission, with coefficient estimate of 3.314145($p > 0.05$). On the other gross domestic product, and foreign direct investment exert insignificant negative impact on carbon-dioxide emission, while impact of trade openness is negative and significant. Reported coefficient estimates stood at -0.0013381($p > 0.05$) for gross domestic product, -0.5944773 ($p > 0.05$) for foreign direct investment and -10.98571($p < 0.05$) for trade openness. R-square value showed that determinants variables employed in this study can jointly explain about 98% of the systematic variation in carbon-dioxide emission. Ultimately, this result established that among the determinant variables considered in the study, energy consumption, population size and trade openness are significant determinants of environmental pollution measured in terms of carbon-dioxide emission.

Table 2: Panels Corrected Standard Errors (PCSE) estimation result (N_20 Specification)

Series: N_20 EC GDP POS TOP DINV FDINV

Variable	Coefficient	Panel Corrected Standard Error	Z-Test stat	Probability
C	434.1405	1740.965	0.25	0.803
EC	12.60901*	3.777704	3.34	0.001
GDP	.0265133	.0142698	1.86	0.063
POS	265.0668*	76.03776	3.49	0.000
TOP	16.58554*	6.546859	2.53	0.011
DINV	-34.30753	28.20466	-1.22	0.224
FDINV	-15.99983	20.29193	-0.79	0.430

R-square=0.8448; Wald chi2(5)=1.05e+06; Prob> chi2 =0.0000

* Connote significance at 5% level of significant

Source: Author's Computation (2021)

Estimation result presented in Table 2 showed that energy consumption, population size, and trade openness exert significant positive impact on nitrous oxide emission, with reported coefficient estimate of 12.60901 ($p < 0.05$) for energy consumption, 265.0668 ($p < 0.05$) for population size and 16.58554 ($p < 0.05$) for trade openness. Impact of gross domestic product on nitrous oxide emission is positive but not significant, with coefficient estimate of 0.0265133 ($p > 0.05$), while both domestic investment and foreign direct investment exert negative insignificant impact on nitrous oxide emission with coefficient estimates of -34.30753($p > 0.05$) and -15.99983 ($p > 0.05$) respectively. R-square statistics reflect that about 84% of the systematic variation in nitrous oxide can be jointly explained by the determinants variables employed in the study. In clear terms, result revealed among other things that energy consumption, population size, and trade openness are significant determinants of environmental pollution measured in terms of nitrous oxide in sub-Sahara Africa.

Table 3: Panels Corrected Standard Errors (PCSE) estimation result (CH_4Specification)

Series: CH_4 EC GDP POS TOP DINV FDINV

Variable	Coefficient	Panel Corrected Standard Error	Z-Test stat	Probability
C	11742.98	1716.681	6.84	0.000
EC	5.568464	3.095512	1.80	0.072
GDP	0.0361665*	.0150826	2.40	0.016

POS	417.5629*	75.25075	5.55	0.000
TOP	17.33032*	6.925413	2.50	0.012
DINV	-28.0913	24.27009	-1.16	0.247
FDINV	-5.665479	20.05179	-0.28	0.778

R-square=0.9209; Wald chi2(5)= 742268.33; Prob> chi2 =0.0000

Note: *for brevity of presentation, intercept deviation terms for each cross sectional unit for the LSDV estimation can be found in appendix Ib with country 1 (Angola) as the reference country.*

** Connote significance at 5% level of significant*

Source: *Author's Computation (2021)*

Estimation result presented in Table 4.11 revealed that gross domestic product, population size and trade openness exert significant positive impact on methane emission with coefficient estimate of 0.0361665 ($p < 0.05$) for gross domestic product, 417.5629 ($p < 0.05$) for population size and 17.33032 ($p < 0.05$) for trade openness. Impact of energy consumption on methane emission is positive but not significant 5% level of significance. On the other hand result showed that both domestic investment and foreign direct investment exert insignificant negative impact on methane emission, with reported coefficient estimates of -28.0913 ($p > 0.05$) and -5.665479 ($p > 0.05$) respectively. R-square statistics revealed that about 92% of the systematic variation in methane emission can be explained jointly by determinants variables included in the model. Succinctly, result presented in Table 4.11 established that gross domestic product, population size and trade openness are significant determinants of environmental pollution measured in terms of methane emission in sub-Sahara Africa,

Based on panel corrected standard error (PCSE) estimation results presented in Tables 1, 2 and 3, the following discoveries as touching core determinants of environmental pollution were established. First, the study discovered that energy consumption exert significant positive impact on carbon-dioxide emission and nitrous oxide emission in sub-Sahara African countries. This discovery reflect that energy consumption contribute significantly to rising level of environmental pollution in Sub-Sahara Africa. In specific terms reported coefficient estimate stood at (22.40624, $p < 0.05$) for carbon-dioxide emission, which reflect that for every one unit (i.e 1 kg of oil equivalent per capita) increase in energy consumption, carbon-dioxide emission will increase significantly by about 22.406 kilo ton, ceteris paribus. Also coefficient estimate for nitrous oxide which stood at (12.60901,$p < 0.05$) reflect that for every one unit (i.e 1 kg of oil equivalent per capita) increase in energy consumption, nitrous oxide emission will increase significantly by one thousand metric tons of $C0_2$ equivalent other things held constant.

Secondly, the study discovered that population size exerts significant positive impact on carbon-dioxide emission, nitrous oxide emission and methane emission in sub-Sahara African countries this discovery underscore that rising population size in most countries of sub-Sahara Africa is one of the major causes of rising environmental pollution in the region. In statistical terms, coefficient estimate stood at (173.7638, $p < 0.05$) for carbon-dioxide emission which reflect that for every one million increase in the population size of a country in the Sub-Sahara region, carbon-dioxide emission will increase insignificantly by about 173.76 kilo tons in the same year, other things held constant. Result showed that for every one million increase in population size, nitrous-oxide emission will increase significantly by about 265.066 thousand metric tons of $C0_2$ equivalent. Reported coefficient estimate for methane emission stood at (417.5629, $p < 0.05$), which connote that for every one million increase in population size, methane emission on the average in a country in the sub-Sahara Africa region will increase by about 417.562 kilo tons of $C0_2$ equivalent.

Thirdly, the study found that trade openness exerts significant negative impact on carbon-dioxide emission but its impact on both nitrous oxide emission and methane emission is positive and significant. this discovery reflect that though high level of trade openness has the tendency to engender significant reduction in environmental pollution measured in terms of carbon-dioxide emission, it can also culminate into significant increase in environmental pollution measured in terms of both nitrous oxide emission and methane emission. In specific terms the result revealed that for every one percent increase in trade openness, carbon-dioxide emission tends to reduce significantly by 10.98571 kilo ton, other things held constant. On the other hand the result showed that for every one percent increase in trade openness, nitrous oxide emission and methane emission will rise significantly by about 16.58554 thousand metric tons of $C0_2$ equivalent and 17.33032 kilo ton of $C0_2$ equivalent, respectively.

Finally on the discourse of core determinants, the study found that gross domestic product exerts significant positive impact on environmental pollution measured in terms of methane emission only, with reported coefficient estimate 0.0361665 ($p < 0.05$), which implies that for every billion US dollars increase in gross domestic product of countries in the Sub-Sahara Africa region, methane emission will rise by about 36.1665 kilo tons of $C0_2$ equivalent). Notably, discoveries made in this study as touching core determinants of environmental pollution are in congruence with some previous empirical studies such as Reza, Samira, Elham and Jack (2017); Olarinde, Martins and Abdulsalam (2014); Soumyananda, (2004).. Notably Reza, *et al* (2017), established that energy consumption, and GDP per capita have significant positive impact on CO_2 emission. Study by Olarinde, Martins and Abdulsalam (2014) established positive and significant relationship between carbon emission and gross domestic product, Soumyananda, (2004) relayed that Trade leads to increase in size of the economy that increases pollution, thus, trade is the cause of environmental degradation ceteris paribus

V. CONCLUSION AND RECOMMENDATIONS

Premise on discoveries made, the study thus concluded that environmental pollution in Sub-Sahara Africa is significantly determined by energy consumption, population size, trade openness and gross domestic product among other variables examined in the study. Thus this study recommends that Sub-Sahara African countries should objectively embrace technological diffusion by encouraging mobilization of finance, investment and innovation in low-carbon production processes. Environmental regulatory frameworks in SSA should advocate for bold pollution-beating commitments from the industrial sector to regulate pollution associated with production processes

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