



Research article

The effects of economic growth on carbon dioxide emissions in selected Sub-Saharan African (SSA) countries

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ABSTRACT

This research article concerns a study of economic growth influences on carbon dioxide emissions in 20 selected Sub-Saharan African (SSA) countries. The study also intends to reexamine energy consumption, tourism sector and population effect on carbon dioxide emissions. The empirical research applies panel linear regression model for the data obtained in these 20 SSA countries throughout 2000 to 2020. The empirical estimation techniques employed in the analysis consist of pooled ordinary least square (OLS), fixed effects model (FEM), random effects model (REM) and robust fixed model, including diagnostic tests such as endogeneity, heteroscedasticity and other measurements. The empirical analysis using the robust fixed effects model has established significant associations between economic growth, energy consumption, tourism sector and population on carbon dioxide emissions in SSA countries between 2000 and 2020. This study has established that a 1% increase in economy growth increases the carbon dioxide emission level by approximately 0.02%. A study has identified that SSA countries' energy consumption, especially from oil, will only contaminate air quality. A study confirmed that international tourist arrivals are one of the factors that significantly caused air quality reduction among SSA countries. However, increasing population and future international agreements and protocols could also mean that carbon emissions can potentially cause less environmental degradation in the region.

1. Introduction

Scientifically, whenever an atmosphere excessively absorbs carbon dioxide, carbon monoxide, nitrous oxide and other gaseous substances, it forms greenhouse gases. In fact, 70% of all greenhouse gas emissions contain carbon dioxide (Espoir et al., 2021). Globally, scholars have been researching greenhouse gas emissions because air pollution statistics and environmental degradation incidents have shown an increasing trend. Generally, SSA countries are vulnerable to climate change (EPA, 2021; Serdeczny et al., 2017). SSA is one of the world's regions where environmental pollution is high (Christie et al., 2013). Recently, greenhouse gas emissions have been increasing across countries, especially in SSA, according to empirical documents about environmental pollution. In their quotes from the Carbon Dioxide Information Analysis Centre, Andres et al. (2011) said that fossil fuel consumption emitted 11.5% of carbon dioxide annually. African countries such as Libya, South Africa, the Seychelles and Equatorial Guinea had carbon dioxide emissions greater than the world average of 1.3 metric tons of carbon per year (Andres et al., 2011).

Scholars have empirically and scientifically identified that greenhouse gas emission levels cause severe adverse effects on our natural environment and human health. Basically, greenhouse gases can contaminate air quality and deplete the ozone layers. According to Gyles (2019), natural resource depletions, volcanism and other pollutants have caused environmental degradation around the world. For instance, a study confirmed that particulate matter (PM 2.5) caused preterm birth (PTB) (Rappazzo et al., 2014). However, the pandemic has proven that movement control in China and India reduced air pollution (Wang et al., 2022c, 2022d).

African OPEC countries have shown that economic growth caused carbon dioxide and methane emissions in the long run (Yusuf et al., 2020). However, panel Autoregressive Distributed Lag (ARDL), MG and PMG identified insignificant associations among energy consumption, methane, carbon dioxide and nitrous oxide between 1970 and 2016. The PSTR estimation has proven the existence of the EKC among 29 African countries between 2005 and 2009 (Mosikari and Eita, 2020). Although energy consumption contributed to carbon dioxide emissions, research still identified that the urban population reduced emissions.

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Acheampong (2018) applied panel vector autoregression (PVAR) and system GMM between 1990 and 2014 in 116 countries. The estimated dynamic panel SYS-GMM identified no significant causal relationship between economic growth and carbon dioxide emissions in the SSA region. The IRF analysis declared that SSA's economic growth, when shocked, will increase carbon dioxide emissions and subsequently decrease and stabilize in the long run. In SSA countries, economic growth significantly contributed to greenhouse gas emissions (Lioussse et al., 2014). Twerefou et al. (2017) established the existence of an EKC between SSA countries' economic growth and environmental degradation from 1990 to 2013. The Kaya theoretical analysis confirmed that economic growth, population and intensity of energy consumption influenced carbon dioxide emissions (Kaya and Yokobori, 1997).

On the one hand, scholars have vastly debated the carbon dioxide emissions emitted from enormous fossil fuel consumption (Manisalidis et al., 2020). In detail, African countries heavily rely on fossil fuel consumption, such as coal, and studies have found that Botswana, Kenya and Senegal coal consumption has increased carbon dioxide emissions by approximately 0.7%–1% annually (Dalirirad and Steckl, 2020). On the other hand, scholars have long debated that these low-income countries are only interested and concentrated on economic growth rather than reducing greenhouse gas emissions (Hanif and Gago-de-Santos, 2017). The study in Tajudeen (2015) supports the claim that African countries lack sufficient funds to impose greener technologies and efficient regulations to reduce carbon dioxide emissions. Previous researchers have widely debated that SSA countries' environmental degradation is caused by numerous factors, such as economic growth, fossil fuel energy consumption, tourism sector, population and other relevant socioeconomic determinants.

Overall, this study intends to investigate the nexus between economic growth, energy consumption and carbon dioxide emissions in the SSA region between 2000 and 2020. It attempts to answer the following three research questions: (1) what is the relationship between economic growth and carbon dioxide emissions in the 20 selected SSA countries? (2) what is the coefficient sign of economic growth in the research period, and does it differ from the theoretical expectation sign? (3) What is the relationship between carbon dioxide emissions, energy consumption, economic growth, tourism and population? In summary, SSA countries draw attention to the production and consumption of goods and services, but they are still lacking in sustainable economic growth that could protect environmental quality. In SSA countries, economic growth is paramount for economic, social and infrastructure development. However, SSA countries' economic growth, energy consumption, tourism and population are assumed to be connected with high carbon dioxide emissions; thus, we urgently require solutions to mitigate the problem for the present and future.

This research report is organized as follows: Section 2 covers a literature review on economic growth and greenhouse gas emissions associations and other variables and relationships with air pollution. Section 3 discusses the traditional panel data estimation methodology and diagnostic tests. Section 4 explains OLS, fixed and random effects as well robust fixed effects results, in which it articulates current findings in the SSA region. Section 5 concludes the research outcomes and poses some suggestions and future directions that could be taken.

2. Literature review

2.1. Economic growth and environmental degradation

Prior literature on the subject has broadly investigated carbon dioxide emissions and their consequences across countries globally. Among them, past studies have scientifically identified that greenhouse gases contaminate air quality (Magazzino, 2017; Mele and Magazzino, 2020), affect human health (Chen and Chen, 2021; Orach et al., 2021) and the natural ecosystem (Xu et al., 2021), deplete ozone layers and impose climate change (Singh and Yadav, 2021). The greenhouse gas emissions

occurred from numerous activities, such as non-renewable energy consumption (Vohra et al., 2021), transportation (Çakar et al., 2021) and industries (Wu et al., 2021b). Scholars have continuously debated that economic growth always adversely imposes environmental degradation. Recently, empirical evidence has declared that environmental degradation and economic development are significantly associated (Wang et al., 2022a). For instance, a 1% increase in economic growth increases air carbon dioxide emission levels by approximately 0.93% in 147 countries between 1990 and 2015 (Li et al., 2021). The dynamic spatial Durbin error model (SDM) interpreted that a 1% increase in economic growth had increased carbon dioxide emissions by approximately 0.6% in 26 European Union countries in the short and long runs (Ren et al., 2021).

The neoclassical economic growth theory supported the view that economic growth, greater population, and industrial activities determined carbon dioxide emissions in China (Wu et al., 2021a). Meanwhile, in China, the Logarithmic Mean Divisia Index (LMDI) decomposition analysis confirmed that economic growth determined the carbon dioxide emissions during the period of 1995–2017 (Gao et al., 2021). In particular, the LMDI analysis decomposed China's economic growth into an equation, where the analysis allows it to measure the GDP effect on pollution. In China, a 1% increase in income per capita led to a 1.28% increase in carbon dioxide emissions (Li et al., 2016). On the other hand, in China, analysis confirmed that the greater the economic growth is, the greater the pollution rate, where air quality in the cities is highly contaminated (Smyth et al., 2008).

On the other hand, the Fully Modified Ordinary Least Squares (FMOLS) confirmed similar findings in Bangladesh, India, Nepal, Pakistan and Sri Lanka from 1972 to 2017 (Khan et al., 2021). Economic activities have been seen to positively increase carbon dioxide emissions in China and India (Pal and Mitra, 2017). The various methodologies employed in such studies still established that a 1% increase in income per capita contributed to a 1.42% increase in carbon dioxide emissions in India (Kanjilal and Ghosh, 2013). Ultimately, economic growth contributed to environmental degradation in Iran (Lotfalipour et al., 2010), China (Wang et al., 2011) and 24 Asian countries (Lu, 2017). Chishti et al. (2021) postulated that terrorism today may also influence human lives, FDI inflows, economic growth and the environment. According to the authors, in the long run, economic growth was positively associated with carbon dioxide emissions in Afghanistan, Iran, Nigeria, Thailand, Syria, Pakistan, Somalia, Yemen, India and the Philippines from 1973 to 2016. Similarly, a 1% increase in GDP caused a 0.26% increase in carbon dioxide emissions in Bahrain, Egypt, Iran, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria and Tunisia (Omri, 2013). Nevertheless, carbon abatement is forecast to induce China's economic growth (Wang et al., 2011).

Contrary to expectations, in SSA countries, economic growth reduced environmental degradation from 2002 to 2017 (Yameogo et al., 2020). The literature indicated that a 1% increase in SSA economies decreased environmental degradation to approximately 0.09%. Meanwhile, economic growth increased carbon dioxide emissions in 38 SSA countries between 1980 and 2017 (Bataka, 2021). The panel data analysis confirmed the association, where the authors urged sustainable development in the long run. Earlier, according to Lee and Brahmasrene (2016), SSA countries' economic growth showed significant positive effects on carbon dioxide emissions from 1988 to 2010. The literature clarified that carbon dioxide emissions increased between 0.3% and 1.4% in response to economic growth. At the same time, there is a promise or compromise by countries to reduce international greenhouse gas emissions to sustain economic growth and development. Recently, some scholars applied the Cobb–Douglas theoretical framework, and the results confirmed that carbon dioxide emissions had actually reduced economic growth in Iran (Oryani et al., 2021). The symmetric and asymmetric ARDL estimations confirmed the negative relationship between environmental degradation and economic growth between 1970 and 2017. Eventually, by late 2000, carbon dioxide emissions were reduced in Jordan, Iraq, Kuwait, Yemen, Qatar, the United Arab Emirates

(UAE), Argentina, Mexico, Venezuela, Algeria, Kenya, Nigeria, Congo, Ghana and South Africa (Narayan and Narayan, 2010).

The EKC postulated that at the early stage, economic growth and environmental degradation increased and later decreased. Likewise, the literature also concluded that the EKC existed in developed countries such as Canada, France, the UK and the USA (Nathaniel et al., 2021). In their submission, Jun et al. (2021) showed that FMOLS validated the EKC theory in Sri Lanka, India, Nepal, Bangladesh and Pakistan between 1985 and 2018. Earlier, in India, research examined an association between economic growth and carbon dioxide emissions using a study that incorporated coal usage and trade openness (Tiwari et al., 2013). The findings validated the EKC theory, where India's economic growth and pollution both increased at the initial stage, and carbon dioxide emissions were subsequently reduced after a certain level. Furthermore, another study also supported the fact that economic growth at a certain level reduced pollution in Turkey (Ozturk and Acaravci, 2013). Asian countries obviously face air pollution; however, the EKC hypothesis failed to establish any significant outcomes in India, Indonesia, Thailand and Malaysia (Lu, 2017). Thus, the authors preferred to examine the Granger causality directions between economic growth and pollution.

In Ethiopia, findings obtained from various methodologies, such as ARDL and DOLS, identified that in the long term, a 1% increase in economic growth only caused a 1.05% increase in carbon dioxide emissions (Hundie, 2021). Meanwhile, a 1% increase in squared GDP reduced carbon dioxide emissions by approximately 0.11% from 1979 to 2014. In Abdouli and Hammami (2017) their systems and different GMM methodologies identified the existence of EKC theory in 17 MENA countries between 1990 and 2012. Initially, a 1% increase in GDP per capita showed an increase of 0.67% in carbon dioxide emissions, while a further increase in economic growth reduced carbon dioxide emissions.

Granger causality analysis normally identifies cause and effect direction variables. The high-income countries agreed that GDP per capita contributed unfavourably to carbon dioxide emissions (Halkos and Gkampoura, 2021). Nevertheless, economic growth and carbon dioxide emissions established bidirectional causality in three different income levels covering 119 countries between 2000 and 2018. Other studies in Brazil and Russia have also established similar findings between the rates of income and emissions (Pao and Tsai, 2011). In South Asian countries, the Dumitrescu-Hurlin test confirmed a one-way causality that ran from squared GDP to carbon dioxide emissions (Anser et al., 2021). In India, research identified a similar outcome where economic growth and carbon dioxide emissions showed a two-way causality (Ahmad et al., 2016). Several studies have examined the link among economic growth, carbon dioxide emissions and coal usage in China and India (Govindaraju and Tang, 2013). Eventually, China's economic growth will influence carbon dioxide emissions, while presently, India's economic growth and pollution process are recognizing a bidirectional causality. Meanwhile, in Tunisia, the ECM identified no association between economic growth and carbon dioxide emissions in the short and long terms (Bakari et al., 2021). However, the Granger causality established a unidirectional causality that ranged from carbon dioxide emissions to economic growth. However, the current literature has identified only insignificant results for Granger causality between economic growth and carbon emissions in India (Kanjalil and Ghosh, 2013). Similarly, a study in the United States showed no Granger causality between carbon dioxide emissions and economic growth (Soytas et al., 2007).

Da Motta (2001) claims that economic growth reduces environmental pollution, and the author has proposed institutional and moral reformation to promote sustainable economic growth. In conclusion, we could say that an increase in GDP that arises from converting energy and natural resources into capital and consumption goods leads to an increase in environmental degradation. Issues related to the environment have gained attention in several quarters because of the need to protect biodiversity and economic activities. Although many studies linking economic growth and environmental quality using various analytical frameworks, methodologies, countries and data sets exist, all their

findings remain mixed and controversial. The associations have mostly produced inconclusive outcomes, such as positively and negatively significant, insignificant, or cause and effect.

2.2. Tourism and environmental degradation

Today, in many countries, the tourism industry is contributing to their economic growth, and those that rely heavily on infrastructure services such as roads, transportation, airports, seaports, and utilities, including the development and operations of tourism such as resort development, land construction and building of different amenities. In late 2000, scholars postulated that while the tourism sector has contributed enormously to overall economic growth, it has also imposed grave environmental degradation and wide social implications (Tovar and Lockwood, 2008). The arguments in the literature showed that demand for travel activities and supply for production processes produced more carbon dioxide emissions (Sun, 2016).

Recent empirical studies have established that tourism industries contributed to environmental degradation in 139 countries throughout 2007 and 2016 (Pulido-Fernández et al., 2019). At the same time, in Southeast and Northeast Asia, the FMOLS confirmed that a 1% increase in the tourism sector led to an approximately 0.22% increase in carbon dioxide emissions (Zhang and Liu, 2019). Qureshi et al. (2017) subsequently increased the number of countries in their analysis using GMM estimation. Their findings indicated that the greater the number of tourists, the higher the carbon dioxide emissions in the 80 countries employed in the study. Specifically, the tourism industry positively influenced carbon dioxide emissions in Pacific and East Asia, the European Union, OECD and non-OECD countries (Zaman et al., 2016) and Cyprus (Katircioglu et al., 2014).

Similarly, the FMOLS analysis results showed that in Malaysia, there was a positive correlation between the vast number of tourist arrivals and greater environmental degradation between 1990 and 2014 (Azam et al., 2018). In the Asia Pacific countries in the long run between 1995 and 2013, the same results were obtained (Shakouri et al., 2017). Although the tourist trade is a low carbon industry in China (Wu and Shi, 2011), the tourism industries on the whole have caused adverse effects on the environment, which is severe across countries in the world. Furthermore, China's tourism industry relied basically and heavily on transportation, which emitted 80% of carbon dioxide in the air between 1990 and 2012 (Tang et al., 2014). Moreover, authors in this field have concluded that tourism transportation contributed 12.6% of carbon dioxide yearly. Similarly, Liu et al. (2011) agreed that China's pollution levels between 1999 and 2004 were directly influenced by transportation means.

Twerefou et al. (2017) also researched the connection among economic growth, environmental degradation and sustainability in SSA countries from 1990 to 2013. The findings confirmed the environmental Kuznets curve in the zone and demonstrated that globalization tended to increase environmental degradation and had negative effects on sustainability, while economic progress had positive impacts on both environmental quality and sustainability. Outcomes from the GMM method recommended a negative relationship between trade and environmental degradation (CO₂ and deforestation). The U-curve was confirmed only in the case of CO₂ emissions. However, scholars have found a nonlinear relationship between tourism and carbon dioxide emissions in South Asia (Sherafatian-Jahromi et al., 2017) and New Zealand (Becken and Patterson, 2006).

2.3. Energy consumption and environmental degradation

Deterioration or degradation in environmental air quality is usually caused by fossil fuel consumption across developing and less-developing countries. Past studies have repeatedly examined the relationship between air pollution and fossil fuel consumption and other energy consumption. Radmehr et al. (2021) investigated factors that contributed to carbon dioxide emissions in European Union country samples between

1995 and 2014. The findings confirmed that in the 2SLS estimation, a 1% increase in non-renewable energy consumption resulted in a 3.83% increase in carbon dioxide emissions. Basically, the research applied methodologies such as panel spatial simultaneous equations with generalized spatial two-stage least squares (GS2SLS). In addition, the research employed a simultaneous equation that incorporated the Cobb–Douglas production function to examine the relationship between economic growth, emissions and renewable energy consumption.

Subsequently, Selvanathan et al. (2021) applied the FMOLS in some South Asian countries, and their analysis revealed that per capita energy consumption significantly increased carbon dioxide emissions in both the short and long runs between 1990 and 2014. As we know, the Middle Eastern countries are well endowed with natural resources such as fossil fuels. According to Alkhatlan and Javid (2013), oil, gas and electricity produce energy that is consumed by the population in Saudi Arabia. Research in Granger causality indicated a strong relationship between energy consumption and gaseous emissions from 1980 to 2011. In Argentina, Yiping et al. (2021) identified cointegration between carbon dioxide emissions, non-renewable energy consumption, economic growth and other variables in the long run between 1970 and 2018. The study applied the ARDL bound test and gradual shift causality and introduced the Maki cointegration test, which dealt with five maximum structural breaks. The ARDL estimation revealed that a 1% increase in non-renewable energy consumption increased carbon dioxide emissions by approximately 0.215% in the short run and 0.460% in the long run. The Granger causality analysis established unidirectional causality, which was conducted from non-renewable energy consumption to carbon dioxide emissions.

Similarly, Ozturk and Acaravci (2013) examined the connection between economic growth, carbon emissions, energy use, trade liberalisation and financial development in Turkey. Applying data for the period 1960 to 2007, the research discovered a positive relationship between trade openness, financial development and carbon emissions. However, there was no link between energy consumption, economic growth and carbon dioxide emissions. Furthermore, another study also confirmed the EKC hypothesis in Turkey. In addition, in Bangladesh, Alam et al. (2012) found that factors ranging from energy consumption to carbon dioxide emissions were unidirectional in the short run, but in the long run, carbon dioxide emissions and energy consumption showed bidirectional causality between 1972 and 2006. In China, Zhang and Cheng (2009) identified only a one-way causality between 1960 and 2007. Kiviyiro and Arminen (2014) also supported the existence of the EKC in some African countries (Democratic Republic of Congo, Kenya, South Africa, and Zimbabwe) between 1971 and 2019. The results confirmed a positive link between foreign aid and carbon dioxide emissions only in Kenya and Zimbabwe, while FDI tended to reduce air pollution in the remaining countries.

2.4. Population and environmental degradation

On the other hand, scholars have also vastly debated population influence on environmental degradation. However, there are studies that revealed that population size has reduced carbon dioxide emissions in highly populated countries such as Brazil (Alam et al., 2016) and in Democratic and Republic Korea, Albania, Armenia, Azerbaijan, Kyrgyz Republic, Macedonia and Afghanistan (Al-mulali et al., 2012). In China, Li et al. (2016) argued that there was only a minor relationship between urbanization and wastewater emissions in 28 Chinese provinces. On the other hand, according to Wang et al. (2022c, 2022d), the continuation of urbanization development will eventually develop additional carbon emissions. In detail, the authors explained that current city development requires a large capacity for hydroelectric plant installation that emits carbon.

We have reviewed the literature extensively and identified three research gaps in existing studies. The current studies mostly concentrate on the nonlinear relationship between national income and greenhouse

gas emissions. However, the literature has limitedly covered fossil fuel factors. Prior studies have vastly concentrated on factors that influence greenhouse gas emission levels, namely, economic growth, energy consumption, population, trade and others (Baz et al., 2020; Tang and Tan, 2016; Usman et al., 2021; Zaman et al., 2017). The literature has shown that scholars have paid vast attention to the nonlinear association between energy consumption, economic growth and carbon greenhouse gas emissions. Recently, panel estimation has failed to identify the existence of the EKC among 23 SSA countries. Thus, the authors considered applying robust estimation such as GMM. However, the author concluded that panel and GMM estimations only provide similar answers. First, both estimations provide slight differences only in the magnitude of coefficients, and the second signs remain the same (Malik et al., 2021). In addition, research also identified that pooled OLS, FEM, and REM produced insignificant associations between greenhouse gas emissions and economic growth in 17 Southern and Western SSA countries (Tsaourai, 2018). We have assumed that there are numerous indicators that directly and indirectly degrade environmental quality. Thus, it is necessary to perform a linear empirical model by incorporating new variables into the equation. The literature is mostly oriented on single country and a large list of country estimations. Studies have considered focusing on single-region heterogeneity. By filling these gaps, this study makes the following contributions to the literature. First, the study completely devotes the linear relationship between economic growth, energy consumption from fossil fuel and air quality. The study referred to neoclassical growth theory and applied the Cobb–Douglas production function to estimate the economic growth and energy consumption impact on air pollution. Second, the study introduces energy consumption from oil to construct traditional panel data and robust fixed effects models to gauge the hypothesis that fossil fuel consumption from oil and the number of tourists positively influence carbon dioxide emissions. Basically, energy use refers to the use of primary energy before transformation to other end-use fuels. Furthermore, a robust fixed effects model applied the GLS method to eliminate heteroscedasticity and autocorrelation issues. The study has considered single-region heterogeneity and filtered only 20 SSA countries that are highly oriented on economic growth, tourism and energy consumption as well as population.

3. Empirical methodology

3.1. Data source

This study obtains secondary data sets for 20 countries in Sub-Saharan Africa between 2000 and 2020 from the World Development Indicators. The 20 SSA countries selected consist of Botswana, Cabo Verde, Cote d'Ivoire, Egypt, Arab Rep., Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mauritius, Morocco, Namibia, Senegal, Seychelles, South Africa, Tanzania, Tunisia, Uganda and Zimbabwe. This research attempts to examine the influence of SSA's economic growth, such as carbon dioxide emissions metric tons per capita, as a proxy. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during the consumption of solid, liquid, and gas fuels and gas flaring. Table 1 displays the names of the variables, measurements and expected signs in the operational process.

3.2. Model estimation

The research attempts to apply a theoretical framework to investigate the influence of economic growth on environmental degradation. According to Gao et al. (2021), China's economic development has positively caused higher carbon dioxide emissions. In particular, Gao et al. (2021) referred to neoclassical growth theory; their research applied LMDI decomposition analysis that integrated economic growth $f = (\text{labour, capital, technology and others})$. After that, the authors applied

Table 1. Table of operationalization and expected sign.

Variables	Description	Measurement	Sign
Dependent Variable:			
<i>CO2E</i>	Carbon Dioxide Emissions	metric tons per capita	
Independent Variables:			
<i>GDP</i>	GDP per capita	Annual %	+
<i>ITA</i>	International Tourists Arrivals	in number of arrivals	+
<i>ln EC</i>	Energy Use	kg of oil eq per capita	+
<i>ln URPOP</i>	Population in City	in %	+

the Cobb–Douglass production function, where carbon dioxide emissions $f =$ (economic growth and other variables). The theoretical framework showed that economic growth is decomposed in the equation to examine its influence on air pollution.

Similarly, this research applies the Cobb–Douglas production function to examine the effect of economic growth on carbon dioxide emissions. Current literature and past studies have claimed that economic growth causes environmental degradation (Chaabouni and Saidi, 2017; Gao et al., 2021). This study replicates a similar growth theory theoretical framework. In general, the Cobb–Douglass production function explains the relationship between economic growth, labour, capital, technology and other potential variables that might fit the theoretical framework. Furthermore, the Cobb–Douglass production function equation states that economic growth accounted for labour, capital and technology. Mathematical manipulation favors the assumption that economic growth causes environmental degradation.

This research utilizes a multiple linear regression model to examine the carbon dioxide relationship with economic growth, tourism, population and energy consumption. Mathematical Eq. (1) is set up to perform the analysis.

$$CO2E_{it} = \gamma_i + \gamma_1 GDP_{it} + \gamma_2 ITA_{it} + \gamma_3 EC_{it} + \gamma_4 URPOP_{it} + \gamma_5 ITE_{it} + \varepsilon_{it} \quad (1)$$

where i signifies the number of countries, $i = 1, 2, \dots, N = 20$, and t represents time in the analysis, $t = 1, 2, \dots, T = 20$. Eq. (1) represents coefficients such as $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ and γ_5 . In addition, the model accounts for the ε_{it} error term, and γ_i signifies a constant coefficient, which varies for each country but is time invariant. The equation states that the dependent variable is *CO2E*, which denotes carbon dioxide emissions, which it measures in metric tons per capita. Eq. (1) also introduces the independent variables: *GDP* denotes GDP per capita that measures growth in annual %; *ITA* represents International tourism that accounts for number of arrivals; *EC* refers to Energy use that measures in kg of oil equivalent per capita; *URPOP* represents Population in the largest city which is measured in % of urban population, and *ITE* means International tourism, in terms of expenditures that are calculated in % of total imports.

3.3. Estimation procedure

To examine the influence of economic growth on carbon dioxide emissions in SSA countries, this research employs the basic ordinary least squares (OLS), fixed effects model (FEM), random effects model (REM), and generalized least squares (GLS). In the final round, the panel data models will perform the Hausman test to statistically determine the best model that fits the analysis. The GLS method produces a robust fixed effects model and is also expected to eliminate the problems of multicollinearity and autocorrelation. Several diagnostic tests, such as multicollinearity, autocorrelation and endogeneity, are also conducted. Additionally, the research pays great attention to the endogeneity problem that may appear or be captured in the regression. The empirical analysis assumes that independent variables are exogenous. However, economic growth may be endogenous and subject to nongaseous emissions such as hydroelectricity and other electric production from

renewable sources, which is excluded in this study. To correct the potential errors, we instrumentalized the variables and performed 2-stage least square (2SLS) estimation. The Durbin and Wu-Hausman tests verify that the regression model is free from the endogeneity problem, as the p values are greater than the 5% significance level.

Overall, our model estimation technique suits data lengths of $N = 20$ and $T = 21$. However, one limitation involves some missing data in the data sets that may result in incomplete or imbalanced panel data analysis in our investigation of the relationship between economic growth and carbon dioxide emissions in the 20 SSA countries between 2000 and 2020. The data are retrieved from online databases such as the World Development Indicators (WDI, 2021). Subsequently, all the variables are transformed into a doubled log in the equation. In this way, natural logarithm eradicates the issues of nonlinear relationships and skewed distributions. Table 1 explains the variables, variable measurements and expected signs.

4. Results and discussion

The panel data analysis for the 20 SSA countries between 2000 and 2020 accounted for only 127 observations out of 420 expected sample sizes of $N = 20 \times T = 21$. As mentioned earlier, some information was unobtainable or missing during the data collection. The result table shows four blocks for OLS, fixed effects, random effects and robust fixed effects models with r-squared values of 0.95%, 0.94% and 0.95%, respectively. The r-squared value of the fixed effect model denotes that 74% of the association is between carbon dioxide emissions, economic growth, tourism, energy consumption and population.

First, the pooled OLS block shows five statistically significant associations between dependent and independent variables. The multicollinearity test result shows that $VIF = 1.36$, where the pooled OLS results are free from multicollinearity issues. However, the heteroscedasticity test reveals that the p value is less than the 5% significance level. This means that the pooled OLS estimation suffers from heteroscedasticity issues. Next, we continued with fixed and random effect estimations and applied the Hausman test to gauge whether the model fit the analysis. The Hausman test suggests that the fixed effects model is preferable for explaining our SSA data. The robust fixed effects model has autocorrelation and heteroscedasticity problems, so it was incompatible. Henceforth, the model that we applied is the generalized least square method with the assumption that it will eliminate both serial correlation and heteroscedasticity problems encountered. In general, the robust fixed effects model (displayed in the robust fixed effects column in Table 1) indicates that the results are statistically and technically valid and reliable in our estimation of the panel data observations.

4.1. Economic growth and carbon dioxide Emissions Associations

A study empirically identified that economic growth, international tourist arrival and energy consumption significantly contribute to carbon dioxide emissions in 20 SSA countries between 2000 and 2020. However, the analysis revealed that the population of SSA countries showed a negative relationship with carbon dioxide emissions (see Table 2).

First, the relationship defines that a 1% increase in economic growth increases carbon dioxide emissions by only 0.02%. The study hypothesized that national income could positively influence environmental degradation. Subsequently, the study has proven that SSA countries' economic activities definitely leave some implications for the environment, especially air quality. The result supports the claims in Wu et al. (2021a) and Gao et al. (2021). Prior literature has applied LMDI and Kaya estimations oriented on decoupling theory, which claim that China's economic growth will impose externalities. However, this study has attempted to occupy traditional panel and robust fixed effect models that referred to growth theory and proved that the GDP per capita of 20 SSA countries reduced air quality. On the other hand, this finding built on existing evidence that SSA countries are prone to climate change because

Table 2. Carbon dioxide emission associations.

Variables	Dependent Variable: Carbon Dioxide Emission Associations			
	OLS	Fixed Effect	Random Effect	Robust Fixed Effect
GDP	.0214115*** (.0076943)	.0001136 (.0019855)	.0009524 (.0020939)	.0214115*** (.0076043)
ITA	1.09e-07*** (1.08e-08)	3.20e-08*** (7.00e-09)	2.82e-08*** (7.12e-09)	1.09e-07*** (1.07e-08)
POP	-7.91e-09*** (1.32e-09)	-4.51e-11 (2.12e-09)	-2.03e-09 (2.03e-09)	-7.91e-09*** (1.30e-09)
EC	.0030129*** (.0000556)	.0024378*** (.0001162)	.0027228*** (.0000983)	.0030129*** (.000055)
Constant	-.8744887*** (.0626703)	-.3492584*** (.0935598)	-.4367587*** (.1439436)	-.8744887*** (.0619373)
R-squared	0.9570	0.9456	0.9460	
Multicollinearity	1.29			
Heteroscedasticity <i>chi2</i>	0.7405			
Normality	.3082			
Prob > F	0.0000	0.0000	0.0000	
Prob > <i>chi2</i>				0.0000
Hausman Test		0.0000		
Autocorrelation		0.0000		
Heteroscedasticity <i>chi2</i>		0.0000		
N	215	215	215	215

Notes: Standard errors in parenthesis. The *, **, and *** represent 10%, 5% and 1% of significance level, respectively or *** $p < .01$, ** $p < .05$, * $p < .1$; GDP is GDP per capita growth (annual %), lnITA is International tourism, number of arrivals, POP is Population (total population) and EC is Energy use (kg of oil equivalent per capita).

the EPA program has begun to address these SSA countries' urban and industrial pollution problems (EPA, 2021).

Second, a 1% increase in international tourist arrivals increases carbon dioxide emission levels by 1.1%. The study has shown that the expected sign and findings agree that an enormous number of tourist arrivals eventually degrade environmental quality. This outcome is in line with Azam et al. (2018), Shakouri et al. (2017) and Qureshi et al. (2017). Scholars have revealed that the tourism industry, which brings international tourists and tourist expenditures to host countries, is associated with environmental degradation. This study has made an attempt to provide a clearer understanding of the SSA tourism sector, where accommodation, transportation and infrastructure were unsophisticatedly built. For example, tourism industry waste generations were dumped in open areas, and later waste mixtures emitted greenhouse gases.

Third, the energy consumption association reveals that a 10% increase in energy consumption equals a 0.03% increase in carbon dioxide emissions. The research findings agree with the research hypothesis that energy consumption will cause carbon emissions. Although the association finds a minor impact, it still agrees with the hypothesis claimed by Yuping et al. (2021), Radmehr et al. (2021) and Alkhatlan and Javid (2013). Basically, prior literature has shown some importance in Granger causality estimation that proved that non-renewable energy caused emissions in the EU countries and in Argentina in the long run. This study has applied energy use from oil that evidently explains why fossil fuel consumption will degrade air quality in SSA countries. For instance, African people preferred to mine and refine oil illegally, which could be another factor for air pollution.

Last, a 1% increase in the urban population decreases carbon dioxide emissions by approximately 7.9%. In detail, the research outcome disagreed with the research hypothesis that the population will cause air pollution. However, this finding is in line with claims made by Alam et al. (2016) and Al-mulali et al. (2012). The authors found conflicting results for nations with a high population density: carbon dioxide emissions and economic growth were shown to have a strong association in Brazil and India, but to have no association at all in China and Indonesia. In the body of prior research, it was said that a linear model would yield a

negative association between population increase and per capita carbon dioxide emissions in Brazil. Recently, Wang, et al. (2022b) has postulated an argument that the aging population improves environmental quality in high-income and lower middle-income groups. Similarly, this study provided a new insight that the SSA population could potentially reduce carbon dioxide emissions.

5. Conclusion

This research has investigated the influence of economic growth, energy consumption, tourism and population on carbon dioxide emissions in 20 SSA countries for two decades between 2000 and 2020. The study concluded that a robust fixed effects model identified significant associations between economic growth, international tourist arrival, energy consumption and population with carbon dioxide emissions. SSA countries' activities in economy, business, and other daily activities significantly increase carbon dioxide emissions. It is obvious that fossil fuel consumption, particularly from oil, will definitely increase the carbon dioxide emission level into the atmosphere. The SSA tourism industry attracted a high influx of international tourists, which eventually increased air pollution. However, the study empirically finds that the population can improve their environmental awareness to reduce air pollution in the SSA region.

This research has established with empirical evidence that population could potentially reduce carbon dioxide emissions in the SSA region. Nevertheless, SSA countries should encourage individuals, households, and other stakeholders to practice greener technologies so that their economic activities that involve the production and consumption of goods and services are sustainable and more pollution free in the long term. Otherwise, total greenhouse gas emissions will increase over the years and cause severe environmental degradation, such as bad air pollution and resource contamination, as well as harmful health complications. With these research findings, SSA countries are urged to focus largely on sustainable development goals (SDGs), where the aim is to achieve clean on-air quality.

We have recognized that the generalizability of the study findings is limited by the factors of data and methodology selections. The study has

only occupied data sets between 2000 and 2020 with only 20 SSA countries. On the other hand, we have only applied traditional panel data estimation. We have urged future researchers to determine economic growth and fossil fuels, namely, coal, natural gas and bitumen, on air quality among SSA countries in large data sets. May apply further models that might account for country heterogeneity and structural breaks, as we believe that economic recession could leave varied impacts on economic growth, energy consumption and urbanization.

Declarations

Author contribution statement

Jayanthi R. Alaganthiran; Merith Ifeoma Anaba, Doctorate: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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