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Renewable Energy Consumption and Consumption-Based Carbon Emissions in Sub-Saharan African Countries

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ABSTRACT

The determinants of production-based carbon emission (PCE) have been extensively examined in the literature. However, PCE only accounts for emissions generated within the territory of a country and does not capture emissions embedded in imported goods. The rapid growth in Consumption-based Carbon Emissions (CCE) in Sub-Saharan Africa (SSA), driven by increasing imports and economic activities, highlights the need for a comprehensive understanding of these emissions. This motivates us to examine the impact of Renewable Energy Consumption (REC) on CCE in SSA. We employed a two-step system Generalized Method of Moments (GMM) methodology, utilizing data from 1995 to 2020. The results show a negative effect of REC on CCE, suggesting that increases in renewable energy consumption tend to reduce CCE. In contrast, the positive impact of real GDP and population indicates that economic growth and population expansion tend to bolster carbon emissions. These findings underscore the importance of implementing policies harmonizing economic growth with sustainable energy strategies. They provide valuable insights for informed environmental and economic planning decisions.

KEYWORDS

Carbon Emissions; Population; Renewable Energy; Two-Step system GMM

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1. Introduction

Recently, global concerns have centred on environmental sustainability in energy production and consumption (Liu et al., 2024). Researchers and policymakers emphasize the importance of investing in renewable energy and energy efficiency to lower carbon emissions (CE) and mitigate climate change effects. Renewable energy sources, such as solar, wind, and hydropower, offer clean and sustainable alternatives that could help regions like Sub-Saharan Africa (SSA), which has one of the highest levels of energy poverty, transition away from reliance on combustible non-renewable resources that significantly contribute to CE (Babajide et al., 2015). Renewable energy technologies have the potential to substantially reduce CE globally (Wicaksana & Karsinah, 2022).

The potential of renewable energy to revolutionize the environmental and economic landscape is profound (Akadiri & Adebayo, 2022). It mitigates climate change and fosters sustainable economic growth and development, which is closely linked to social well-being (Adebayo et al., 2022). In SSA, focusing on green technologies presents an opportunity to address energy access challenges for many of the population. This is critical, given that a significant segment relies on traditional biomass and other unsustainable energy sources, harming the environment and public health. By embracing renewables, SSA can ensure access to reliable energy sources.

Furthermore, the potential for renewable energy technologies to promote self-reliance in the region cannot be overstated. Developing modern biomass technologies and harnessing abundant renewable energy resources can drive local and national energy independence, resulting in environmental benefits and enhanced economic and social stability (Adebayo et al., 2020).

This study is motivated by the rapid growth in Consumption-based Carbon Emissions (CCE) in SSA (see Figure 1). CCE accounts for emissions embedded in imported goods, unlike Production-based Carbon Emissions (PCE), which only considers emissions generated within a country's territory. This distinction is crucial for SSA, where imports play a significant role in economic activities.

Therefore, our paper aims to analyze the impact of Renewable Energy Consumption (REC) on CCE in SSA. By focusing on CCE, we provide a more comprehensive understanding of carbon emissions in the region, considering the effects of international trade.

This study makes several contributions to the literature. First, it addresses the gap in research on the SSA region, which, according to the IMF (2023), is highly vulnerable to climate change despite contributing little to PCE in global emissions. Second, it employs the two-step system Generalized Method of Moments (GMM) methodology, using data from 1995 to 2020 to provide robust estimates. Third, it adopts the IPAT (Impact, Population, Affluence, and Technology) equation framework, offering a systematic approach to selecting variables. The findings highlight the negative effect of REC on CCE, suggesting that increasing renewable energy consumption reduces CCE, while economic growth and population expansion tend to increase CCE. These insights are crucial for developing policies harmonizing economic growth with sustainable energy strategies.

After this introduction, section 2 reviews the literature. Section 3 presents the methodology. Section 4 presents empirical results and discussions. Section 5 concludes and recommends.

2. Literature Review

The IPAT equation, as stated by Hao and Shao (2021), provides a theoretical framework for quantifying the relationship between renewable energy and carbon emissions. It asserts that the environmental effect (I) is determined by population (P), affluence (A), and technology (T). According to this hypothesis, using renewable energy can help reduce carbon emissions by decreasing dependence on fossil fuels and embracing eco-friendly technology (Aguirre & Ibikunle, 2014).

The literature has explored various factors that influence the deployment of renewable energy, including climate change vulnerability, carbon intensity, and carbon taxes (Hao & Shao, 2021). Researchers have found that countries with less dependence on fossil fuels and more supportive policies for renewables tend to be more successful in increasing the use of renewable energy (Ashraf et al., 2023). Arroyol and Miguel (2020) also discuss multiple theoretical frameworks that elucidate the dynamics between renewable energy and environmental factors. They recommended that countries leverage renewable sources they have a comparative advantage over, whether hydro or solar.

Renewable energy sources are generally considered more sustainable and environmentally friendly than conventional fossil fuel-based energy generation (Oyekale et al., 2020). However, the actual ecological consequences of renewable energy production are multifaceted. For example, Gibson et al. (2017) highlight that although renewable energy can decrease greenhouse gas emissions, advancing these technologies can also result in environmental degradation, loss of biodiversity, and fragmentation of habitats. Hydropower projects, for instance, have been associated with substantial disturbances to ecosystems and local communities, while biofuel production can contribute to deforestation and the displacement of indigenous populations. Solar and wind power can negatively impact bird and bat populations (Pratiwi & Juerges, 2020).

Numerous studies have examined the relationship between renewable energy consumption (REC) and carbon emissions (CE). Apergis et al. (2010) found that REC negatively impacted CE in 19 developed and developing countries. Similarly, Khoshnevis et al. (2018) demonstrated that REC reduces CE across 25 African economies using the Pooled Mean Group (PMG) methodology. Dong et al. (2019) evaluated the influence of renewable energy certificates (REC) on CE in 120 nations, finding a significant effect on CE.

In contrast, Nguyen and Kakinaka (2019) found that REC had a significant and persistent positive effect on CO2 emissions in low-income economies from 1990 to 2013, while the impact was adverse in high-income economies. Aziz et al. (2021) observed a negative relationship between REC and CO2 emissions in the MINT (Mexico, Indonesia, Nigeria, and Turkey) countries. Mahmood et al. (2019) also reported a negative and significant impact of REC on CO2 emissions in Pakistan, and similar trends were observed by Leitão et al. (2020) for BRICS countries. Li and Haneklaus (2021, 2022) reported similar results for China and India. Hasanov et al. (2021) found total factor productivity (TFP) and REC decrease CO2 emissions in BRICS economies. Further research by Akram et al. (2020), Saidi and Omri (2020), Piłatowska et al. (2020), Leitão and Lorente (2020), and Shahnaz et al. (2021) supports these findings.

Despite the substantial body of literature, the relationship between renewable energy and carbon emissions remains complex and multifaceted (Gibson et al., 2017). While renewable energy holds great promise for reducing carbon emissions, careful management is required to minimize unintended consequences. Further investigation is needed to comprehensively understand the environmental trade-offs and formulate strategies to effectively utilize renewable energy in an environmentally friendly manner (Gibson et al., 2017).

The literature review indicates a need for more comprehensive research on renewable energy's impact on consumption-based CO2 emissions, particularly in Sub-Saharan Africa (SSA). Moreover, only a few researchers have considered the CCE.

3. Methodology

3.1. Data and sources

The paper used a panel of 45 SSA from 1995 to 2020. The availability of data justifies the use of periods. The inclusion of SSA data in this paper is warranted based on its unique qualities, which provide an opportunity for investigation. SSA region needs significant renewable energy infrastructure. The region has the lowest degree of electrification compared to all other regions globally and is home to around 600 million inhabitants with limited access to power. Moreover, it has one of the least established policy frameworks that promote energy accessibility. The region also emits the least CO2 but is most vulnerable to climate change issues.

Table 1. Measurement and Sources data.

Series	Notations	Measurements	Sources
Consumption-Based Carbon Emissions	CCEjt	Country 'j' Consumption- based carbon dioxide (CO2) emissions measured in million tons of CO2, (MtCO2)	GCA
Renewable Energy Consumption	RECjt	Country 'j' Renewable Energy (% of total final energy consumption)	WDI
Real Gross Domestic Product	GDPjt	Country 'j' GDP, constant 2015 US$	WDI
Population	POPjt	Country 'j' Population, Total	WDI

Note: GCA stands for Global Carbon Atlas while WDI means World Development Indicators. Source: Author's Compilation.

The SSA countries considered are; Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, the Democratic Republic of the Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon The Gambia, Ghana, Guinea, Guinea-Bissau, Côte d'Ivoire, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, South Sudan, Sudan, Tanzania, Togo, Uganda and Zambia.

3.2. The model and method of data analysis

The paper used the IPAT framework of Dietz and Rosa (1997), which is expressed as:

$$I = P \times A \times T \tag{1}$$

I signify environmental impact, P means population, A is Affluence, and T represents technology. They further stated that equation 1 can be expressed in a stochastic model:

$$I = aP^{b1}A^{b2}T^{b3}e \tag{2}$$

Where α is a constant term, $\beta_1, \beta_2, and\ \beta_3$ are the exponential terms for P, A, and T, and e is the error term. Hence, the model is log-transformed into equation (3):

$$ln\, I = \alpha + b_1\, ln\, P + b_2\, ln\, A + b_3\, ln\, T + e \tag{3}$$

This paper employed its variables based on the framework and other empirical studies like Alsagr and Hemmen (2021) as expressed in equation (4):

$$ln\, CCE_{jt} = b_1 + b_2 REC_{jt} + b_3\, ln\, GDP_{jt} + b_4\, ln\, POP_{jt} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \tag{4}$$

Where μ_{it} represents an unknown country specific while γ_{it} is an unknown year specific, finally, ε_{it} is the error term. Other notations are expressed in Table 1.

Equation 4 considers the lag of consumption-based carbon emissions to account for dynamics.

$$ln\, CCE_{jt} = b_1 + b_2 CCE_{jt-1} + b_3 REC_{jt} + b_4\, ln\, GDP_{jt} + b_5\, ln\, POP_{jt} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \tag{5}$$

The paper controls for the possibility of heterogeneity and endogeneity biases by employing a two-step system GMM by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998). They proposed two equations: levels first and difference equations, expressed in equations 6 and 7.

$$y_{jt} = \Upsilon y_{jt-1} + \beta_{xjt} + \mu_{it} \tag{6}$$

$$y_{jt} - y_{jt-1} = \Upsilon(y_{jt} - y_{jt-2}) + \beta(x_{jt} - x_{jt-1}) + (\mu_{jt} - \mu_{jt-1}) \tag{7}$$

Following Roodman (2009), the Hansen test is utilized to determine if there are any inappropriate restrictions, while the Arellano-Bond test is employed to assess the second-order correlation in the first-differenced residual.

4. Empirical Results and Discussions

4.1. Descriptive Statistics and Trend Analysis

The paper examines the summary statistics of the series presented in Table 2.

Table 2. Summary Statistics.

Series	observations	Mean	Std. dev.	Minimum	Maximum
CCE	1,170	15.2649	64.3755	0.0476	495.1708
REC	1,179	66.9178	25.7909	0.7100	98.3400
RGDP	1,158	2034.2940	2691.8030	217.6250	16747.3
POP	1,196	17,700,000	27,500,000	75, 304	210,000,000

Note: The differences in the number of observations are because we used an unbalanced panel data. Source: Author's Compilation.

The mean of CCE is 15.2649 million tons of CO2, indicating the average level of CCE in the observed data. The relatively high standard deviation (64.3755) suggests considerable variability in CCE across the observations, with a minimum of 0.0476 and a maximum of 495.1708.

The mean REC is 66.9178 per cent of total energy consumption, suggesting the average level of REC between 1995 and 2020. The standard deviation (25.7909) indicates some variability in REC across observations, with a minimum of 0.7100 and a maximum of 98.3400.

The mean real GDP is US$2,034.2940, reflecting the average economic output between 1995 and 2020. The high standard deviation (US$2,691.8030) suggests significant real GDP variability across the observations. The minimum is US$217.6250, and the maximum is US$1,6747.3.

The mean total population is 17,700,000, representing the average population size in the observed data. The high standard deviation (27,500,000) indicates substantial variability in population sizes across observations, with a minimum of 75,304 and a maximum of 210,000,000.

Table 3 presents the correlation results. REC has a negative association with CCE, while RGDP and POP have positive associations with CCE. This could be an indicator of the nature of relationships we may observe in the inferential estimation.

Table 3. Correlation Statistics.

Series	*ln*CE	REC	*ln*RGDP.	*ln*POP
*lnC*CE	1.0000			
REC	-0.1786 (0.5436) **	1.0000		
*ln*RGDP	0.3937 (0.5537) *	-0.7856 (0.1286) **	1.0000	
*ln*POP	0.6329 (0.0453) **	0.5209 (0.4523)	-0.4044 (0.6524)	1.0000

Source: Author's Compilation.

The trend analysis in Figure 1-2 further motivates us to examine the dynamics of consumption-based carbon emissions in SSA. For example, since the Global financial crisis of 2007/2008, CCE has been declining in Europe (see the example of the United Kingdom in Fig. 2). On the contrary, CCE has been increasing in SSA since 2000. It declined between 2014 and 2017, partly due to the crude oil market collapse, which affected the economies of many oil exporting countries, some SSA countries inclusive. The CCE also saw another decline during the COVID-19 pandemic. We can understand from the trends that although SSA adds little to the PCE, its CCE has been increasing. From the REC front, REC has been increasing in Europe and Central Asia (see Fig. 4). It has been the case since the first Conference of the Parties (COP1) that took place from March 28 to April 7, 1995, in Berlin, Germany. Contrarily, REC has been declining in SSA for most of the period (see Fig. 3). The same trend is observed for the Middle East and North Africa as well as South Asia.

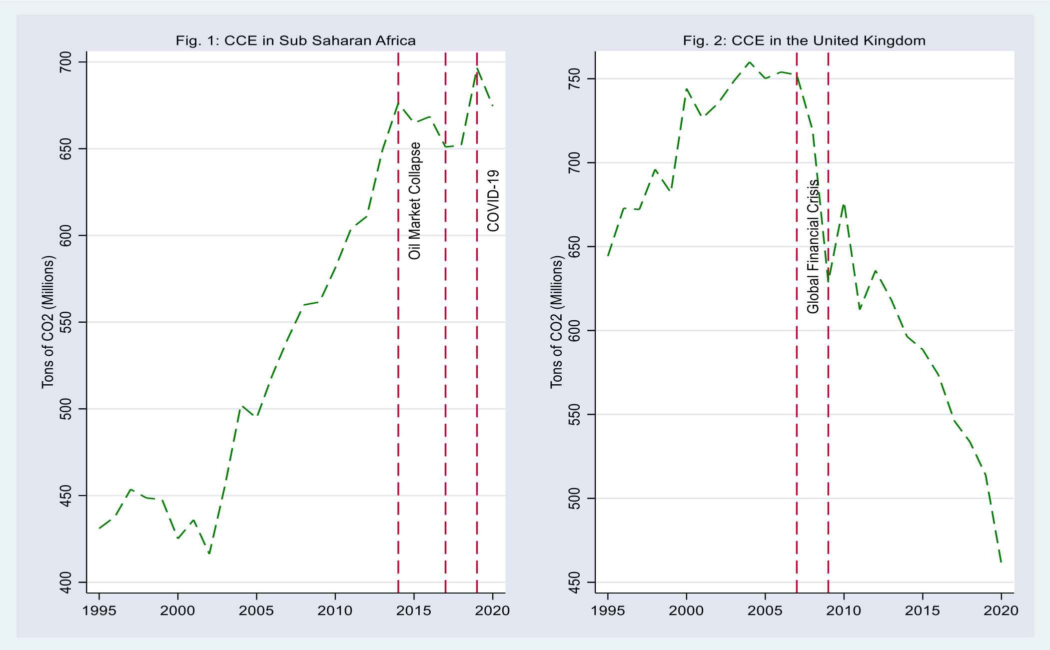

Figure 1-2. Trends of Consumption-based Carbon Emissions in Sub-Saharan Africa and the United Kingdom (1995-2020).

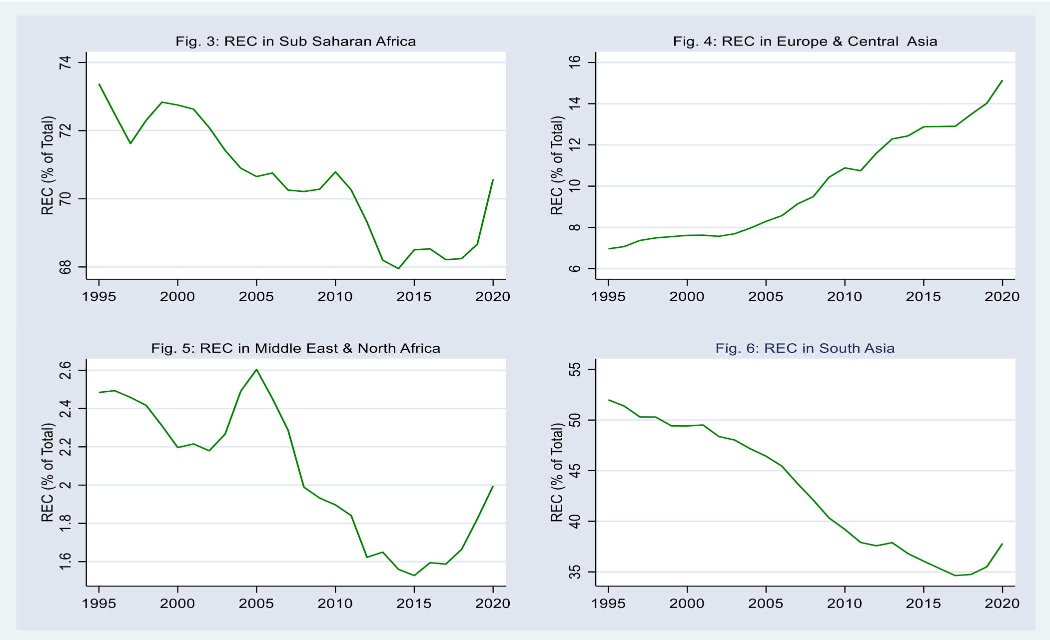

Figure 3-6. Trend of Renewable Energy Consumption in Sub-Saharan Africa, Europe & Central Asia, Middle East & North Africa and South Asia (1995-2020).

4.2. Inferential Analysis

Table 4. Two-Step System GMM.

Series	Coefficient	Standard Error
*ln*CCEt-1	0.5523	0.1715***
REC	-0.0153	0.0069**
*ln*RGDP	0.3062	0.1644*
*ln*POP	0.5157	0.1955**
Cons	-8.8761	3.4561
Observations	1086	
P value for AB (2) Test	0.280	
P value for Hansen Test	0.461	
Number of Groups	45	
Number of Instruments	28	
F Statistics	1696.62***	

*Note: *p values less than .1, **p values less than .05 while ***P-values less than .01. Source: Author's Compilation.*

The coefficient of the lag value of CCE at 0.5523 is statistically different from zero. The coefficient indicates a positive impact of the lagged CCE on the current CCE. It suggests that past CCE positively influences present emissions. A 1 per cent change in CCE of the previous year will lead to a 0.55 per cent increase in CCE in the current year. Therefore, in addition to other factors, the previous year's emissions affect carbon emissions in the current period.

The coefficient of REC at -0.0153 signifies a negative impact of REC on CCE. The relationship is statistically significant, as the p value is less than 0.05. The negative coefficient suggests that increased REC is associated with a decrease in carbon emissions. Specifically, a one-percentage-point increase in the share of renewable energy is associated with a 1.53% decrease in carbon emissions.

lnRGDP at 0.3062 indicates a positive impact of real GDP on CCE. The relationship is statistically significant at 10 per cent because the probability value is less than 0.1. A positive coefficient suggests that economic growth increases CCE. Therefore, a 1 per cent change in economic growth increases CCE by 0.31 per cent.

lnPOP at 0.5157 represents the positive impact of population on CCE in SSA. The positive coefficient implies that a larger population is associated with higher CCE. The probability value is less than 0.05, suggesting that population size significantly influences carbon emissions. A 1 per cent change in population pushes CCE by 0.52 per cent.

The long-run results are presented in Table 5.

Table 5. Two-Step System GMM (Long Run Elasticities).

Series	Coefficient	Standard Error
REC	-0.0341	0.0097***
*ln*RGDP	0.6840	0.2597***
*ln*POP	1.15205	0.0698***
Observations	1086	

*Note: *** means values less than .01. Source: Author's Compilation.*

The coefficient -0.0341 with a negative sign indicates an inverse relationship between REC and CCE in the long run. As REC increases, CCE decreases. In other words, higher adoption of renewable energy lowers CCE, reflecting a potential environmentally friendly energy transition.

lnRGDP at 0.6840 indicates a positive relationship between real GDP and CCE. This means that as real GDP increases, CCE also increases. As measured by real GDP, economic growth is associated with higher CCE, suggesting challenges in decoupling economic growth from environmental impact.

The positive sign of lnPOP at 1.1521 indicates a positive and significant relationship between the total population and CCE. The coefficient is significant at 1 per cent. As the total population increases, CCE also increases. This means that population growth is associated with higher consumption of carbon-related items in SSA, emphasizing the importance of considering demographic factors in environmental policy and planning.

4.3. Diagnostics

The F-statistic is statistically significant at 1 per cent, suggesting that the instruments jointly have a strong explanatory power. The AB (2) test assesses the second-order serial correlation in the first-difference residuals. The P value of 0.280 is not statistically significant at any significant level, as the probability value is above 0.1. Therefore, we fail to reject the null hypothesis of no second-order serial correlation. We also showed the result of the Hansen Test. This is to assess the validity of the instruments in the GMM framework. The null hypothesis is that the instruments are valid and uncorrelated with the error term. Therefore, the P value of 0.461 is statistically not significant.

4.4. Discussion of Findings

The paper sheds light on renewable energy's impact on consumption-based carbon emissions in SSA, providing valuable insights. The coefficient of the CCE's lag value underlines past CCE's persistence in influencing current levels. This suggests the importance of considering trends and implementing effective strategies to break the cycle of escalating emissions.

Notably, the coefficient of renewable energy consumption, at -0.0153 in the short run and -0.0341 in the long run, highlights that increased REC is associated with decreased CCE, emphasizing the potential role of sustainable energy practices in mitigating environmental impact. The result aligns with the work of Mukhtarov et al. (2023) for Azerbaijan and Nguyen and Kakinaka (2019) for 107 economies. The results also align with the IPAT framework of Dietz and Rosa (1997). The framework hypothesizes that adopting renewable energy reduces the use of fossil fuels, which produce more carbon. The idea here is that, as countries adopt renewable energy, they reduce carbon emissions, which are considered harmful and detrimental to the environment.

On the economic front, the positive coefficient of real GDP suggests a link between economic growth and higher carbon emissions. This underscores the challenges of decoupling economic development from environmental consequences. Erkut (2022) got the same results. He argued that economic growth may slow the prospects of environmental sustainability unless deliberate efforts are made to make growth sustainable.

Similarly, the positive coefficient of population size emphasizes the role of demographic factors in carbon emissions, which aligns with the IPAT hypothesis. As population size increases, so does the associated CCE, emphasizing the need for comprehensive environmental policies that account for population dynamics.

5. Conclusion and Recommendations

Our findings underscore the multidimensional nature of the factors influencing CCE, with challenges and opportunities for effective carbon mitigation. The results indicated a significant negative impact of REC on CCE in the examined SSA. The lagged value of CCE was also seen to positively impact the current value of CCE. Economic growth and population also showed a positive and statistically significant impact on CCE.

The paper suggests critical recommendations based on the findings as follows:

I. Given the negative impact of renewable energy consumption on CCE, prioritize and incentivize the adoption of renewable energy sources. This could be done by reducing taxes on sustainable products and taxing environmentally unsustainable products.

II. Since economic growth positively impacts CCE, the Ministries of Finance and National Planning in SSA may wish to integrate sustainable practices into economic development strategies to mitigate the carbon emissions associated with growth. This can be done by cutting budgetary allocations for carbon-related items and substituting them with environmentally friendly equipment.

III. Policymakers may also consider population dynamics in environmental policy planning. Develop strategies to manage the environmental impact of population growth. Sensitizing the citizenry to the danger of uncontrolled population growth would go a long way toward persuading them to slow down reproduction for a better and more sustainable environment.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Author contributions

Conceptualization: Marvelous Aigbedion; Investigation: Sani Abubakar; Methodology: Sani Abubakar; Formal analysis: Sani Abubakar; Writing – original draft: Sani Abubakar; Writing – review & editing: John Olu-Coris Aiyedogbon, Marvelous Aigbedion.

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