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Sectoral growth and carbon dioxide emission in Africa: can renewable energy mitigate the effect?

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ABSTRACT

Owing to increased energy consumption, the growth of various sectors of economies has the tendency to increase carbon dioxide emissions, a major component of greenhouse gases that causes climate change and global warming. A suggested panacea is to increase the development and usage of renewable energy which is cleaner and emits less carbon dioxide. In this study the carbon dioxide emission effect of growth in the agricultural sector, industrial sector, and service sector is assessed. It goes on to analyse the moderation role of renewable energy in the sectoral growth-carbon dioxide emissions nexus. Using data from 32 African countries for the period 2002–2021, the study finds that expansion in agricultural sector, industrial sector and service sector exerts upward pressure on carbon dioxide emissions for the region while renewable energy reduces carbon emissions. Furthermore, renewable energy interacts with the agricultural and industrial sectors to reduce their impact on carbon emissions while the opposite is observed for the service sector. Other findings are that trade openness, urbanization and income increase carbon dioxide emissions. The study recommends the need to remove financial impediments that constrain firms operating in the various sectors of African economies. This will enhance their acquisition of efficient technologies for operations in order to reduce carbon dioxide emissions. Also, governments in the region should increase financial support for the development and adoption of renewable energy. Incentives should be introduced to “lure” firms to adopt renewable energy. Imposition of a heavy tax on firms in the service sector whose operations cause higher emission may help ensure the sector becomes environmentally friendly.

1. Introduction

All economies throughout the world have desired to attain higher growth and development. This often entails the various economic sectors expand by increasing their output. Literature has revealed that the expansion of economic activities can increase carbon dioxide emissions owing to the reliance on energy for production activities (Aboagye, 2017). There is also the extraction of natural and environmental resources which contributes to environmental degradation (Kwakwa, Alhassan, & Adu, 2020). However, production activities in these sectors usually come to a halt whenever there is any energy crisis. Thus, energy is regarded as the blood of all sectors of the economy. Consequently, it will be difficult to be abandoned even though increased usage leads to higher carbon dioxide emission (Bekun, Alola, Gyamfi, Kwakwa, & Uzuner, 2022).

To expand the economy without compromising the quality of the environment, the adoption of renewable energy has been recommended. The reason is that renewable energy is environmentally friendly and it

guarantees energy security. The process of generating renewable energy does not involve much carbon dioxide emission unlike energy from fossil fuels (Kwakwa, 2020). Also, using energy from renewable sources does not lead to carbon emission (Adams, Klobodu, & Apio, 2018). Relying on energy from fossil fuel which is often imported from other countries has its own security implication. Any disruption in the production and supply chain of imported fuel may affect economic activities. Moreover, crude oil price fluctuations have had a devastating effect on importing countries (Kwakwa, Adu, & Osei-Fosu, 2018). There are therefore economic and environmental reasons to switch to renewable energy for economic activities (Gyamfi, Kwakwa, & Adebayo, 2022).

Over the past few years, renewable energy development has witnessed massive investment. The IEA (2021; 2022) has revealed that in 2020 renewable energy investment formed 45% of total expenses in the power sector. This figure jumped by 8% in 2021. In 2022, about US\$ 1.3 trillion was spent on transition technologies and energy efficiency representing a 50% increment from 2019 (IRENA, 2023). Electricity generation from renewable sources stands at around 28.7% of global

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electricity following 7% growth in 2021 (IEA, 2022). In addition, the consumption of renewable energy has also increased from 15 thousand TWh in 2000 to 20 thousand TWh in 2021 (Our World in Data, 2023). Comparatively, renewable energy development and consumption in Africa is very low (IRENA, 2023) while the share of renewable energy in total energy consumption for sub-Saharan African has been decreasing over the past decades. Fossil fuel source dominates the electricity supply in many countries on the continent. In some cases, it forms over 65% of electricity generated (World Bank, 2023). Meanwhile, there has been a renewed interest among African countries to attain a low carbon economy following the need to attain sustainable development (Musah et al., 2023; AfDB, 2023).

However, there have been studies that found that the adoption of renewable energy does not necessarily translate into lower carbon dioxide emissions. Some studies (Kwakwa, 2021; Ghorbal, Farhani, & Youssef, 2022; Ali, Audi, Senturk, & Roussel, 2022; Mentel, Wolanin, Eshov, & Salahodjaev, 2022) have found that renewable energy decreases carbon dioxide emissions; while others (Long, Naminse, Du, & Zhuang, 2015; Hasnisah, Azlina, & Taib, 2019) found renewable energy increases carbon emissions. Some studies reported insignificant effects of renewable energy on carbon emissions (Amri, 2017; Pata & Kartal, 2023).

With African countries' quest to attain higher income levels, it is important to ensure that economic expansion does not negatively affect the quality of the environment since a large number of its citizens depend on the natural environment for their livelihoods (Alhassan et al., 2019) coupled with the fact that it has been settled that the continent is the most vulnerable to climate change (Arku, 2013). Africa's vulnerability to climate change is premised on the fact that its agricultural system is 95% rain-fed, agriculture share in GDP and employment is high (AfDB, 2023), and it has low capacity to adapt to climate change. Climate change therefore will have varied of dire consequences on the continent including water and food systems, health, infrastructure development and poverty levels (AfDB, 2023). It will also worsen drought, desertification, climate migration, conflicts and social breakdowns (Renewal, 2019). With many African countries being parties to many international treaties and conventions such as the Paris Agreement, reducing carbon dioxide emissions in Africa becomes necessary. Yet, the trend of carbon dioxide emissions in Africa has been increasing over the years. For instance, carbon dioxide emissions increased from 402 thousand kt in 1990 to 820 thousand kt in 2019 for the sub-Saharan Africa alone (World Bank, 2023). It is in this regard that African countries have stated their commitments to building among others a low carbon economies in their Nationally Determined Contributions (AfDB, 2023). Such an agenda among other things call for an assessment of possible drivers of carbon dioxide emissions to shape policy formulation. In an era that growth agenda is pursued by African countries which has seen an expansion in all the three sectors-agricultural sector, industrial sector and service sector (World Bank, 2023) the questions that come to mind are what is the effect of their growth on carbon emission? and can renewable energy moderate their effects?

Records show that the growth levels of agricultural, industrial and service sectors of the African continent has increased over the years with carbon dioxide emissions (World Bank, 2023). Studies on their effects on carbon emissions is under researched (Adom et al., 2018; Kwakwa, Adzawla, Alhassan, & Oteng-Abayie, 2023). Expansion of the economy from agriculture to industrial-dominated sector increases carbon dioxide emission (Raihan and Tuspekova 2022; Amin et al., 2022; Azam et al., 2023) while a dominant service sector of the economy is associated with less carbon dioxide emission (Butnar & Llop, 2011; Amin, Song, & Farrukh, 2022; Ali, Tursoy, Samour, Moyo, & Konneh, 2022). The reasons assigned are that agricultural sector expansion reduces forest cover and increases the use of dirty source of energy which leads to increased carbon dioxide emission. The level of carbon emission increases the more during the industrial stage of development because of the energy-intensive technology required for production. The service sector on the

other hand is deemed more efficient than the agricultural and industrial sectors (Kwakwa, 2022; Ehigiamusoe, 2020). Some studies contradict the above claims and findings (Elfaki et al., 2021; Samargandi, 2017) indicating there could be some prevailing conditions that characterize these sectors which may determine the effect sectoral growth has on carbon dioxide emissions.

Most of the above studies and others in the literature have predominantly focused on countries outside Africa. Consequently, knowledge of the environmental effect of economic expansion as seen from the key sectors in Africa will help formulate the right policies because of the vigorous industrialization agenda pursued towards the attainment of higher growth and development on the continent, although the agricultural sector has been the main stain of Africa's economy for years. Also, the service sector is gaining momentum to the extent that in some African countries, it is the dominant sector (World Bank, 2023). As indicated already, renewable energy development is very low among African countries although there has been renewed interest to increase its generation and usage (Musah et al., 2023). It becomes imperative to also assess how the adoption of renewable energy by the sectors of Africa's economy could affect the level of carbon dioxide emission.

Some authors have opined that renewable energy may directly affect the level of carbon emissions or may moderate the carbon emission effects of economic activities (Kwakwa, 2021; Balsalobre-Lorente, Driha, Leitão, & Murshed, 2021). Studies that have examined the moderation role of renewable on the effect of sectoral growth on carbon emission is limited to fewer works like Shah, AbdulKareem, and Abbas (2022) and Mentel et al. (2022). Their respective empirical assessments were narrowed to how renewable energy moderates the effects of industrial and agricultural sectors on carbon emissions. They reported that renewable energy reduces the positive impact of sectorial growth. With no evidence on the service sector and since so far the analysis is from different economies, a single study to unravel the case for all three sectors for a particular country or economic bloc will be very informative. Thus, owing to the scarcity of such knowledge on Africa and outside the continent, the study seeks to analyze the following using data on Africa: a) the effect of agricultural sector growth, industrial sector growth and service sector growth on carbon dioxide emission in Africa; b) the direct effect of renewable energy on carbon dioxide emissions in Africa; and c) the moderating effect of renewable energy on the sectoral growth-carbon dioxide emission relationship in Africa. The outcome of the study will be helpful in shaping policy discourse on climate issues for the continent.

By achieving the above objectives three contributions will be made to the literature: a) although studies have assessed the effect of renewable energy on carbon dioxide emissions little evidence has come from Africa. This study bridges this gap by using data from 32 African countries to explore the emission effect of renewable energy; b) aside from the work of Aboagye, Appiah-Konadu, and Acheampong (2020) many studies that have assessed the effect of sectors on carbon emissions did so for a single sector providing little to no evidence about the others. In this study, the analysis entails all the three main sectors of African economies- agricultural, industrial and service sector; c) there is a paucity of studies on the moderation effect of renewable energy on the relationship between sectoral growth and carbon dioxide emission (Shah et al., 2022; Mentel et al., 2022). This study extends the knowledge in this area.

The remaining section of the paper is as follows: section two presents a review of related studies; section three focuses on data and estimation issues; section four is on the discussion of results; and section five is on the conclusion and recommendations.

2. Literature review

2.1. Sectoral growth and carbon emissions

Economies are largely made of three sectors namely the agricultural

sector, the industrial sector and the service sector. Economic expansion grows with these sectors although their share in the economy tends to vary. Their impact on environmental quality has been debated in the literature (Panayotou, 1997; Grossman & Krueger, 1995). The effect of these sectors has been linked with the environmental Kuznets curve (EKC) hypothesis which suggests the relation between economic developments and environmental degradation is inverted U-shaped. Generally, it is argued that because the agricultural sector entails activities including clearing of the forest it increases carbon emission. As a result, at the early stage of development where the economy is dominated by this sector, carbon emission is high. When economic development later sees the dominance of the industrial sector, carbon emission increases more. The reason is that industrialization requires more raw materials to be extracted from the environment. It is energy-intensive than the agricultural sector (Panayotou, 1997; Grossman & Krueger, 1995). Its growth will mean that more energy is used which translates into higher carbon emissions (Kwakwa, Acheampong, & Aboagye, 2022). However, an efficient industrial sector is argued to lead to lower carbon emissions (Adom, Kwakwa, & Amankwaa, 2018). At a higher stage of development dominated by the service sector, carbon emission reduces since it is not energy intensive (Kwakwa & Adu, 2015; Ehigiamusoe, 2020).

Some studies have been conducted to empirically assess the above arguments and have reported mixed evidences. On the effect of agricultural impact on environmental degradation, Raihan and Tuspeko (2022a) reported for the economy of Kazakhstan that agricultural growth reduces carbon dioxide emissions. Also, Raihan et al. (2023) revealed that the expansion of Thailand's agricultural sector reduces carbon emissions. Adekoya, Ajayi, Suhrab, and Oliyide (2022) obtained a negative effect of agriculture on carbon dioxide in resource-rich African countries. Raihan and Tuspeko (2022b) reported of a carbon dioxide reduction effect of agriculture in Turkey. Some authors attributed this outcome to practices including minimum tillage which reduces the usage of fossil fuel usage and increase carbon sequestration in the soil; and the ability of players in the agricultural sector to acquire energy-efficient implements for their operations.

On the other, among a group of developing countries Alavijeh, Salehnia, Salehnia, and Koengkan (2022) showed that growth in the agricultural sector increases carbon emissions. The impact was found to increase at higher quartiles. Kwakwa et al., (2022a) found Ghana's agricultural sector increases carbon dioxide emissions.

Since many of the existing studies had used total agricultural output for analysis Chidiebere-Mark et al. (2022) justified for the need to look at specific agricultural activities. It was found that expansion in agricultural activities and output such as fertilizer usage, livestock and cereal growth have accounted for higher carbon dioxide emissions in Africa. Kwakwa et al. (2023) found fertilizer usage increases Ghana's carbon dioxide emissions. These offer insight into some key agricultural activities that could trigger carbon emission. Other studies including Shah et al. (2022) and Udembu (2022) found agriculture to increase BRICS' and Nigeria's emissions respectively while Samargandi (2017) found agriculture has an insignificant effect on carbon emissions in Saudi Arabia. The differences in these results have been attributed to differences in estimation techniques, data set and sampled countries.

On industrialization, Sikder et al. (2022) found that industrialization increases carbon dioxide in developing countries. In Tunisia Kwakwa (2020) also found industrial growth is associated with higher carbon emissions. Azam et al. (2023) recorded that there is a positive relationship between industrial activities and carbon emissions in OPEC member countries. Ghana's carbon emission has recently been found to be positively affected by industrial growth in Kwakwa (2022a). Song et al. (2022) have also found that Korea's carbon emission rises with industrialization. Turkey's carbon emission was reported by Raihan and Tuspeko (2022) to be positively affected by industrial growth. Kwakwa, Arku, and Aboagye (2014) found for the Ghanaian economy that industrialization has an inverted U-shaped effect on carbon

emissions. Studies like Elfaki et al. (2021) recorded that industrial growth reduces carbon dioxide emissions among ASEAN + 3 economies. Many of the above studies that have reported of a positive effect of industrial sector on carbon emission argument has been that the sector is not environmentally friendly since it is energy-intensive.

Focusing on the service sector which also has mixed reported effects on carbon emissions, Aboagye et al. (2020) found that it has an inverted U-shaped relationship with carbon emissions in Ghana. Gan, Wang, and Voda (2022) showed that it increases China's carbon emissions. Adebayo, Oladipupo, Rjoub, Kirikkaleli, and Adeshola (2022) found that structural change towards the service sector reduces carbon dioxide in Turkey. Nwani, Bekun, Agboola, Omode, and Effiong (2022) analysis of African countries obtained a negative relationship between the service sector and carbon dioxide emissions. Wang, Dong, and Dong (2022) also found that digital service in China reduces carbon emission. Ali et al. (2022) obtained a negative effect of service growth on carbon emission in Pakistan. Amin et al. (2022) obtained a similar outcome for selected Asian countries. Martínez (2013) reported a carbon emission reduction effect of the service sector in Sweden. However, Martínez and Silveira (2012) reported that growth in the service sector increased energy consumption and carbon dioxide emissions in Sweden. Their opinion was that service growth triggers the usage of energy in related energy intensive sectors. Butnar and Llop (2011) also found service sector increases carbon dioxide emissions in Spanish and Samargandi (2017) obtained a positive effect of the service sector on carbon emissions in Saudi Arabia.

The different effects reported of the service sector could be based on the extent that it dominates the economy of the country under study. Usually, in studies that a negative effect was reported the service sector dominates the economy. With the differences in the effects of sectoral growth it is possible that when it is moderated by a clean-environment enhancing variable like renewable energy the story may change.

2.2. Renewable energy- CO_2 emissions nexus

The literature has acknowledged that despite the importance of energy an increase in its consumption leads to more carbon dioxide emissions. To avert this situation a switch to renewable energy has been recommended (Bekun et al., 2022). The strength of renewable energy is the low carbon emission associated with it. It is a cleaner source of energy and is considered environmentally friendly. Renewable energy is also more efficient than fossil fuel (Gyamfi et al., 2022). This implies that it can aid in economic expansion while reducing environmental pollution (Yang, Zhang, Liu, & Zhou, 2022). However, renewable energy may trigger higher carbon emissions when it propels economic growth and leads to increased demand for energy-intensive gadgets (Yang et al., 2022).

Evidence from empirical studies on the above argument has been conflicting. Kwakwa and Alhassan (2018) obtained for the Ghanaian economy that renewable energy usage reduces CO_2 emissions. Adams and Nsiah (2019) found that renewable energy usage in Africa increases carbon emissions. The works of Kwakwa (2020) found that renewable energy reduces CO_2 emissions respectively in Tunisia while Amri (2017) found an insignificant effect of renewable energy on carbon emission in Tunisia. A study by Ali et al. (2022) found that renewable energy reduces South Africa's carbon dioxide emissions. Mentel et al. (2022) found that renewable energy reduces the level of carbon emission in Sub-Saharan Africa. Edziah, Sun, Adom, Wang, and Agyemang (2022) in their study that focused on oil-producing countries in Africa reported that renewable energy reduces carbon dioxide emissions. In Tunisia Ghorbal et al. (2022), found that renewable energy consumption increases carbon dioxide emissions. Morocco's carbon emission was found to be negatively related to renewable energy usage by Bouygrissi et al. (2022).

Studies on the effect of renewable energy on carbon emissions in Asian countries abound. Jena, Mujtaba, Joshi, Satovic, and Adeleye

(2022) found renewable energy reduces carbon dioxide emissions in India, China and Japan. Aydin, Koc, and Sahbaz (2023) confirmed the carbon dioxide emission reduction effect in Japan. Ridzuan, Marwan, Khalid, Ali, and Tseng (2020) found that renewable energy reduces CO₂ emissions in Malaysia. China's renewable energy was reported by Long et al. (2015) to be positively affected by renewable energy. Also, Hasnisah et al. (2019) in a study on Asian countries reported a positive effect of renewable energy on carbon dioxide emission while the work by Pata and Kartal (2023) showed that renewable energy does not statistically affect the level of carbon dioxide emissions in South Korea. To offer evidence from a new angle, Moreso, Khezri, Heshmati, and Khodaei (2022) used different source of renewable energy and found for a group of Asian countries that among countries with lower economic complexities, the use of wind and solar energy reduces carbon dioxide emissions while the effect is opposite for countries with more complexities.

For the economies of the UK and Spanish Aydin et al. (2023) and Pilatowska, Geise, and Włodarczyk (2020) found that using more renewable energy reduces CO₂ emissions, respectively. Rahman and Alam (2022) also found renewable energy reduces Australia's carbon emissions while non-renewable energy increases emissions. Bekun, Alola, Gyamfi, Kwakwa, and Uzuner (2022) in their study found renewable energy to reduce carbon emissions from cement production among EU countries. Italy's level of carbon dioxide emission is reported by Ali and Kirikkaleli (2022) to be negatively related to renewable energy. Similar results have been reported by Bento, Cerdeira, and Moutinho (2016) for the country. Also, Destek and Aslan (2020) reported the following findings from their study: carbon dioxide emission in France and Germany is reduced by biomass consumption; solar energy reduces emissions in France and Italy; and hydroelectricity reduces emissions in Italy and the United Kingdom. Murshed et al. (2022) assessed Argentina's level of carbon dioxide emission and found it to be reduced by renewable energy. A study using 22 Central and South American countries by Ben Jebli, Ben Youssef, and Apergis (2019) found renewable energy mitigates the level of carbon dioxide emissions. Studies focusing on South American countries like Murshed et al. (2022) also found that renewable energy reduces carbon emissions.

With the overwhelming carbon emission reducing effect reported on renewable energy, the positive effect ones could be as result of the rebound effect taking place or biomass component forms significant portion of renewable energy used for analysis. Now, since the above studies assessed the direct effect of renewable energy its moderation effect through sectoral growth will offer more insight into its role in curbing carbon emission.

2.3. Moderation role of renewable energy in carbon dioxide emission

Some studies have examined how renewable energy can moderate the effect of some economic variables on carbon dioxide emissions. Such studies seek to ascertain how indirectly renewable energy adoption for some activities can affect the level of carbon dioxide emissions. The effect of such analysis reported has been mixed. For instance, Kwakwa (2021) reported that the usage of renewable energy for the extraction of natural resources (by the extractive sector) helps to reduce carbon dioxide emissions in sub-Saharan Africa. York and McGee (2017) found renewable energy can decouple carbon dioxide emission from economic growth in Europe. Kwakwa and Alhassan (2018) in their study reported that urbanization usage of renewable energy increases carbon dioxide emissions in Ghana.

Murshed et al. (2022) found that renewable energy moderates the effect of globalization on carbon emissions in Argentina. Mentel et al. (2022) found that renewable energy usage helps to reduce the effect of industrialization on carbon emissions in Africa. Ehigiamusoe and Dogan (2022) reported that income weakens the effect of renewable energy on carbon dioxide emissions among low-income countries. Balsalobre-Lorente et al. (2021) reported that renewable energy moderates the

carbon emission effect of financial development among EU countries. Shah et al. (2022) noted among BRICS economies that renewable energy moderates the effect of agriculture on carbon emissions.

2.4. Summary and gaps in the literature

Arguments have been propounded to explain the effect of economic sectors on carbon emissions. Similar ones exist on the effect of renewable energy. While the majority of the evidences indicates that agricultural expansion and the industrial sector increase carbon dioxide emission, the service sector and renewable energy reduce the level of carbon emissions. Also, evidence from Africa is gaining momentum. However, a few of the studies in and outside Africa focused on the effect of a single sector instead of providing evidence of all three sectors. Also, studies have not shown much evidence of the moderation role of renewable energy in the sectoral growth-carbon emission nexus. These identified gaps in the literature are addressed in the current study.

3. Methodology

3.1. Theoretical framework and empirical modelling

The theory that forms the basis for this study is the Stochastic Impacts by Regression on Population, Affluence, & Technology (STIRPAT) model by Dietz and Rosa (1997). It argues that level of environmental degradation, impact (I) is a function of population pressure (P), affluence or economic growth (A) and technology (T). This theory is appropriate for the study due to the relevance of the components to the African continent. Higher economic growth has become the target of governments, it is the second most populous continent in the world, and technological development is comparatively lower. The mathematical expression of the model is expressed as:

$$I = a.P^{\lambda}.A^{\gamma}.T^{\sigma}.v \quad (1)$$

where a , λ , γ , σ , e and v stand for parameters to be estimated. CO₂ emissions constitute an environmental problem because of its contribution to global warming and changes in the climate. It therefore replaces Impact (I). Urbanization share in total population (UB) will represent population pressure (P). Affluence is represented by income (YPC). Based on the argument by Dietz and Rosa (1997) that technology is not just the state of machines or equipment for production but rather the existing socio-economic features of an economy, as well as following previous studies (Ghazali & Ali, 2019; Wang et al., 2017; Zhang & Zhao, 2019) trade openness, renewable energy consumption (REN) and sectoral growth (SECT) are incorporated in the model. The inclusion of these variables are justified based on the objectives of the study. It is also plausible since the level of renewable energy, trade openness and sectoral activities reflect Africa's socio-economic state. This results in:

$$CO_2 = a.UB^{\lambda}.YPC^{\gamma}.TO^{\sigma}.REN^{\delta}.SECT^{\beta}v \quad (2)$$

where a , γ , λ , σ , δ , β and v are parameters to be estimated in addition to those already explained. Transforming equation 2 into natural logarithm for panel data gives:

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSECT_{it} + v_{it} + \epsilon_{it} \quad (3)$$

where i and t denote the individual countries and time(year) dimension correspondingly; ϑ and ϵ represent the county effect and error term respectively, L is the symbol for natural logarithm; and the rest remains the same. To assess the moderation role of renewable energy in the sectoral growth-carbon emission nexus, an interactive term between the two ($LREN \times LSECT$) is created and added to the model to get:

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSECT_{it} + \theta (LREN_{it} \times LSECT_{it}) + v_{it} + \epsilon_{it} \quad (4)$$

In analyzing the moderation effect of renewable energy the following interpretation matters:

If $\beta > 0$ and $\theta > 0$ it implies sectoral growth increases CO₂ emissions and it is reinforced by renewable energy.

If $\beta > 0$ and $\theta < 0$ it implies sectoral growth increases CO₂ emissions but the effect is reduced by renewable energy.

If $\beta < 0$ and $\theta > 0$ it implies sectoral growth decreases CO₂ emissions and it is reversed by renewable energy.

If $\beta < 0$ and $\theta < 0$ it implies sectoral growth decreases CO₂ emissions and it is reinforced by renewable energy.

Since the study is interested in assessing the effect of growth of economic sectors namely, agricultural sector, industrial sector and service sector the sectoral component (LSECT) in equation 3 and 4 is replaced separately with agricultural sector (LAGSECT), industrial sector (LINDSECT) and service sector (LSERSECT) to get the following equations

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LAGSECT_{it} + v_{it} + \epsilon_{it} \quad (5)$$

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LINDSECT_{it} + v_{it} + \epsilon_{it} \quad (6)$$

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSERSECT_{it} + v_{it} + \epsilon_{it} \quad (7)$$

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSECT_{it} + \theta (LREN_{it} \times LAGSECT_{it}) + v_{it} + \epsilon_{it} \quad (8)$$

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSECT_{it} + \theta (LREN_{it} \times LINDSECT_{it}) + v_{it} + \epsilon_{it} \quad (9)$$

$$LCO_{2it} = \alpha + \lambda LUB_{it} + \gamma LYPC_{it} + \sigma LTO_{it} + \delta LREN_{it} + \beta LSECT_{it} + \theta (LREN_{it} \times LSERSECT_{it}) + v_{it} + \epsilon_{it} \quad (10)$$

The interpretations of the interaction terms follow what has been given under equation 4.

3.2. Data source and description

Working on the objective of the study, 32 African countries that had enough data for the variables of interest were used. The list of these countries is in Table 1. The period of study 2002–2021 was chosen due to available data. All data were taken from [World Bank \(2023\)](#) World Development Indicators. CO₂ emissions is measured by CO₂ metric tons

Table 1
List of countries used for the study.

| Countries | | |
|--------------|---------------|--------------|
| Algeria | Angola | Congo. DR |
| Ghana | Nigeria | Mauritania |
| Namibia | Benin | Tunisia |
| Guinea | Guinea.Bissau | Cote D'voire |
| Congo Rep | Senegal | Mozambique |
| Liberia | Cameroon | Togo |
| Sierra-Leone | Kenya | Egypt |
| Comoros | Uganda | Mauritius |
| Madagascar | Rwanda | Gambia |
| SouthAfrica | Botswana | Morocco |
| Tanzania | | Burkina Faso |

per capita while urbanization was measured as urban population (% of total population). Renewable energy consumption was represented by renewable energy consumption (% of total final energy consumption). Trade openness was measured as Trade (% of GDP). Agricultural sector was measured as agriculture, forestry, and fishing, value added (% of GDP); industrial sector was measured as industry (including construction), value added (% of GDP) and service sector was measured as services, value added (% of GDP).

These measurements follow what has been commonly used by many of the previous studies ([Gyamfi et al., 2022](#); [Adom, Kwakwa, & Amankwa, 2018](#)). Table 2 shows the descriptive statistics and correlation of the variables to get an initial picture of the data used for the analysis.

3.3. Estimation procedures

Cross-sectional dependence among panel data impairs the results. For this reason studies of this nature have to check whether there is cross-sectional dependence among the variables or not. The presence of such a situation will then determine the type of unit root test to use. Unit root also leads to spurious regression. So when variables at levels contain unit root they are differenced to remove the unit root. In this study, if there is no cross-sectional dependence, unit root test such as [Im, Pesaran, and Shin \(2003\)](#), and [Maddala and Wu \(1999\)](#) are appropriate. However, in the presence of cross-sectional dependence [Pesaran \(2007\)](#) Panel Unit Root test (cross-sectionally augmented IPS, CIPS) is the preferred choice. After the unit root test, cointegration analysis is done to ascertain the existence of a long-run relationship among the variables. The Pedroni and Westerlund cointegration tests are employed for this exercise in this study. Both tests work with the null hypothesis of no cointegration among the series. The long-run effect of income, urbanization, trade openness, renewable energy consumption, and agricultural, industrial and service sector growth on carbon dioxide emission is then analysed. The fully modified ordinary least squares (FMOLS) estimator for heterogeneous panel data as proposed by [Pedroni \(2001\)](#) is employed for estimating the long-run effects of the variables in equations 5–10. Reasons for using the FMOLS include the fact that it addresses the problem of endogeneity and serial correlation often associated with panel data which can generate inappropriate results ([Pedroni, 2001](#)).

The panel FMOLS estimator is generally given by:

$$\hat{\beta}_{fmol} = \left[\sum_{i=1}^N \sum_{t=1}^T (x_{it} - \bar{x}_i) \right]^{-1} \left[\sum_{i=1}^N \sum_{t=1}^T (x_{it} - \bar{x}_i) \hat{y}_{it}^+ + T \hat{\Delta}_{\epsilon\mu}^+ \right]$$

where $\hat{\Delta}_{\epsilon\mu}^+$ is the serial correlation correction term and \hat{y}_{it}^+ is the transformed variable of y_{it} to achieve the endogeneity correction.

During the estimation, the study acknowledged the fact that the inclusion of South Africa in the sampled African countries may create outlier concerns because it is largest emitter of GHGs in Africa, with estimated 42% of the continent's emissions coming from South Africa alone ([Kohler, 2013](#)). The sample is further dominated by Sub Sahara African (SSA) and South Africa is also a bigger emitter of CO₂ than all other SSA countries combined ([World Bank, 2023](#)). Although the power of taking logs helps solve the outlier problem of the data, another estimation without South Africa is performed as a robustness check of your main results.

4. Results and discussion

4.1. Cross-sectional dependence

[Table 3](#) presents results of the cross sectional dependence tests for the series and it shows a rejection of the null hypothesis. This is an indication that there is cross-sectional dependence among the variables. Based

Table 2

Descriptive and correlation analysis.

| Statistic | LCO ₂ | LUB | LYPC | LTO | LREN | LAGSEC | LIND | LSERSEC |
|-----------|------------------|----------|----------|----------|-----------|----------|----------|----------|
| Mean | -0.765441 | 3.685456 | 7.254869 | 4.124129 | 3.697487 | 2.737711 | 3.161061 | 3.834863 |
| Median | -0.962195 | 3.740309 | 7.157210 | 4.089250 | 4.172077 | 2.983417 | 3.192315 | 3.865799 |
| Maximum | 2.148572 | 4.293045 | 9.301947 | 5.055365 | 4.587719 | 4.104478 | 4.192366 | 4.210909 |
| Minimum | -3.483007 | 2.748936 | 5.811188 | 3.031221 | -2.813411 | 0.553273 | 1.516429 | 3.236055 |

| Correlation | LCO ₂ | LUB | LYPC | LTO | LREN | LAGSEC | LIND | LSERSEC |
|------------------|------------------|-----------|-----------|-----------|-----------|-----------|-----------|----------|
| LCO ₂ | 1.000000 | | | | | | | |
| LUB | 0.544841 | 1.000000 | | | | | | |
| LYPC | 0.930092 | 0.405486 | 1.000000 | | | | | |
| LTO | 0.413556 | 0.342291 | 0.367973 | 1.000000 | | | | |
| LREN | -0.716180 | -0.443993 | -0.631743 | -0.197005 | 1.000000 | | | |
| LAGSEC | -0.791707 | -0.263675 | -0.829568 | -0.493413 | 0.468487 | 1.000000 | | |
| LIND | 0.421066 | 0.256364 | 0.436972 | 0.419999 | -0.287703 | -0.599906 | 1.000000 | |
| LSERSEC | 0.385823 | -0.052676 | 0.401780 | -0.108590 | -0.180890 | -0.357492 | -0.189148 | 1.000000 |

Table 3

Results for series cross-section dependence test.

| Series | Test | | | |
|------------------|---------------------|----------------------|-----------------------------|---------------|
| | Breusch-Pagan LM | Pesaran scaled LM | Bias-corrected scaled LM | Pesaran CD |
| LREN | 3866.25*** | 107.00*** | 106.11*** | 52.029*** |
| LCO ₂ | 3559.12*** | 97.25*** | 96.36*** | 43.70*** |
| LTO | 1916.06*** | 47.58*** | 46.76*** | 12.85*** |
| LUB | 8817.74*** | 264.21*** | 263.37*** | 72.46*** |
| LYPC | 5547.82*** | 160.39*** | 159.55*** | 61.04*** |
| LAGSECT | 2308.70*** | 57.55*** | 56.71*** | 11.55*** |
| LINSECT | 2635.99*** | 67.94*** | 67.10*** | 2.00** |
| LSERSECT | 2242.72*** | 55.45*** | 54.61*** | 3.95*** |

*** and ** denote 1% and 5% level of significance respectively.

on this it is better to use the CIPS unit root when assessing the stationarity property of the variables.

4.2. Unit root and cointegration results

The CIPS unit root results are captured in [Table 4](#) while cointegration results are reported in [Tables 5-8](#). The results from the unit root test show the variables are stationary at first difference. Thus, at levels, the variables contain unit roots which makes them inappropriate for regression analysis. Once the unit root is removed at first difference then they become fit for regression analysis. In [Table 5](#), the Pedroni cointegration results show there is evidence of cointegration among the variables for the model with agricultural growth. This is because the Panel PP-Statistic, Panel ADF- Statistic, Group PP-Statistic and Group ADF- Statistic reject the null of no cointegration. In [Tables 6 and 7](#) the model with industrial growth and service growth respectively are found to have cointegrated variables based on the Panel PP-Statistic, Panel ADF-

Table 4
CIPS Unit root test results.

| Series | At levels | First difference | Conclusion |
|------------------|-----------|------------------|------------|
| LREN | -2.77 | -3.88*** | I(1) |
| LCO ₂ | -2.56 | -4.02*** | I(1) |
| LTO | -2.54 | -4.05*** | I(1) |
| LUB | -1.06 | -2.61* | I(1) |
| LYPC | -2.09 | -3.49*** | I(1) |
| LAGSECT | -2.19 | -3.47*** | I(1) |
| LINSECT | -2.70 | -3.42*** | I(1) |
| LSERSECT | -2.20 | -3.60*** | I(1) |

*** and * denote 1% and 10% level of significance respectively.

Table 5

Pedroni cointegration test for model with the agricultural sector.

| Statistic | Prob | Weighted | Statistic | Prob. |
|---|--------------|----------|--------------|--------|
| Alternative hypothesis: common AR coeffs. (within-dimension) | | | | |
| Panel v-Statistic | -2.194523 | 0.9859 | -3.950770 | 1.0000 |
| Panel rho-Statistic | 4.201205 | 1.0000 | 3.944699 | 1.0000 |
| Panel PP-Statistic | -2.535344*** | 0.0056 | -6.464725*** | 0.0000 |
| Panel ADF-Statistic | -2.046903** | 0.0203 | -4.643310*** | 0.0000 |
| Alternative hypothesis: individual AR coeffs. (between-dimension) | | | | |
| Group rho-Statistic | 6.136178 | 1.0000 | | |
| Group PP-Statistic | -7.221872*** | 0.0000 | | |
| Group ADF-Statistic | -2.918204*** | 0.0018 | | |

** and * denote 5% and 10% level of significance respectively.

Table 6

Pedroni cointegration test for model with the industrial sector.

| Statistic | Prob | Weighted | Statistic | Prob. |
|---|--------------|----------|-----------|-----------|
| Alternative hypothesis: common AR coeffs. (within-dimension) | | | | |
| Panel v-Statistic | -1.435940 | 0.9245 | -4.532019 | 1.0000 |
| Panel rho-Statistic | 5.078018 | 1.0000 | 5.061834 | 1.0000 |
| Panel PP-Statistic | -9.158535*** | 0.0000 | -9.797766 | 0.0000*** |
| Panel ADF-Statistic | -4.982688*** | 0.0000 | -4.790971 | 0.0000*** |
| Alternative hypothesis: individual AR coeffs. (between-dimension) | | | | |
| Group rho-Statistic | 6.797982 | 1.0000 | | |
| Group PP-Statistic | -13.16867*** | 0.0000 | | |
| Group ADF-Statistic | -2.497849*** | 0.0062 | | |

** and * denote 5% and 10% level of significance respectively.

Statistic, Group PP-Statistic and Group ADF- Statistic. The Westerlund cointegration test also confirms cointegration among the variables ([Table 8](#)). The confirmation cointegration is an indication that income, urbanization, trade openness, and growth in the agricultural sector, industrial sector, and service sector can determine the level of carbon emissions in the long run.

4.2. The effect of renewable energy, income, urbanization, trade openness and sectoral growth

From [Table 9](#), renewable energy is seen to have a negative relationship with carbon dioxide emissions. An increase in renewable energy consumption is thus associated with a reduction in carbon dioxide

Table 7

Pedroni cointegration test for model with the service sector.

| Statistic | Prob. | Weighted Statistic | Prob. |
|---|------------------|--------------------|---------------------|
| Alternative hypothesis: common AR coeffs. (within-dimension) | | | |
| Panel v-Statistic | −2.088850 | 0.9816 | −4.538537 1.0000 |
| Panel rho-Statistic | 4.996173 | 1.0000 | 5.151934 1.0000 |
| Panel PP-Statistic | −7.921406*** | 0.0000 | −12.18424*** 0.0000 |
| Panel ADF-Statistic | −4.255066*** | 0.0000 | −6.009334*** 0.0000 |
| Alternative hypothesis: individual AR coeffs. (between-dimension) | | | |
| | <u>Statistic</u> | <u>Prob.</u> | |
| Group rho-Statistic | 6.804050 | 1.0000 | |
| Group PP-Statistic | −17.56718*** | 0.0000 | |
| Group ADF-Statistic | −3.284597*** | 0.0005 | |

** and * denote 5% and 10% level of significance respectively.

Table 8

Westerlund Cointegration results.

| Model with | Westerlund Statistic | P-value |
|---------------------|----------------------|---------|
| Agricultural sector | −2.02** | 0.021 |
| Industrial sector | −2.08** | 0.020 |
| Service sector | −2.70** | 0.024 |

***, **, and * denote 1%, 5% and 10% levels of significance respectively.

emissions. This finding is in line with the widely held belief that renewable energy is environmentally friendly. It does not emit harmful greenhouse gasses and as such using more of it helps in having a cleaner environment as it helps in reducing the amount of carbon dioxide emissions in the atmosphere (Gyamfi et al., 2022). Increasing renewable energy has therefore been beneficial to the continent in terms of getting lower carbon dioxide emissions. The results suggest that renewable energy can be employed for economic activities without impacting negatively on the environment. Although compared with other continents the renewable energy development and consumption in Africa is low recent attempts by governments on the continent to increase their renewable energy share of total energy might have helped in this regard. Of course, the capital requirement for developing renewable energy might have delayed the continent from tapping its vast renewable energy resources. The few renewable energy resources that have been developed or utilized mainly from hydro and some biomass may have triggered carbon dioxide emissions to reduce. Aydin et al. (2023), Murshed et al. (2022) and Pilatowska et al. (2020) recorded renewable energy consumption reduces carbon dioxide emissions.

An expansion in economic activities associated with the three sectors is observed to increase carbon dioxide emissions in the region. From the results an increase in the agricultural sector increases carbon dioxide emissions. The sector continues to remain a significant component of many economies in the continent (World Bank, 2023). Africa's agriculture relies on rudimentary technology and mechanization is associated with few large-scale farms. Where mechanization is also employed there is much dependence on fossil fuel energy. Modernizing agriculture has necessitated the increased use of energy in the agricultural sector for many activities including powering trucks for preparation of fields, planting and harvesting. Also, energy is used by some to light up and heat barns for animals.

Extensive farming involving the clearance of forest resources has characterized Africa's agriculture. The environmentally unfriendly nature of farming and rearing of animals has led to the destruction of many forest covers and the pollution of water bodies. The above situation could be responsible for the increased carbon dioxide emissions associated with expansion in the agricultural sector. The outcome supports some previous work (Chidiebere-Mark et al., 2022; Shah et al., 2022; Alavijeh et al., 2022).

While industrialization is championed among many developing countries as a means of attaining higher economic growth and

development, the sector's heavy reliance on energy especially fossil fuel energy has always raised a concern. The reason is that as the industrial sector grows, it is expected more energy will be used which will translate into higher carbon dioxide emissions. The results from the study as reported in Table 9 shows that an expansion in Africa's industrial sector has an environmental damaging effect through carbon dioxide emissions. This may be that many of the equipment for manufacturing purposes are energy intensive. Moreover, there is the inability on the part of many firms to buy efficient machines for their operations. Many of the machines are beyond their effective functioning years and have become obsolete. They may be faulty and still used for operations. The effect is that more energy will be used which will translate into higher carbon dioxide emissions. The industrial sector expansion on the continent has also been associated with the increased production of many environmentally polluting goods which could lead to higher carbon dioxide emissions. The results reported in this study corroborate with Azam et al. (2022), Raihan and Tuspeková (2022) and Song et al. (2022).

In the economic development stages, it is argued that the service sector dominates the rest at higher levels of development. The service sector unlike the agricultural and industrial sectors is thought of as being environmentally friendly (Ehigiamusoe, 2020). This is because its dependence on energy is lower than the industrial sector and its dependence on the extraction or destruction of natural resources is limited (Ehigiamusoe, 2020). It is therefore usually expected to contribute to a cleaner environment through lower carbon dioxide emissions. However, the results from the study show a significant positive relationship between an expansion in the service sector and carbon dioxide emissions. This means that an expansion in the sector leads to higher carbon dioxide emissions. This could be because the service sector is not the dominant sector on the continent yet. As a result, the service sector is unable to yield a cleaner environment in the continent. Energy is required for the service sector for heating, lighting and cooling office space. Many appliances operate on energy. The expansion of the service sector also implies that more office spaces have to be built and furnished. This may account for higher carbon dioxide emissions. In addition, the service sector in Africa has been characterized by unregulated activities as a result many firms are fond of engaging in environmentally unfriendly activities. Electricity theft is common among firms in the service sector which may also account for higher carbon dioxide emissions. Transportation sector relies heavily on fossil fuel which emits more carbon dioxide. Thus, the expansion of some of these sub sectors of the sector might have caused an increase in carbon dioxide emissions. The evidence here is in line with Butnar and Llop (2011) and Samargandi (2017).

To cater for the fact that inclusion of South Africa may create outlier concerns because it contributes about 42% of the continent's emissions (Kohler, 2013); as well as being a bigger emitter of CO₂ than all other SSA countries combined (World Bank, 2023), another regression estimation was performed to check for the robustness of the results despite the fact that the logs of the variables were used. From the results reported in Table 10 it is observed that the outcome does not differ much in term of the direction of the effect, magnitude and significance from what was reported in Table 9.

4.3. Moderation effect of renewable energy via sectoral growth

To assess the effect of renewable energy on carbon dioxide emissions through sectoral activities, regression analysis that included the interactive terms of each sector and renewable energy was done. The results from the said analysis are reported in Table 11. Renewable energy is directly seen to reduce carbon dioxide emissions for all the models as it was reported earlier. The explanations given earlier to justify the results are still valid here too. Paying attention to how renewable energy usage can affect the carbon dioxide emissions from the three sectors it is seen that expansion in the agricultural sector increases carbon dioxide emissions. However, interacting agricultural sector growth with

Table 9

FMOLS Regression results for models without interaction terms.

| Variable | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
|--------------------|-------------|------------|-------------|------------|-------------|------------|
| LYPC | 0.500*** | 0.025 | 0.462*** | 0.025 | 0.477*** | 0.024 |
| LUB | 0.998*** | 0.039 | 0.993*** | 0.041 | 0.962*** | 0.039 |
| LTO | 0.215*** | 0.012 | 0.217*** | 0.012 | 0.248*** | 0.012 |
| LREN | -0.217*** | 0.015 | -0.240*** | 0.016 | -0.193*** | 0.016 |
| LAGSECT | 0.042*** | 0.015 | | | | |
| LINSECT | | | 0.044*** | 0.015 | | |
| LSERSECT | | | | | 0.142*** | 0.024 |
| Adj-R ² | 0.99 | | 0.99 | | 0.99 | |

***denote 1% level of significance.

Table 10

FMOLS Regression results for models without interaction terms excluding South Africa.

| Variable | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
|--------------------|-------------|------------|-------------|------------|-------------|------------|
| LYPC | 0.496*** | 0.025 | 0.203*** | 0.007 | 0.474*** | 0.0251 |
| LUB | 1.024*** | 0.039 | 1.011*** | 0.0003 | 0.988*** | 0.040 |
| LTO | 0.221*** | 0.012 | 0.089*** | 0.001 | 0.254*** | 0.013 |
| LREN | -0.222*** | 0.015 | -0.165*** | 0.016 | -0.198*** | 0.016 |
| LAGSECT | 0.041*** | 0.015 | | | | |
| LINSECT | | | 0.048*** | 0.015 | | |
| LSERSECT | | | | | 0.145*** | 0.024 |
| Adj-R ² | 0.98 | | 0.98 | | 0.99 | |

***denote 1% level of significance.

Table 11

FMOLS regression results for moderation analysis.

| Variable | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
|---------------------|-------------|------------|-------------|------------|-------------|------------|
| LYPC | 0.505*** | 0.008 | 0.462*** | 0.023 | 0.461*** | 0.099 |
| LUB | 0.979*** | 0.012 | 0.989*** | 0.036 | 1.024*** | 0.180 |
| LTO | 0.217*** | 0.003 | 0.217*** | 0.011 | 0.287*** | 0.054 |
| LREN | -0.178*** | 0.010 | -0.193*** | 0.025 | -0.980** | 0.385 |
| LAGSECT | 0.090*** | 0.012 | | | | |
| LREN × LAGSECT | -0.013*** | 0.003 | | | | |
| LINSECT | | | 0.114** | 0.039 | | |
| LREN × LINSECT | | | -0.017* | 0.009 | | |
| LSERSECT | | | | | -0.482 | 0.346 |
| LREN × LSERSECT | | | | | 0.175*** | 0.080 |
| Adj- R ² | 0.99 | | 0.99 | | 0.99 | |

***, ** and * denote 1%, 5% and 10% level of significance respectively.

renewable energy leads to a reduction in the levels of carbon dioxide emissions. This means that although the agricultural sector may be environmentally unfriendly and may lead to higher carbon dioxide emissions, the use of renewable energy for an agricultural purpose has the potential to reduce the carbon dioxide emission effect associated with the activities of the sector.

The agricultural sector is noted for direct or indirect usage of energy. The former comes in the form of using energy to enable farmers to operate many machines for farming purposing including clearing of fields, planting, watering, spraying, harvesting and the transportation of inputs and outputs. It also includes the use of light in some animal farms and electricity or other energy sources for killing and dressing on animals. The indirect usage of energy is noted from fertilizer and pesticide usages. In Africa unclean energy sources are used for most of these activities which pollutes the environment. The results indicate that relying on renewable energy for such activities will help reduce carbon dioxide emission since it is associated with little carbon emissions and is also efficient. This confirms results of [Shah et al. \(2022\)](#).

The effect of industrialization is also seen to be positive. The industrial sector is more dependent on energy usage. However, the more energy usage causes carbon dioxide emissions to increase. The results show that interacting renewable energy with industrial expansion leads to reduced levels of carbon dioxide emissions. This goes to suggest that although energy is needed for production activities including

manufacturing, packaging, bottling and distribution within the industrial sector the reliance on non-clean energy source for these activities will keep on being associated with more carbon dioxide emissions. However, a switch to renewable energy which is cleaner energy and more efficient makes operations in the industrial sector become less polluting leading to lower carbon dioxide emissions. The result is in line with [Mentel et al. \(2022\)](#).

It is also seen that when the expansion of the service sector interacts with renewable energy it is associated with higher carbon dioxide emissions. This result means that using more renewable energy for activities like lighting and cooling office space can increases carbon dioxide emissions following service sector growth. This could be that the service sector in Africa has not yet become efficient and environmentally friendly. Another reason is that the efficiency of renewable energy could propel service sector growth. Such growth may be associated with more energy consumption thereby increasing carbon emission as argued by [Yang et al. \(2022\)](#). This result is also reasonable in the sense that renewable energy production is low in Africa. So, with increased energy demand following higher sectoral growth, firms may be compelled to resort to non-renewable source of energy. Moreover, with higher growth of service sector, when more renewable energy is used, there is the possibility of rebound effect to trigger carbon emissions.

The regression results for the moderation analysis that excludes South Africa is reported in [Table 12](#). It is observed that the outcome does

Table 12

FMOLS regression results for moderation analysis excluding South Africa.

| Variable | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
|---------------------|-------------|------------|-------------|------------|-------------|------------|
| LYPC | 0.536*** | 0.006 | 0.460*** | 0.441*** | 0.066*** | 0.099 |
| LUB | 1.045*** | 0.009 | 1.008*** | 0.940*** | 0.105*** | 0.180 |
| LTO | 0.222*** | 0.002 | 0.218*** | 0.263*** | 0.033*** | 0.054 |
| LREN | -0.180*** | 0.008 | -0.206*** | -0.766*** | 0.269*** | 0.385 |
| LAGSECT | 0.066*** | 0.010 | | | | |
| LREN × LAGSECT | -0.007*** | 0.002 | | | | |
| LINSECT | | | 0.095*** | 0.020 | | |
| LREN × LINSECT | | | -0.015*** | 0.004 | | |
| LSERSECT | | | | | -0.381 | 0.246 |
| LREN × LSERSECT | | | | | 0.119** | 0.057 |
| Adj- R ² | 0.98 | | 0.98 | | 0.98 | |

***, ** and * denote 1%, 5% and 10% level of significance respectively.

not differ much in term of the direction of the effect, magnitude and significance from what was reported in Table 11.

4.4. Other findings

Results in Tables 9-12 also show that income, urbanization, trade openness have a positive relationship with carbon dioxide emissions. An increase in income levels on the continent translates into a higher level of carbon dioxide emissions. This outcome which is not different from what has been reported in many of the previous studies such as Kwakwa, Alhassan, and Adu (2020) and Aboagye (2017) for some African countries and Adebayo et al. (2022) outside the continent could be attributed to the increase in demand for energy-intensive goods as income increases. In addition, the increase in income implies an expansion in economic activities which might have taken place at the expense of the environment via increased usage of environmental resources. This implies that the demand for energy-intensive gadgets as well as consumption of goods and other services increase with income which leads to higher carbon emissions.

The urbanization effect noted to be positive is an indication that urban growth in Africa leads to more carbon dioxide emissions. The literature has documented that environmental stress from urbanization comes in many ways including clearing of forest resources for residential and office buildings, heavy vehicular traffic; slum conditions, and urban poverty (Adom et al., 2018; Sadorsky, 2013; Musah, Kong, Mensah, Antwi, & Donkor, 2021). Africa's case to a large extent conforms with the argument in the literature. The transportation network is not at its best; the materials for building constructions are not environmentally friendly; urban poverty remains high and the pace of deforestation partly due to urban growth is worrying. This development might have accounted for the positive effect of urbanization on carbon dioxide emissions. Previous studies such as Musah et al. (2021) and Polloni-Silva et al. (2021) have found similar results.

Trade openness is reported to have a positive effect on carbon dioxide emissions. The outcome suggests that opening up the continent for international trade might have led to the influx of energy-intensive goods which has led to higher carbon dioxide emissions. The quest to export more goods might have led to increased production at the firm level. This might have triggered more energy consumption leading to higher carbon dioxide emissions. Many of the goods imported may also not be energy efficient which may lead to increased carbon dioxide emissions. In the light of this it can be said that the environmental destruction effect of trade openness holds for African countries confirming Vural (2020) and Nathaniel and Iheonu (2019).

5. Conclusion

Africa's economic growth has been impressive in recent times. However, the level of carbon dioxide emission which has more than doubled between 1990 and 2020 is an issue of concern due to its effect

on climate change which adversely affects the continent more than any other continent. The expansion of the agricultural, industrial and service sectors in one way or another increases the consumption of energy, a crucial input that may compound the level of carbon dioxide emissions. In order not to stifle economic activities and at the same time promote environmental quality, renewable energy adoption has been recommended. However, renewable energy development and consumption are lower in Africa than in other continents. The study assesses the effect of renewable energy consumption, agricultural, industrial and service growth on carbon dioxide emissions. In addition, it does an assessment of the moderation role of renewable energy on the effects of agricultural, industrial and service growth on carbon dioxide emissions. The STIRPAT model served as the theoretical foundation for the study and relied on data from 32 African countries over the 2002–2021 period.

The results from the FMOLS regression method show growth in the agricultural, industrial and service sectors increases carbon dioxide emissions while renewable energy reduces carbon dioxide. Moreover, renewable energy moderates the effects that agricultural and industrial sectors' growth have on carbon dioxide emissions by reducing their impacts. In the case of service sector, renewable energy further increases the positive effect it has on carbon emission. It can be said that renewable energy can help promote a quality environment by reducing the positive effects agricultural and industrial growth have on carbon dioxide emissions.

The results have a number of implications. First, there is a need to enhance the development of renewable energy for the region. This calls for removing credit constraints for firms that invest in renewable energy. Governments on the continent must attract foreign direct investment specifically into the renewable energy sector. Incentive packages like tax holidays will be helpful in this direction. Regarding the adoption of renewable energy governments should make it unattractive for firms operating in various sectors to continue to rely on fossil fuel sources of energy. Special attention should be given to the service sector by imposing higher taxes on firms whose operations lead to higher carbon dioxide emissions. Also, the acquisition of energy-efficient technologies for operations in the sectors can reduce the rate of energy usage and hence carbon dioxide emissions. Paying attention to the supply chain of various activities in the service sector will help to also identify environmental polluting sources for appropriate measures to be taken. Similarly, an assessment of the carbon emission generating potential of the various sub sectors of the service sector can offer useful revelations for policymaking. It is time urgent action is taken to ensure that in putting up building structures to accommodate the expansion of service sector, environmentally friendly materials are used. Hastening the design of efficient transport network which is closely linked with the service sector operations may reduce the carbon emission effect of the service in Africa. Strict enforcement of environmental laws regarding activities of the service sector is suggested to reduce its carbon emission. The study limited itself to African countries for the period 2002–2021. Future studies can perform regional comparative studies. Studies to

assess the adoption of renewable energy at the sectoral level will be appropriate.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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