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Does carbon emission react to oil price shocks? Implications for sustainable growth in Africa

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ABSTRACT

This study examines the asymmetric effect of oil price changes on CO_2 emissions for 30 African countries from 1987 to 2019. Using the panel non-linear autoregressive distributive lag (NARDL) methodology, the study reveals that an asymmetric relationship exists between oil price and CO_2 emission as positive changes in the oil price are associated with a reduction in CO_2 emissions. The negative change is also found to be associated with an increase in CO_2 emission across the panel countries. In addition, in the long run, the degree of CO_2 emission response to positive changes in oil price is more in oil-importing countries relative to oil-exporting countries. While CO_2 emission response in oil-exporting countries responds more to negative changes in oil prices than in oil-importing countries. When we examine the response of GDP to a reduction in CO_2 emission, we found that while a negative change in CO_2 is associated with an increase in GDP in oil-importing countries, negative changes in CO_2 emission significantly lead to a reduction in GDP in net oil-exporting countries. The study suggests strengthening the call for carbon emission reduction, especially in oil-exporting countries as oil price does not exhibit enough push factor towards the mitigation of CO_2 emission in the continent.

1. Introduction

The quest for high economic growth in developing economies, especially in African countries, intensifies the consumption of fossil fuels (including oil) as the main source of energy. This is responsible for increased carbon emissions, which damage the environment and induces climate change. The increasing adverse effects of environmental degradation and climate change necessitated the need for sustainable development policies, which can concurrently ensure economic growth and preserve the global environment. However, economies across the world (including African economies) largely depend on fossil fuels for energy supply and numerous economic activities. Thus, the effort towards promoting economic growth is accompanied by the unrestricted use of fossil fuel, thereby increasing carbon emissions. Scholars (Dong et al., 2017; Majeed & Luni, 2019; Ferreira et al., 2022; Wang et al., 2022) have suggested that the most effective way to manage energy consumption is through energy prices.

See appended missing references for AQ4

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Crude oil is an important and largest source of energy, especially for developing countries in Africa. It is a fossil-based fuel and a major source of carbon emissions in the world. Hence, many studies have linked oil price shocks to carbon emissions. Meanwhile, oil price shocks cause uncertainty to both producers and consumers, and the optimal effect of oil price shocks on carbon emissions and economic growth is hotly contested. The dilemma between carbon emission, oil price shocks, and growth especially among developing nations like Africa has been an ongoing discussion in academic literature (Obindah et al., 2019). Regulating carbon emissions is often justified as necessary in ensuring environmental protection and sustainable economic growth and development. Increased growth naturally implies increase carbon emission, especially for the majority of African countries that depends largely on crude oil and other fossil fuel.

In that regard, previous studies that investigated the relationship between oil price shock, carbon emissions, and economic growth assumed a linear as well as symmetric relationship between the variables. The reality is that the unexpected rise (positive shock) and fall (negative shock) in oil prices could have an asymmetric impact on carbon emissions and growth in most African countries. It is well established that shocks in oil prices could disrupt economic growth and affect the rate of emission in a country, however, there are still unanswered questions about the nexus between oil price shocks, carbon emission, and growth in Africa. Is the nexus between oil price shocks, carbon emission, and growth in Africa linear or nonlinear? Is the relationship between the variables symmetric for oil-importing and oil-exporting African countries? Is the relationship the same for both the short run and the long run? This study attempts to provide answers to these questions.

This paper addresses this issue by examining the asymmetric effect of oil price shock on carbon emissions and economic growth in Africa. Carbon emissions and economic growth are of interest for two reasons. First, is the call to reduce carbon emissions and mitigate the environmental problem ensuing from carbon emissions. Relative to other continents, Africa is not a significant source of greenhouse gas emissions since the continent only accounts for 2 to 4 percent of the world's carbon dioxide emissions from energy and industrial sources (World Development Indicator [WDI], 2022). However, from 2014 to 2018, CO2 emissions increased by 3 percent in the continent (WDI, 2022). This implies that African countries should pursue policies that can minimize their greenhouse emissions as climate change not only threatens sustainable growth, but most African countries may lack the resources to address the future impact of climate change. Empirical literature suggested that oil price shocks could influence carbon emissions, and tend to impact sustainable growth, especially in Africa where economic growth remains low. As such, the empirical results on how oil price shocks could influence carbon emission in Africa remains ambiguous.

Second, the economic situation of a country may affect its policies on carbon emissions and may cause countries to react differently to oil price shocks. For instance, in net oil-exporting countries, a positive shock may connote the need for increased economic growth which may imply an increase in carbon emission, whereas in net oil-importing countries may reflect a decrease in carbon emission due to scarcity of energy. Kassouri et al. (2022) submit that the nexus between oil prices and carbon emissions depends on the source of the shock. The study revealed that the explanatory power of the oil demand shocks is relatively stronger than that of oil supply (inventory) shocks, and positive oil price shocks triggered by oil supply shocks are not likely to reduce carbon emissions.

Due to the importance of crude oil to growing economies, especially in terms of the economic growth of African countries, oil price shocks and CO_2 emission control policies have growth implications. The idea is that the instability in oil prices could spark the need for CO_2 emission control but have a negative effect on the economic growth of an emerging country. This suggests an asymmetric relationship between CO_2 emission, oil price shock, and economic growth. Thus, this study examines the relationship between oil price shocks and CO_2 emission in Africa using the Non-Linear Autoregressive Distributive Lag (NARDL) framework to distinguish the positive and negative effects of oil price shocks on carbon emissions of top net oil-exporting and net oil-importing countries in Africa.

Therefore, this study made numerous contributions to the literature. First, the study considered the nonlinear and asymmetric relationship between oil price shock, carbon emissions, and economic growth in Africa. Previous empirical studies concentrated on the static or dynamic relationship between crude oil price volatility and CO_2 emission without recourse to the asymmetric effects of oil price shocks on CO_2 emission in Africa. Second, the study evaluated the nonlinear nexus of oil price shocks on CO_2 emissions for both oil-importing and oil-exporting African countries. Third, the study examined the short-run and long-run responses of CO_2 emissions to asymmetric oil price shocks. In addition, the study interrogates the response of economic growth to oil price shocks and CO2 emissions in Africa. Furthermore, some authors advocate the use of efficient technology (Mensa et al., 2019; Mohamued et al. (2021), others suggest increasing investment in renewable energy (Sadorsky, 2009). This nature of outlook may produce a nascent result for the economy, as investments in alternative fuels are still emerging and, in most cases, insignificant in many African countries. Since economic growth largely depends on energy consumption, we explore the nexus between oil price shocks, carbon emissions, and economic growth.

2. Literature review

The theoretical framework of this study is anchored on the environmental Kuznets curve (EKC) augmented hypothesis propounded by Krueger (1991, 1995). The EKC hypothesis posits that carbon emission increases during the early stage of economic growth until per capita income reaches its maximum. Carbon emission begins to fall after society has reached the maximum per capita income. Based on the EKC hypothesis, carbon emissions in most African countries should be on the rise due to growth drive. Thus, since growth necessitates carbon emission, oil price shocks (increase) indicate energy scarcity, such shock could affect growth and subsequently the level of carbon emission in Africa.

Carbon emissions are associated with numerous adverse effects including health problems (Farooq et al., 2019). Thus, it attracted the interest of researchers and policymakers across the world. Although industrialization and urbanization have been recognized as the main culprits of carbon emissions (Sarwar and Alsaggaf, 2019; Sarwar, 2019; Syed and Bouri, 2021; Sahu et al., 2022), oil price shocks and their effect on carbon emissions and economic activities have been an important topic of discussion in academic literature (Jiao et al., 2021; Mensa et al., 2019; Gazdar et al., 2019; Eslami et al.2021; Dabbous & Tarhini,2021). For instance, Gazdar et al. (2019) found that oil price volatility has a positive effect on economic growth among Gulf Cooperation Council (GCC) countries. Stylina-Iris et al. (2019) use SVAR to examine whether oil price shocks affect carbon emission allowance traded under the European Union emission trading system. They found that an unexpected oil supply disruption has an imminent but weak positive effect on carbon emission prices. Such shocks tend to reduce carbon emissions in the European Union. Mensa, et al. (2019) examine the causal relationship between energy consumption, economic growth, carbon emission, and oil price in Africa. They found a unilateral causality that runs from fossil energy consumption to economic growth and a unilateral causality that runs from oil price to economic growth, energy consumption, and carbon emission. Earlier, Aydin and Acar (2011) also found oil price shocks have significant effects on carbon emissions reduction in Turkey. Sharma et al. (2021a,b,c,d) investigated the dynamic influence of energy consumption and financial service delivery on carbon emissions in countries in South and Southeast Asia. The study discovered that at lower income levels, energy consumption causes environmental pollution, however, at higher income levels, the adverse effect of energy consumption on carbon emissions is minor in the region.

Some studies suggested the role of increased investment in renewable energy in mitigating carbon emissions. According to Sadorsky (2009), an increase in oil prices has a small negative impact on GDP and renewable energy consumption in the G7 countries. However, the increase in real GDP per capita and CO2 per capita is found to be the major drivers of renewable energy consumption in the G7 countries. In a related study, Alper and Oguz (2016) found that renewable energy consumption has negatively reduced carbon emissions in EU countries. Boufateh (2021) found that renewable energy in Tunisia is found to reduce carbon emissions. Interestingly, Boufateh found that other factors such as institutional, financial regulations, and governance constitute a drawback to the reduction in carbon emission in Tunisia. Mo, Chen, Nie, and Jiang (2019) examined the effect of crude oil prices on economic growth in BRICS countries. Using the wavelet quantile test, the study found that oil price stimulates economic growth and CO2 emission in the long run in most BRICS countries although this effect is heterogeneous across the different countries.

In recent times studies such as Jiao et al. (2021) have examined the place of technological innovation on carbon emissions. For instance, Jiao et al. (2021) investigated the impact of India's exports, technological innovation, and oil prices on carbon emissions. Using the nonlinear autoregressive distributed lag (NARDL) technique, the study discovered that an increase in exports and technological innovation increased carbon emissions, whereas a decrease in exports, increased oil prices, and increased income inequality resulted in a reduction in carbon emissions in the long run. In a related study, Sharma et al. (2021) examined the effect of technological innovation on renewable energy use among BRICS countries. The study found that technological innovation contributes to the escalating usage of cleaner energy among BRICS countries. Equally, Waheed et al. (2020) identified that the promotion of non-oil exports can serve as a good strategy for ensuring sustainable economic growth – growth devoid of environmental degradation.

Beyond the effects of oil price on carbon emission is the asymmetric effect caused by oil price shock. Studies such as Hooker (2002), Cunado and de Gracia (2005), and Ghosh and Kanjilal (2014) argued that the changes in oil prices require non-linear and asymmetric specifications to correctly capture the causal effects. Recent studies that examined the asymmetric effect of oil price volatility report mixed results. Ullah et al. (2020) studied the asymmetric effects of oil price changes on environmental pollution across the top ten carbon emitters of the world. The study observed that the effect of oil price shock on carbon emission differs across countries. The study showed that even within a country the short-run effect of oil price shock may differ in the long run. A positive shock in oil prices reduces carbon emissions in most carbon-emitting countries. The study by Ullah et al. (2020) focused more on the major top ten countries, thus, neglecting the response of medium and low emitters and by extension ignoring the growth factor of emerging countries. Akinsola and Odhiambo (2020) examined the asymmetric impact of oil prices on economic growth in seven low-income oil--importing countries in sub-Saharan Africa. The study found a long-run negative impact of oil price increases on economic growth among low-income importing countries. Obindah, Nnaemekaand Romanus (2019) found similar results in some selected African countries in the short run. The studies, however, did not examine whether the increase or decrease in oil prices has a similar effect on the GDP of oil-exporting countries in Africa. Sarwar et al. (2022) used nonlinear ARDL to investigate the nexus between blue and green economic activities and carbon emissions in Saudi Arabia. The study reported that energy indicators, including oil prices, do not ensure carbon neutrality.

Using the Driscoll Kraay model in analyzing the effect of global oil price volatility on greenhouse gas (GHG) emission, Mohamued et al. (2021) found a positive relationship between innovation and GHG emission reduction initiatives among oil-importing countries. Innovation, however, increases emissions in oil-exporting countries. An increase in oil price reduces carbon emissions in oil-importing countries while increasing emissions in oil-exporting countries. The study observed that oil-exporting countries lack the incentives to decrease carbon emissions as an increase in oil prices adds to their GDP growth.

Sharma et al. (2021) explored if economic development drivers enhance environmental pollution in Southeast Asian countries. Utilizing the Westerland cointegration test and cross-sectional distributed lag mean estimate, the study discovered that increasing economic activity raises CO_2 emissions in the long term. Zhang et al. (2022) investigated the impact of export diversification, stock market development, and wealth inequality on carbon intensity in nine of the world's top carbon-generating countries. Using the Westerlund and CS-ARDL estimate techniques, the study discovered that stock market size, export diversification, and wealth inequality increase carbon intensity in the selected countries.

On whether oil price change increases investments in renewable energy thus reducing carbon emissions; findings in academic literature have been mixed. Using the Markov regime-switching regression, Dutta et al. (2020) investigated whether green investments are related to oil price shocks. The study found that the effect of oil prices on environmental investment is insignificant; however, green assets are more susceptible to oil market volatility than oil price shocks. Kouton (2020) for instance examined the impact of renewable energy consumption on inclusive growth in 44 African countries using the system generalized method of moments. The study found that renewable energy consumption has a positive and significant effect on inclusive growth in the selected African countries, thus, encouraging investment in renewable energy. In Nigeria Ayodele and Alege (2021) found a unidirectional causality that runs from renewable energy consumption to oil price volatility. The study, however, noted that real GDP has the highest variation effect on renewable energy in Nigeria. Thus, explaining the place of GDP in crude oil price and carbon emission nexus.

Several studies examined the relationship between CO2 emissions and economic growth in Africa. Usama (2011) for instance, examined the causal relationship between oil consumption and economic growth of the Middle East and Northern Africa (MENA) countries. The study found bidirectional causality between oil consumption, CO2 emission, and GDP growth among the MENA countries. The study by Mardani et al. (2018) documented several studies that established the causality between CO2 emission and economic growth. Bouznit and Pablo-Romero (2016) examined CO2 emissions and economic growth in Algeria and found that in developing countries like Algeria, it is difficult to curb CO2 emissions without compromising economic growth. Similarly, Muhammad (2019) found CO2 emissions to increase with the increase in economic growth in developed and MENA countries. The findings of these studies indicate that regulating CO2 emissions is a daunting task, especially in Africa where there is much dependence on fossil energy. Much recently, Ayad et al. (2022) found that there is increase in environmental degradation and CO2 emission in MENA countries when there is uncertainty, increase energy consumption and population.

In sum, there is reliable evidence which shows a strong relationship between CO_2 emission and oil price. Studies have shown that the relationship could be asymmetric and nonlinear. As pointed out in the literature, the amount of CO2 emission is largely determined by the price of fossil fuel, the volume of economic activities *inter alia*, in Africa CO2 emission, is relatively low; although it has been on the rise over the years. The infrastructure for alternative energy is still nascent and costly, although there is a call for CO2 emission reduction, the price of crude oil many argued could be a push factor towards carbon emission reduction.

This study underlines the importance of understanding the link between oil price shocks, carbon emissions, and economic growth in Africa. While previous research focused on policy interventions such as carbon taxes, subsidies, technological innovations, and investment in renewable energy to mitigate the negative effects of carbon emissions, this study looks at the role of crude oil price in mitigating carbon emissions in Africa. Furthermore, the current study investigates the carbon emission response to changes in oil price across African oil exporting and importing countries.

Arguably, the response of CO_2 emission to oil price in Africa could be affected by whether or not the country is a net oil-exporting or oil-importing country. In Africa where major oil-exporting countries that are largely dependent on cheap fossil coexist with net oil-importing countries, the linear response paradigm is no longer adequate in understanding how CO2 emissions respond to changes in oil price. Thus, we assess how CO2 emission responds to an increase or decrease in oil price in Africa for net oil-importing countries, net oil-exporting countries and the individual countries.

3. Methodology

The panel data used in the analysis of this study is annual data from 1987 to 2019 for 30 African countries. We took a sample of the first 30 African countries in terms of top crude oil-exporting and importing as samples for this study. The countries were divided into net oil-exporting countries and net oil-importing countries in Africa. Net oil-exporting countries include Nigeria, Angola, Algeria, Egypt, Libya, Gabon, Ghana, Sudan, Republic of Congo, Equatorial Guinea, Chad, Cameroon, Cote d'Ivoire and Tunisia. Net oil importing Countries are South Africa, Morocco, Zambia, Serre-Leone, Kenya, Mauritius, Mozambique, Namibia, Senegal, Tanzania, Togo, Zimbabwe, Benin, Botswana, and The Gambia.

The data used are real gross domestic product (GDP), crude oil prices, urban population, energy consumption, and CO_2 emissions. CO_2 emission per capita in metric tons of carbon dioxide per person is measured from the consumption and flaring of fossil fuels. Data on energy consumption and crude oil price were obtained from the U.S. Energy Information Administration (EIA), 2022 respectively. Data on real GDP (millions of $US), CO2 emissions and urban population (millions) are taken from the United Nations economic database. Energy consumption in millions of kilowatt-hours is measured as fossil fuels consumed. Oil price is the average annual price of West Texas Intermediate (WTI) crude oil price. We used the WTI crude oil price as a proxy for domestic oil price for the countries because of the unavailability of data. This approach is in line with Gbatu et al. (2017) where WTI crude oil price was used to stand as a uniform substitute for oil price.

We use the Panel non-linear autoregressive distributive lag (NARDL) to estimate the asymmetric impact of oil price changes on CO_2 emissions. The panel NARDL approach is suitable for non-stationary panel data because it is efficient in capturing the short-term dynamics of variables and their adjustment to long-run equilibrium (Pedroni, 1999, 2001).The use of the heterogeneous dynamic panel approach is appropriate when dealing with non-stationary variables with the same order of integration such as [I(1)], or mixed order of integration such as ([I(1)] and [I(0)]) as long as none of the variables is integrated of [I(2)]. Following the work of Majumdar and Parikh (1996) and the large strand of the empirical literature that included GDP and population as factors affecting CO2 emission, we specify the CO2 emissions response of 30 African countries thus;

$$CO_{2it} = \beta 0_{it} + \beta_1 URP_{it} + \beta_2 GDP_{it} + \beta_3 ENE_{it} + \beta_4 OIL_{it} + U_{it} \tag{1}$$

Subsequently, we employ the non-linear ARDL on panel data of 30 African countries (Shin, Yu & Greenwood-nimmo, 2014). The study employed the asymmetric panel NARDL model to study the non-linear relationship between crude oil price shocks, per capita CO_2 emission and per capita GDP in Africa. The advantage of the NARDL method is that the crude oil price can be decomposed into positive and negative change and the long and short-run asymmetric effect on the CO2 emission is examined across countries. Decomposing the oil into positive and negative changes makes it easy to see how CO2 emission responds to positive and negative oil price changes. The panel NARDL model is stated thus:

$$\begin{aligned}\Delta\, LCO2_{it} = \beta 0_i + \beta_{1i} LCO2_{it-1} + \beta_{2i} LURP_{it-1} + \beta_{3i} LGDP_{it-1} + \beta_{4i} LENE_{it-1} \\ + \beta_{5i}^{+} LOIL_{i,t-1}^{+} + \beta_{5i}^{-} LOIL_{i,t-1}^{-} + \sum\nolimits_{t-j}^{p1} \gamma_{1ij} \Delta \mathrm{LC02}_{i,t-j} \\ + \sum\nolimits_{t-j}^{p2} \gamma_{2ij} \Delta LURP_{i,t-j} + \sum\nolimits_{t-j}^{p3} \gamma_{3ij} \Delta LGDP_{i,t-j} \\ + \sum\nolimits_{t-j}^{p4} \gamma_{4ij} \Delta LENE_{i,t-j} + \sum\nolimits_{t-j}^{p5} \left(\gamma_{5i}^{+} LOIL_{i,t-j}^{+} + \gamma_{5i}^{-} LOIL_{i,t-j}^{-} \right) + \varepsilon_{it}\end{aligned} \tag{2}$$

Where LCO2 is the logarithm of CO2 emission, LGDP is the logarithm of GDP per capita, LOIL is the logarithm of crude oil price, LENE is the logarithm of energy consumption and LURP is the logarithm of the urban population, β_1 …. β_5 are the long-run parameter, γ_1 … …. γ_5 are the short-run parameters, Δ is the difference operator, β_{5i}^{+} and β_{5i}^{-} capture the long-run effect of crude oil price on carbon emission, $\sum_{t-j}^{p5} \gamma_{5i}^{+}$ and $\sum_{t-j}^{p5} \gamma_{5i}^{-}$ captures the short-run positive and negative effects of oil price shock on carbon emission ε_{it} is the error term.

The purpose of the NARDL is to determine whether oil price shocks have an asymmetric effect on CO2 emission in Africa. Thus, we decompose the oil price variable into positive ($LOIL^{+}$) and negative ($LOIL^{-}$). We carry out the Wald test to test the asymmetric effects thus:

$$\gamma_{5i}^{+} LOIL_{i,t-j}^{+} + \gamma_{5i}^{-} LOIL_{i,t-j}^{-} \tag{3}$$

We use the bound test to test the existence of long-run cointegration among the variables. If the result supports the long-run cointegration relationship, the error correction model (ECM) will be obtained from equation (1) and the second step of the NARDL procedure will be estimated. The existence of cointegration implies we estimate the following NARDL cointegrating regression model.

$$\begin{aligned}\Delta\, LCO2_{it} = \beta 0_i + \sum\nolimits_{t-j}^{p1} \gamma_{1ij} \Delta LC02_{i,t-j} + \sum\nolimits_{t-j}^{p2} \gamma_{2ij} \Delta LURP_{i,t-j} \\ + \sum\nolimits_{t-j}^{p3} \gamma_{3ij} \Delta \mathrm{LGDP}_{i,t-j} + \sum\nolimits_{t-j}^{p4} \gamma_{4ij} \Delta LENE_{i,t-j} \\ + \sum\nolimits_{t-j}^{p5} \left(\gamma_{5i}^{+} LOIL_{i,t-j}^{+} + \gamma_{5i}^{-} LOIL_{i,t-j}^{-} \right) + \theta_{i,j} ECM_{i,j} + \varepsilon_{it}\end{aligned} \tag{4}$$

All other variables remain the same except that the error correction ECM term is introduced. The term $\theta_{i,j}$ is the error correction parameter that captures the rate of return to long-run equilibrium when there is an oil price shock, while ECM is the residual obtained from equation (1). Where

$$\mathrm{ECM_{i,t}} = LCO2_{it} - \beta 0_{it} - \beta_1 LURP_{it} - \beta_2 LGDP_{it} - \beta_3 LENE_{it} - \beta_4 LIOL_{it} \tag{5}$$

We select the optimal lag length using the Schwarze Bayesian Criterion (SBC). The maximum lag length is 2. The preliminary tests employed include the panel unit root test, cross-sectional dependence test and the Pedroni panel cointegration test (Pedroni, 1999, 2004). The panel unit root tests consist of Levin et al. (2002) t-statistics, Im et al. (2003) W-statistic, ADF-Fisher and PP-Fisher Chi-square statistics. The Levin et al. (2002) t-statistics assume a homogeneous unit root process among the variables while Im, Persaran and Shin (2003) W-statistic, ADF-Fisher and PP-Fisher Chi-square statistics assume a heterogeneous or individual unit root process.

4. Results

We begin the analysis of this study by examining the nature of the data. Table 1 depicts the descriptive statistics and correlation of the variables used in the study. The data comprises 1020 observations for each variable. Table 1 shows that deviation is more in CO2 emission relative to the other variables used in the model. This implies that CO2

Table 1
Descriptive statistics and correlation matrix.

Variables	LCO2	LENE	LGDP	LOIL	LURP
Panel A: Summary Statistics					
Mean	15.500	7.701	23.540	3.589	15.313
Median	15.316	7.610	23.455	3.437	15.391
Maximum	20.035	10.705	26.944	4.602	18.448
Minimum	11.040	4.587	18.934	2.669	11.643
Std. Dev.	1.770	1.302	1.441	0.641	1.308
Observations	1020	1020	1020	1020	1020
Panel B: Correlation Matrix					
LCO2	1				
LENE	0.553***	1			
LGDP	0.83	0.332***	1		
LOIL	0.209***	0.145***	0.246***	1	
LURP	0.747***	−0.024302	0.872***	0.223***	1

Note: ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

emission deviates widely from its mean and across countries; suggesting that some countries emit CO2 more than others. Oil price change has the least deviation from its mean. This is because the price of crude is determined by the international market. The minimum and maximum values of crude oil prices show that oil prices can go as high as doubling its minimum price. The correlation analysis reveals a positive correlation between CO2 emissions, GDP, energy consumption and urban population. Except for energy consumption and urban population all other variables positively correlated with one another. The correlation between energy consumption and urban population is however insignificant. The correlation coefficients indicate that the problem of collinearity or multicollinearity does not exist among the variables.

We examine the stationarity of the variables over the period covered in this research. The unit root tests were carried out using panel unit root with intercept. The panel unit root test consists of the Levin, Lin and Chu test (Levin, Lin & Chu, 2002), IM, Pesaran and Shin (IM, Pesaran & Shin, 2003), the Fisher ADF and Fisher PP statistics (Maddala and Wu, 1999; Choi, 2001). Table 2 presents the results from the panel unit root tests.

The results of the panel unit root tests reveal that at level, the null hypothesis of the presence of unit root in the variables is not rejected for LCO2, LGDP, LOIL and LENE. The series LURB is however stationary at level. The other variables are stationary at first difference. The results imply that all the variables are stationary at the first difference for all the panel unit root tests except urban population which is stationary at level. This denotes that carrying out a non-linear ARDL is an appropriate estimation method.

Next, we test for the existence of long-run cointegration among the variables. The study employed the Pedroni (1999, 2004) panel cointegration test that accounts for both within and that test the between group cointegration. The Pedroni (1999, 2004) cointegration test is a residual-based cointegration test that allows the short-run and the long-run coefficients to differ across cross-sections. Table 3 contains the results of the Pedroni cointegration test. The Pedroni cointegration test consists of seven statistics. The Pedroni cointegration test shows that out of the seven statistics only one -the group rho-statistic- rejects the null hypothesis of no cointegration if we assume no trend for the variables. When we included the trend, the result indicates that three of the test statistics-panel v-Statistic, panel rho-statistic and group rho-statistic- reject the null hypothesis of no cointegration. According to Pedroni (2004) and Örsal (2014), among the seven statistics, the panel ADF and group ADF are considered to be more reliable statistics, thus, we reject the null hypothesis of no cointegration. This implies that long-run cointegration exists for both the within and the between dimension among the variables.

Table 3
Pedroni panel cointegration tests.

Statistics	without trend		with trend	
	Statistic	Prob.	Statistic	Prob.
Within-Dimension				
Panel v-Statistic	1.480*	(0.069)	−0.801	(0.788)
Panel rho-Statistic	−1.571**	(0.058)	−0.251	(0.401)
Panel PP-Statistic	−7.292***	(0.000)	−8.074***	(0.000)
Panel ADF-Statistic	−4.682***	(0.000)	−5.207***	(0.000)
Between-Dimension				
Group rho-Statistic	−0.650	(0.258)	0.720	(0.764)
Group PP-Statistic	−11.257***	(0.000)	−14.79***	(0.000)
Group ADF-Statistic	−4.018***	(0.000)	−5.223***	(0.000)

Note: probability values in parentheses. ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

After substantiating the stationarity of the panel series and the long-run cointegration relationship, we carried out the long-run and short-run estimates using the panel-NARDL. The aim is to ascertain the asymmetric effect of change in crude oil price on CO2 emission in Africa. The results of the non-linear ARDL are presented in Table 4.

Table 4 provides the result from the non-linear ARDL model. The Table shows both the long-run and the short-run response of CO2 emission to energy consumption, GDP, crude oil prices and urban population. Crude oil prices are separated into positive and negative changes. A one percent positive change in oil price is related to a 0.047 percent decrease in CO2 emission in Africa. The result also indicates that a one percent negative change in oil price is related to a 0.139 percent increase in CO2 emission in Africa. The Wald test statistics of 25.131 confirm that the positive and negative oil prices are significant-thus, the asymmetric effect of oil price changes on CO2 emissions exists in the long run. This implies that both the positive and negative oil price changes affect CO2 emission in the selected countries in an asymmetric way. Table 4 also shows that urban population, GDP, and energy consumption have a positive and significant effect on CO2 emission. That is, for a one percent increase in energy consumption, GDP and urban

Table 2
Panel unit root tests.

Variable	Level				1st diff				Remark
	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square	
LCO2	−1.261	−0.803	71.274	96.162	−11.5***	−17.35***	380***	1683***	I(1)
	(0.104)	(0.211)	(0.197)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	
LGDP	−1.594	1.458	59.403	63.920	−4.526***	−8.9***	198.9***	580.2***	I(1)
	(0.99)	(0.928)	(0.570)	(0.409)	(0.000)	(0.000)	(0.000)	(0.000)	
LENE	−1.227	0.277	57.178	65.244	−11.1***	−14.8***	320***	1331***	I(1)
	(0.110)	(0.609)	(0.650)	(0.365)	(0.000)	(0.000)	(0.000)	(0.000)	
LOILP	2.383	2.162	25.776	25.310	−22.1***	−17.2***	364***	478***	I(1)
	(0.991)	(0.985)	(1.000)	(1.000)	(0.000)	(0.000)	(0.000)	(0.000)	
LURP	−13.39***	−12.2***	309***	210.***	–	–	–	–	I(0)
	(0.000)	(0.000)	(0.000)	(0.000)					

Note: probability values in parentheses. ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

Table 4
Result of non-linear ARDL estimate.

Variable	Coefficient	t-Statistic	Prob.*
Long Run Equation- Dependent Variable: CO2 Emission			
LENE	0.357***	6.332	0.000
LGDP	0.617***	8.464	0.000
LOIL_positive	−0.047***	−2.847	0.005
LOIL_negative	0.139***	6.041	0.000
LURP	0.773***	10.834	0.000
Short Run Equation- Dependent Variable: ΔCO2			
ECM	−0.472***	−6.760	0.000
Δ (LCO2(-1))	−0.058	−1.034	0.301
Δ (LENE)	0.281***	2.961	0.003
Δ (LENE(-1))	0.043	0.562	0.574
Δ (LGDP)	−0.001	−0.003	0.997
Δ (LGDP(-1))	−0.124	−0.688	0.492
Δ (LOIL_positive)	0.002	0.045	0.964
Δ (LOIL_positive(-1))	0.039	0.789	0.430
Δ (LOIL_negative)	0.021	0.377	0.706
Δ (LOIL_negative(-1))	−0.066	−1.625	0.105
Δ (LURP)	−14.925	−1.469	0.142
Δ (LURP(-1))	13.074	1.370	0.171
C	−6.293***	−6.542	0.000
Akaike info criterion			−1.439
Schwarz criterion			0.515
Hannan-Quinn criterion			−0.696
S.E. of regression			0.135
Wald Statistics			25.131
Prob, value (Wald statistics)			(0.000)

Note: ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

population, CO2 emission increases by 0.357, 0.617 and 0.773 percent respectively. These are all significant at a one percent significant level. The implication here is that the substantial increase in CO_2 emission in Africa is caused by these factors.

For the short-run effect of oil price change, in Table 4 oil price seems not to have a significant effect on CO2 emission in Africa. The t-statistics and Wald test indicates that the positive and negative changes in crude oil price have no significant effect on CO_2 emission in Africa in the short run. However, energy consumption is the main factor affecting CO_2 emission in the short run. The error correction term that shows the speed of adjustment indicates a 0.472 percent return to equilibrium when there is a shock in the system. This is significant at one percent. The result in Table 4 meets the apriori expectation that an increase in oil price would have a negative effect on CO2 emission.

To further examine the effect of oil price on CO_2 emission, we disaggregate our sample into oil-exporting and oil-importing countries and then estimate the asymmetric effect based on equation (2). The result of the response of CO_2 emission in net oil-exporting countries and oil-importing countries to positive and negative changes in crude oil price is presented in Table 5.

In Table 5, we observed that oil price increase has a negative impact on CO_2 emission in both net oil-exporting and importing countries. The results in Table 5 reveal that a one percent positive change in oil price is related to a 0.038 and 0.081 percent decrease in CO_2 emission in both net oil-exporting and oil-importing countries respectively. The result also indicates that a one percent negative change in oil price is related to a 0.204 and 0.108 percent increase in CO2 emission in net oil-exporting countries and net oil-importing countries respectively. The Wald tests indicate that the positive and negative changes in oil prices are significant, implying that both the positive and negative oil price changes affect CO2 emission in the selected countries in an asymmetric way. The outcome from Table 5 is intuitive as it shows that in the period of oil price increase, the reduction in CO2 emission is more in net oil-importing countries than in oil-exporting countries. The results further show that when there is a decrease in crude oil price, the increase in CO2 emission is more in oil-exporting countries than in oil-importing countries.

The results in Table 5 further draw attention to dynamic response of CO2 emission in oil-exporting countries where positive change in oil price is associated with CO2 emission reduction.

Next, we examine the short-run effect of changes in oil prices on CO2 emissions in various countries. The result is presented in Table 6. The result in Table 6 reveals that oil price increase seems to exhibit a significant negative impact on CO2 emissions in Algeria, Libya, Cote

Table 5
Effect of oil price change on CO_2 emissions in oil-exporting and Importing Countries.

Variable	Coefficient	t-Statistic	Prob.*	Coefficient	t-Statistic	Prob.*
	Oil-Exporting			Oil-Importing		
Long Run Equation- Dependent Variable: CO2 Emission						
LENE	0.449***	4.352	0.000	0.355***	5.209	0.000
LGDP	0.493***	4.114	0.000	0.709***	7.394	0.000
LOIL_ positive	−0.038**	−1.93	0.027	−0.081***	−4.667	0.000
LOIL_ negative	0.204***	4.896	0.000	0.108***	3.763	0.000
LURP	0.985***	4.815	0.000	0.670***	7.171	0.000
Short Run Equation- Dependent Variable: ΔCO2						
COINTEQ01	−0.545***	−4.166	0.000	−0.469***	−4.176	0.000
Δ (LCO2(-1))	−0.013	−0.128	0.898	−0.157*	−1.811	0.071
Δ (LENE)	0.152	0.980	0.328	0.307***	3.356	0.001
Δ (LENE(-1))	−0.064	−0.449	0.654	0.084	0.902	0.368
Δ (LGDP)	0.237	0.738	0.461	−0.393	−1.417	0.158
Δ (LGDP(-1))	−0.041	−0.131	0.896	0.200	0.669	0.504
Δ (LOIL_positive)	0.071	0.754	0.451	−0.151***	−2.061	0.040
Δ (LOIL_positive(-1))	0.145**	1.903	0.058	−0.012	−0.206	0.837
Δ (LOIL_negative)	0.057	0.727	0.468	−0.013	−0.143	0.886
Δ (LOIL_negative(-1))	−0.120	−1.454	0.147	−0.082	−1.690	0.092
Δ (LURP)	−34.432	−1.630	0.104	13.451	0.834	0.405
Δ (LURP(-1))	26.995	1.359	0.175	−18.215	−0.716	0.475
C	−7.757***	−4.005	0.000	−5.493***	−4.102	0.000
Akaike info criterion		−1.025				−1.808
Schwarz criterion		0.649				0.609
Hannan-Quinn criterion		−0.366				−0.864
S.E. of regression		0.169				0.090
Wald-Statistics		12.337				21.858
P-value (Wald-Stat)		(0.000)				(0.000)

Note: ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

Table 6
Short-run effect of oil price change on CO2 emissions across countries.

Country	ECM	D(LENE2)	D(LGDP)	D(LOIL_POS)	D(LOIL_NEG)	D(LURP)	C
Net oil-exporting							
Dependent Variable: ΔCO2							
Algeria	−0.368***	0.174	0.709	−0.168***	−0.095***	1.586	−5.204
	(0.000)	(0.148)	(0.124)	(0.000)	(0.000)	(0.795)	(0.252)
Nigeria	−0.123***	0.148	2.704**	0.474***	0.129**	−23.898	−0.793
	(0.008)	(0.240)	(0.049)	(0.005)	(0.048)	(0.852)	(0.892)
Angola	−0.978***	0.038	1.114***	0.278**	−0.025	−9.139	−13.742
	(0.000)	(0.827)	(0.011)	(0.041)	(0.712)	(0.686)	(0.216)
Egypt	−0.266***	0.302	−0.163	0.107***	−0.065***	−4.293	−3.706
	(0.000)	(0.385)	(0.844)	(0.004)	(0.004)	(0.938)	(0.298)
Libya	−0.279***	0.141***	−0.186	−0.042*	0.061***	−4.189	−3.713
	(0.000)	(0.005)	(0.200)	(0.060)	(0.007)	(0.638)	(0.197)
Gabon	−0.237***	0.290***	0.519*	0.215***	−0.095***	4.216	−3.429
	(0.000)	(0.002)	(0.054)	(0.001)	(0.003)	(0.749)	(0.324)
Ghana	−0.694***	−0.480***	−0.251	0.047	0.057**	−3.983	−9.794
	(0.000)	(0.001)	(0.758)	(0.149)	(0.037)	(0.811)	(0.194)
Sudan	−0.198***	0.187***	−1.019**	−0.089	−0.020	−1.888	−2.723
	(0.000)	(0.074)	(0.041)	(0.212)	(0.642)	(0.388)	(0.188)
Republic of Congo	−0.084***	1.303***	0.818***	0.077**	0.184***	5.155	−1.523
	(0.001)	(0.000)	(0.015)	(0.084)	(0.009)	(0.863)	(0.497)
Equatorial Guinea	−0.296***	0.064***	0.975***	−0.180	0.190	−7.179	−3.369
	(0.001)	(0.003)	(0.005)	(0.507)	(0.321)	(0.883)	(0.293)
Chad	−0.203***	0.388***	−1.157*	0.369	0.374*	0.551	−2.768
	(0.003)	(0.007)	(0.075)	(0.175)	(0.084)	(0.999)	(0.397)
Cameroon	−0.198***	0.501***	−0.075**	0.009***	−0.022***	−1.180	−2.743
	(0.001)	(0.000)	(0.027)	(0.019)	(0.001)	(0.407)	(0.374)
Cote d'Ivoire	−0.467***	0.651***	0.524	−0.181**	0.140**	1.902	−6.827
	(0.000)	(0.006)	(0.302)	(0.030)	(0.023)	(0.943)	(0.302)
Tunisia	−0.252***	−0.069***	−0.254	0.048***	−0.063***	1.507	−3.499
	(0.000)	(0.002)	(0.195)	(0.001)	(0.000)	(0.146)	(0.280)
Net oil-importing							
Dependent Variable: ΔCO2							
South Africa	−0.777***	0.434***	0.213	0.069***	−0.089***	0.322	−10.726
	(0.000)	(0.001)	(0.240)	(0.000)	(0.000)	(0.936)	(0.188)
Morocco	−0.198***	0.501***	−0.075***	0.009***	−0.022***	−1.180	−2.743
	(0.001)	(0.000)	(0.027)	(0.019)	(0.001)	(0.407)	(0.374)
Zambia	−0.148***	0.933***	0.256	−0.296***	−0.092***	0.957	−2.113
	(0.000)	(0.000)	(0.281)	(0.000)	(0.001)	(0.471)	(0.295)
Serre-Leone	−0.423***	−0.036	1.268***	0.082	−0.316***	5.017	−6.138
	(0.001)	(0.458)	(0.011)	(0.570)	(0.027)	(0.746)	(0.396)
Kenya	−0.227***	0.829***	−0.021	0.212***	−0.198***	6.927	−3.585
	(0.000)	(0.003)	(0.978)	(0.001)	(0.001)	(0.879)	(0.213)
Mauritius	−0.566***	−0.353***	0.587	0.271***	−0.009	−10.834	−7.608
	(0.000)	(0.001)	(0.459)	(0.000)	(0.205)	(0.746)	(0.192)
Mozambique	−0.306***	0.158***	−0.740	−0.593***	0.310***	6.022	−4.442
	(0.000)	(0.004)	(0.268)	(0.001)	(0.003)	(0.695)	(0.1500
Namibia	−0.786***	−0.011	−2.044**	−0.100**	−0.050*	1.591	−10.664
	(0.000)	(0.721)	(0.037)	(0.027)	(0.067)	(0.972)	(0.163)
Senegal	−0.363***	0.357***	0.670	0.004	−0.053***	12.663	−5.415
	(0.000)	(0.006)	(0.382)	(0.879)	(0.050)	(0.660)	(0.251)
Tanzania	−0.715***	−0.035	1.763*	−0.145***	0.054***	7.714	−10.772
	(0.000)	(0.313)	(0.068)	(0.001)	(0.005)	(0.444)	(0.257)
Togo	−0.372***	0.420***	−0.556**	0.246***	−0.525***	−2.875	−4.792
	(0.001)	(0.000)	(0.048)	(0.012)	(0.001)	(0.973)	(0.457)
Zimbabwe	−0.738***	0.064	−0.265*	0.087***	0.053	3.766	−9.976
	(0.000)	(0.717)	(0.069)	(0.072)	(0.103)	(0.255)	(0.197)
Benin	−0.114***	−0.050***	−0.303	−0.083**	0.070***	−1.843	−1.384
	(0.000)	(0.002)	(0.648)	(0.023)	(0.018)	(0.917)	(0.250)
Botswana	−0.623***	0.190*	−1.812**	−0.272***	0.677***	2.002*	−8.304
	(0.000)	(0.061)	(0.023)	(0.002)	(0.001)	(0.058)	(0.140)
The Gambia	−0.270***	0.012	−0.121	0.035***	−0.057***	−0.440	−3.558
	(0.000)	(0.576)	(0.111)	(0.007)	(0.001)	(0.607)	(0.189)

Note: probability values in parentheses. ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

d'Ivoire, Zambia, Mozambique, Benin and Botswana in the short run. While the positive changes in oil price have a significant positive influence on CO2 emission in Nigeria, Angola, Egypt, Gabon, Republic of Congo, Cameroon, Tunisia, South Africa, Morocco, Kenya, Mauritius, Togo, Zimbabwe and the Gambia. Again, we observed that the changes in crude oil price have no significant effect on CO2 emissions in Ghana, Sudan, Equatorial Guinea, Chad, Serre-Leone, and Senegal.

Similarly, the negative changes in crude oil price positively affect CO2 emission in Nigeria, Libya, Ghana, the Republic of Congo, Chad, Cote d'Ivoire, Mozambique, Tanzania, Benin, and Botswana; while the negative changes in CO2 emission further exhibited a negative effect on CO2 in Algeria, Egypt, Gabon, Cameroon, Tunisia, South Africa, Morocco, Zambia, Serre-Leone, Kenya, Senegal, Togo, and the Gambia. The negative oil price change is insignificant in Angola, Sudan, Equatorial Guinea, Mauritius, and Zimbabwe. Overall, in the short run, we find that a positive increase in oil prices is associated with a decrease in CO2 emission in both oil-importing countries and oil-exporting countries. More importantly, we document that the degree to which CO2 emissions respond to the positive changes in crude oil price is more in net oil-importing countries than in net oil-exporting countries. In Table 6, it is also evident that the disequilibrium due to shocks from the crude oil price is corrected within a year in all the countries examined. The gleanings from the results in Table 6 are that the positive changes in crude oil prices negatively impact CO2 emission. Second, negative changes in crude oil prices exhibit a positive effect on CO2 emission in net oil-importing countries than in net oil-exporting countries. Additionally, the asymmetric effect of the changes in crude oil price on CO2 emission does not differ significantly in net oil-importing and net oil-exporting countries of Africa as both positive and negative changes tend to elicit almost similar responses.

Knowing how important energy consumption is to the economic growth of developing nations, we examine how GDP responds to positive and negative changes in CO2 emissions in Africa. The result is presented in Table 7. The result in Table 7 indicates that a positive change in CO2 emission causes positive changes in GDP in the panel. However, such an increase is found to be more for oil-exporting countries than for oil-importing countries. The negative changes in CO2 emission are associated with an increase in GDP for oil-importing countries but engender a decrease in GDP for net oil-exporting countries.

The findings are robust to different subsamples of oil-importing and oil-importing, as well as individual African countries. Also, the diagnostic test for serial correlation, functional form, and heteroskedasticity show the model performs well in all the tests. In addition, the stability test of the cointegration parameters was verified using the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMSQ) tests. The CUSUM and CUSUMSQ revealed all the parameters are stable.

5. Discussion of findings

This study estimates confirm that oil price has an asymmetric effect on carbon emission in the long run for both oil-importing countries and oil-exporting countries of Africa. The findings show that an increase in oil prices leads to a decrease in both carbon emissions and economic growth. However, the carbon emission-reduction impact of oil price increases is more for oil-importing countries than the oil-exporting countries. The result suggests that previous studies may have overlooked the asymmetric effect of oil price shock on carbon emissions in Africa. In particular, the study shows that a reduction in oil prices still has a negative effect on carbon emissions even among some oil-importing countries in Africa.

The findings are in line with the substitution and income effect of price change. An increase in oil price makes energy more costly for oil-importing countries as such are more likely to seek other alternatives to fossil fuels, thus, reducing CO2 emissions. On the other hand, a decrease in oil price implies cheap energy sources from fossil fuels, thus, increasing the consumption of more fossil fuels which leads to an increase in CO2 emissions. Also, most of the oil-exporting countries in Africa export crude and import processed oil products (like diesel, Premium motor spirit, and the like) thus, they are still affected by the market price of crude oil through imported finished products of crude oil. As such the increase in oil price has a direct impact on the citizens of oil-exporting countries and they will want to reduce energy sources from crude oil; thus, reducing CO2 emissions. The idea is that, since there is a strong link between the oil price and CO2 emission, any shock in the price of oil price affects CO2 emission.

The finding of this study is in line with Stylina-Iris et al. (2019) who observed that the positive change in crude is having a gradual effect on CO2 emission in some European countries. Similarly, Ullah et al. (2020) submit that the increase and decrease in oil prices cause a significant effect on CO2 emission. Moreover, the findings are in line with (Alper and Oguz (2016) and Boufateh (2021) who show that an oil price increase does not affect CO2 emission uniformly. In addition, the finding

Table 7
Result of Asymmetric effect of CO2 emission on GDP in Africa.

Variable	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
	All Countries		Net-Import Countries		Net-Export Countries	
Long Run Equation- Dependent Variable: GDP						
LENE	0.230***	(0.000)	0.260***	(0.000)	0.761***	(0.000)
LCO2_positive	0.134***	(0.000)	0.089*	(0.071)	0.578***	(0.000)
LCO2_negative	0.236***	(0.000)	0.219***	(0.000)	−0.437**	(0.016)
LOIL_positive	−0.052	(0.110)	0.015	(0.717)	−0.081	(0.149)
LOIL_negative	0.259***	(0.000)	0.250***	(0.000)	−0.008	(0.903)
LURP	2.115***	(0.000)	1.941***	(0.000)	−0.542	(0.269)
Short Run Equation -Dependent Variable: ΔLGDP						
ECM	−0.082**	(0.022)	−1.226**	(0.022)	−0.064*	(0.087)
D(LGDP(-1))	0.070	(0.153)	−0.039	(0.538)	–	–
D(LENE)	0.043	(0.102)	0.047	(0.301)	0.020	(0.547)
D(LENE(-1))	–	–	–	–	0.010	(0.786)
D(LC02_positive)	0.035*	(0.066)	0.006	(0.823)	0.045	(0.336)
D(LC02_positive(-1))	–	–	–	–	0.038	(0.295)
D(LC02_negative)	−0.018	(0.640)	−0.034	(0.598)	0.102**	(0.024)
D(LC02_negative(-1))	–	–	–	–	0.046	(0.348)
D(LOILP_positive)	0.005	(0.634)	−0.004	(0.809)	−0.023	(0.412)
D(LOILP_positive(-1))	–	–	–	–	−0.023**	(0.041)
D(LOILP_negative)	0.007	(0.490)	0.006	(0.702)	0.021	(0.304)
D(LOILP_negative(-1))	–	–	–	–	0.031	(0.226)
D(LURP)	1.264*	(0.054)	0.748	(0.203)	4.028	(0.313)
D(LURP(-1))	–	–	–	–	−1.213	(0.795)
C	−0.840**	(0.019)	−0.731	(0.116)	1.631*	(0.085)
Mean dependent var		0.061813		0.045953		0.07727
S.E. of regression		−3.79751		−3.97132		−3.52481
Sum squared resid		−2.41746		−2.734		−1.71662
Log-likelihood		−3.27343		−3.48799		−2.81291
S.E. of regression		0.04097		0.033445		0.051016
Wald-Statistics		56.141		25.282		11.481
P-value (Wald-Stat)		(0.000)		(0.000)		(0.000)

Note: probability values in parentheses. ***, **, and * indicate that the test statistics is significant at 1%, 5%, and 10% levels, respectively.

of this study is similar to the results of Bouznit and Pablo-Romero (2016), Usama (2011), and Muhammed (2019) who revealed that crude oil remains a useful source of energy in Africa. Relative to other sources of energy, fossil fuel like crude remains relatively cheaper and accessible compared to other sources like renewable energy. This is because the facility and infrastructure necessary for other sources are scarce and economically not viable for most individuals and businesses (Alper and Oguz, 2016).

6. Conclusion and policy implications

This study examines the asymmetric effect of crude oil prices on CO2 emissions in Africa. The panel non-linear ARDL was employed as the estimation technique. The net oil-exporting countries examined in this study are Nigeria, Angola, Algeria, Egypt, Libya, Gabon, Ghana, Sudan, the Republic of Congo, Equatorial Guinea, Chad, Cameroon, Cote d'Ivoire, and Tunisia. While the net oil-importing countries include South Africa, Morocco, Liberia, Serre-Leone, Kenya, Mauritius, Mozambique, Namibia, Senegal, Tanzania, Togo, Zimbabwe, Benin, Botswana, and the Gambia. From the regression result, three important conclusions can be drawn. First, an increase in the price of oil price provides incentives to reduce CO2 emissions in net oil-exporting and importing countries of Africa. Second, positive oil price change decreases incentives to reduce CO2 emissions in oil-exporting countries. Third, while negative changes in CO2 emission increases GDP in net exporting countries, negative changes in CO2 emission tend to reduce GDP in net oil-exporting countries thus, discouraging CO2 emission reduction in net oil-exporting countries. The result implies that advocating for CO2 reduction has a strong negative impact on the income of net-exporting countries, thus, many net oil-exporting countries in Africa may find it difficult to comply with the CO2 emission agreement.

Other outcomes in the study reveal that a high population is associated with an increase in CO2 emissions in all African countries. As expected, higher energy consumption increases CO2 emissions in all the selected countries. Positive changes in CO2 emission are associated with increases in GDP. Thus, a reduction in CO2 implies decreasing production and a shrinking economy, especially in net oil-exporting countries. This implies that net-exporting countries are more susceptible and growth dependent on oil as such countries may continue to emit or may not be willing to keep to emission control agreement. To attenuate the environmental impact of CO2 emission, this study recommends an increasing call on CO2 emission reduction especially in oil-exporting countries of Africa as oil price does not exhibit enough push factor towards CO2 emission mitigation in the continent.

The limitation of this study is that it did not consider the subsample of the African countries based on income levels. Since the level of income has been identified as a fundamental driver of carbon emission, further studies which considered countries based on different classifications of incomes (Low-income, Low-middle income, Middle-come, and High-income countries) can provide more insight into the nexus between the oil price, carbon emissions, and economic growth in the continent.

Authors contributions

Innocent Okwanya, Patricia O. Abah: Conceptualization, Methodology, Software, Literature review, **Ilhan Ozturk**, **Festus Victor Bekun**:Supervision, Writing, Reviewing and Editing, **Eje-Ojeka G. Amaka, Abdulkareem Alhassan:** Data curation, Writing, Visualization, Results.

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.

Data availability

Data will be made available on request.

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