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Energy Resource Melioration and CO_2 Emissions in China and Nigeria: Efficiency and Trade Perspectives

Abstract

Circular economy is one effective strategy to achieve a healthy environment and efficient use of resources. In this study, the trade relationship between China and Nigeria is used to establish how circular economy ameliorates climate change. On the basis of CO_2 emissions, data from 1991 to 2014 are obtained and measures for energy efficiency in the mining and extractive-related sectors from energy intensity are derived using Fisher ideal index decomposition. This study utilizes panel-corrected standard error, feasible generalized least squares, autoregressive distribute lag bound, and Bayesian VAR models. These techniques suggest that energy efficiency in the mining and extractive-related sector and the circular economy have not translated into CO_2 emission reduction in both countries. However, economic growth, energy use (non-renewable energy), and clean energy substitution (renewable energy) are essential factors in mitigating CO_2 emissions. Given such evidence, resource melioration for energy consumption and economic growth have indispensable roles in reducing CO_2 emissions.

Keywords: Circular economy; CO_2 emissions; energy resource melioration; efficiency; trade

1. Introduction

Circular economy is an effective strategy to achieve a healthy environment and efficient resource usage. According to *The Circularity Gap Report 2019*, circular economy ensures resource efficiency and maximizes the chances of climate change reduction. Thus, circular economy is a significant game changer in the fight against CO_2 emissions, and yet largely ignored in efforts to achieve the Paris agreement.

Circular economy is a regenerative system in which resource input, waste, and emission are minimized through repurposing, reusing, refurbishing, and recycling (United Nations Climate Change, 2019). Although this description may relate more to production process or practices within a country, international trade can also ensure circular economy. In this global era, countries can reduce its negative impact on the environment by refurbishing products and waste materials into relevant products for the international market. An example of such circular economy is the trade between China and most African countries, their fastest growing trading partner according to the China African Research Initiative (CARI). Specifically, the goal to continue the circular economy has raised the trade relationship between China and Nigeria. The latter has become a destination of low-cost electronic gadgets produced by the Chinese industry from byproducts and materials that are considered wastes[1]. Nigeria remains one of China's top trading partners for exports, contracts, and investments of oil and gas. In 2018, Nigeria has imported $13.5 billion worth of goods and services from China compared with only $2.68 billion from the United States (US). Similarly, Nigeria exported goods with a total of $18.5 billion to China compared with $5.7 billion to the US (CARI, 2019). China also holds substantial parts of oil drilling in Nigeria, with four licenses worth over $4 billion in oil and infrastructure development projects (LeVan et al., 2018). Such trades between the two countries ensure resource efficiency and help the environment by preventing wastes that may increase CO_2 emissions in landfills (Mangla et al., 2020).

Similar to a circular economy, efficient use of energy is recommended to ensure a healthy environment in the future. Mining and extractive-related sectors cause the highest environmental degradation. Thus, these sectors have always been highlighted in terms of energy efficiency practices, especially in emerging economies. However, energy efficiency may not reduce CO_2

[1] From developing high-quality and costly products for European and American markets.

emissions if companies do not use clean energy and reduce waste. Thus, the circular economy must be partnered with sustainable practices to optimize and meliorate basic resources, such as water and fossil fuel, for extraction and mining operations.

Despite the benefits of a circular economy, its practice has not been properly adopted in certain nations, such as China and Nigeria. The pollution levels in these countries remain high. CO_2 emissions in China have increased rapidly (i.e., 0.3 to point 1) from 1990 to 2015. This phenomenon indicates the similar increase of residential and industrial energy consumption of non-renewable or clean energy over time. However, a different trend is observed in Nigeria, wherein residential and industrial energy consumption remains low due to the lack of available energy required to satisfy the growing demand. Thus, Nigeria shows CO_2 emissions with a negative value (see Figure 1), which indicates its gradual fluctuations. The continuous CO_2 radiation in China and Nigeria is dangerous to humanity and the natural ecology and likely to cause deaths. Thus, identifying the real determinant of CO_2 emissions in the two countries is imperative.

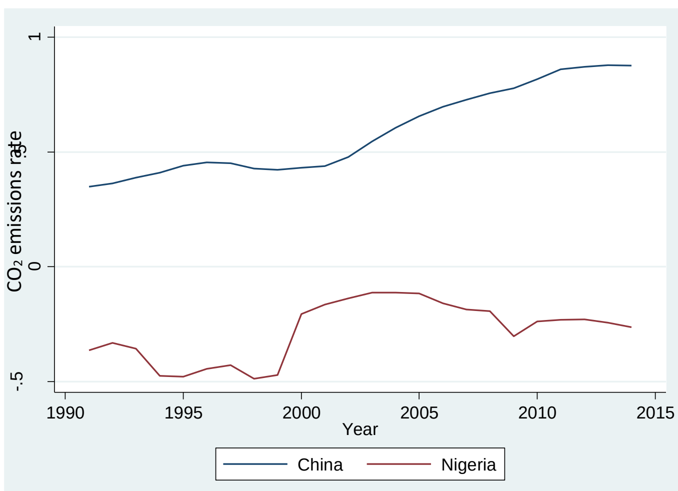

Figure 1. Annual rate of CO_2 emissions in China and Nigeria

The extent of calamity attributed to CO_2 emissions in the environment is well known. All governments and individuals are encouraged to minimize their CO_2 emissions due to its negative effects on the environment. To achieve this goal, the simplest approach is energy use reduction (also known as energy efficiency), which can reduce the necessary amount of electricity and thereby lead to a drastic decline in CO_2 emissions. The growing level of energy efficiency in varying industries translates to a substantial investment, but in numerous cases, pays back immediately through of energy cost reduction. However, improving energy efficiency does not always result in CO_2 emission reduction (Napp et al., 2012; Zaidi et al., 2019). Energy efficiency must be used depending on varying situations per country. Fossil fuel supply, such as petrol used by cars or electricity extracted from a coal-fired plant, must improve in efficiency to reduce the CO_2 emission growth. However, obtaining power from nuclear or renewable sources shows insignificant impact on CO_2 emissions.

Energy sources of low-emission technologies can pay back investments in terms of environmental quality by reducing the CO_2 emission growth. However, renewable energy is not 100% free of CO_2 emissions. Full reductions can only be achieved if power grids are based on renewable energy, thereby reducing the reliance on fossil power (Bulut, 2017; Mangla et al., 2018). Thus, applying renewable energy strategies can effectively address climate change and improve the environment. By extension, 100% renewable energy strategy is possible by 2025, and projections show that CO_2 emissions can decline by 119% (Xia, 2019). Notably, renewable energy sources have low or zero emissions and are thus environmentally friendly.

In addition to efficient energy usage, trade has another important connection to CO_2 emissions. Trade theory suggests that trade volume influences CO_2 emissions through three major channels: scale, composition, and technique effects (Grossman and Krueger, 1991). In the scale effect, increments in economic activities result in continued increase in CO_2 emissions. Trade can also influence the growth of CO_2 emissions if export products inherently emit greenhouse gases. The overall level of emissions thereby increases, which is known as the composition effect. Moreover, CO_2 emissions are reduced via the transfer of clean technologies when production methods are replaced, which is known as the technical effect (Wang et al., 2019).

The determinants of CO_2 emissions have been previously investigated. Tajudeen et al. (2018) and Hu, Li, and Zhang (2019) confirmed the reliability of energy efficiency in controlling the CO_2 emission growth. Chong et al. (2019) reported that the interaction of CO_2 emissions with energy usage negatively affects the environment due to increased discharge. Other studies found that economic growth is the primary driver of CO_2 radiation (Muhammad and Khan, 2019;

Munir et al., 2020; Muhammad, 2019; Adedoyin et al., 2020; Cherni and Essaber Jouini, 2017; Wang et al., 2019) and that trade plays a major role in influencing the CO_2 emission growth (Essandoh et al., 2020; Zhang et al., 2019; Balsalobre-Lorente el at., 2019; Haug and Ucal, 2019). However, such studies have done little to address scope restriction and real measures of energy efficiency violations. First, research focused on European and American cases, and rarely considered the China–Nigeria nexus. Second, studies that considered China and Nigeria have used energy intensity as a proxy for energy efficiency. This approach is likely to provide biased results, and the overall finding holds little justification. Against this background, the present study investigates the role of energy efficiency and the trade relationship between China and Nigeria on the basis of CO_2 emissions.

A Fisher ideal index decomposition analysis is used to construct the real measure of energy efficiency. Econometric procedures through PCSE, FGLS, ARDL bound, and Bayesian VAR models are adopted to account for nonlinear relationships among variables and thus evaluate the interaction of energy efficiency and trade with CO_2 emissions. Given that resource efficiency is more appealing to the mining and extractive-related industries, data from this sector are used as basis for the measures of energy efficiency. Primary findings show that *trade has no significant association with CO_2 emissions, whereas clean energy substitutions help reduce the CO_2 emission growth.* Moreover, CO_2 emission reduction in China depends on the level of economic growth and clean energy substitution, but that in Nigeria does not decrease despite the increase in economic growth and clean energy substitutions. Given these findings, policymakers must judiciously use all avenues available to achieve full clean energy utilization and economic growth.

This study provides three major contributions to existing literature. First, this study is a pioneer in considering the real measures of the energy efficiencies of China and Nigeria. Second, the circular economy through trade does not necessarily translate into CO_2 emission reduction. By contrast, resource melioration energy (clean energy) reduces CO_2 emissions and improves energy efficiency. Third, CO_2 emissions differ from country to country, and the measures for mitigating these emissions also vary. For example, Nigeria shows a high level of CO_2 emissions despite its economic growth and increased use of clean energy. By contrast, China's investments in clean energy have started paying off by reducing CO_2 emissions. Therefore, policymakers are advised to carefully consider the country level or nature of CO_2 emissions before implementing decisive actions. Resource melioration for energy consumption in the two countries appears to be an advantage in addressing the excessive CO_2 emission growth. Both countries have not benefited from energy efficiency practices in the mining and extractive-related industries. Thus, companies must examine and practice their energy efficiency strategies through cleaner energy utilization.

The remaining parts of this study are organized as follows. Section 2 reviews the relevant literature. Section 3 introduces the research design and data used. Section 4 provides an analysis with interpretations. Section 5 discusses the main results and presents the policy implications. Section 6 concludes the entire paper.

2. Literature review

Relevant studies on the determinants of CO_2 emissions are reviewed and categorized into five groups that link CO_2 emissions to (1) energy efficiency, (2) energy use, (3) economic growth, (4) trade, and (5) renewable energy.

2.1 Carbon emissions and energy efficiency

Energy efficiency can either become a major contributor to the CO_2 emission growth or reduction in an economy. Previous research is reviewed from this perspective. Tian et al. (2016) tested the energy intensity and found that certain commercial trucks in China have low emissions but high energy efficiency. Vieira et al. (2018) assessed the rational use of electricity in Brazil and confirmed that three government policy programs reduce CO_2 emissions. The most significant impact is felt in residential sectors. Khoshroo et al. (2018) stressed that maintaining energy-saving production in turnip production farms in Iran requires the selection of energy-saving farm machinery with the most appropriate power and size. Machinery usage results in the highest energy savings and reduces CO_2 emissions by 7% on the average. Zhang and Liu (2020) reported contrary results, whereas corporate carbon information disclosure (CID) does not improve environmental performance.

Tajudeen et at. (2018) applied the structural time series and least squares dummy variable models through an econometric procedure to quantify the degree to which energy efficiency reduces CO_2 emission growth. Their econometric results showed that improved energy efficiency is the primary factor for CO_2 emission reduction, despite its income level contributing to CO_2

emission growth. Although clean energy consumption reduces CO_2 emissions, its impact is insignificant compared with that of energy efficiency. Chong et al. (2019) used the logarithmic mean Divisia index (LMDI) decomposition method and concluded that the end users of electricity and fuel used in electricity generation are more often related to high CO_2 emissions than the end-use energy and electricity supply efficiencies that adversely reduce the CO_2 emission growth. Hu et al. (2019) collected data on 29 provinces of China over the period of 2002-2014 to determine the links between sulfur dioxide emissions, gross domestic product, and energy efficiency. Their results confirmed that emissions in these provinces are in line with GDP growth. However, the opposite applies to energy efficiency, which when improves cause emissions reduction.

Following the goal of firms for productivity and empirical findings are supported by productivity theory, firms are expected to provide minimal energy inputs and maximize production. Therefore, the following hypothesis is proposed:

H_1: Energy efficiency has a negative relationship with CO_2 emissions.

2.2 CO_2 emissions and non-renewable energy use

Kaya identity theory (1997) stresses the link between energy consumption and global CO_2 emissions produced by human activities. In the present study, this theory is further extended by seeking the view regarding the extent of connection between carbon emissions and energy use or consumption. A good example is the study of Chong et al. (2019), who used the LMDI decomposition method to derive the major technical factors that determine energy-related CO_2 emissions in Malaysia. Increments in electricity consumption and structural changes in fuel–electricity considerably increase energy-related CO_2 emissions. Gu et al. (2019) reported neutral results for 30 provinces in China, confirming that technical progress and energy consumption contribute to CO_2 emission growth but reduce its growth rate over time. Results show that the level of CO_2 emission growth or reduction depends on the regional technological progress.

Wasti and Zaidi (2020) used the ARDL method to extend the link among variables, including CO_2 emissions and energy consumption, in Kuwait from 1971 to 2017. Their findings confirmed that CO_2 release and energy consumption help the economy grow, but an increase in CO_2 emissions multiplies the level of energy consumption. Neves et al. (2017) reported that electricity usage in 15 OECD economies reduces the utilization of fossil fuel while CO_2 emissions continue to grow. Valadkhani et al. (2019) further emphasized the nexus using the data of 60 countries for the period of 1965–2016. The countries with the highest income reduce their carbon emissions by replacing gas with oil or coal with hydroelectric power.

Given these findings, non-energy usage that likewise has high emissions cannot be expected to reduce CO_2 emissions. Thus, the following hypothesis is proposed:

H_2: *Energy use has a positive relationship with CO_2 emissions*.

2.3 CO_2 emissions and economic growth

Country-level economy also plays a supportive role in CO_2 emission reduction. For instance, Muhammad and Khan (2019) analyzed the data of 35 host and 118 source countries from 2001 to 2012. The generalized methods of moments and fixed and random effects show that the CO_2 emissions of host countries contribute to economic growth, whereas those of source countries decrease their economic growth but have no tangible effect on host countries. For five ASEAN countries, Munir et al. (2020) used the Granger non-causality CD and heterogeneity and found that economic growth helps increase CO_2 emissions in Malaysia, Philippines, Singapore, and Thailand. However, no such connection was found in Indonesia. Muhammad (2019) further confirmed that in 68 countries, CO_2 radiation is high in developed and MENA countries as a result of economic growth. Moreover, the reduction in CO_2 emissions in emerging countries is due to economic growth.

However, Adedoyin et al. (2020) obtained unique findings that CO_2 radiation and economic growth are unrelated in BRICS countries. Cherni and Essaber Jouini (2017) used the ARDL approach and discovered that economic growth and CO_2 emissions in Tunisia are indispensable because of their high interdependence. Wang et al. (2019) found that economic growth contributes to the rapid growth of CO_2 emissions in the US from 1990 to 2016. Moreover, energy intensity performs efficiently in reducing the CO_2 emission growth. Li et al. (2020) found that economic growth improves the quality of environment in developed and developing countries, given the significant reduction in CO_2 emissions.

Based on the above discussion, economic growth is expected to increase CO_2 emission growth due to the increase in the production of goods and services. Thus, the following hypothesis is proposed:

H_3: Economic growth has a positive relationship with CO_2 emissions.

2.4 Carbon emissions and trade

The nexus between carbon emissions and trade has been emphasized for over a decade due to its influence on the environment. Essandoh et al. (2020) collected data on 52 countries to investigate the nature and ways in which international trade and foreign direct investment affect CO_2 emissions. Panel pooled mean group–autoregressive distributive lag results show that trade contributes to CO_2 emission reductions in advanced countries, but elevates CO_2 emissions in emerging economies. Zhang et al. (2019) reported different results for BRICS countries. China imports large amounts of energy and CO_2 emission from BRICS countries, but exports smaller amounts of energy and CO_2 emission to BRICS countries than to non-BRICS countries. Using a nonlinear asymmetric ARDL model, Haug and Ucal (2019) found that for importation in Turkey, an increase in translates to an increase in CO_2 emissions, but a decrease has no connection with CO_2 emissions. For exportation, an increase does not affect CO_2 emissions but a decrease drastically increases the growth of CO_2 emissions.

In a frequency analysis, Mutascu (2018) used wavelet tools to measure the link between trade openness and CO_2 emissions in France. At a high frequency, trade openness and CO_2 emissions has a neutral relationship, indicating that no correlations exist. At a moderate rate, CO_2 emissions drastically increase trade openness, and trade openness contributes to the rise of CO_2 emissions. However, Wang and Ang (2018) argued that growth in the volume of international trade increases CO_2 emissions, whereas energy intensity and goods connected to trade can considerably reduce emissions. Hasanov et al. (2018) confirmed that increments in export and import decrease the growth of CO_2 emissions in nine oil-exporting economies. By contrast, Zakari and Tawiah (2019) reported neutral results, given that no short-term causality is confirmed between trade and CO_2 emissions in Nigeria.

Against this background, trade shows a positive impact on CO_2 emissions. For this reason, the following hypothesis is proposed:

H_4: Trade has a positive relationship with CO_2 emissions.

2.5 CO_2 emissions and clean energy

Another determinant of CO_2 emissions is renewable energy. Given its possible result of reduced or zero emissions, renewable energy has a positive effect on CO_2 emissions. Lin and Zhu (2019) found that technological progress in China differs according to the province, thereby effectively curtailing climate change. Therefore, research and development in public and private enterprises encourages innovation. In support, Charfeddine and Kahia (2019) found that renewable energy consumption can improve environmental quality in MENA countries. Chen et al. (2019) assessed the relationship between renewable and non-renewable energy consumption at the regional level in China. Renewable energy consumption helps reduce CO_2 emission growth, with a considerable portion originating from the central region of China. However, renewable energy consumption in western and eastern areas of China promotes CO_2 emission growth.

Cheng et al. (2019) conducted an independent cross-quantile analysis to link renewable energy supply, environmental patent development, economic growth, exports, foreign direct investment, and domestic credit to CO_2 emissions in BRICS countries. Their findings supported the belief that renewable energy consumption reduces the growth of CO_2 radiation within the highest 95th quantile. Waheed et al. (2018) obtained similar results that renewable energy consumption in Pakistan reduces CO_2 emission growth.

Based on the above discussion, the use of renewable energy is expected to curtail the CO_2 emission growth. Therefore, the following hypothesis is proposed:

H_5: Clean energy substitution has a negative relationship with CO_2 emissions.

In summary, previous studies focus on the western world and only a few consider Africa, especially its western regions. Countries in West Africa, such as Nigeria, have high levels of emissions because they are oil-producing nations. According to the World Bank data on CO_2 emission, Nigeria is the fourth highest emitter in Africa and has the highest increasing rate of emission. CO_2 emission from Nigeria is approximately 0.26% of total global emission. Notably, China is the highest CO_2 emitter in the world and the largest global trading partner of Africa with its fastest growing market and Nigeria as second-highest buyer. Given this background, the impact of trade relationships and the industrial effect of CO_2 emissions in the two countries requires crucial assessment. Accordingly, this study investigates the role of circular economy in alleviating the issues of CO_2 emissions by obtaining energy efficiency using the decomposition analysis. *This method is the first of its kind when considering the energy efficiency and trade between China and Nigeria.*

3. Research methodology

This study used two procedures for its main analysis. First, a decomposition analysis was performed to identify the real measure of energy efficiency. Second, econometric procedures were utilized to explore the links among CO_2 emissions, energy efficiency, energy use, economic growth, trade, and clean energy substitution in the two countries, combined and independently.

3.1 Data and sampling

Annual data spanning the period of 1991-2014 for China and Nigeria were selected based on availability. First, energy intensity was decomposed using data on the entire economy output (*Y*) and energy consumption (*E*). The output (*Yi*) and energy consumption (*Ei*) of mining and extractive-related sectors were also used. *E* and *Ei* were proxied by aggregate energy utilization (in kilo tons of oil equivalent) as obtained from the International Energy Agency. *Y* was represented by the real GDP (at constant 2005 prices in USD) obtained from the United Nations Statistical Division database for two energy-consuming sectors, namely, industrial and residential. *Yi* was represented by the measure of economic output related to the mining and extractive-related sectors.

Panel and time series analyses of the determinants of CO_2 emissions used energy efficiency indices obtained from energy intensity decomposition. Then, CO_2 emissions in tons per capita (CO_2) were used. Trade (*TR*) was proxied by GDP (%), and energy use (*EU*) was proxied by oil equivalent per capita (kg). Economic growth (*GDP*) was proxied by GDP (constant 2010 USD), and clean energy substitution was proxied by alternative and nuclear energy (ANE) (% of total energy use) obtained from World Development Index (WDI). The descriptive statistics of the data for the first- and second-step estimations are provided in Tables A.1 and A.2 of the Appendix, respectively.

3.2 Decomposition analysis model

The impact of energy efficiency on CO_2 emissions in China and Nigeria are evaluated using the input–output approach. The relationship between energy efficiency and CO_2 emission for China and Nigeria is modeled with reference to Tajudeen et al. (2018).

First, energy intensity is estimated via index analysis following the Fisher ideal index approach, as follows:

$$EI_t = \sqrt{Laspeyres \times Paache} \times 100, \tag{1}$$

$$\text{Laspeyres} = \frac{\sum E_{1it}\, Y_{0i}}{\sum E_{0i}\, Y_{0i}} \text{ x } 100, \tag{2}$$

$$\text{Paasche} = \frac{\sum E_{1it}\, Y_{1it}}{\sum E_{0i}\, Y_{1it}} \text{ x } 100, \tag{3}$$

where EI_t refers to the energy intensity for a given period, and E_1 and E_0 represent the energy consumption in current and base years, respectively. Y_1 and Y_0 represent the output in current and base year, respectively. Subscript i refers to the individual sector of the economy, and t denotes time.

Moreover, the energy efficiency index is represented using the Fisher ideal index (Fisher, 1921) and LMDI (Ang, 2005) to overcome the disadvantage observed in energy intensity. This disadvantage is caused by the decomposition of energy intensity as energy efficiency and activity indices without unexplained residuals.

$$EFI_t = (\text{Laspeyres} \times \text{Paasche})^{\frac{1}{2}}, \qquad ACI_t = (\text{Laspeyres} \times \text{Paasche})^{\frac{1}{2}}. \tag{4}$$

However, the energy intensity index is given as the product of the energy efficiency and activity indices, as follows:

$$EI_t = EFI_t \times ACI_t. \tag{5}$$

Using Eq. (4), we estimate energy saving (ΔES_t) with time as a result of improvement in energy intensity. This estimation can be expressed as follows: $\Delta ES_t = E_t - \widehat{E_t}$. Therefore, the improvement in energy efficiency in an economy can be estimated as:

$$EF_t = \Delta ES_t = \frac{EFI_t}{EI_t} + \frac{ACI_t}{EI_t}, \quad (6)$$

where E_t is the actual energy use and $\widehat{E_t}$ is the energy that would have been used had energy intensity remained at a base-year level.

Disaggregated data that account for all possible economic activities help improve the reliability of decomposition analysis. Although previous studies have applied this method, this study is constrained by data limitations[2].

3.3 Determinants of the change in CO_2 emissions

3.3.1 Panel data model

To assess the nexus between CO_2 emissions and energy efficiency in China and Nigeria as a group, a framework is constructed for investigating the impact of energy efficiency improvements on CO_2 emission by adding economic growth, energy use, and clean energy substitution to the following model:

$$In\,CO_{2it} = \alpha_0 + \alpha_1 InEF_{it} + \alpha_2 InEU_{it} + \alpha_3 InGDP_{it} + \alpha_4\, InTR_{it} + \alpha_5\, InANE_{it} + e_{it}, \quad (7)$$

where CO_2 represents CO_2 emission, *EF* measures energy efficiency improvements, *EU* is energy use, *GDP* measures economic growth (GDP growth rate), *TR* is trade per GDP, and *ANE* is clean energy substitution. Subscript *i* refers to each country's fixed effects, that is, the countries and time are denoted by subscripts i ($i = 1, -- N$) and t ($t = 1, -- T$), respectively, and e_i is the error term (Tajudeen et al., 2018).

Considering the nature of our panel data (i.e., small N), PCSE[3] and FGLS[4] estimators are used for the determinants of CO_2 emissions in a dynamic panel model. The PCSE model is a

[2] Decomposed along two sectors (industrial and residential) for the period of 1991–2014
[3] Panel-corrected standard error
[4] Feasible generalized least squares

good fit when the study aims to test a hypothesis, and the FGLS model is a good estimator when the primary interest is to verify the accuracy of coefficients of the estimates (Chong et al., 2019). PCSE and FGLS estimators are adopted to determine the extent to which energy efficiency affects CO_2 emissions while in contact with other control variables, such as energy use, economic growth, trade, and clean energy substitution.

3.3.2 Time series model

By using a similar exposition for the panel model in Eq. (7), we derived a model for analyzing the impact of energy efficiency improvement on CO_2 emissions as follows:

$$In\,CO_{2t} = \alpha_0 + \alpha_1 InEF_t + \alpha_2 InEU_t + \alpha_3 InGDP_t + \alpha_4\, InTR_t + \alpha_5\, InANE_t + e_t, \qquad (8)$$

where CO_2 represents CO_2 emission, *EF* measures energy efficiency improvements, *EU* is energy use, *GDP* measures economic growth (GDP growth rate), *TR* is trade per GDP, *ANE* denotes clean energy substitution, and *t* is time (Tajudeen et al., 2018).

To test for the impact of energy efficiency improvement on CO_2 emissions on a country basis, the ARDL bound test is introduced to enable tests on the model fitness in the short and long terms. The ARDL bound test is widely used due to its essential predictive techniques for differentiating long- and short-term models irrespective of the level of data stationarity.[5] First, the series is estimated whether to meet the long-term criteria; if so, then the error correction model (ECM) test is carried out to determine the short-term relationship among the series. However, if the bound test fails to meet the criteria, then VAR estimation is carried out to test the connection of selected variables. This model is selected due to its ability to check the past value of variables. Therefore, this approach can improve our estimation, because a country can be energy inefficient at a point in time but later regain energy efficiency. Such disparities in periods can be tested with the ARDL bound test.

4. Empirical results

[5] Enable the estimation of data series at both levels and the first different value.

4.1 Empirical results of energy intensity decomposition

This study uses the Fisher ideal index to decompose the energy intensity of China and Nigeria for the period of 1991–2014. Figure 2 illustrates the decomposition results for the two countries.

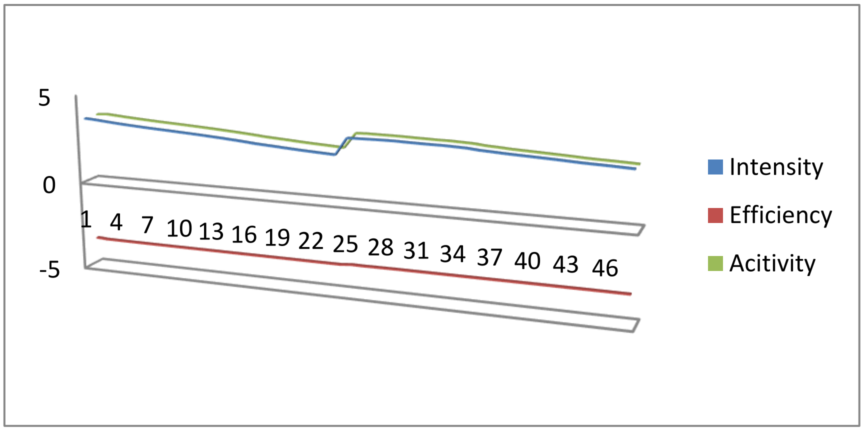

Figure 2. Energy indices for China and Nigeria.

The graph shows that the energy intensity and activity indicators are positive whereas energy efficiency is negative. The positive relationship between energy intensity and activity indicates improvements during 1991–2014. By contrast, the negative coefficient of energy efficiency shows that despite the increments in energy intensity and activity, energy efficiency shows no improvement during this period.

Table 1(a) provides a summary of results for China and Nigeria (as a group) for the period of 1991–2014. The energy intensity indices exhibit a 3.692% increment, which is slightly higher than that of activity (an increase of 3.409%). As illustrated in Figure 2, the energy efficiency indices have negative values, showing a decline of −3.416%. This result indicates that although a country may have increased energy intensity and activity, energy efficiency does not necessarily improve. Further empirical tests are carried out to realize how the same finding can be obtained at an individual country level.

Table 1(a). Summary of the statistics of energy intensity in China and Nigeria

Indices	Mean	S.D.	Min	Max

Intensity	3.692	0.287	2.749	3.722
Efficiency	−3.416	0.034	−3.454	−3.376
Activity	3.409	0.252	2.871	3.743

Table 1(b). Summary of the statistics of energy intensity at the country level

Country	Indices	Mean	S.D.	Min	Max
China	Intensity	3.209	0.293	2.750	3.699
	Efficiency	−3.448	0.011	−3.454	−3.398
	Activity	3.317	0.277	2.871	3.743
Nigeria	Intensity	3.529	0.173	3.230	3.722
	Efficiency	−3.384	0.008	−3.405	−3.376
	Activity	3.502	0.186	3.192	3.720

4.2. Country-level results of decomposed energy indices

Table 1(b) shows the decomposition results for the individual country level for the period of 1991–2014. The result indicates that the indices trending in the two countries exhibit drastic variations. Energy intensity and activity indices trend positively in both countries, whereas energy efficiency indices trend negatively. The energy intensity of Nigeria (3.529%) is slightly higher than that of China (3.209%). Similarly, activity is trending higher in Nigeria (3.502%) than in China (3.317%). However, the decline in energy efficiency indices for China (−3.448%) is higher than that for Nigeria (−3.384%). Although percentage merging is low, these results indicate that a rise in energy intensity and activity results in a decline in energy efficiency in China in comparison with that in Nigeria. Against this background, we extend our research to identify other possible indices that may contribute to this decline.

4.3. Empirical results of the determinants of CO_2 emissions

As discussed in Section 2.2, the variables for analysis include CO_2 emissions, energy efficiency (derived from energy intensity decomposition), energy use, GDP, trade, and clean energy substitution. All of these variables are in the natural log form.

Panel data and time series models are estimated, as indicated in Eqs. (7) and (8), respectively. A stationarity test using the Im–Pesaran–Shin unit-root procedure reveal that only energy efficiency is stationary at level series at 5% significance. Thus, the variables are then estimated at first different values, and the results confirmed stationarity for all the series at 1%, 5%, and 10% significance levels. Having established the variable series, we then performed panel data and time series analyses.

4.3.1. Panel data results

The PCSE and FGSL models for China and Nigeria from 1991 to 2014 are estimated. Tables 2 and 3 present the panel regression estimates obtained using Eq. (7). A robust model that adopted the standard error is used to compare the results.

Table 2 shows the findings from the PCSE model. The overall results confirm that energy efficiency, energy use, economic growth, and clean energy substitution are statistically significant. Energy efficiency, economic growth, and clean energy substitution have a positive relationship whereas the energy use coefficient shows a negative relationship with CO_2 emissions. These results indicate that a 1% increase in energy efficiency increases CO_2 emissions by 2.121%. A positive sign can mean that policies are not effectively implemented at a point in the past, which may be the cause of CO_2 emission growth. CO_2 radiation increases by 0.474% and 0.657% as a result of a 1% increase in economic growth and clean energy substitution, respectively. However, the coefficient of energy use confirms that a 1% increase in energy use contributes to a 0.299% decline in CO_2 emissions.

The determinant of energy efficiency is further estimated and the overall results show that CO_2 emissions, energy use, and clean energy substitution are statistically significant. CO_2 emissions and energy use have a positive relationship with energy efficiency. By contrast, clean energy substitution is negatively related to energy efficiency. Specifically, 1% increment in CO_2 emissions and energy use leads to an increase in energy efficiency by 0.018% and 0.076%, respectively. By contrast, clean energy substitution reduces energy efficiency by 0.107% within the studied period.

The fitness and accuracy of the PCSE model is further tested using the FGLS procedure. The overall results in Table 3 are inconsistent with those presented in Table 2. Energy efficiency, energy use, economic growth, and clean energy substitution are statistically significant at 10%, 10%, 1%, and 1%, respectively. Knowing that energy efficiency, economic growth, and clean energy substitution are positively related to CO_2 emissions is important. This relationship indicates that a 1% increase in energy efficiency, economic growth, and clean energy substitution increases CO_2 emissions by 2.121%, 0.474%, and 0.657%, respectively. By contrast, energy use reduces the level of CO_2 emissions by 0.299%.

Table 2. PCSE estimation results

CO_2 = f (EF, EU, GDP, TR, CES)		
	Coefficient	Prob.
EF	2.121	0.165*
EU	−0.299	0.143*
GDP	0.474	0.000***
TR	0.123	0.391
CES	0.657	0.000*
Beta	2.468	0.660
R^2	0.971	
EF = f (CO_2, EU, GDP, TR, CES)		
CO2	0.018	0.160*
EU	0.076	0.000***
GDP	−0.008	0.374
TR	−0.015	0.270
CES	−0.107	0.000***
Beta	−3.525	0.000***
R^2	0.952	

Note: * and *** indicate that the variable coefficient is at the 10% and 1% significance levels, respectively.

Table 3. FGLS estimation results

CO_2 = f (EF, EU, GDP, TR, CES)		
	Coefficient	Prob.
EF	2.121	0.165*
EU	−0.299	0.144*
GDP	0.474	0.000***
TR	0.123	0.404
CES	0.657	0.000***
Beta	2.468	0.659
Likelihood	53.491	
EF = f (CO_2, EU, GDP, TR, CES)		
CO2	0.018	0.160*
EU	0.076	0.000***
GDP	−0.008	0.382

TR	−0.015	0.269
CES	−0.107	0.000***
Beta	−3.525	0.000***
Likelihood	167.707	

Note: * and *** indicate that the variable coefficient is at the 10% and 1% significance levels, respectively.

The determinant of the energy efficiency model shows that energy efficiency decreases only when the level of clean energy substitution increases. CO_2 emissions and energy use are important indices that contribute to the improvements in energy efficiency. Overall, as a determinant of CO_2 emissions, only economic growth has predictive power to reduce the CO_2 emission growth in the two countries. This result is attributed to the fact that products are made using devices with low energy emissions, and thus the level of CO_2 emissions decreases. From the perspective of the energy efficiency determinant, we observed that CO_2 emissions and energy use are important predictors of energy efficiency.

4.3.2. Time-series results

An individual country model is analyzed to estimate the impact of energy efficiency on carbon. To consider the period in which energy efficiency may not have been in place, the ARDL bound test is used to account for the past event of the explanatory variables and check for long-term equilibrium that exists in the model.

Table 4 shows the ARDL bound analysis for China. The results indicate that long-term equilibrium exists among the variables. The upper bound of the F-statistic (38.12042) is higher than that of the T-statistic at all levels (i.e., 10%, 5%, and 1%). This finding confirms that the series are co-integrated in the long term. As such, the ECM test is further analyzed, as shown in Table 4. The long-term estimation confirms that energy efficiency has a positive relationship with the current levels of CO_2 emission at the 5% significance level. This relationship means that only the current value of energy efficiency rise can lead to an increase in CO_2 emissions with an average value of 69.299%. Similarly, 1% increments in economic growth and trade adversely lead to increments of 2.179% and 0.669% in CO_2 emissions, respectively. Poor implementation can be considered a factor in this negative impact on CO_2 emissions. As expected, clean energy substitution negatively affects CO_2 emission at the 10% significance level. This finding means that clean energy substitutions reduce the CO_2 emission growth by 0.635% in China.

Table 4. Long- and short-term estimations for China

Bound test : F-statistic = 38.12042		
T-statistic	Lower bound: I(0)	Upper bound: I(1)
	10% 2.08	10% 3
	5% 2.39	5% 3.38
	1% 3.06	1% 4.15
Long-term estimation: $CO_2 = f(EF, EU, GDP, TR, CES)$		
	Coefficient	Prob.
EF_t	69.299	0.072**
EU_t	−0.806	0.579
GDP_t	2.179	0.153*
TR_t	0.669	0.094**
CES_t	−0.635	0.159*
C	214.2794	0.072**
Short-term estimation: $CO_2 = f(EF, EU, GDP, TR, CES)$		
	Coefficient	Prob.
CO_{2t-1}	0.739	0.000**
EF	−0.463	0.715
EF_{t-1}	2.254	0.000***
GDP_t	−0.399	0.000***
CES_t	−0.550	0.000***
CES_{t-1}	0.099	0.006***
ECM_{t-1}	−0.332	0.000***
Diagnostic test		
	Coefficient	Prob.
R-square	0.988	
RESET Test	0.675	0.539
Jarque–Bera	0.058	0.972

Note: *, **, and *** indicate that the variable coefficient is at 10%, 5%, and 1% significance levels, respectively.

The ECM coefficient is negative as expected and low (0.332) at the 1% significance level. The R-squared value is approximately 98%, indicating that over 98% of the model has been estimated. Moreover, Jarque–Bera and RESET tests show that the probability exceeds 5%, thereby confirming the fitness and accuracy of the proposed model. The short-term estimation indicates that the past values of CO_2 emissions, energy efficiency, and clean energy substitution have a negative influence on CO_2 emissions. These factors increase this variable by 0.739%, 2.254%, and 0.099%, respectively. By contrast, the present values of economic growth and clean energy substitution have a strong positive influence on CO_2 emission. These factors reduce the growth of CO_2 emissions by 0.339% and 0.550%, respectively. Overall, economic growth and clean energy substitution positively affect CO_2 emissions in China.

The ARDL bound test is used to check the long-term relationship among the series for Nigeria. The bound test F-statistic (1.941168) is lower than the T-statistic of the upper bound for all levels, that is, 10%, 5%, and 1%, as shown in Table 5. This result indicates the absence of a long-term relationship among the variables. Thus, a short-term relationship is checked among the variables using the Bayesian VAR model. The results show that CO_2 emissions, energy efficiency, and clean energy substitution are statistically significant. Increasing the positive coefficients of CO_2 emissions, energy efficiency, and clean energy substitution can also increase CO_2 emissions.

Table 5. Short-term estimation for Nigeria

Bound test : F-statistic = 1.941168						
T-statistic			Lower bound: I(0)		Upper bound: I(1)	
			10%	2.26	**10%**	3.35
			5%	2.62	**5%**	3.79
			1%	3.41	**1%**	4.68
Bayesian VAR Estimates						
	CO2	**EF**	EU	**GDP**	**TR**	**CES**
CO2(−1)	0.046	0.007	−5.197	−3.091	−0.210794	0.014994
	(0.097)	(0.007)	(77.794)	(4.610)	(3.02748)	(0.08230)
	[0.471]	[0.993]	[−0.067]	[−0.068]	[−0.06963]	[0.18219]
CO2(−2)	0.008	0.002	−0.138	−0.827	−0.011	0.006
	(0.049)	(0.003)	(39.899)	(2.310)	(1.553)	(0.042)
	[0.158]	[0.609]	[−0.004]	[−0.004]	[−0.007]	0.132]
EF(−1)	7.399	0.554	1482.946	8.811	58.631	−0.445
	(6.899)	(0.052)	(5606.21)	(3.312)	(218.175)	(5.93098)
	[1.072]	[10.737]	[0.265]	[0.268]	[0.269]	[−0.075]
EF(−2)	3.742	0.122	1049.490	6.241	41.486	−0.094861
	(5.569)	(0.042)	4526.47)	(2.712)	(176.155)	(4.78874)
	[0.672]	[2.920]	[0.23186]	[0.235]	[0.236]	[−0.019]
EU(−1)	7.211	1.141	3.481	2024.808	1.251	2.971
	(0.001)	(9.107)	(0.100)	(5.807)	(0.004)	(0.001)
	[5.905]	[0.001]	[3.505]	[3.505]	[3.305]	[2.805]

EU(−2)	1.951	3.121	1.771	1028.530	6.481	1.521
	(6.105)	(4.507)	(0.050)	(2.907)	(0.002)	(5.205)
	[3.205]	[6.905]	[3.505]	[3.505]	[3.405]	[2.905]
GDP(−1)	2.073	3.043	1.862	1.131	7.083	1.443
	(2.113)	(1.515)	(1.710)	(0.100)	(6.612)	(1.813)
	[1.012]	(1.515)	[1.112]	[1.112]	[1.112]	[8.113]
GDP(−2)	4.663	7.003	4.652	2.821	1.772	3.383
	(1.013)	(7.716)	(8.411)	(0.050	(3.312)	(8.914)
	[4.513]	[9.113]	[5.513]	[5.613]	[5.413]	[3.813]
TR(−1)	−1.641	−6.211	−0.023	−0.1373	−0.001	−2.031
	(0.003)	(2.305)	(2.544)	(1.509)	(0.100)	(0.003)
	[−0.005]	[−0.003]	[−0.009]	[−0.009]	[−0.009]	(0.0031)
TR(−2)	−3.871	9.611	−0.006	−0.3446	−0.002	−4.801
	(0.002)	(1.205)	(1.272)	(7.508)	(0.050)	(0.001)
	[−0.003]	[0.008]	[−0.005]	[−0.005]	[−0.005]	[−0.004]
CES (−1)	−0.018	0.002	−29.385	−1.751	−1.134	−0.015
	(0.113)	(0.004	(92.191)	(5.410)	(3.588)	(0.099)
	[−0.161]	[0.174]	[−0.319]	[−0.323]	[−0.316]	[−0.154]
CES (−2)	−0.008	3.891	−7.827	−4.651	−0.3045	−0.006
	(0.057)	(0.004)	(46.629)	(2.710)	(1.815)	(0.049)
	[−0.139]	[0.091]	[−0.168]	[−0.170]	[−0.167]	[−0.112]
R-squared	0.2446	0.942	0.0330	0.0326	0.0338	0.008

5. Discussion and implications

5.1 Results discussion

The findings in Table 2 illustrate that energy efficiencies in China and Nigeria adversely affect the CO_2 emission growth. Despite the increase in energy efficiency, CO_2 emission levels continue to rise in both countries. Although energy efficiency can reduce CO_2 emissions, arguably the case is not always true because energy efficiency does not necessarily equate to utilization of cleaner source of energy. Similar to observations in developing countries, our results are likely driven by the use of high-emission energy sources in both countries. Energy supplies are from fossil fuels, such as petrol in a car or electricity from high emission sources. Given that Nigeria is an oil producing country, increasing emission from drilling may overshadow its government efforts for energy efficiency. Similarly, the rapid manufacturing and industrialization of China have outgrown its efforts of efficient energy. Moreover, reaping the benefits of energy efficiency investment takes a long time. As a result, both countries have yet to see the benefits of energy efficient in terms of CO_2 emission reduction.

The nature of the trade between China and Nigeria may cause the lack of connection to CO_2 emissions. Most of the trade relationships between China and Nigeria are not based on energy-related goods. Thus, CO_2 emissions has a negligible impact or none at all, contrary to the findings of Essandoh et al. (2020). Energy extraction is the major source of CO_2 emissions in these countries. Moreover, the level of CO_2 emissions is increased by economic growth and clean energy substitution and reduced by energy consumption.

At the country level, results show that CO_2 emissions in China are engineered by energy efficiency, energy use, economic growth, and trade. Thus, the magnitude of CO_2 emissions increases due to the increments in the above four factors. However, clean energy substitution reduces the growth of emissions in the long term because of low- or zero-emission discharge. This finding is in line with those of Charfeddine and Kahia (2019) for MENA countries. However, the short-term estimation confirms that only economic growth and clean energy substitution have the power to reduce CO_2 emission growth in China. Trade has no proven record of increasing or decreasing CO_2 emissions.

CO_2 emissions in Nigeria highly differ from those in China. The estimation equation shows that trade has no impact whereas energy efficiency, energy use, economic growth, and clean energy substitution exert a distorting influence on CO_2 emissions. These results indicate that energy efficiency, energy use, economic growth, and clean energy substitution contribute to increased CO_2 emission levels in Nigeria, contrary to those of Charfeddine and Kahia (2019) for MENA countries.

5.2 Policy implications

In accordance with the conclusion of previous studies, several relevant policies are omitted in this work. First, clean energy substitution plays an essential role in reducing CO_2 emissions. Clean energy sources must have low or zero emissions. Extracting power from such a source minimizes the level of CO_2 emissions in the environment. Therefore, the government or policymakers must explore relevant techniques that foster the use of clean energy sources for energy consumption. *Resource melioration* can be achieved by deploying additional funds for the purchase of clean energy and through other means, such as FDI, loans, and fiscal benefits.

Through FDI, foreign investors can be encouraged to invest in clean energy. In addition, local investors can be motivated to venture into clean energy by offering funds and relaxing part of the taxes that discourage investments.

Second, this study finds that the level of economic growth exerts a positive impact on mitigating CO_2 emissions. For this reason, policymakers or the government must prioritize economic growth. A high level of economic growth is likely to translate into CO_2 emissions through production maximization. Firms often produce goods and services through the maximization of resources, such as energy use. Thus, the government must provide a prevailing environment for the operation of firms to encourage economic growth.

Third, energy efficiency exerts a negative impact on CO_2 emissions. Firms must go beyond observing energy efficiency at all costs and use clean energy sources to improve energy efficiency. This approach can reduce the CO_2 emission growth. The government has to subsidize renewable energy technologies to encourage firm usage of clean energy. A platform, such as a tax holiday, must be provided to firms that successfully utilize clean energy in their production. This approach can promote the application of clean energy sources, improve energy efficiency, and reduce CO_2 emissions.

Aside from these general policy recommendations, specific policy recommendations must be highlighted according to the varying conditions per country. This study is centered on the resource melioration of energy consumption as a primary driver to mitigate CO_2 emissions in China and Nigeria. Against this background, the following policies are recommended (see table 6).

Table 6. Policy recommendations for China and Nigeria

S/N	China Policy Recommendation	Nigeria Policy Recommendation
1	The government must encourage investment in renewable energy technologies by offering loans and relaxing operating taxes.	The government and policymakers must propagate awareness about the use of renewable energy technologies.
2	Firms must use renewable energy	The government must subsidize renewable

technologies in their production to achieve a sustainable environment with the highest production capacity possible and promote economic growth.	energy technologies to enable income earners to afford their use.

6. Conclusion

Circular economy is an effective strategy to achieve a healthy environment and efficient use of resources. In this study, the trade relationship between China and Nigeria is used to establish how circular economy ameliorates climate change. Three methods are developed and used to determine the effect of circular economy on climate change by investigating energy efficiency improvement and trade openness on CO_2 emissions at the macro level for China and Nigeria. First, a Fisher index decomposition analysis is carried out to derive energy efficiency from energy intensity. Second, PCSE, ARDL bound, and Bayesian VAR models are used to examine the impact of energy efficiency improvement on CO_2 emissions alongside the control factors.

The econometric analysis results at the group level show that energy efficiency improvement causes the highest increase in CO_2 emissions at an average of 2.121% per annum due to the inability of accepting clean energy. Energy use has a positive impact on the environment due to its reduction of CO_2 emissions. This positive impact, however, has a low rate of 0.299% per annum. The results confirm the absence of a significant relationship between trade and CO_2 emissions. China and Nigeria do not trade items that are based on clean energy, but rather trade mainly consumable goods and services that are unrelated with the level of CO_2 emissions. Therefore, the circular economy between China and Nigeria does not necessarily help reduce CO_2 emissions.

Test results of the determinants of energy efficiency reveal that CO_2 emission has a low average annual negative impact of 0.018% on energy efficiency. Energy use influences 0.076% of CO_2 emission growth per year. Clean energy has the most substantial impact with over

0.107% reduction in CO_2 emission growth per annum. Trade is neither negatively nor positively related to CO_2 emissions.

The increments in CO_2 emissions in China are a result of the remarkable growth of the economy and trade without considering environmental quality. However, the increase in clean energy sources reduces the CO_2 emissions by an average of 0.635% per year. Similarly, the short-term estimation shows that economic growth and clean energy source are drivers that decrease CO_2 emission growth. The Bayesian VAR model indicates that energy efficiency and clean energy source positively affect CO_2 emissions in Nigeria.

References

Adedoyin, F. F., Gumede, M. I., Bekun, F. V., Etokakpan, M. U., & Balsalobre-lorente, D. (2020). Modelling coal rent, economic growth and CO_2 emissions: Does regulatory quality matter in BRICS economies?. *Science of the Total Environment, 710,* 136284.

Ang, B. W. (2005). The LMDI approach to decomposition analysis: a practical guide. *Energy policy*, *33*(7), 867-871.

Balsalobre-Lorente, D., Bekun, F. V., Etokakpan, M. U., & Driha, O. M. (2019). A road to enhancements in natural gas use in Iran: A multivariate modelling approach. *Resources Policy*, *64*, 101485.

Bulut, U. (2017). The impacts of non-renewable and renewable energy on CO_2 emissions in Turkey. *Environmental Science and Pollution Research*, *24*(18), 15416-15426.

Charfeddine, L., & Kahia, M. (2019). Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: A panel vector autoregressive (PVAR) analysis. *Renewable Energy*, *139*, 198-213.

Chen, Y., Zhao, J., Lai, Z., Wang, Z., & Xia, H. (2019). Exploring the effects of economic growth, and renewable and non-renewable energy consumption on China's CO_2 emissions: Evidence from a regional panel analysis. *Renewable Energy*, *140*, 341-353.

Cheng, C., Ren, X., Wang, Z., & Yan, C. (2019). Heterogeneous impacts of renewable energy and environmental patents on CO_2 emission-Evidence from the BRIICS. *Science of the*

Total Environment, *668*, 1328-1338.

Cherni, A., & Jouini, S. E. (2017). An ARDL approach to the CO_2 emissions, renewable energy and economic growth nexus: Tunisian evidence. *International Journal of Hydrogen Energy*, *42*(48), 29056-29066.

Chong, C. H., Tan, W. X., Ting, Z. J., Liu, P., Ma, L., Li, Z., & Ni, W. (2019). The driving factors of energy-related CO_2 emission growth in Malaysia: The LMDI decomposition method based on energy allocation analysis. *Renewable and Sustainable Energy Reviews*, *115*, 109356.

Circularity Gap Report Initiative (CGRi) (2019). Circularity Gap Report 2019. Available at https://www.circularity-gap.world/ (accessed in March 2020).

Essandoh, O. K., Islam, M., & Kakinaka, M. (2020). Linking international trade and foreign direct investment to CO_2 emissions: Any differences between developed and developing countries?. *Science of The Total Environment*, 712, 136437.

Fisher, I. (1921). The best form of index number. *Quarterly Publications of the American Statistical Association*, *17*(133), 533-551.

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement* (No. w3914). National Bureau of Economic Research.

Gu, W., Zhao, X., Yan, X., Wang, C., & Li, Q. (2019). Energy technological progress, energy consumption, and CO_2 emissions: Empirical evidence from China. *Journal of Cleaner Production*, *236*, 117666.

Chong, C. H., Tan, W. X., Ting, Z. J., Liu, P., Ma, L., Li, Z., & Ni, W. (2019). The driving factors of energy-related CO_2 emission growth in Malaysia: The LMDI decomposition method based on energy allocation analysis. *Renewable and Sustainable Energy Reviews*, *115*, 109356.

Hasanov, F. J., Liddle, B., & Mikayilov, J. I. (2018). The impact of international trade on CO_2 emissions in oil exporting countries: Territory vs. consumption emissions accounting. *Energy Economics*, *74*, 343-350.

Haug, A. A., & Ucal, M. (2019). The role of trade and FDI for CO_2 emissions in Turkey: Nonlinear relationships. *Energy Economics*, *81*, 297-307.

Hu, B., Li, Z., & Zhang, L. (2019). Long-run dynamics of sulphur dioxide emissions, economic growth, and energy efficiency in China. *Journal of Cleaner Production*, *227*, 942-949.

Khoshroo, A., Izadikhah, M., & Emrouznejad, A. (2018). Improving energy efficiency considering reduction of CO_2 emission of turnip production: A novel data envelopment analysis model with undesirable output approach. *Journal of Cleaner Production*, *187*, 605-615.

LeVan, A. C., & Ukata, P. (Eds.). (2018). *The Oxford Handbook of Nigerian Politics*. Oxford University Press.

Li, G., Zakari, A., & Tawiah, V. (2020). Does environmental diplomacy reduce CO_2 emissions? A panel group means analysis. *Science of The Total Environment*, 722, 137790.

Lin, B., & Zhu, J. (2019). Determinants of renewable energy technological innovation in China under CO_2 emissions constraint. *Journal of Environmental Management*, *247*, 662-671.

Luthra, S., Kumar, A., Zavadskas, E. K., Mangla, S. K., & Garza-Reyes, J. A. (2019). Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy. *International Journal of Production Research*, 58(5), 1-17.

Mangla, S. K., Luthra, S., Rich, N., Kumar, D., Rana, N. P., & Dwivedi, Y. K. (2018). Enablers to implement sustainable initiatives in agri-food supply chains. *International Journal of Production Economics*, *203*, 379-393.

Mangla, S. K., Luthra, S., Jakhar, S., Gandhi, S., Muduli, K., & Kumar, A. (2020). A step to clean energy-Sustainability in energy system management in an emerging economy context. *Journal of Clean Production*, *242*, 118462.

Muhammad, B. (2019). Energy consumption, CO_2 emissions and economic growth in developed, emerging and Middle East and North Africa countries. *Energy*, 179, 232 - 245.

Muhammad, B., & Khan, S. (2019). Effect of bilateral FDI, energy consumption, CO_2 emission and capital on economic growth of Asia countries. *Energy Reports*, *5*, 1305-1315.

Munir, Q., Lean, H. H., & Smyth, R. (2020). CO_2 emissions, energy consumption and economic growth in the ASEAN-5 countries: A cross-sectional dependence approach. *Energy Economics*, *85*, 104571.

Mutascu, M. (2018). A time-frequency analysis of trade openness and CO_2 emissions in France. *Energy Policy*, *115*, 443-455.

Naeem, M., Tiwari, A. K., Mubashra, S., & Shahbaz, M. (2019). Modeling volatility of precious metals markets by using regime-switching GARCH models. *Resources Policy*, *64*, 101497.

Napp, T., Shah, N., & Fisk, D. (2012). What's energy efficiency and how much can it help cut emissions. *The Guardian, 5 June, 2012*.

Neves, S. A., Marques, A. C., & Fuinhas, J. A. (2017). Is energy consumption in the transport sector hampering both economic growth and the reduction of CO_2 emissions? A disaggregated energy consumption analysis. *Transport Policy*, *59*(C), 64-70.

Tajudeen, I. A., Wossink, A., & Banerjee, P. (2018). How significant is energy efficiency to mitigate CO_2 emissions? Evidence from OECD countries. *Energy Economics*, *72*, 200-221.

Tian, J., Yang, D., Zhang, H., & Liu, L. (2016). Classification method of energy efficiency and CO_2 emission Intensity of Commercial Trucks in China's Road Transport. *Procedia Engineering*, *137*, 75-84.

United Nations Climate Change (2019). Circular Economy Crucial for Paris Climate Goals. Available at https://unfccc.int/news/circular-economy-crucial-for-paris-climate goals (accessed in March 2020).

Valadkhani, A., Smyth, R., & Nguyen, J. (2019). Effects of primary energy consumption on CO_2 emissions under optimal thresholds: Evidence from sixty countries over the last half century. *Energy Economics*, *80*, 680-690.

Vieira, N. D. B., Nogueira, L. A. H., & Haddad, J. (2018). An assessment of CO_2 emissions avoided by energy-efficiency programs: A general methodology and a case study in Brazil. *Energy*, *142*, 702-715.

Waheed, R., Chang, D., Sarwar, S., & Chen, W. (2018). Forest, agriculture, renewable energy, and CO_2 emission. *Journal of Cleaner Production*, *172*, 4231-4238.

Wang, H., & Ang, B. W. (2018). Assessing the role of international trade in global CO_2 emissions: An index decomposition analysis approach. *Applied Energy*, *218*, 146-158.

Wang, Q., Jiang, X. T., Ge, S., & Jiang, R. (2019). Is economic growth compatible with a reduction in CO_2 emissions? Empirical analysis of the United States. *Resources, Conservation and Recycling*, *151*, 104443.

Wang, R., Zameer, H., Feng, Y., Jiao, Z., Xu, L., & Gedikli, A. (2019). Revisiting Chinese resource curse hypothesis based on spatial spillover effect: A fresh evidence. *Resources Policy*, *64*, 101521.

Wasti, S. K. A., & Zaidi, S. W. (2020). An empirical investigation between CO_2 emission, energy consumption, trade liberalization and economic growth: A case of Kuwait. *Journal of Building Engineering*, *28*, 101104.

WEF (2020) From linear to circular - Accelerating a proven concept. https://reports.weforum.org/toward-the-circular-economy-accelerating-the-scale-up-across-global-supply-chains/from-linear-to-circular-accelerating-a-proven-concept/

Xia, V. (2019) when 100% renewable energy doesn’t mean zero carbon. https://earth.stanford.edu/news/when-100-renewable-energy-doesnt-mean-zero-carbon.

Yang, Q., & Song, D. (2019). How does environmental regulation break the resource curse: Theoretical and empirical study on China. *Resources Policy*, *64*, 101480.

Zakari, A., & Tawiah, V. (2019). Impact of electricity consumption, financial development, trade openness on CO_2 emissions: Evidence from Nigeria. *Economic Studies*, *28*(4), 143 - 157.

Zaidi, S. A. H., Wei, Z., Gedikli, A., Zafar, M. W., Hou, F., & Iftikhar, Y. (2019). The impact of globalization, natural resources abundance, and human capital on financial development: Evidence from thirty-one OECD countries. *Resources Policy*, *64*, 101476.

Zhang, Z., Xi, L., Bin, S., Yuhuan, Z., Song, W., Ya, L., & Guang, S. (2019). Energy, CO_2 emissions, and value added flows embodied in the international trade of the BRICS group: A comprehensive assessment. *Renewable and Sustainable Energy Reviews*, *116*, 109432.

Zhang, Y. J., & Liu, J. Y. (2020). Overview of research on carbon information disclosure. *Frontiers of Engineering Management*, 7, 47-62.

Appendix

Table A1. Energy indices for China

Year	Intensity	Efficiency	Activity
1991	3.69897	−3.39794	3.69897
1992	3.655765	−3.43926	3.742763
1993	3.599365	−3.44192	3.692289
1994	3.546087	−3.4447	3.645265
1995	3.500962	−3.44637	3.603902
1996	3.459852	−3.44778	3.565996
1997	3.421507	−3.44852	3.529355
1998	3.388737	−3.44922	3.498164
1999	3.356653	−3.44976	3.467317
2000	3.321257	−3.45028	3.433111
2001	3.286468	−3.45046	3.398747
2002	3.248522	−3.45077	3.361501
2003	3.206988	−3.45171	3.322128
2004	3.165157	−3.45231	3.281696
2005	3.118288	−3.45262	3.235541
2006	3.066289	−3.45272	3.183775
2007	3.008504	−3.45271	3.125951
2008	2.968478	−3.45315	3.086943
2009	2.929462	−3.453	3.047595
2010	2.885564	−3.45387	3.005707
2011	2.845948	−3.4542	2.966855
2012	2.81309	−3.45431	2.934254
2013	2.780597	−3.45436	2.901866
2014	2.749999	−3.45438	2.871326

Table A2. Energy indices for Nigeria

Year	Intensity	Efficiency	Activity
1991	3.69897	3.69897	3.69897
1992	3.704857	−3.40534	3.71978
1993	3.713786	−3.39739	3.712691
1994	3.721741	−3.39246	3.71085
1995	3.722056	−3.38797	3.70234
1996	3.704206	−3.38797	3.684489
1997	3.691634	−3.38797	3.671915
1998	3.680566	−3.38707	3.659086
1999	3.678036	−3.38687	3.656168
2000	3.656781	−3.386	3.633225
2001	3.631813	−3.38538	3.607041
2002	3.569873	−3.38254	3.539608
2003	3.539083	−3.38144	3.506695
2004	3.500659	−3.37802	3.461692
2005	3.47356	−3.37785	3.43426
2006	3.448011	−3.37727	3.407616
2007	3.42029	−3.37669	3.378772
2008	3.391863	−3.37685	3.350666
2009	3.358291	−3.37752	3.318374
2010	3.324844	−3.37576	3.28156
2011	3.302383	−3.37576	3.259099
2012	3.28439	−3.37581	3.241208
2013	3.256343	−3.37835	3.218006
2014	3.22977	−3.37853	3.191786