



Article

Sources and Sectoral Trend Analysis of CO₂ Emissions Data in Nigeria Using a Modified Mann-Kendall and Change Point Detection Approaches

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Abstract: In Nigeria, the high dependence on fossil fuels for energy generation and utilization in various sectors of the economy has resulted in the emission of a large quantity of carbon dioxide (CO₂), which is one of the criteria gaseous pollutants that is frequently encountered in the environment. The high quantity of CO₂ has adverse implications on human health and serious damaging effects on the environment. In this study, multi-decade (1971–2014) CO₂-emissions data for Nigeria were obtained from the World Development Indicator (WDI). The data were disaggregated into various emission sources: gaseous fuel consumption (GFC), liquid fuel consumption (LFC), solid fuel consumption (SFC), transport (TRA), electricity and heat production (EHP), residential buildings and commercial and public services (RSCPS), manufacturing industries and construction (MINC), and other sectors excluding residential buildings and commercial and public services (OSEC). The analysis was conducted for a sectorial trend using a rank-based non-parametric modified Mann–Kendall (MK) statistical approach and a change point detection method. The results showed that the CO₂ emissions from TRA were significantly high, followed by LFC. The GFC, LFC, EHP, and OSEC had a positive Sen’s slope, while SFC, TRA, and MINC had a negative Sen’s slope. The trend analysis indicated multiple changes for TRA and OSEC, while other sources had a change point at a particular year. These results are useful for knowledge of CO₂-emission sources in Nigeria and for future understanding of the trend of its emission for proper environmental planning. The severe effects of CO₂ on the atmospheric environment of Nigeria may be worsened in the future due to some major sources such as transportation services and electricity generation that are inevitable for enviable standard of living in an urban setting.

Keywords: CO₂; emission sources; WDI data; trend analysis; Mann-Kendall



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1. Introduction

Globally, carbon dioxide (CO₂) is one of the common environmental pollutants, and it accounts for more than 70% of the greenhouse effects. It also has varieties of adverse effects on human health and environmental implications [1]. It affects the amount of solar radiation that penetrates through the atmosphere and reaches the surface of the earth as well as outgoing radiation from the surface of Earth. The potential atmospheric and ecological implications of CO₂, among others, consist in global warming, irregular rainfall pattern, over-flooding, extreme weather phenomena, sea-level rises, alterations in crop growth, and disruptions to aquatic water systems. The excessive accumulation of CO₂ in the atmosphere alters the atmospheric radiation budget either by the absorption or emission

of heat [2]. The human activities that contribute to the atmospheric CO₂ are agriculture, urbanization, deforestation, mining, transportation, fuel combustion, waste disposal, and burning. Apart from anthropogenic activities, the atmospheric concentration of CO₂ could also be increased from natural emission sources such as organic decomposition, ocean release, and volcanic eruption in the regions of the world that are prone to tectonic activity, although in a small quantity compared to that emitted from human activities.

The increasing economic activities and technological advancement in the developed and developing countries has greatly boosted economic growth and development, leading to the setting of industries and diversification in industrial activities. In Nigeria, the economic activities cover industrial, manufacturing, agricultural, financial, educational, and tourist sectors. These sectors heavily and solely depend on petroleum and petrochemical resources as the primary sources of energy for effective operations and existence of the sectors due to an epileptic power supply from the natural grid. Despite the contribution of economic activities to gross domestic product (GDP), each sector remains a potential source of CO₂ emissions into the atmosphere. Apart from these, the Nigerian population had increased tremendously in the past few decades. The United Nations reported Nigeria as Africa's most-populous country with about 60% growth from 1990 to 2008 and 170 million people as of 2012. It is projected to reach 0.5–1 billion people by the early 21 century [3]. Other anthropogenic activities such as deforestation, bush burning, and transportation could also increase CO₂ in the atmosphere. The oil and gas sector also emits a large quantity of CO₂ due to gas flaring, illegal refinery, illegal oil refining, frequent pipeline explosions, gas leakage, and venting. Industrial processes such as petroleum-processing refinery, smelting, cement industry, and mining contribute significantly to the atmospheric load of CO₂. In urban centres, road transportation has been reported to be a major source that contributes about one-fifth of the total CO₂ emissions [4,5]. The International Energy Agency [6] found road transportation as a whole to be responsible for 20% of CO₂ emission. In the residential area, most houses rely on kerosene, fuel wood, generators for domestic purposes, cooking, lighting of rural and urban household bulbs, and other electrical appliances where power supplies and distribution are often inconsistent and unreliable. The industries also depend on diesel-powered backup generators for production activities as an alternative to the epileptic power supply [7]. Open burning is a common practice in the urban areas where the waste disposal and management are poorly organised. This contributes to a significant amount of CO₂ emissions into the atmosphere.

A large number of studies have been conducted on CO₂ emissions globally by employing different statistical tools in developed and developing countries. Most studies ascertained both local and global atmospheric implications of CO₂ and reported energy consumption due to economic growth and development as the main reason for increased CO₂ concentration in the atmosphere. This might be due to the fact that trend analysis requires long-time-period data of several decades, which were not available by the real-time measurement in most studies. Short monitoring periods and a small sample size could not be used for trend analysis due to difficulty in identification of rates of change as well as their interpretations. Moreover, the historical to present-day CO₂ emissions sources and distribution among different sectors of the economy are scarce. The analysis of multidecade and historical CO₂ emissions data are of paramount scientific and practical relevance in the prediction of a country's economic development and as well in developing a framework for its emission-reduction strategies to safeguard human health and to sustain environmental quality [8].

The monitoring of CO₂ is highly imperative as it forms the basis of data collection for decision making, regulatory purposes, and future forecasting. However, very few studies have been reported on continuous measurements of CO₂ concentrations. Despite the fact that several studies have reported various emission sources of CO₂ at both local and regional levels, the monitoring periods in most studies are short, yielding a small data size. The inconsistency in data-collection procedures also posed a difficulty in obtaining CO₂ emissions data. These drawbacks are overcome in this study by employing secondary

emissions data collected by an international monitoring organisation. Therefore, this study models CO₂ emissions from various sectors in Nigeria using data sourced from the World Bank database.

Previous studies on the trend analysis of CO₂ emissions were conducted in advanced and emerging countries [9–14]. For instance, [10] found evidence for statistically significant trends in CO₂ emissions of the following countries, namely, India, South Korea, the Islamic Republic of Iran, Mexico, Australia, Indonesia, Saudi Arabia, Brazil, South Africa, Taiwan, and Turkey, including the world total. The authors concluded that projections for CO₂ emissions are influenced by several factors, including fuel consumption types, economic growth rates, and political initiatives. In the case of CO₂ emissions from car travel in Great Britain, [11] found that, although CO₂ emissions continued to increase, the growth rate became substantially lower in the beginning of the 2000s. [12] demonstrated that based on a medium GDP growth rate for 2015–2030 under a business-as-usual scenario, the CO₂ emission trends of China's primary aluminium industry could increase by 60%. By looking at sectoral CO₂ emissions in 41 world regions, [2] found that CO₂ emissions will continue to increase in the construction sectors in all countries. Based on the survey of the available studies, little or no consideration has been given to a natural-resource-rich country like Nigeria. To the best of our knowledge, this is the first study exploring the possible trends and tipping point in CO₂ emissions across different sectors in an oil-dependent developing country. This study departs from the former studies and attempts to fill several gaps in the existing literature in at least two points. First, our study contributes to the growing literature on the determinants of CO₂ emissions by examining trends and the tipping point in CO₂ emissions in order to find out the sector contributing the most to environmental pollution in the study area. Secondly, it is well established that CO₂ emissions are not globally uniform across different sectors [15]. The consideration of CO₂ emissions by sectors could provide new insights on future development and sustainable management of CO₂ emissions across economic sectors.

Parametric and non-parametric statistical tests are some of the approaches used to detect trends of environmental data such as hydrological and hydrometeorological data. Parametric tests had been considered to be more powerful, but their main drawback is that the data must be independent, identical, and normally distributed [16]. These are rarely true in environmental data. The non-parametric test overcomes this limitation in its approach via Mann-Kendall trend analysis [8,16–20]. Therefore, this study employed World Development Indicator (WDI) data to conduct the trend analysis of CO₂ emissions from different sources and sectors in Nigeria using a non-parametric Mann-Kendall test. The research questions driving the study were: is there a presence of monotonic trend in the disaggregated CO₂ emission data? what is the magnitude of the trend change? and what is the change point of the trend in each of the CO₂ emissions data? The remainder of the article is structured as follows: Section 2 discusses the methodology; Section 3 presents statistical tools employed to answer the research questions put forward in the study; results, discussion, and policy implications are presented in Sections 4 and 5 has the conclusion.

2. Methodology

2.1. Source of Data and Coverage

This study was conducted in Nigeria, a country in sub-Saharan Africa with per capita CO₂ emissions of around 2.8 tonnes. CO₂ emissions data in the country were sourced from the World Development Indicators of 2018 with respect to sources and sectors. Detailed information on the selected sources and sectors is presented in Table 1. Based on the available information, the study used data from 1971 to 2014 indicating a total of 44 data points for each of the variables. Recent period could not be incorporated due to availability of the data.

Table 1. Variable Description.

Variable ID	Description. CO ₂ Emissions from:
GFC	Gaseous fuel consumption (% of total)
LFC	Liquid fuel consumption (% of total)
SFC	Solid fuel consumption (% of total)
TRA	Transport (% of total fuel combustion)
EHP	Electricity and heat production, total (% of total fuel combustion)
RBCPS	Residential buildings and commercial and public services (% of total fuel combustion)
MINC	Manufacturing industries and construction (% of total fuel combustion)
OSEC	Other sectors, excluding residential buildings and commercial and public services (% of total fuel combustion)

Source: World Development Indicator (WDI), 2018.

2.2. The Mann-Kendall Test

The Mann-Kendall (MK) test is rank-based non-parametric statistical method that is used to determine the monotonic upward or downward trend of a time series and long-term data in predicting the future outcome by using historical records [8,21]. The basic assumptions of the MK test are that a value can always be declared less than, greater than, or equal to another value; that data are independent; and that the distribution of data remain constant in either the original or transformed units [17]. The MK test had been used widely by several researchers most especially in climatological, hydrological, visibility, and air-pollution studies [12,13,19,20,22–24]. In this study, the MK test was applied to CO₂ emissions data based on its invariance to data transformation and wide application in environmental studies. Briefly, the fundamental equations for calculating Mann-Kendall statistics S , $V(s)$, and standardized test statistics Z are as follows [17,25,26]:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sig}(X_j - X_i) \quad (1)$$

here $i = 2, 3, \dots, n$; $j = 1, 2, \dots, i - 1$ and

$$\text{sig}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \quad (2)$$

A normal approximation to the Mann-Kendall test with variance $V(s)$ is given as:

$$V(s) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=2}^q t_p(t_p-1)(2t_p+5) \right] \quad (3)$$

here $p = 2, 3, \dots, q$, t_p is the number of ties for the p^{th} value, and q is the number of tied values.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

where X_i and X_j are the time series data in the chronological order, n is the length of the time series, t_p is the number of ties for p^{th} values, and q is the number of tied values. A positive Z value implies an upward trend in the data series, while a negative value indicates a downward trend. Additionally, if $|Z| > Z_{1-\alpha/2}$, (H_0) is rejected. This shows the presence

of a statistically significant upward or downward monotonic trend in the data series. The critical value of $Z_{1-\alpha/2}$ for an alpha level of 0.05 from the standard normal table is 1.96. To reach this objective, the first step is to identify the major sectoral pattern of emission contributions to the total atmospheric CO₂ load. The magnitude of the trend is estimated by Sen's slope approach, which is the slope interpreted as a change in measurement per change in time.

$$Q' = \frac{x_{t'} - x_t}{t' - t} \quad (5)$$

Q' is the slope between data points $x_{t'}$ and x_t , which are the data measurement at time t' and t . The Sen's slope estimator is simply given by the median slope:

$$\beta = \begin{cases} Q'_{\frac{N+1}{2}}, & \text{Nisodd} \\ \frac{1}{2} \left(Q'_{\frac{N}{2}} + Q'_{\frac{N+2}{2}} \right), & \text{Niseven} \end{cases} \quad (6)$$

N is the number of calculated slopes. A positive value of β indicates an increasing trend, and a negative value indicates a decreasing trend in the time series data.

Peculiar features of time series data, which can affect the results of the MK test, are the presence of seasonality patterns and serial autocorrelation [25]. However, significant serial correlation present in time series data can be accounted for by using the modified MK test via a non-parametric block bootstrap technique, which incorporates the Mann-Kendall trend test [21,27]. The block bootstrap is a powerful approach in the presence of series that are serially autocorrelated [28,29]. This technique uses the predetermined block lengths in resampling the original time series, thus retaining the memory structure of the data. If the value of the test statistic falls in the tails of the empirical bootstrapped distribution, there is likely a trend in the data.

The existence of seasonality patterns and serial autocorrelation in the time series data was checked by plotting the autocorrelation coefficients against lags (correlogram). The autocorrelation coefficients for lag were calculated as follows [24,25].

$$r_k = \frac{\sum_{i=1}^{n-k} [(x_i - \bar{x}_-)(x_{i+k} - \bar{x}_+)]}{\left[\sum_{i=1}^{n-k} (x_i - \bar{x}_-)^2 \right]^{1/2} \left[\sum_{i=k+1}^n (x_i - \bar{x}_+)^2 \right]^{1/2}} \quad (7)$$

3. Statistical Analysis

The variables were summarised using descriptive statistics and one-way analysis of variance, while preliminary time series analysis was done using a time plot and the autocorrelation function (ACF) to detect patterns, seasonality, and serial autocorrelation. Each of the research questions were answered using the block bootstrap Mann-Kendall test, Sen's slope, a sequential plot, and the signed Wilcoxon test. All analysis was carried out in the R statistical software package with a concentration on the modifiedmk, trend change, and Wilcoxon functions

4. Results, Discussion, and Policy Implications

The descriptive statistics of the variables are presented in Table 2. It showed that CO₂ emissions from the transport (TRA) sector were significantly higher than those from other channels, while emissions from liquid fuel consumption (LFC) and electricity with heat production (EHP) were next to it in the rank with the former greater than the latter. In addition, CO₂ from gaseous fuel (GFC), manufacturing industries and construction (MINC), as well as residential buildings and commercial and public services (RBCPS) were statistically different from each other. However, no statistical significance was found in the CO₂ emissions from solid fuel consumption (SFC) and other sectors, excluding residential buildings and commercial and public services (OSEC). The time plot of the series presented

in Figure 1 showed that the series have a sinusoidal pattern with a significant peak and a trough at different periods indicating likelihood of the trend. The autocorrelation function (ACF) of each variable is depicted in the Figures 2 and 3. The vertical line (a “spike”) on the graphs corresponds to each lag, while the height of each spike showed the value of the autocorrelation function for the lag. The spike that rises above or below the dashed lines indicated statistically significant autocorrelation at that lag. The occurrence of spikes above and below the dashed line of the ACF plot in the variables considered in the study clearly revealed the presence of serial autocorrelation. As earlier noted, the presence of serial autocorrelation posed a serious setback for the traditional Mann-Kendall test, and this can result in the detection of a false trend. One of the robust methods that account for serial autocorrelation in Mann-Kendall test is the block-bootstrapped Mann-Kendall Test (BBMKT). Hence, this resampling and modified version of MKT was used to calculate the test statistic for each of the variables. The number of bootstrapped simulations and the block length used for the test were 2000 and 5, respectively. The result of the test is presented in Table 3. The table shows the Z-value, the S-value, the Sen’s slope, and the change period, which indicated the BBMKT test-statistic value, the direction of the trend, the magnitude of the trend, and the period in the series where the direction of the trend was reversed. Consequently, the null hypothesis that there is no existence of a monotonic trend in GFC, SFC, EHP, RBCPS, and MINC data cannot be rejected at 5% level of significance in that the absolute values of the test statistic in these variables were greater than 1.960. However, the presence of a monotonic trend in the CO₂ emissions from LFC, TRA, and OSEC cannot be ascertained at a 5% level. In terms of the direction of the trend, the positive value of the S-statistic for GFC, LFC, EHP, and OSEC indicated that these variables had an upward trend during the period under consideration, while emissions from SFC, TRA, RBCPS, and MINC had a downward trend. The rate of change in the trend as depicted by Sen’s slope revealed that GFC, LFC, EHP, and OSEC increased annually by 63.2%, 39.6%, 47.0%, and 6.5%, respectively, while the annual rate of decline in emissions form SFC, TRA, RBCPS, and MINC were estimated to be 2.3%, 11.9%, 24.1%, and 21.8%, respectively. Figure 4 presented the sequential trend-change-detection plot. The point of intersection of the prograde and the retrograde on each plot marked the change point. The probable change point for GFC, LFC, and EHP were detected to be 1986, 1975, and 1987, respectively while that of SFC, RBCPS, and MINC were 1982, 2004, and 1984, respectively. However, the plots of TRA and OSEC intersected at several locations because there were no clear trends in them. In summary, a statistically significant monotonic trend was found in the GFC, SFC, EHP, RBCPS, and MINC data. The rates of increase in emissions from GFC and EHP were found to be 63.2% and 47.0%, respectively. This indicated that emissions from GFC accounted for about 57.4% of the increment due to it and EHP. Additionally, emissions from SFC, RBCPS, and MINC had reduced over the period under consideration with 2.3%, 24.1%, and 21.8%, respectively. This indicated that emissions from RBCPS and MINC were 10 and 9 times more likely to reduce when compared with the rate of reduction in SFC, respectively.

Table 2. Descriptive statistics of the disaggregated emissions data.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
GFC	44	16.540 ^d	9.721	1.091	8.390	23.443	34.411
LFC	44	43.371 ^b	19.251	15.518	32.507	57.404	76.819
SFC	44	0.436 ^g	0.537	0.009	0.088	0.471	2.071
TRA	44	47.935 ^a	5.060	35.389	43.818	52.239	56.305
EHP	44	27.540 ^c	6.718	13.587	22.983	32.363	39.062
RBCPS	44	9.853 ^f	4.088	2.465	6.577	12.171	17.292
MINC	44	11.493 ^e	3.410	4.250	9.611	13.972	18.430
OSEC	44	3.191 ^g	2.979	0.028	1.453	4.065	11.406

The supercripts indicates significant difference at 5% level with a > b > c > d > e > f > g. Mean separation was done by Duncan Multiple Range Test (DMRT).

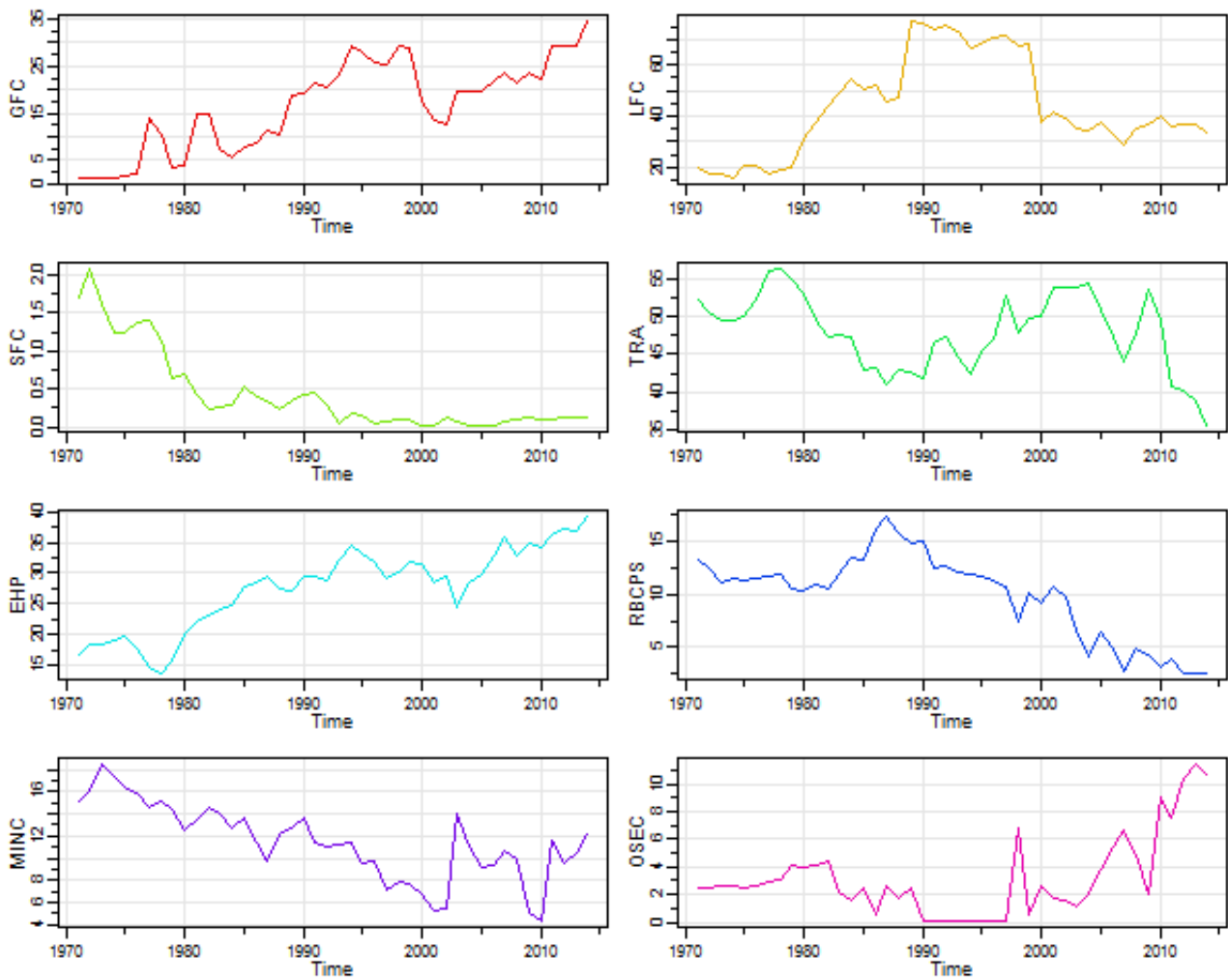


Figure 1. Time plot of CO₂ emissions data.

Table 3. Modified Mann-Kendall analysis results.

Variable	Z-Value	S-Value	Sen's Slope	Change Period
GFC	6.423	636	0.632	1986
LFC	1.224	122	0.396	1975
SFC	−5.795	−574	−0.023	1982
TRA	−1.912	−190	−0.119	Multiple
EHP	6.908	684	0.470	1987
RBCPS	−5.229	−518	−0.241	2004
MINC	−5.836	−578	−0.218	1984
OSEC	1.588	158	0.065	Multiple

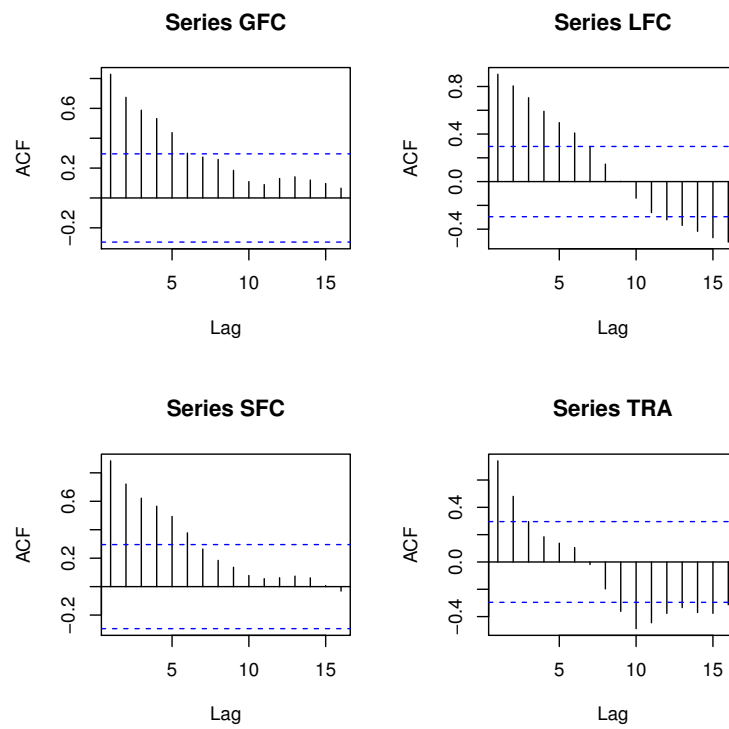


Figure 2. Autocorrelation function of CO₂ emissions data.

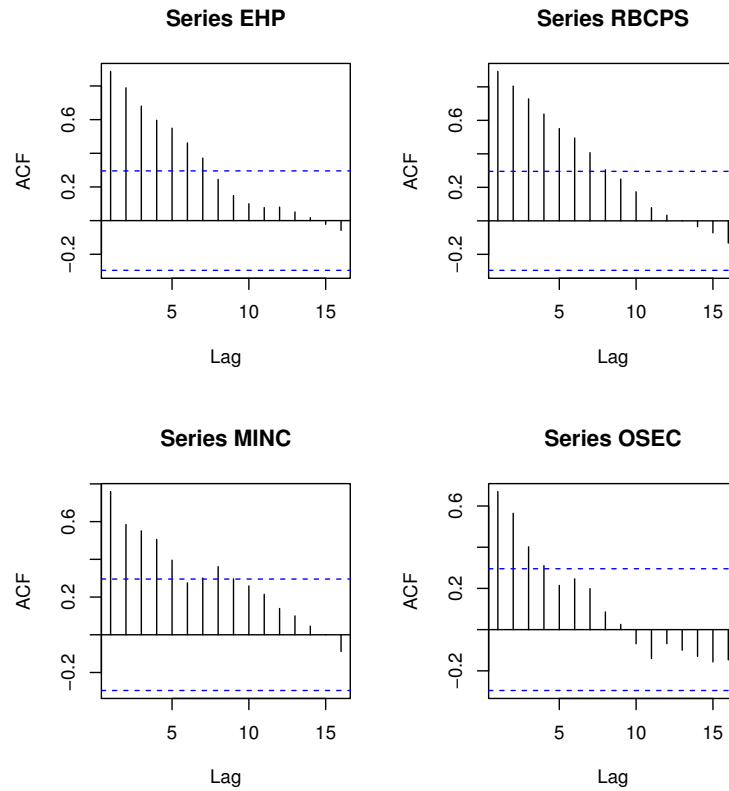


Figure 3. Autocorrelation function of CO₂ emissions data.

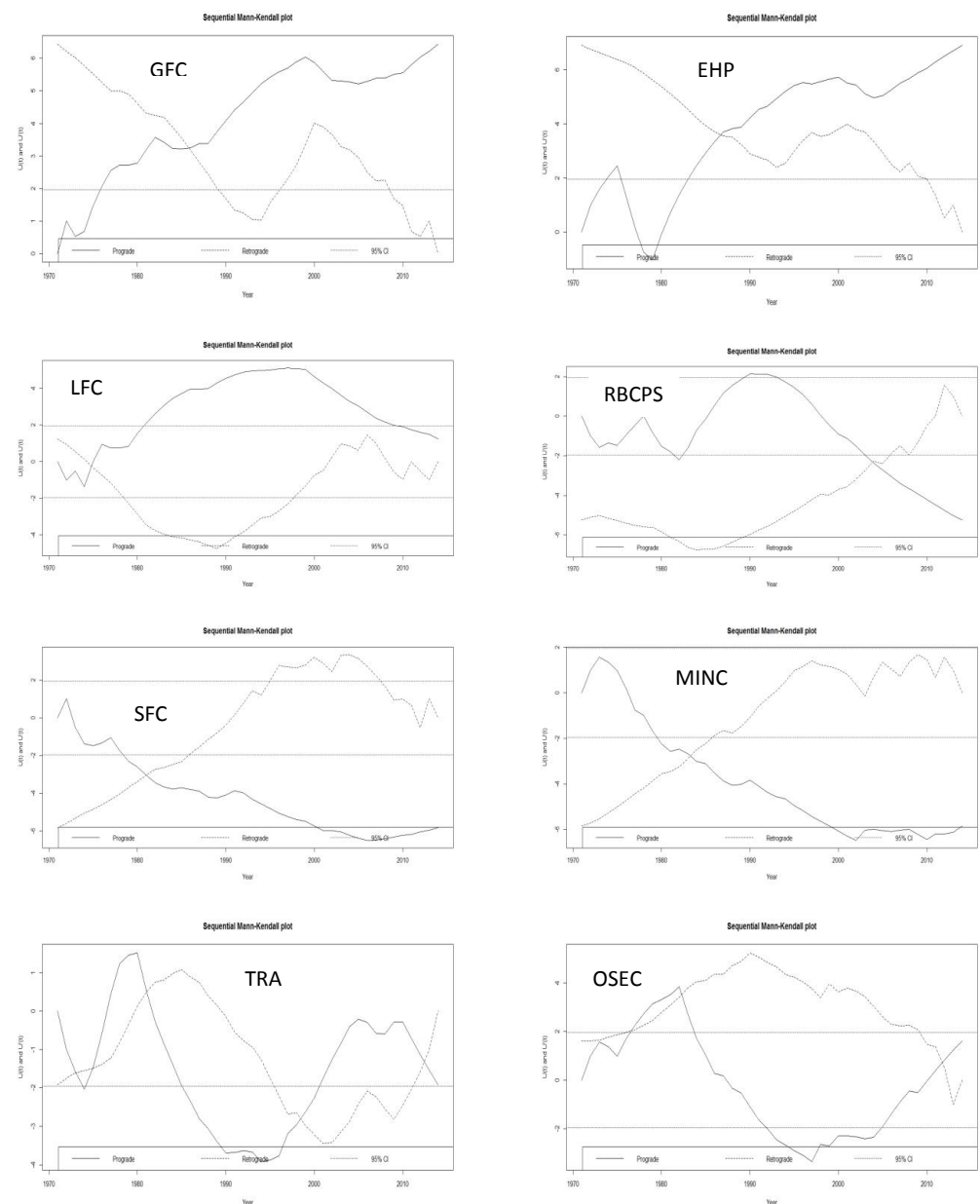


Figure 4. Sequential trend-change-detection plot.

The subject of trend detection in CO₂ emissions data has received a great deal of attention lately, especially in connection with the anticipated changes in global climate [30]. The Mann-Kendall approach used in our study allowed us to detect different trend types not only monotonically but also non-monotonically. The simulation results indicate the significance of monotonic trends in CO₂ emissions from gaseous fuel consumption, solid fuel consumption, electricity and heat production, residential buildings, and manufacturing industries and construction sectors. Based on these findings, one may claim that controlling carbon emissions from the aforementioned sectors mainly depends on monitoring the inherent monotonic trends. As a result, the forecasting exercise of CO₂ emissions trends in these sectors can be improved based on information about the monotonic trends of CO₂ emissions. However, the presence of non-monotonic trends in CO₂ emissions stemming from liquid fuel consumption, the transport sector, and other sectors excluding residential buildings make it difficult to predict the future trends of CO₂ emissions based on the dynamics of CO₂ emissions in these sectors. This is partly due to the complex structure of CO₂ emissions in these sectors [30–34]. By looking at the direction of the trends, we

observed that GFC, LFC, EHP, and OSEC displayed an upward trend with annual rates of 63.2%, 39.6%, 47.0%, and 6.5%, respectively. Governments should improve energy efficiency in the gas fuel consumption sector, the liquid fuel consumption sector, fuel combustion from other sectors, and electricity and heat-production sectors and should save energy by converting the current raw fuel sources from heavy to light oil, promoting research and development activities of low-carbon fuels, particularly those with fuel consumption. This will reverse the current positive trend observed in fuel consumption. Another key finding is that the annual rate of decline in emissions from SFC, TRA, RBCPS, and MINC were estimated to be 2.3%, 11.9%, 24.1%, and 21.8%, respectively. Despite evidence of decreasing trends, it is important to indicate that the rate of decrease is relatively lower compared to the annual increasing rate of GFC, LFC, EHP, and OSEC. This indicates that further efforts are required to formulate appropriate incentives to increase energy conservation and reduce emissions from SFC, TRA, RBCPS, and MINC—for example, by creating a fuel standard for public transport and particular vehicles.

5. Conclusions

The study focused on the trend analysis of carbon dioxide emissions, which was disaggregated into various components based on the sources and sectors of the economy generating them. The modified Mann-Kendall test, which corrects for the presence of a seasonal effect via block bootstrap was used to study the likelihood of a monotonic trend as well as its direction, magnitude, and change point in the dataset. Based on the results, gaseous fuel, solid fuel, liquid fuel, etc. all showed an upward trend and breaks at various periods covered in the study. However, no specific break can be established in emissions from transportation. The conclusion from the study suggests that CO₂ emissions from various sectors have maintained an upward trend and this portends serious health implications and environmental hazards. This most-dangerous and prevalent greenhouse gas is the major cause of climate change, which results in food-supply disruptions, extreme water, and increased wildfires, as well as respiratory diseases through smog and air pollution. An industrialized country like Nigeria needs an enhanced Carbon-Dioxide Emissions Reduction Strategy (CDERS) to reverse the growth rate. This underscores the fact that all human activities that trigger this leading greenhouse gas have to be discouraged. It is also paramount to note that there are few or no sectors of the economy globally that do not contribute to greenhouse gas production. Ranging from manufacturing to agriculture to transportation to power production and so on, all release greenhouse gases to the atmosphere, and reduction in all emissions can be achieved through advanced practices that deviate from fossils fuels. Another potent dimension of CDERS is the use of technologies that decrease greenhouse gas emissions, and this includes swapping fossil fuels for renewable sources, boosting energy efficiency, and discouraging carbon emissions by putting a price on them. Bearing in mind sustainable development, the improvement in energy efficiency and a workable energy supply system with low or no CO₂ is imperative. The results of this study create a scenario for a better understanding of CO₂ emissions in Nigeria as well as the knowledge of emission trends. As part of CO₂-reduction measures, there is a need for development of a framework for emissions control, proper ecosystem balance, utilization of greenbelts, and the development of control measures for the mitigation of anthropogenic CO₂ emissions. The energy-efficiency strategies and conservation practices should also be considered for future CO₂ emission reduction.

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