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Research Article

Analysis of annual CO_2 gas emissions in West Africa

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Abstract

Temporal trends and variability of annual anthropogenic CO2 emissions in 16 West African countries over the 1970-2015 period are analyzed using EDGAR data. HUBERT segmentation methods and Empirical Modal Decomposition (EMD) were used to characterize the time-series of each country and detect breakpoints in anthropogenic emissions, respectively. This segmentation technique allowed us to observe that the number of breakpoints varies between 2 and 7, with unequal durations and intensities. However, the minimum and maximum numbers of these breakpoints are observed in the time series evolution of annual emissions in Nigeria (2), Niger (7) and Senegal (7). Results obtained by the EMD approach showed that the highest growth rate in anthropogenic CO2 emissions was obtained in Nigeria (1.812 kton.yr-1), while the lowest was observed in CaboVerde (0 kton.yr-1). These trends are correlate with the demographic and economic growth of these countries.

Keywords: Co_2 Emissions Variability; Empirical Mode Decomposition Method; Segmentation method; West Africa

Introduction

The emission of greenhouse gases, particularly carbon dioxide (CO_2), is one of the main contributors to climate change. CO_2 emissions are mainly due to the use of fossil fuels and industrial production, and are constantly increasing at a global scale. West Africa is a developing region that is particularly vulnerable to the negative impacts of climate change [1], including drought, flooding and coastal erosion. In effect, during the 2000-2010 period, this region has lost 1.1% forest cover per year. In term of climate parameters, one observed an increasing of temperature from 0.2 to 0.8 C since the end of 1970s [1] and, a strong reduction of precipitation in the Sahel with a southward migration of 200 km of the isohyets. In additional, it estimated at 40 to 60% (15 to 30%) the decreasing of the annual averaging debit of the main rivers in West Africa [2]. Understanding CO_2 emissions in this region is therefore crucial for developing effective mitigation and adaptation policies. However, estimating annual CO_2 emissions in West Africa presents challenges due to variability and uncertainty in the available data [1] Several studies have been conducted to quantify CO_2 emissions in West Africa [1,3-5]. For example, a recent study conducted by [3]. (2019) used a combination of satellite data and models based on forest fires and agricultural practices to estimate CO_2 emissions in the West African region. Results showed that forest fire emissions were highest in the arid Sahel regions, while agricultural emissions were more distributed across the region. Another study assessed CO_2 emissions in urban areas in the West African region, focusing on emissions from road traffic. The results showed that CO_2 emissions were concentrated in large cities such as Lagos, Abidjan and Accra [4]. Using long in situ time series of CO_2 concentration of Lamto station (Côte d'Ivoire) [1], observed a strong seasonal and interannual variability of CO2 associated to the biomass fires regime and the large-scale circulation of air coming from North-east of the continent. These authors obtained an increasing rate of 7 ppm.yr-1 of CO_2 concentration. This trend closes to the world trend, whilst this region is not classified as an important zone of CO_2 emission. These innovate and appreciated results provide by these studies open several perspectives fields such as the quantification of the different CO_2 emissions sources using time series at different timescales. This study aims to analyze CO_2 emissions in 16 West African countries over a 46-year period from 1970 to 2015 using data provided by the Emissions Database for Global Atmospheric Research (EDGAR) [6]. We use two trend analysis methods, the segmentation method and the empirical mode decomposition method, to assess the temporal trends and variability of CO_2 emissions in the region. In section 2, the study region, including its geography and the countries included in the analysis are described. Section 3 presents the data used in the study, including their source and temporal coverage. The trend analysis methods are presented in section 4. The results of analysis are presented in Section 5, followed by a discussion in Section 6. Finally, section 7 is devoted to conclusions, as well as avenues for future research.

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Study Area

The area of interest covers West Africa. It extends in latitude from the Equator (0°N) to the South of Algeria (25°N) and in longitude from Senegal (20°W) to Cameroon (15°E). The 16 countries in the study area are: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Sierra Leone, Senegal and Togo (Figure 1).

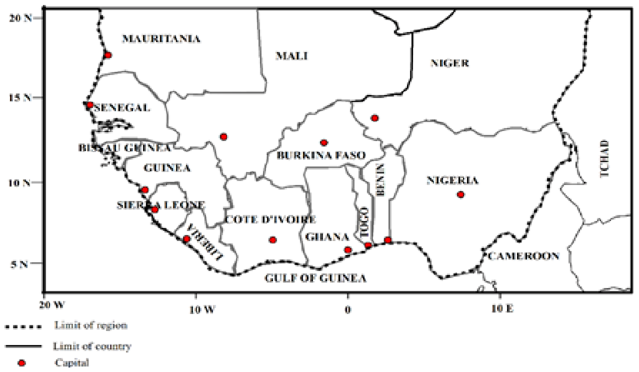

Figure 1: Studyarea. Scale: 1/2500000

Data

The data consist of time series of annual inventory emissions of carbon dioxide (CO_2) emissions from these 16 West African countries. They are provided by the Emissions Database for Global Atmospheric Research (EDGAR) [6] and span a period of forty-six years (from 1970 to 2015) at 0.1°x0.1° spatial and 1-year temporal resolutions [7]. These annual anthropogenic CO_2 emissions are due to fossil fuel use and industrial processes (cement production, limestone and dolomite carbonate use, non-energy fuel use and other combustions, chemical and metal processes, solvents, agricultural liming and urea, waste and fossil fuel fires).Short-cycle biomass burning (such as agricultural waste burning), large-scale biomass burning (such as forest fires), and carbon emissions/removals related to land use, land-use change, and forestry are excluded.

Trend Analysis Method

We use the segmentation of [8] to detect the presence or absence of one or more break points in the inter annual behavior of the time series constituted by the annual anthropogenic carbon dioxide (CO_2) emissions released into the atmosphere in the different countries of the study area. The temporal evolution of annual CO_2 emissions can sometimes include breakpoints that express changes in the regime of this parameter. These changes clearly show an increase or decrease in emission intensity from one period to another. To highlight these likely changes in the year-to-date (YTD) CO_2 emissions, Hubert's statistical test or segmentation [8] was applied to the time series of each country. This technique allows the initial series to be broken down into two or more-time sub-series and to highlight the presence or absence of one or more breakpoints characteristic of probable changes in the regime of the parameter studied. The YTD time series of CO_2 emissions analyzed may also exhibit trends. To characterize these trends, the method based on empirical modal decomposition (EMD) [9] was applied to the time series of each country. This method decomposes the original signal into a finite number of intrinsic mode functions (IMF) with different time scales, and the trend function with at most one extremum corresponds to the last intrinsic function. This intrinsic trend corresponds here to the instantaneous rate of change of emissions in kton CO_2 per year (kton.yr^{-1}). The EMD method provides a better estimate of the trend than the conventional linear regression technique [9].

Results

The temporal analysis of the annual CO_2 gas emissions exhibits several changes in interannual variability in some countries during the study period. These changes which are characterized by some breakpoint obtained by Hubert segmentation statistical test [8] (have unequal durations and intensities (Table 1). The number these breakpoints ranged between 2 and 7. The minimum and maximum numbers of breakpoint are observed in Nigeria (2), and Niger (7) and Senegal (7) annual CO_2 gas emissions time series evolution respectively. The first and the main breakpoints occur in 1972 in Nigeria and around the 1990s in all West Africa countries. The periodicity of the appearance of these breakpoints ranged between 1 and 25 years. Negative trends have been observed in Cabo Verde (-132.84%), Liberia (-145.06%), and Sierra Leone (-26.56%) before and after 1981, 1989 and1991, respectively. These values show a reduction of CO_2 emissions in these countries. Positive trends that signify an increase of CO_2 gas emissions have been observed in the other West African countries with varying intensity and duration from one country to another. The strongest trends of relatively short durations are generally observed in the 1970s. The maximum positive trend value has been recorded in Mauritania before and after the 1991s (Table 1).

Country	Breakpoint year	Mean value before breakpoint	Mean value after breakpoint	Rate of CO2 gas emissions (%)
Benin	1995	446.238	1293.375	65.49
	1999	1293.375	1841.733	29.77
	2002	1841.733	2582.367	28.68
	2005	2582.367	4198.4	38.49
	2008	4198.4	4992.233	15.9
	2011	4992.233	5654.275	11.71
Burkina Faso	1978	491.456	660. 556	25,60
	1987	660.556	852. 233	22.5
	1993	852.233	1219.718	30.14
	2004	1219.718	1520.6	19.79
	2007	1520.6	2012.167	24.43
	2010	2012.167	2271.82	11.43
Cabo Verde	1975	45.817	82.833	44.69
	1978	82.833	111.167	25.49
	1981	111.167	47.744	-132.84
	1999	47.744	73.64	35.16
	2009	73.64	93.9	21.58
Cote d'Ivoire	1995	3377.289	5057.733	33.22
	1998	5057.733	6479.582	21.94
	2009	6479.582	7711.85	15.98
	2013	7711.85	9544.85	19.2
Gambia	1976	41.929	78.51	46.59
	1986	78.51	111.7	29.71
	1996	111.7	138.8	19.52
	2000	138.8	168.683	17.71
	2006	168.683	207.125	18.56
	2010	207.125	242.44	14.56
Ghana	1981	2676.159	3961.017	32.44
	1997	3961.017	6803.463	41.78
	2005	6803.463	8859.125	23.2
	2009	8859.125	11872.75	25.38

	2011	11872.75	14337.85	17.19
Guinea	1978	650.478	900.038	27.73
	1986	900.038	1169.808	23.06
	1998	1169.808	1426.489	17.99
	2007	1426.489	1694.033	15.79
	2010	1694.033	1951.48	13.19
Bissau Guinea	1978	43.489	79.333	45.18
	1987	79.333	154.059	48.5
	1996	154.059	180.85	14.81
	2002	180.85	218.025	17.05
	2006	218.025	262.225	16.86
	2010	262.225	304.42	13.86
Liberia	1974	342.98	614.7	44.2
	1978	614.7	838.545	26.69
	1989	838.545	342.173	-145.06
	2000	342.173	556.578	38.52
	2009	556.578	757.167	26.49
Mali	1976	297.986	464.1	35.79
	1986	464.06	586.086	20.82
	1993	586.086	929.578	36.95
	2002	929.578	1076.325	13.63
	2006	1076.325	1294.025	16.82
	2010	1294.025	1530.9	15.47
Mauritania	1978	202.667	429.846	52.85
	1991	429.846	1141.778	62.35
	2000	1141.778	1508	24.28
	2005	1508	1995.6	24.43
	2010	1995.6	2414.8	17.35
Niger	1978	366.133	649.037	43.58
	1986	649.037	873.99	25.74
	1996	873.99	1133.867	22.92
	2002	1133.867	1377.475	17.68
	2006	1377.475	1612.533	14.57
	2009	1612.533	1866.9	13.62
	2012	1866.9	2138.067	12.68
Nigeria	1972	37882.1	68801.832	44.94
	1991	68801.832	83971.371	18.06
Senegal	1975	1511.367	2175.563	30.53
	1991	2175.563	2780.25	21.75
	1997	2780.25	3896	28.64
	2000	3896	4780.95	18.5
	2004	4780.95	5913.25	19.14
	2008	5913.25	7051.025	16.13
	2012	7051.025	8021.567	12.1
Sierra Leone	1978	394.233	592.875	33.5
	1986	592.875	809.02	26.72
	1991	809.02	639.256	-26.56
	2000	639.256	822.04	22.24
	2005	822.04	991.85	17.12
	2009	991.85	1193.85	16.92
Togo	1985	432.544	653.44	33.8
	1995	653.44	1003.2	34.86
	1998	1003.2	1269	20.94
	2007	1269	1662.133	23.65
	2010	1662.133	2249.32	26.11

Table 1: Summary of annual CO2emissions breakpoint year obtained by segmentation method and associated rate of CO2gasemissions in West African countries.

Country	Trend
Burkina Faso	0.112
Niger	0.103
Mali	0.075
Mauritania	0.146
Senegal	0.210
Bissau Guinea	0.017
Cabo Verde	0
Guinea	0.083
Sierra Leone	0.035
Gambia	0.013
Liberia	0.003
Cote d'Ivoire	0.335
Ghana	0.689
Togo	0.112
Benin	0.125
Nigeria	1.812

Table 2 : Linear trend with slopes in kton CO2 per year.

The maximum (~1.812kton. yr^{-1}) and minimum (~0kton. yr^{-1}) trends are observed in Nigeria and Cabo Verde, respectively.The upward linear trend shows the increasing CO_2 gas emissions in all West African countries over the 1970-2015 period.

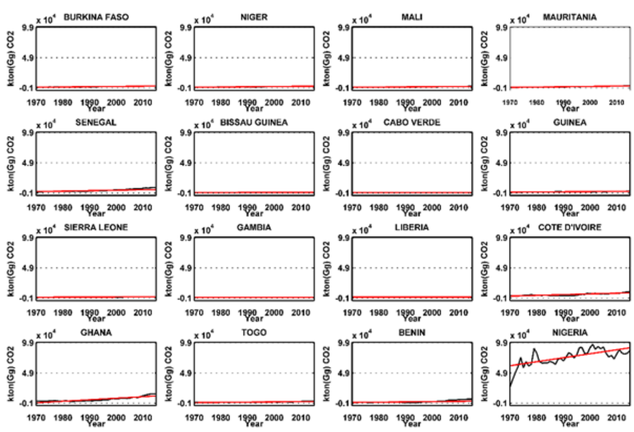

Figure 2 : Intern annual variability of annual CO2gasemissions in kton.yr-1 in West African countries. The linear trend (in red) obtained by EMD was added on each figure.

Discussion

Temporal trends in annual anthropogenic CO_2 emissions were analysed during the 1970-2015 period over the 16 West African countries. The results for each country indicated that CO_2 emissions exhibited a high annual variability with an increasing trend. Nigeria, Côte d'Ivoire, Ghana and Senegal have the highest CO_2emission values (>1340 Kton) with rates of 12.10%, respectively. These high values are probably due to the increase in anthropogenic activities associated with population and economic growth in these countries. Similar trends are also observed in the study of [10] over the 1960-2010 period in 39 African countries. In fact, these four countries (i.e., Nigeria, Côte d'Ivoire, Ghana and Senegal) are the most industrialised and highly populated in West Africa with population growth rates of 2.63%, 3.26%, 2.62% and 2.65% per year respectively during the 45 years [11]. This is corresponding to a population increase of roughly 231%, 330%, 226% and 220% respectively over the 1970-2015 period, which is of the same order of magnitude as the increase in bio fuel emissions. Moreover [12,13], highlighted that bio fuel emissions have increased at a higher rate than other sources due to an increase in low-income population in sub-Saharan Africa, where biomass constitutes about 80% of the total energy consumption. In addition, results of this study corroborate those of [14] on carbon emissions between 1990 and 2019 in West Africa. These authors showed that the regional net warming potential between 1990 and 2019 was estimated to be 11.44 Pg and Nigeria had the highest potential at 18.7%, closely followed by Mali and Ghana at 15% and 13.2%, respectively. Similarly, using Kaya identity, [15] indicated that the largest CO_2 emitters in West Africa in 2017 were respectively Nigeria (86 $MtCO_2$), Ghana (14 $MtCO_2$), Cote d'Ivoire (10.2 $MtCO_2$) and Senegal (8.5 $MtCO_2$), in agreement to our results. The authors explained this result by many factors, including GDP. In fact, they noted that countries with high CO_2 emissions per capita also have high GDP per capita. Our results showed that anthropogenic CO_2 emissions increased significantly in 32% of the countries of the West African sub-region in agreement with GDP per capita in the same period [16] arrived at the same conclusion for other regions. These authors highlighted that in South Africa, between 1994 and 2019, CO_2gasemissions levels were generally correlated with economic growth. Furthermore, in Africa, many studies have concluded that pollutant emissions are increasing [1,12,16]. In the present study, trends of CO_2emissions are in the same order of magnitude compared to those obtained for the other pollutants (i.e., BC, OC, NOx, CO, SO_2 and NMVOCs) in different African regions. For example, [12] showed that all pollutant emissions are globally increasing in Africa during the period 1990-2015 with a growth rate of 95%, 86%, 113%, 112%, 97% and 130% for BC, OC, NOx, CO, SO_2 and NMVOCs, respectively. These authors also pointed out that West Africa is the highest emitting region for some pollutants such as CO, mainly due to domestic fires and traffic activities. CO is an atmospheric pollutant that is emitted mainly from anthropogenic sources [17]. It was reported that many processes that emit CO also emit CO_2, and therefore knowledge of CO emission rates can provide additional information on CO_2 emissions [18,19] The work of [1] using atmospheric concentrations of CO_2 and the tracer CO measured continuously at Lamto showed that both compounds had strong similarities between their seasonal cycles and similar emission sources as well as high and very significant correlation values depending on the time of year and concluded that the trend of CO partly explains that of CO_2. Therefore, in this study different trends of CO_2 by country are not surprising since the values of CO_2 obtained in some regions of West Africa from direct measurements are very high compared to those in other regions of the world. Unlike the four countries mentioned above, Cabo Verde, Gambia, Guinea Bissau and Liberia showed lower levels of CO_2 emissions and a reduction in CO_2 emissions for particular years (Table 2), indicating a low level of industrialisation in these countries [20] . Furthermore, for many years, most tropical countries such as Ghana [21] and Côte d'Ivoire [5] have considered themselves as being net carbon sinks or, at worst, carbon neutral. This assertion is based on the relatively low level of industrialisation in these countries. But given the intensification of industrial processes and the use of fossil fuels, it is conceivable that their CO_2 emissions will increase significantly as indicated by the upward trends (in red) observed in long-term change in temporal evolution CO_2 gas emission in each West African country (Figure 2).

Conclusion

Anthropogenic CO_2 emissions in 16 West African countries over a 46-year period from 1970 to 2015 were analyzed on an annual scale using EDGAR data. The results show that CO_2 emissions exhibit high annual variability for each country. Furthermore, the results have shown that CO_2 emissions have increased significantly in 32% of West African sub-region countries, in agreement with GDP per capita over the same period in these countries. Nigeria, Côte d'Ivoire, Ghana and Senegal presented the highest CO_2 emission values (> 1340 kton) associated with strong upward trends. In contrast, CaboVerde, Gambia, Guinea-Bissau and Liberia showed the lowest emission levels with reductions in specific years. Statistical analysis using the HUBERT segmentation method highlighted the different breakpoints and their duration in the CO_2 emissions time series of each of these 16 countries. The application of this method enabled us to identify that the breakpoints in the various time series are in the interval [2,7] indicating several regime changes in CO_2 emissions. However, the time series observed in Gambia (2 points) shows the lowest number of breakpoints, where Senegal and Nigeria (7 points) show the highest number of breakpoints. Furthermore, EDGAR data used here are based on inventories, statistical models and generated knowledge, presenting sometimes very large uncertainties throughout the African region due to the scarcity of quality data. This can underestimate and/or overestimate the sources and trends of CO_2 in particular and GHGs in general in the region. Thus, to reduce uncertainties, an extensive network of GHG measurements in Africa is a privileged observable that can both help diagnose the impact of human activities and help model the various components of the carbon cycle.

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