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Anthropogenic CO_2 emission and climate change in the Congo basin countries

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Abstract

This study identifies the drivers of carbon dioxide emission and measures its effects on climate change in the countries of the Congo Basin. It applies panel Autoregressive Distributed lag (ARDL) model to Kaya's (1990) identity framework, which breaks up the main determinants of carbon dioxide emissions into energy intensity, carbon intensity, population and per capita gross domestic product. To take into account the ecological specificities of these countries, we add other variables; like "biocapacity" and "ecological balance". Using data for the 1971-2016 period, the results show that economic growth has a more negative effect on environmental quality in the Congo Basin, followed by energy intensity, carbon intensity and population density. "Biocapacity" and "ecological balance" have negative and positive coefficients, suggesting that they respectively are a "carbon sink" and "emission source" for CO_2, although the coefficients are non-significant. Particular attention should therefore be given to forest protection and ecological transition, problems arising from population explosion and the resulting uncontrolled urban development.

JEL classification: Q430, Q480, Q530.

Keywords: Anthropogenic emission, Congo Basin, Climate change, Carbon dioxide, Biocapacity, Ecological balance, Carbon sink, Carbon source

1. Introduction

Within the framework of the fight against climate change proned by the Kyoto Protocol, the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change that held in Paris in November 2015 ended with the main recommendation of lowering of the level of global warming to 1.5° Celsius in the long run[1]. Even if it is generally admitted that sub-Saharan Africa contributes only 3 to 4% of the world's greenhouse gases emissions (Boutin, 2014), it is also true that they are quite as exposed, if not more exposed as; the principal polluters of the planet (China, the United States of America, European Union, Brazil, and Russia) to the detrimental

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[1] The Paris accord particularly envisages the lowering of global warming of by 3°C from the present level and "keep the rise in the average temperature of planet below 2°C compared to the preindustrial level, and to continue the actions taken to limit the rise of the temperatures to 1,5°C ".

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consequences of this externality. In fact, because of the world public good[2] property of the environment on the one hand, and the transferable nature of air pollution on the other, these countries must seek an equitable balance between the quest for economic growth and safeguarding of environmental quality. More specifically, the Congo Basin is the 2nd largest forest area in the world after the Amazonian forest whose potential role in the regulation of climate is undeniable.

This study aims at identifying the determinants of greenhouse gas emissions in the Congo Basin countries. Climate change refers to a durable modification of the statistical parameters of the climate of the planet (Stern, 2006). These modifications can be the result of natural factors, not easily controllable, and/or of anthropogenic factors; which are due to human actions. According to Sir David King, former Principal Scientific Adviser of the British Government, cited in Stern's report (2006), *"climate change constitutes the most serious problem with which we are confronted, even more, serious than the threat of terrorism"*. This report talks about the close relationship which exists between the world economic outcomes and man's actions which contribute to the climate change on the one hand, and on the other hand between these results and the role of technological change in the reduction of emissions of greenhouse gases, as well as variations that exist between these actions and their consequences.

The majority of African governments wish to achieve economic emergence. This achievement is based on the progressive realization of several major projects referred to as "structuring" in various sectors of the economy. This increased economic activity is expected to raise the level of greenhouse gases (GHG) released in the atmosphere, notably carbon dioxide which represents about 82% of global GHG emissions (IPCC, 2007). According to the Intergovernmental Panel on Climate Change (IPCC, 2007), to moderate the increasing threat associated with global warming, it is imperative to reduce by three times the world level of GHG relative to the levels in 2000.

The purpose of this study is therefore to determine the main anthropogenic factors behind the generation of carbon dioxide in the Congo Basin countries. These factors could amplify or moderate carbon dioxide emissions, given the significant endowment of these countries in forest resources.

[2] This is a resource, good, or service benefitting all humanity, whose exploitation or protection can justify an international collective action. For more details, relating to this concept, see Kindleberger (1986).

The remainder of the paper is organised as follows. Section 2 reviews the literature connected to the topic. Section 3 presents some stylized facts. Section 4 presents the data and empirical methodology. Section 5 reports and discusses the main findings. Section 6 concludes the paper and provides implications.

2. Literature review

We first present a theoretical review of the literature, followed by an empirical review.

2.1. Theoretical literature review

It is unanimously admitted that the primary goal of economic growth is to improve the living conditions and human welfare. However, some of its effects such as an increase in pollution raise the question of its long-term sustainability. To address this dilemma, the opposite positions of economists converge today towards the adoption of a model of "sustainable development" (Brundtland Report, 1987)[3]. In fact, within the framework of the United Nations' world conference on the environment and development held in 1992 in Rio de Janeiro, a close relationship between environmental quality and the development process was clearly established, such that no development strategy can be conceived without suitable management of natural resources. However, the conditions for the application of such an ideal model are the subject of controversies where traditional cleavages of economics reappear.

On the one hand, liberal theorists consider that it is possible to find substitute resources to those which are being exhausted in future. It is thus necessary to reveal innovations through technical progress, which will take over the resources that are disappearing and to support the substitutability of natural capital for example by another which is produced physical capital (Solow, 1974; Hartwick, 1977). This school of thought preaches "weak sustainability" and promotes the evaluation in monetary terms of environmental resources. In this line, certain researchers questioned themselves on the possibility of a "decoupling" between growth and the environment, i.e. the possibility of a separation between the creation of wealth and environmental pollution.

[3] According to the Brundtland Report, sustainable development is a "process of change by which the exploitation of resources, the orientation of investments, technical and institutional changes are in harmony and reinforce the present and future potential of satisfaction of the needs of man".

According to the OECD (2008), "decoupling" broadly refers to the act of "breaking the link between environmental ills and economic goods". Studies on this notion which intuitively start with the environmental Kuznets curve (EKC) date from the early 2000s (Laurent, 2011) and make it possible to carry out the ecological transition of an economy.

On the other hand, unlike the neo-classical school of thought, the "ecological" school contests this "productivist" design of sustainable development because of the irreplaceable nature of certain resources and the irreversibility of their disappearance. This school of thought recommends a growth model based on the replacement of non-renewable resources by renewable resources to preserve natural capital. To evaluate the impact of human activities on the environment, it is necessary to calculate the ecological footprint, or the number of hectares enabling the production of resources used by this population and assimilate the waste it produces. The ecological footprint is calculated regarding the manner of living of the studied population. This school of thought thus militates for "strong sustainability" and supports the maintenance of a critical stock of natural capital. In fact, in this hypotheses defended by Daly (1990) and Pearce (1992), the stock of per capita natural resources should not drop. Daly holds that natural and artificial capital are complements and not substitutes. Jackson (2010) precisely makes restrictions in his study "Prosperity without growth: the transition towards a sustainable economy" on the idea of a possible "decoupling", i.e. of separation of the economy and the environment, thus confirming the fact that natural capital and artificial capital are complementary. At the limit, we can talk of "decoupling" if the growth rate of pressure on the environment (for example carbon dioxide emissions) becomes lower than that of growth in GDP. Specifically, it would be more correct to talk of "absolute decoupling" if the GDP grows when the pressure on the environment (increase in the volume of carbon dioxide emissions) remains constant or decreases; and of "relative decoupling" when the GDP increases more than proportionally to the increase in the pressure on the environment. Attempts have been made to empirically verify all these theoretical positions and empirical models implemented whose results are quite as debatable as the theoretical positions.

2.2. Empirical literature review

This study is based on the theoretical assertion of a possibility of decoupling according to Jackson (2010), i.e. of a "decoupling" which can either be "absolute" or "relative" between economic growth (GDP) and environmental quality, measured by the level of CO_2 emissions. We thus admit that economic growth will always require a certain level of emission of greenhouse gases, "zero pollution" being a non-existing concept in economics. As concerns climate, whatever the nature of the development programs implemented, it could easily be disturbed or even be completely destroyed by the negative effects of climate change (Odingo, 2008). The four scientific evaluations carried out by the IPCC hold that: global warming is not only a reality but also an unambiguous reality (IPCC, 2007)[4]. Consequently, it is not possible to separate climate change from the process of economic development and vice versa. It will only be possible to take it into account.

The majority of the empirical studies on economic growth and environmental quality establish a "decoupling" which can either be nonlinear or linear. For the nonlinear relationship, existing studies investigated the environmental Kuznets curve (EKC) between growth and the environment since the studies of Grossman and Krueger (1991, 1995). In 1955, Simon Kuznets studied the effects of economic growth on income inequality in the United States. The results of this study enable him to establish a nonlinear relationship (concave curve) in the form of an inverted U-shaped curve between the two variables. This suggests that income increases with inequalities until a certain threshold. After this threshold, any increase in income could generate a reduction of inequalities. At the beginning of the 90s, this reasoning is transposed to the relationship between economic growth and environmental quality. Thus, adopting a similar approach, Grossman and Krueger (1991, 1995) detect a U-shaped curve or EKC between economic growth and several indicators of pollution in the context of the North American Free Trade Agreement (NAFTA). Similarly, Shafik and Bandyopadhyay (1992) in the World Bank report on development in the world; and Panayotou (1993) for the International Labour Organisation (ILO) also find an inverted U-shaped curve between income per capita and environmental pollution in their studies.

[4] Synthesis report of the GIEC, quoted by IPCC, 2007.

Kaufmann et al. (1998) use fixed and random effects panel data models with a quadratic function for a sample of 23 countries between 1974 and 1989 and obtain an EKC for the Sulphur dioxide concentrations. Following these seminal studies, many others have examined the links between economic growth and pollutant emissions using a variety of econometric approaches and sample of countries grouped according to spatial and economic criteria. Depending on the type of econometric specification, the authors detected an increasing monotonous relationship between pollution and economic growth (Begum et al., 2015; Gill et al., 2017), a decreasing monotonous relationship (Ahmed and Long, 2012; Shahbaz et al., 2016), an inverted U-shaped relationship (Lean and Smyth, 2010; Jebli et al., 2015; Apergis et al., 2017; Wang et al., 2017; Avom et al., 2020), a U-shaped relationship (Chandran and Tang, 2013; Saboori et al., 2012; Ozturk and Al-Mulali, 2015), and more complex relationships, particularly the "*N*" and inverted shaped curves (Sinha et al., 2017; Fosten, 2012; Nkengfack et al., 2020).

However, previous studies mostly use only income and consumption of energy as drivers of CO_2 emissions. Other components such as energy intensity and carbon intensity are not considered. Doing so, these studies might have provided an incomplete picture of the effect and the significance of these factors.

The 1970s, however, marked a period rich in debates between researchers on the sources of environmental pollution. These debates led to the design of mathematical expression of the factors which create an environmental impact. This expression is known as the IPAT (*Impact-Population-Affluence-Technology)* which shows that the impacts *(I)* on the environment are the result of the level of the population of a country *(P)*, level of consumption *(A)* of this population and type of technology *(T)* used to produce the goods.

Thus,

$$I = P * A * T \tag{1}$$

For some, the three factors (*P*, *A*, and *T*) are significant in the explanation of the level of carbon dioxide emission, but the most significant factor is the size of the population and its growth rate (Ehrlich and Holdren, 1971). For other authors, it is the technology used in production activities which is the principal factor of air pollution (Commoner, 1972).

Consequently, the approach suggested by the Japanese economist Yoichi Kaya in 1990 in his study "*Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios"* is inspired by the IPAT model and reconciles the two approaches. It makes it possible to describe in a linear way the impact of human activities on carbon dioxide emissions (Chertow, 2001). This led to what is known today as the "Kaya equation".

The chemical formula of carbon dioxide is noted "CO_2". It is the main additional (caused by man) greenhouse gas. The Kaya identity follows the simple and obvious principle:

$$CO_2 = CO_2 \tag{2}$$

Given the total quantity of energy consumed, measured in Ton Oil Equivalent (TOE)[5], multiplying and dividing the preceding equality by TOE, yields:

$$CO_2 = \left(\frac{CO_2}{TOE}\right) * TOE \tag{3}$$

This relationship means that the carbon dioxide emissions are now related to $\left(\frac{CO_2}{TOE}\right)$ and the quantity of energy consumed, where $\left(\frac{CO_2}{TOE}\right)$ is the "carbon dioxide content of the energy consumed". In fact, it refers to the "energy mix", i.e. the different types of energy a country possesses and uses in different proportions to satisfy its energy needs. This ratio can vary largely, depending on the type of energy used.

By multiplying and by dividing the right hand side of the preceding equation by the amount of wealth created, measured by the GDP, we obtain:

$$CO_2 = \left(\frac{CO_2}{TOE}\right) * \left(\frac{TOE}{GDP}\right) * GDP \tag{4}$$

[5] The TOE (ton oil equivalent) is the measuring unit of quantity of energy used. By way of equivalence, 1TEP=11.6 MWh.

This means that the carbon dioxide emissions are now explained by the "carbon dioxide contents of energies", multiplied by $\left(\frac{TOE}{GDP}\right)$, which in fact is the share of energy in the national income referred to as "radiant intensity of the economy", multiplied by the volume of the national income. The expression $\left(\frac{TOE}{GDP}\right)$ concretely stands for the quantity of energy necessary to manufacture a product or to provide a service. The more technology is developed, the more this intensity drops.

Introducing the level of the population (POP) into the analysis, we obtain:

$$CO_2 = \left(\frac{CO_2}{TOE}\right) * \left(\frac{TOE}{GDP}\right) * \left(\frac{GDP}{POP}\right) * POP \quad (5)$$

Where the ratio $\left(\frac{GDP}{POP}\right)$ is the output per capita.

Thus, the IPCC (2007) through this method finds that an annual growth of carbon dioxide emissions in the world from 1970 to 2004 is attributed to the four variables as follows (table 1).

Table 1. Kaya decomposition for the world economy between 1970 and 2004

Variables	**Rate (in %) of annual average growth**
Population	+1,6
GDP per capita	+1,8
Energy intensity	-1,2
Carbon intensity	-0,2
Net effect on CO_2 emissions	+1,9

Source : IPCC (2007).

It can be deduced from this table that the progress observed in the energy efficiency (-1,2%) and the "decarbonisation" of the energy consumption (-0,2%) are not enough to compensate for the rise in population and the income per capita which are sources of a clear increase of 1,9% of carbon dioxide emissions. In fact, the harmful climatic effect of the volume of the world economy (increase in the population, increase in wealth) exceeds the beneficial effect (technological improvement) which makes it possible to consume less energy per unit of growth and to emit less carbon per consumed unit. Consequently, it appears clearly that the challenge of decoupling between GDP growth and emissions of greenhouse gas necessary to achieve the climatic goals that the political class established from this study is very challenging. In the present situation, an absolute reduction of the world emissions of greenhouse gases depends on a reduction of the radiant and carbonic intensity at a faster pace than income and demographic growth put together.

Lastly, applying the Kaya equation to the case of Brazil, Trotignon (2014) specifically analyses the impact of sectors: land use, attribution and change of land and forestry on carbon dioxide emissions. The results show that the effect of this sector in the variation of total emissions proves to be predominant in Brazil, being a stimulating factor in the period of massive deforestation (1994-2000) and a moderating factor when the programs for the sustainable management of forests were set up (2000-2005). Lin et al. (2015) use the Kaya decomposition to investigate the impact of urbanization on CO_2 emission in Nigeria during the period from 1980 to 2011. The result of the estimates shows that industrial value added has an inverse and significant relationship with CO_2 emissions. Looking at the Kaya's drivers, the estimates indicate that GDP per capita, population, energy intensity and carbon intensity have positive and significant impacts on CO_2 emission. Tavakoli (2018) uses the Kaya (1990) framework to evaluate four driving forces of GHG emissions among top ten emitters in 2015. The empirical result suggests that the magnitude of the effect of each driver (carbon intensity, energy intensity, GDP and population) were highly different from one country to another.

3. Some stylized facts on CO_2 emissions

3.1. World geographic comparisons of CO_2 emission and its drivers

Global CO_2 emissions increased by 57% between 1990 and 2015, while at the African level, they increased by 116% over the same period (IEA, 2017). According to Table 2, global CO_2 emissions increased from 24.05 billion tons in 2000 to 36.13 billion tons in 2015. These emissions are mainly generated from East Asia and Pacific (EAP) countries. With 822 million tons, sub-Saharan Africa remains the least contributor to these emissions. Table 2 also provides an idea of the determinants of these emissions. Per capita GDP increased significantly from \$5491 constant 2010 to \$10217 constant 2010 between 2000 and 2015. All regions of the world experienced a similar increase, although sub-Saharan Africa (SSA) lagged behind. On the other hand, the production technique is inefficient in SSA, compared to the world average and that of the other regions. Given that, the high value of energy intensity indicates much energy is used to produce one unit of output, the heavy dependence of sub-Saharan African countries on fossil fuels and the inefficient use of technology would lead to an increase in CO_2. The population density has increased by nine points globally and by 15 points for sub-Saharan Africa.

Table 2. Situation of CO_2 emissions and its determinants in the world

Region	CO_2 emissions (billions of kt)		GDP per capita (2010 Constant $)		Energy intensity (MJ/$2011 PPP GDP)		Carbon density (tCO2/terajoule)*		Population density	
	2000	2015	2000	2015	2000	2015	2000	2015	2000	2015
SSA	0.564	0.822	596,414	1669,088	9.979	7.050	34.2	34.2	31,322	46,861
MENA	1.473	2.59	3066,4	7388,593	4.88	5.26	Na	Na	28,08	37,94
LATCAR	1.357	1.91	4389,8	8856,928	4.16	3.82	Na	Na	25,99	31,08
ECA	6.506	6.24	11627,6	22499,58	7.16	5.60	Na	Na	31,40	33,07
EAP	6.313	14.2	4044,31	9526,576	6.05	4.54	Na	Na	83,96	93,60
World	24.059	36.13	5491,57	10217,544	6.640	5.131	55.2	56.1	48,008	57,643

*Note: na indicates that data were not available for the country group; * Data are for Africa not SSA; SSA= Sub-Saharan Africa; MENA = Middle East and North Africa; ECA= Europe and Central Asia; LATCAR = Latin America and the Caribbean; EAP=East Asia and pacific.*

Sources: author's construction from the World Bank (2018) and the IEA (2018).

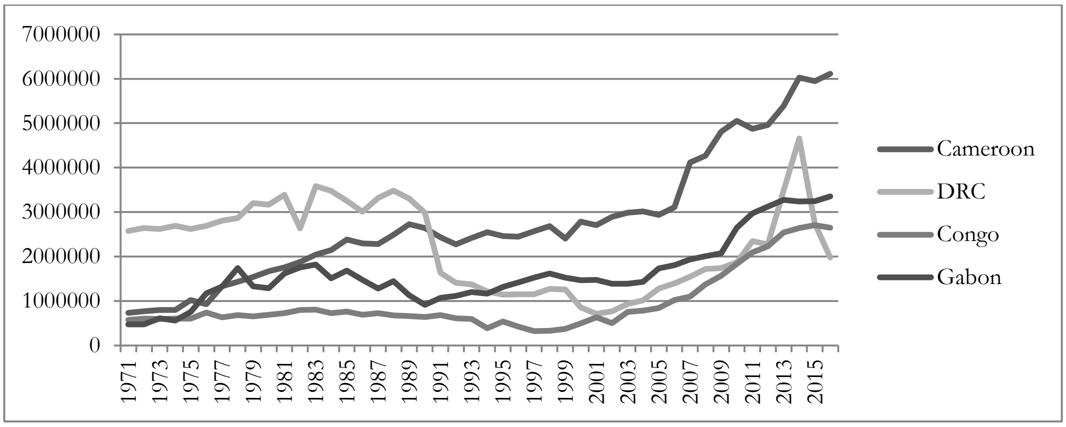
3.2. Presentation of the study area

Situated in sub-Saharan Africa, the Congo Basin is the catchment area of the Congo River. It consists of ten countries, located in Central Africa and Southern Africa. However, most of these countries are in central Africa. The Congo Basin covers approximately 4 million km^2, with 93.2 million inhabitants. The population density varies between countries. Exports revenues mostly come from oil, wood, cocoa, coffee, and of some minerals (diamond, gold, etc.).

When we look at this area from an ecological angle, we tend to retain only the six countries which make up the “forests of the Congo basin” which are Cameroon, the Central African Republic, Congo, the Democratic Republic of Congo, Gabon and Equatorial Guinea. The Congo Basin is the second largest forest of the world, after that of Amazonia. It shelters one of the richest dense tropical forests of the world in biodiversity but is, unfortunately, witnessing constant deforestation, with a rate of deforestation of about 0.16% per annum. This significant endowment in forests is important given the paramount role played by forests in the reduction of greenhouse gases. It is thus necessary to make an inventory of emissions of greenhouse gases in this area. Although Africa contributes only approximately 4% of GHG emissions in the world as mentioned, its forests can nevertheless absorb 20% of the total carbon in the world.

Figure 1 shows the pattern of CO_2 emissions in selected countries of the Congo Basin between 1971 and 2016. During this period, the cumulated amount of CO_2 released by these countries in the atmosphere increased by 223.26%, from 4.359 million tons to 14.093 million. With 6.113 million tons of CO_2 emitted in 2016, Cameroon is the top emitter, followed by Gabon, Congo and Democratic Republic of Congo (DRC), respectively.

Figure 1. Trend of CO_2 emissions in the Congo basin



Source: Authors from IEA (2018).

The rapid growth of the population and the inefficient use in technologies probably led to an increase in CO_2 emissions in the Congo Basin. Figures 2 to 5 review the Kaya's drivers of CO_2 in 2015 for the countries considered in the Congo Basin for the period from 1990 to 2015.

Figure 2. Per capita GDP (2010 constant $)

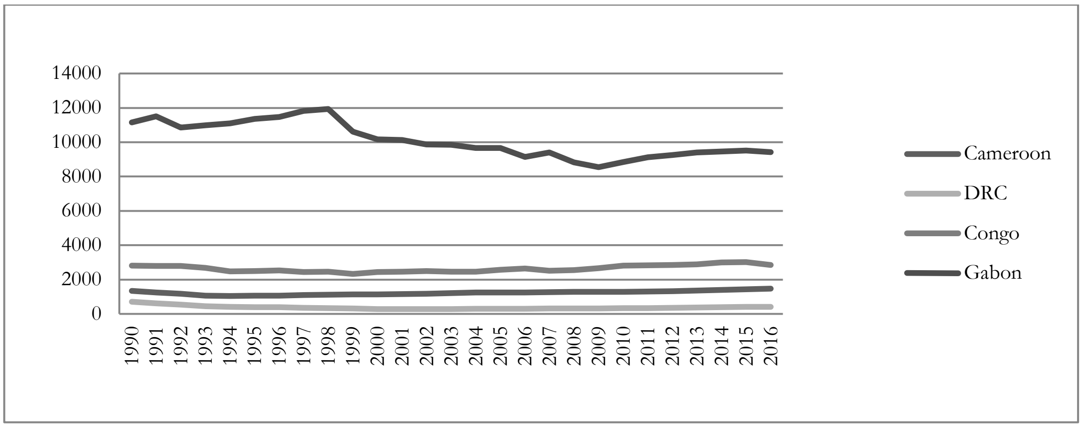


Figure 3. Carbon intensity (tCO_2/terajoule)

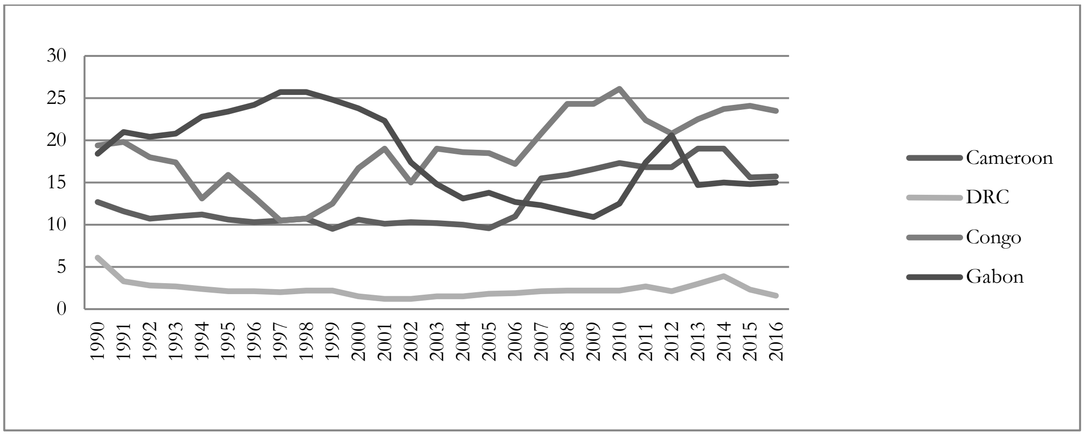


Figure 4. Population density (people per sq. km of land area)

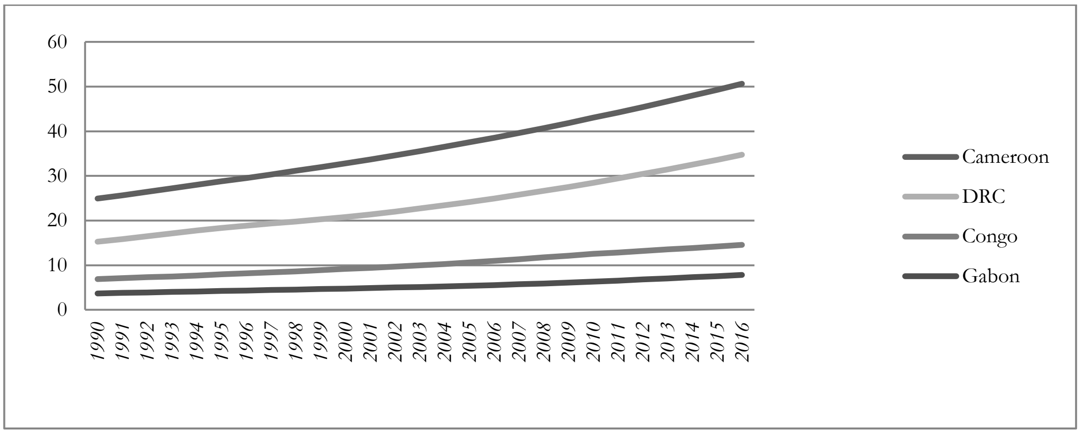
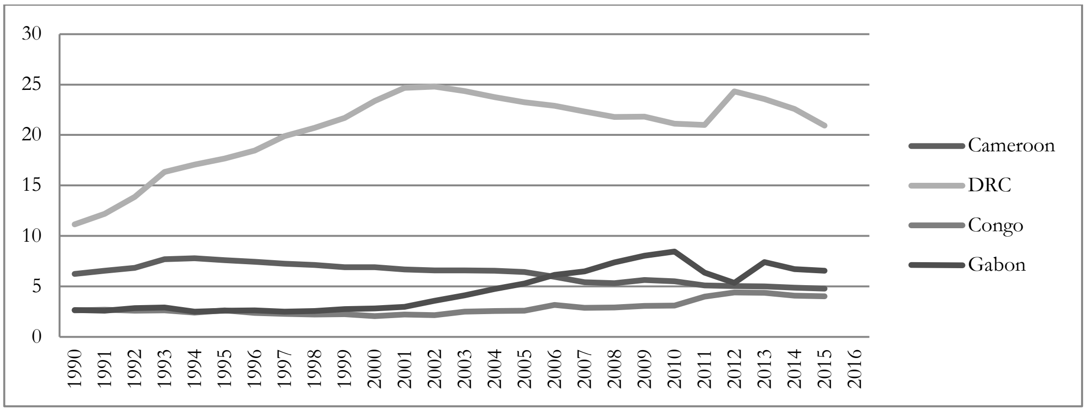


Figure 5. Energy intensity (MJ/$2011 PPP GDP)



Source: Authors from World Bank (2018) and IEA (2018).

4. Methodology

We present the specification of the empirical model to be implemented, followed by the sources and nature of our data; and finally the estimation strategy.

4.1. Specification of the model

To evaluate the driving force of CO_2 emission in the Congo basin, we use the Kaya (1990) framework as presented in the literature review. However, this framework does not take into account the "carbon sinks" and other "sources" of CO_2 emission. In fact, the ecological footprint of a geographical area could be a factor of reduction of greenhouse gases (carbon sink) insofar as it could make it possible to confine carbon and consequently reduce the quantity of carbon dioxide emitted. Contrarily, other factors such as the density of the population and the level of consumption of this population could constitute supplementary "sources" and result in the emission of more carbon dioxide. However, a drawback of this model as recognized by the IPCC is non-independence between the variables.

For this reason, we introduce two additional variables to the original model. These variables are the "ecological footprint", i.e. "*the biological surface necessary for the production of the goods and services consumed by a population and to assimilate and absorb the pollutant emissions of this population"* (Piguet et al., 2007); and the "biocapacity", representing an estimate of all the resources consumed by a population, either of domestic or foreign origin (imports), the relationship between the ecological footprint and the "biocapacity" is called "ecological balance".

On this basis, equation (5) then becomes:

$$CO_2 = \left(\frac{CO_2}{TOE}\right) * \left(\frac{TOE}{GDP}\right) * \left(\frac{GDP}{POP}\right) * \left(\frac{POP}{ECOL}\right) * \left(\frac{ECOL}{BIOCA}\right) * BIOCA \tag{6}$$

The ratios $\left(\frac{POP}{ECOL}\right)$ and $\left(\frac{ECOL}{BIOCA}\right)$; respectively, indicate the density of the population and the ecological balance (credit or deficit) of the country. A country will be in an ecological situation of credit if it is endowed with more space to produce than that which the population needs for its consumption. Otherwise, it is in an ecological situation of deficit.

The specificities of each country can make it have different reactions relative to climate change. These specificities make panel data regression to appear more suitable as method of data analysis. Taking into account the additional dependent variables and transforming equation (6) in the natural log-form accordingly to Tavakoli (2018) yields:

$$Y_{it} = \beta_i + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + \beta_6 X_{6it} + \varepsilon_{it} \tag{7}$$

Where Y_{it} refers to the amount of CO_2 emissions in country *i* at period *t*; X_{1it} stands for the carbon intensity in country *i* at period *t*, X_{2it} is the energy intensity of country *i* at period *t*, X_{3it} is the per capita GDP in country *i* at period *t*, X_{4it} is the population density in country *i* at period *t*, X_{5it} is the ecological balance in country *i* at period *t* and X_{6it} is the biocapacity in country *i* at period *t*. Since equation *(7)* is expressed in the natural log-form, the values β_j (j=1 … 6) are interpreted as elasticities. β_i is the country fixed effects and ε_{it} is the error term.

4.2. Data

Data used in this study is collected from secondary sources. They were compiled from the "World Development Indicators" of the World Bank (WB, 2018), the International Energy Agency (IEA, 2018), and the Global Footprint Network. The study period spans from 1971 to 2016, that is to say, 46 years. The countries used in the sample include Cameroon, Democratic Republic of Congo, Republic of Congo and Gabon. The selected sample and the time are dictated by the existence of relevant data.

4.3. Estimation procedure of the model: The panel ARDL approach

This study uses the panel autoregressive distributed lag (ARDL) approach to propose the inventory of carbon emission in the Congo basin countries. The ARDL framework is advantageous over other models because it easily allows the calculation of both short and long-run effect (Sadorsky, 2014). The ARDL model can be applied whether all the variables are *I(0)*, *I(1)* or both *i.e. I(0)* and *I(1)*.

The dynamic form of the ARDL (p, $q_{1,\ldots,} q_k$) is specified as follows:

$$Y_{it} = \sum_{j=1}^{p} \alpha_{ij} Y_{i,t-1} + \sum_{j=0}^{q} \beta'_{ij} X_{i,t-1} + \mu_i + \varepsilon_{it} \tag{8}$$

Where X_{it} is a vector of independent variables; a_{it} are scalars; β'_{ij} is the vector of elasticities; μ_i is the country fixed effects; ε_{it} is the error term; Y_{it} is the dependent variable.

Following Pesaran et al. (1999), the unrestricted error correction model is formulated as follows:

$$\Delta Y_{it} = \varphi_i (Y_{i,t-1} - \beta'_{ij} X_{i,t-1}) + \sum_{j=1}^{p} \alpha_{ij} \Delta Y_{i,t-1} + \sum_{j=0}^{q} \beta'_{ij} \Delta X_{i,t-1} + \mu_i + \varepsilon_{it} \tag{9}$$

Where φ_i is the error-correction term which determines the speed of adjustment by which the system backs to the equilibrium. It should be negative and statistically significant to confirm the existence of a long-run cointegrating relationship among the variables. The short-run effects of each dependent variable are captured by the difference terms Δ. The optimal lags (p, q_1, …, q_k) are chosen by minimising the Aikaike Information Criterion.

However, it is important to choose the appropriate estimator between the "pooled mean group" (PMG) and the "mean group" (MG) estimator. The PMG assumes the long-run coefficient to be homogenous while the short-run coefficients are allowed to be heterogeneous. Conversely, the MG estimator allows the long-run parameters to be heterogeneous. The selection of the appropriate model is done through the Hausman specification test. The null hypothesis of the test assumes that the MG estimator is efficient while the alternative hypothesis assumes that the PMG estimator is efficient.

5. Results and their interpretation

Before the main results, it is important to check for the unit root properties of the variables and determine whether the model is cointegrated.

5.1. Results of the unit roots test

One of the issues to be addressed with data with large *T* is the need to test for the presence of unit roots in the data. In the presence of non-stationary variables, the estimation could lead to spurious regressions. Another challenge with the PMG estimator is that model does not apply to series integrated in the second difference and above. For these reasons, we rely on three unit roots test for our variables: Levin-Lin-Chu (2002), Choi (2001) and of Im-Pesaran-Shin (2003). The Levin-Lin-Chu (2002) test assumes that the individuals are heterogeneous (on the one hand heterogeneity due to the existence of constants specific to each individual) while Choi (2001) and of Im-Pesaran-Shin (2003) assumes that the individuals are homogeneous. All the tests assume the presence of a unit root as the null hypothesis while the alternative hypothesis assumes that the variables are stationary. According to the results of the unit-roots test reported in Table 3, the maximum order of integration of our variables is *I(1)*.

Table 3. Results of the unit roots tests

Variables	LLC		Choi		IPS		Conclusion
	Level	1st difference	Level	1st difference	Level	1st difference	
Y	0.626	-3.646***	0.496	-2.560***	0.747	-5.732***	I(1)
X_1	-0.833	-6.923***	-0.740	-2.715***	-0.460	-6.730***	I(1)
X_2	-0.733	-3.895***	1.403	-2.403***	0.665	-3.162***	I(1)
X_3	-1.315*	-	-0.319	-3.716***	-1.745**	-	I(0)
X_4	-5.16***	-	-1.86**	-	-9.61***	-	I(0)
X_5	-0.444	-5.193***	0.380	-7.605***	-1.229	-8.674***	I(1)
X_6	-1.496*	-	-0.558	-6.731***	-1.50***	-	I(0)

*Note: ***, ** and * denotes stationary at 1%, 5% and 10% statistical significance level, respectively.*

Source: Authors.

5.2. Panel cointegration test

We apply the Pedroni (2004) residual cointegration to check for the existence of a long-run relationship between our variables. The test is based on two types of cointegration tests and seven statistics. The tests are classified based on the within-dimension and the between-dimension of the autoregressive coefficients for each country in the panel. The null hypothesis is that there is no cointegration and the alternative is that there is cointegration between variables. The results of the Pedroni (2004) cointegration test are presented in Table 4. Four statistics for the within-dimension and two statistics for the between-dimension are statistically significant, indicating that our model is cointegrated. The results of the panel cointegration tests strongly support the existence of a long-run equilibrium cointegrating relationship between CO_2 emissions and its driving forces.

Table 4. Results of the panel cointegration test

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	**Prob.**	**Weighted Statistic**	**Prob.**
Panel v-Statistic	-1.208514	0.8866	-1.971689	0.9757
Panel rho-Statistic	0.095971	0.5382	0.190363	0.5755
Panel PP-Statistic	-7.807503	0.0000***	-5.757207	0.0000***
Panel ADF-Statistic	-2.231903	0.0128**	-1.789501	0.0368**
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-Statistic	1.492202	0.9322		
Group PP-Statistic	-8.568284	0.0000***		
Group ADF-Statistic	-2.453085	0.0071***		

*Note: *** denotes significance at the 1% level.*

Source: Authors.

5.3. Long and short-run estimates

The PMG and MG estimators are used to investigate the short- and long-run effects of the driving factors of CO_2 in the Congo Basin. The results are reported in Table 5. The p-value (0.0000) of the Hausman specification test is lower than the common alpha level (0.05), suggesting that the MG estimators is preferred over the PMG estimator. Therefore, our discussions only focuses on the estimates form the MG. Looking at the estimated coefficients of the long-run, except “ecological balance” and the “biocapacity” which have a negative and non-significant effect on carbon emissions, the coefficients of the other variables are positive and statistically significant. By order of importance, economic growth has a more pernicious effect on environmental quality in the Congo basin, followed by energy intensity, carbon intensity and population density.

In fact, a 1% increase in energy intensity (i.e. the quantity of energy used per unit of income) increases CO_2 emissions by 102.9%. The same behaviour is observed with regard to the other variables. In fact, the carbonic intensity has a coefficient that is positive and significant at the 1% level. It suggests that a rise in the carbonic intensity of 1% leads to an increase of 97.60% of the carbon dioxide emission. The GDP per capita, as well as the density of the population, are also "sources" of carbon. A 1% an increase in these variables will lead to a rise in the carbon dioxide emissions of 104.7 and 96.4% respectively.

Table 5. Results of the regression

	PMG		**MG**	
Variables	**Coef**	**(se)**	**Coef**	**(se)**
Long-run				
X_1	0.938***	(0.0231)	0.976***	(0.0184)
X_2	0.913***	(0.0394)	1.029***	(0.0151)
X_3	0.942***	(0.0738)	1.046***	(0.0369)
X_4	1.046***	(0.0158)	0.964***	(0.0228)
X_5	-0.00762	(0.00935)	-0.00166	(0.0101)
X_6	-0.00855	(0.0145)	-0.000991	(0.00938)
Short-run				
Error correction	-1.181***	(0.175)	-0.726***	(0.111)
ΔX_1	-0.171	(0.187)	0.262**	(0.109)
ΔX_2	-0.137	(0.174)	0.247**	(0.113)
ΔX_3	-0.115	(0.154)	0.349***	(0.117)
ΔX_4	-0.410	(1.031)	0.0804	(0.599)
ΔX_5	0.00219	(0.00718)	-0.000815	(0.00555)
ΔX_6	0.000352	(0.00416)	0.000435	(0.00544)
Constant	1.140	(1.066)	-0.133	(0.201)
Observations	176			176
Hausman test (P-value)			269.92 (0.0000)	

****: Significant at 1 %; **: Significant at 5 %.*

The values in brackets represent the standard deviations.

Source: Authors.

Considering the short-run analysis, the estimated coefficient of the error correction term is negative, less than one (-0.726), and statistically significant. This provides additional evidence on the existence of a long-run relationship amount our variables. Further, the coefficient of the error correction term shows that deviations from the long-run equilibrium are corrected by 72.6% every year.

Turning to the explanatory variables, the result shows that increases in CO_2 in the short run is mostly driven by energy intensity, carbon intensity and economic growth. The effect of urbanization remains positive but non-significant. The elasticity of CO_2 with respect to "ecological balance" and "biocapacity" are negative and positive, respectively, but statistically insignificant. This suggests that these variables do not yet have a significant effect on the environmental quality in the Congo Basin both in the long- and short-run.

Globally, the results of this study are in line with previous authors who report that an increase in energy intensity – as an indicator of the inefficiency of production technologies – significantly increase the level of pollution in SSA (Nkengfack et al., 2019). However, a comparison with existing studies is difficult because they used the static panel method or decomposition technique. Also, the positive and statistically significant effect of carbon intensity on CO_2 is reported by the literature. Tavakoli (2018) finds evidence that carbon intensity is a critical factor leading to more GHG in China. However, the results show that the effect of carbon intensity, energy intensity, income and population growth differ significantly from one country to another among the top ten emitters.

The negative effect of economic growth on environmental quality is consistent with the findings of Shahbaz et al. (2013) in South Africa, and Lin et al. (2015) in Nigeria. Also, Nkengfack and Kaffo Fotio (2019) report a positive and significant effect of economic growth on CO_2 emissions in Algeria, Egypt and South Africa. The high coefficient of per capita GDP in this study suggests that future economic growth in the Congo Basin will have a larger impact on carbon emissions.

The positive effect of population on carbon emissions is also found in the literature. Tavakoli (2018) reports that population is the most important factor behind CO_2 emissions in Japan, Russia and Iran. Poumanyvong and Kaneko (2010) also find that the increase in population size is associated with the increase in atmospheric pollution. This result is in line with the Congo Basin experience as the region has one of the highest fertility rates of the world. Thus, the increase in population size would increase carbon emissions through its impact on energy demand, mainly fuelled by fossil fuels.

On the other hand, the variable "ecological balance" reduces CO_2 emission both in the long run and short run; while the impact of “biocapacity” is negative and positive, respectively in the long run and the short run. However, these impacts appear non-significant. Thus, we cannot yet conclude that “ecological balance” and “biocapacity” respectively constitute; a “sink” and “source” of CO_2 emission in the Congo Basin. These results are against intuition. With respect to “biocapaciy”, we could explain its insignificant coefficient by the constant increase in the rate of deforestation in the Congo Basin. The low significance of the “ecological balance” could on its part be explained by the weakness of the consumption levels of the populations.

Consequently, we suggest that the governments concerned reinforce the afforestation programmes in the zone; and encourage economic operators (private and public) to operate an ecological transition for green growth for which energy transition is essential. It is a question of generally moving from the current energy system using extremely polluting fossil energies towards an energy mix made up mainly of renewable energies for most of the human activities (transport, industries, lightings, etc.).

6. Conclusions and policy implications

This study has as objective to make an inventory of the emissions of greenhouse gases, approximated by the carbon dioxide (CO_2) in the countries of the Congo Basin and identify its principal determinants. We use the Kaya decomposition to which we add two new variables. After having checked the stationarity properties of the variables and the existence of a long-term relationship, our econometric model is estimated by the panel autoregressive distributed lag (ARDL) model. The Hausman specification indicates that the best results are provided by the MG estimator. The results suggest that the main sources of carbon dioxide emission in these countries, by order of importance, are: energy intensity, carbon intensity, Gross domestic product per capita and the population density. However, the coefficients of “ecological balance” and “biocapacity” are not statistically significant, both in the long- and short-run, governments should reinforce the afforestation programs to prevent the high rate of deforestation in the Congo Basin. Also, particular attention should be given to the transformation of the production structures, to facilitate the acquisition of clean technologies that minimize the negative impacts of the realization of projects in their quest for economic emergence.

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