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Is There a Relationship between CO2 Emissions by Sources, Electricity Consumption and Economic Growth in Côte d'Ivoire? Evidence from an ARDL Investigation

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Abstract

This paper investigates the impact of different sources of CO_2 emissions together with electric power consumption on per capita GDP in Côte d'Ivoire with data ranging from 1970 to 2019. We found cointegration relationships between per capita *GDP* and the variables of interest. CO_2 emissions, CO_2 emissions from liquid fuel consumption, electric power consumption and investment have positive impact on per capita *GDP*. A simultaneous increase of electric power consumption and CO_2 emissions in the long run has a negative impact on per capita *GDP*. Causality runs from CO_2 emissions, electric power consumption and investment to per capita *GDP*. In the short run, electric power consumption positively impacts per capita *GDP*. Labor force has a negative impact on per capita *GDP*. Causality runs from electric power consumption to per capita *GDP*. Similar results are obtained when CO_2 emissions from liquid fuel consumption are used in place of global CO_2 emissions.

Keywords: CO_2 emissions, electric power consumption, economic growth, *ARDL*, Cointegration

1. Introduction

1.1 The Problem

Recent floods observed in Europe and Asia brought to the spotlight once again concerns about climate change. Indeed, scientist questioned whether, climate change helped fuel the disaster. Among the suspected factors that may have been the root of this disaster is the warming of climate that could supercharge rainstorms. It was observed that on July 13, 2021, in Germany for instance, 15 centimeters of rain fell in 24 hours[1]. Scientist are assessing the extent to which human related emissions could have caused this disaster[2]. In Asia (China, Sri Lanka, Philippines etc) similar flooding events were also observed.

Although these deadly events are yet to occur here in West Africa, the Authorities at national as well as regional levels should be aware of the extent of such disaster and take precautionary measures where possible. How could that be done? Through climate change awareness and deliberate actions toward curbing carbon dioxide (CO_2) emissions, countries could slow the pace of global warming.

Although this could be considered as a normal path of action (common sense), it embodies a kind of dilemma for developing countries in general. Indeed, these developing countries are on the path of structurally transforming their economies. This calls for increase production of goods and services and mass consumption. To produce more goods and services entails more infrastructure constructions, more farming (especially in developing countries with rapid deforestation), more industries etc. These activities lead inevitably to deforestation, forest degradation, more engine exhaust fumes, more forest burning, more electricity and heat production as well as consumption activities. They contribute significantly to CO_2 emissions and thus cause global warming.

1.2 Importance of the Problem

Developing countries should therefore endeavor to use in their production systems, technologies that are CO_2

efficient (Green technology). However, such technology may not be readily available or too expensive and beyond the financial capabilities of these countries. Yet, these countries need to continue production of goods and services. In Côte d'Ivoire, owing to massive expansion of extensive slash-and-burn agriculture, uncontrolled harvesting of forests for timber and fuelwood, bushfires and illegal mining, deforestation has accelerated at a rapid rate. Indeed, from the country's independence in 1960 to date the country has lost 13 million hectares of forest cover reducing it from 37% to around a mere 11%. From 1990 to 2015, the country had the highest deforestation rate in the world (REDD+, 2020).

Keeping in mind that, Côte d'Ivoire has vowed, according to its Nationally Determined Contribution (NDC) a 28% reduction in greenhouses gas (GHG) emissions from the 2012 levels i.e. 24.5 MtCO2eq by 2030 (REDD+, 2020), what should be done in the face of such dilemma? Knowing that production and consumption activities result inevitably in CO_2 emissions which in turn impact economic growth, it is important to disaggregate CO_2 emissions by source to capture the emission source that contributes most to economic growth. In so doing, government authorities could easily redirect policy decision to tackle CO_2 emissions more effectively.

It is important to indicate that CO_2 emissions result mainly from gaseous fuel[3] consumption and liquid fuel consumption. By understanding the type of fuel consumption that contribute the most (the least) to economic growth, policies could be designed to address CO_2 emissions. This therefore calls our attention onto the sources of CO_2 emissions that are economic growth enhancing with the view to improving them whereas restricting or controlling the sources that limit economic growth. In so doing, the country will be able to contribute its piece in the struggle to halt global warming.

The main objective of this paper is therefore to contribute to a better understanding of the impact of electric power consumption and different sources of CO_2 emissions on economic growth. More specifically, the paper seeks to determine the short and long run dynamics between CO_2 emissions from different sources, electric power consumption and per capita *GDP* growth.

1.3 Selected Literature

Many scholars have tried to understand the relationship between carbon dioxide emissions, energy consumption and economic growth. These scholars include Saboori and Sulaiman (2013), Magazzino (2014), Lacheheb et al. (2015), Mezghani and Haddad (2016), Omri (2017), Samu et al (2019), Xu et al. (2019), Khan et al. (2019), Bekun et al (2019), Gessesse (2020), Maalej and Cabagnols (2020) and Khan et al (2020) just to cite the most recent ones. These studies can be grouped into two categories. The first category concerns the Environmental Kuznets Curve (*EKC*) hypothesis augmented with energy consumption variable. The second category deals with the energy / electricity consumption and economic growth nexus.

The EKC hypothesis augmented with energy consumption

Saboori and Sulaiman (2013) analyzed the cointegration and causal relationship between economic growth, carbon dioxide emissions, and energy consumption in selected Association of Southeast Asian Nations (*ASEAN*) countries using an Autoregressive Distributed Lag methodology as well as Granger causality test based on Vector Error-Correction Model. The data used ranged from 1971 to 2009. They found a long-run relationship among the variables in all the countries considered. In addition, the *EKC* hypothesis was supported for Singapore and Thailand in the long run. This indicated that a significant non-linear relationship between CO_2 emissions and economic growth existed.

Omri (2013) investigated the nexus between CO_2 emissions, energy consumption, and economic growth. He used simultaneous-equations models with panel data for 14 Middle East and North Africa (*MENA*) countries. The data for the study ranged from 1990 to 2011. He found a bidirectional causal relationship between energy consumption and economic growth and a bidirectional causal relationship between economic growth and CO_2 emissions for the region.

Magazzino (2014) examined the relationship between CO_2 emissions, energy consumption, and economic growth in Italy over the period from 1970 to 2006 in a *VAR* setting. He found no long-run relationship between CO_2 emissions, energy consumption, and economic growth. However, there was a bidirectional causality between CO_2 emissions and economic growth, as well as between CO_2 emissions and energy consumption.

Lacheheb et al. (2015) examined the existence of the *EKC* hypothesis between economic growth and CO_2 emission in Algeria using an *ARDL* framework. The data for the study ranged from 1971 to 2009. They found no support for the *EKC* hypothesis. In addition, the long-run models showed that income and population had a significant impact on CO_2 emission, especially from solid fuel consumption and electricity and heat production.

Mezghani and Haddad (2016) examined inter-temporal dynamics between Saudi Arabian real *GDP* (with and

without oil), electricity consumption, and CO_2 emissions in a Time-Varying Parameters Vector Autoregressive setting. The data used ranged from 1971 to 2010. They found that the observed high volatility of electricity consumption in the 1970s and 1980s was likely to have had persistent negative effects on oil *GDP* levels, CO_2 emissions, and positive effects on real non-oil *GDP* levels.

Rahman and Kashem (2017) examined the long and short-run dynamics and causal relationships between carbon emissions, energy consumption, and industrial growth in Bangladesh in an *ARDL* setting. They used data covering the period from 1972 to 2011. They found evidence for cointegration between carbon emissions, energy consumption, and industrial production in Bangladesh. Moreover, industrial production and energy consumption have a significant positive impact on carbon emissions both in the short and long run. Their results also showed a unidirectional causality running both from industrial production and energy consumption to carbon emissions.

Wahid et al. (2017) studied the empirical relationship between economic growth, CO_2 emission, power consumption, fossil fuel energy consumption, and financial development in Bangladesh. They used data ranging from 1985 to 2013. They found a significant relationship between economic growth and power consumption, economic growth, and fossil fuel energy consumption in the long run. Moreover, the authors found bidirectional causality among economic growth and power consumption, financial development and economic growth, fossil fuel energy consumption, and economic growth in the short run.

Bekun et al. (2019) revisited the dynamic relationship between electricity consumption, real gross domestic product per capita, and carbon dioxide emissions in Nigeria in a dynamic ordinary least square (*DOLS*) and fully modified ordinary least square (*FMOLS*) settings for long-run coefficients. The data used ranged from 1971 to 2014. They found a long-run equilibrium relationship between electricity consumption, real per capita *GDP*, and CO_2 emissions. Moreover, in the long run, there was a significant positive relationship between economic growth and electricity consumption. One-way causality is also observed from electricity consumption to economic growth.

Khan et al. (2019) examined the influence of energy consumption (coal consumption, oil consumption, and gas consumption) and economic growth on environmental degradation in Pakistan in a dynamic *ARDL* setting. The results indicated that economic growth, coal consumption, oil consumption, and natural gas consumption have a positive impact on the environmental degradation in Pakistan both in the short-run and long-run.

Samu et al. (2019) explored the relationship between electricity consumption, real per capita *GDP*, and carbon dioxide emissions in Zimbabwe in a dynamic ordinary least square (*DOLS*) setting. They found support for a long-run equilibrium relationship between electricity consumption, carbon dioxide emissions, and real gross domestic product per capita over the sampled period. Moreover, there was in the long run a significant positive relationship between real income and electricity consumption. One-way causality is also observed running from electricity consumption to real GDP.

Xu et al. (2019) in their article titled "Comparison of CO_2 emissions reduction efficiency of household fuel consumption in China" used data ranging from 2003 to 2015 and found support to the EKC assumption. They also showed that per capita *GDP* is positively related to CO_2 emissions and natural gas consumption has a negative impact on CO_2 emissions; however, liquefied petroleum gas (*LPG*) consumption has a positive effect on CO_2 emissions. They, therefore, concluded that increasing natural gas consumption can effectively slow down environmental degradation in China.

Gessesse (2020) examined the nexus of carbon dioxide emissions, energy consumption, and *GDP*. He used an Autoregressive Distributed Lag (*ARDL*) bounds test approach to assess the long-run dynamics in an error-correction model setting. The data used ranged from 1971 to 2015. The objective of the study was to i) examine the relationship between CO_2 and *GDP* with the view to validating the existence of the *EKC* hypothesis; and ii) detect the direction of causality between CO_2 emissions, energy consumption, and economic growth while scrutinizing their impacts. He found confirmation of long-run and short-run dynamics among the variables and that the EKC exists in China. Moreover, CO_2 emissions are more explained by energy consumption and contribute twofold to *GDP*. In the long run, there was significant negative causality from CO_2 emission and *GDP* to energy consumption. He, therefore, recommended that the Chinese economic development structure be re-designed towards an energy-saving and decarbonized economic structure.

Khan et al. (2020) investigated the nexus between energy consumption, economic growth, and CO_2 emission in Pakistan in an *ARDL* setting. The data used ranged from 1965 to 2015. They found that energy consumption and economic growth increased the CO_2 emissions in Pakistan both in the short-run and long-run.

Maalej and Cabagnols (2020) investigated the relationship between economic growth, final consumption,

investment, energy use, and CO_2 emissions in two groups of the Middle East and North Africa countries: Oil Poor Countries (*OPC*) and Oil-Rich Countries (*ORC*) in a Feasible generalized least squares panel setting. The data used covered the period 1974–2014. They found no significant relationships between energy use and *GDP* in *ORC*, whereas CO_2 emissions and *GDP* were positively linked. In *OPC*, they found a positive link between *GDP* and energy use, whereas the impact of CO_2 emissions on *GDP* tends to be negative. They, therefore, argued that the relationships between economic growth, energy use, and CO_2 emissions differ noticeably and structurally between *OPC* and *ORC*.

The energy / electricity consumption and economic growth nexus

Odhiambo (2009) examined the intertemporal causal relationship between energy consumption and economic growth in Tanzania during the period from 1971 to 2006 in an ARDL setting. The author found a stable long-run relationship between energy consumption and economic growth as well as a unidirectional causality running from total energy consumption to economic growth. Moreover, the study showed that energy consumption spurs economic growth in Tanzania.

Imran and Siddiqui (2010) investigated the causal relationships between energy consumption and economic growth within a multivariate framework that included capital stock and labor input for the panel of three South Asian Association for Regional Cooperation (SAARC) countries (Bangladesh, India, and Pakistan). The data used ranged from 1971 to 2008. The empirical results provided support for the cointegration relationship between energy consumption and economic growth in the long run and long-run unidirectional causality running from energy consumption to economic growth.

Adom (2011) investigated the direction of causality between electricity, and economic growth in Ghana. The data used ranged from 1971 to 2008. He found unidirectional causality running from economic growth to electricity consumption. Thus, electricity consumption increases with economic growth.

Kwakwa (2012) examined the causality between disaggregated energy consumption (electricity and fossil consumption) and overall growth, agricultural, and manufacturing growth in Ghana's economy over the period 1971 to 2007. He found a unidirectional causality from overall growth to electricity and fossil consumption; a unidirectional causality from agriculture to electricity consumption both in the short and long run; and a feedback relationship between manufacturing and electricity consumption. According to his findings, energy was not an essential factor of production in the agricultural sector but it was in the manufacturing sector. He therefore, recommended that efforts be made towards ensuring a high supply of energy to the manufacturing sector so as to keep up its contribution to the economy.

Azam et al. (2015) in a study titled "The Causal Relationship Between Energy Consumption and Economic Growth in the ASEAN-5 countries" and using annual time series data ranging from 1980 to 2012 provided support for one co-integrating relationship among the variables in the case of some of the countries i.e. Indonesia, Malaysia, the Philippines, and Singapore; They found two co-integrating relationships among the variables for Thailand. The authors also found that energy consumption had a significant and long-run relationship with economic growth for almost all ASEAN-5 countries. Thus, policymakers should formulate policies conducive to energy development which will consequently accelerate sustainable economic growth in ASEAN countries.

Hossen and Hasan (2018) attempted to uncover the relationship between electricity consumption and economic growth in Bangladesh. They adopted co-integration and causality tests using time series data spanning from 1972 to 2011. They found that all the variables were co-integrated with one co-integrating vector. There was also unidirectional causality running from electricity consumption to *GDP*, electricity consumption to CO_2 emissions, and *GDP* to CO_2 emissions without having any reverse causation, implying that electricity consumption affects both *GDP* and CO_2 emissions.

Sarker et al. (2019) examined the causal relationship between economic growth and energy consumption in Bangladesh. The authors used data ranging from 1981 to 2017 and performed Johansen co-integration and Granger causality tests. They found that energy consumption and economic growth have a long-term bi-directional relationship and that, energy consumption has a positive relationship with economic growth. Thus, economic development in Bangladesh is highly dependent on energy consumption.

Dey and Tareque (2020) assessed long-run and short-run dynamics as well as the causal relationship between electricity consumption and real *GDP* in Bangladesh for the period of 1971 to 2014 in an *ARDL* setting. They found evidence for both short-run and long-run dynamics. Moreover, unidirectional causality was found running from per capita electricity consumption to per capita real *GDP* in the short run. They also found that in the long run there was bidirectional causality between per capita electricity consumption and per capita real *GDP*.

Okoye et al. (2021) analyzed the energy consumption and economic growth nexus in Nigeria in an *ARDL* setting. The data used ranged from 1981 to 2017. They found that energy consumption and gross fixed capital formation significantly determine the growth of economic activities in Nigeria.

Pearson (2021) investigated the effect of renewable energy on economic growth in Croatia from the period 1996 to 2018. The author used an *ARDL* framework and found long-run relationships between renewable energy, energy consumption, and economic growth. Moreover, his results indicated that renewable energy has a positive and significant effect on economic growth in the short and long run.

Alnour (2021) analyzed the dynamic effect of energy consumption and CO_2 emissions on economic growth in Sudan using data ranging from 1971 to 2015. The author used *ARDL* and *VAR* models. He found evidence for the long-run relationship among the variables of interest. Moreover, energy consumption and CO_2 emissions exert a positive and significant effect on economic growth in the long run and there was a unidirectional causality running from energy consumption to economic growth.

2. Stylized Facts

2.1 Trend of CO_2 Emissions and Per Capita GDP

The evolution of CO_2 emissions has not been steady in Côte d'Ivoire whether it is total CO_2 emissions or CO_2 emissions from different sources. It is observed from Figure 1, that total CO_2 emissions were on an upward sloping trend although not steady from 1970 to 1988 reaching a peak where it stood at 9,160*Kt*. During that period total CO_2 emissions resulted solely from liquid fuel consumption. It then dropped sharply from 1989 to 1992 prior to the devaluation of the country's currency that occurred in 1994. CO_2 emissions from liquid fuel consumption followed the same trend. This is so because it was the main source of CO_2 emissions in the country. In 1995, with the start of gaseous fuel consumption, total CO_2 emissions resumed with an upward trend. With the rising of gaseous fuel consumption, a decline in liquid fuel consumption is observed but not enough to significantly affect the general trend of total CO_2 emissions in the country.

CO_2 emissions from gaseous fuel consumption had an upward sloping trend throughout the period ranging from 1996 to 2018 with the exception of the year 2003 where a slight decrease was observed. This decline could result from the political unrest that occurred in the country in September 2002.

The total CO_2 emissions had an upward trend but, it was one that was not smooth. It was after 2009 that CO_2 emissions resumed with an upward trend. Indeed, it rose from 5,658*kt* in 2009 to 11,089*kt* in 2014 representing a 95% increase. This trend was also observed with CO_2 emissions resulting from liquid fuel consumption. In this case, the increase ranged from 2,731.915 in 2009 to 5,962.542 in 2014 representing a 118.25% increase in five years. This trend did not continue after 2014. Indeed, a decline of total CO_2 emissions was observed thereafter and continued till 2019.

It is also important to note that during the period of the sharp increase in total CO_2 emissions (2009-2014), it was also observed that per capita *GDP* rose from 2012 where it stood at US$ 1,223.632 to 2019 where it reached US$ 1,727.284. This indicates a break from the historical trend which was downward sloping. This could be an indication for structural break. However, this break should be tested empirically.

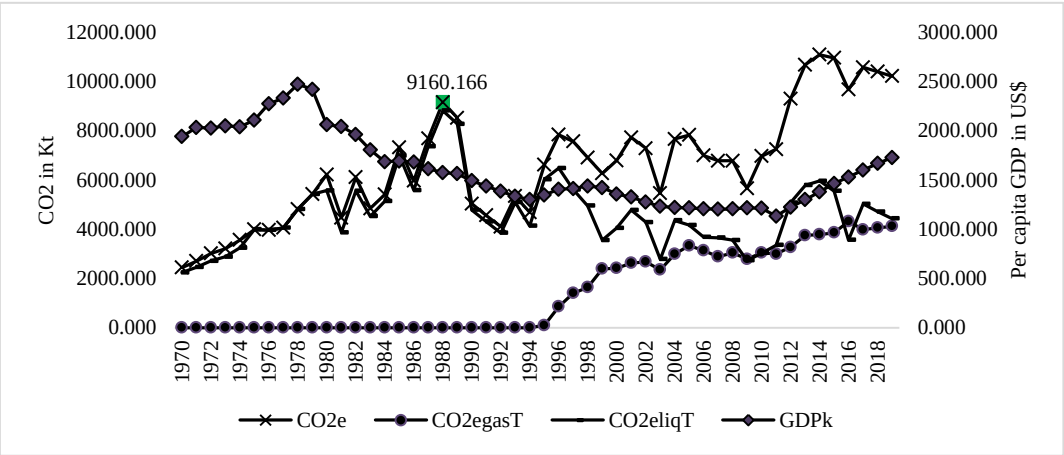


Figure 1. Total CO_2 emissions, CO_2 emission by sources and per capita *GDP* in Cote d'Ivoire from 1970 to 2019

Source: Authors calculation from World Development Indicator (World Bank 2021).

2.2 Trend of Electric Power Consumption and Per Capita GDP

In Figure 2, the trend of electric power consumption and per capita *GDP* were considered. Overall, electric power consumption has been upward sloping over the period of analysis. However, a close observation shows a sharp rise in electric power consumption in the 70's. Indeed, it went from 97*kWh* per capita in 1970 to 198.8*kWh* per capita in 1979. This period coincides with the period of high per capita *GDP* which was also tagged as the period of the Ivorian miracle. Indeed, during that period, per capita *GDP* reached its highest level which was US$ 2,471 in 1978.

It is also observed that electric power consumption dropped in the following years. Indeed, it went from 198.8 in 1979 to 131.898 in 1984. Per capita *GDP* followed similar trend. It shall be recalled that the years 1983 and 1984 were years of severe drought in Côte d'Ivoire. This could explain, to some extent the decline in electric power consumption observed during that period. After 1984, electric power consumption has been upward sloping although not steadily.

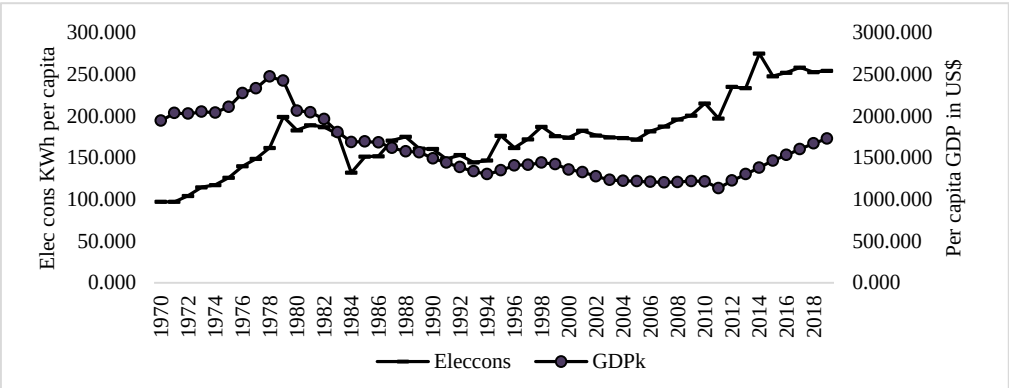


Figure 2. Electric Power Consumption and per capita *GDP* in Cote d'Ivoire from 1970 to 2019

Source: Authors calculation from World Development Indicator (World Bank 2021).

2.3 Trend of Electric Power Consumption Per Capita and CO_2 Emissions

In Figure 3, it is observed that, both electric power consumption and CO_2 emissions have an upward sloping trend over the period of analysis. They followed almost identical pattern indicating that the more electric power is consumed the more CO_2 is emitted.

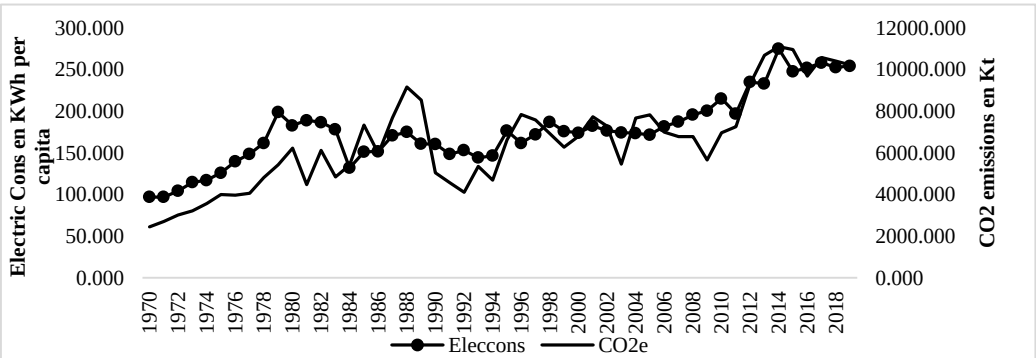


Figure 3. Electric Power Consumption per capita and CO_2 emissions in Cote d'Ivoire from 1970 to 2019

Source: Authors calculation from World Development Indicator (World Bank 2021).

3. Method

Following past research as presented in the above brief literature review, we posit the following relationship between per capita *GDP* ($lngdpk_t$), CO_2 emissions ($lnco2e_t$). We also considered the alternative sources of CO_2 emissions. Thus, we consider two additional models. The first one includes CO_2 emissions from gaseous fuel consumption ($lnco_2egas_t$) and the second one includes CO_2 emissions from liquid fuel consumption. The other variables are electric power consumption ($lnelec_t$), Gross Fixed Capital Formation as a proxy for investment

($lninvt_t$), and Labor force participation ratio ($lnlabpr_t$). We also include an interaction variable to capture the combined effect of CO_2 emissions and electricity consumption.

$$lngdpk_t = \alpha_0 + \alpha_1 lnco2e_t + \alpha_2 lnelec_t + \alpha_3 lninvt_t + \alpha_4 lnlabpr_t + \alpha_5 lneleco2e_t + \varepsilon_t \quad (1)$$

$$lngdpk_t = \alpha_0 + \alpha_1 lnco2egas_t + \alpha_2 lnelec_t + \alpha_3 lninvt_t + \alpha_4 lnlabpr_t + \alpha_5 lneleco2egas_t + \varepsilon_t \quad (2)$$

$$lngdpk_t = \alpha_0 + \alpha_1 lnco2eliq_t + \alpha_2 lnelec_t + \alpha_3 lninvt_t + \alpha_4 lnlabpr_t + \alpha_5 lneleco2eliq_t + \varepsilon_t \quad (3)$$

With $t = 1,2, \ldots, T$, $lnco2e_t$ is the natural logarithm of CO_2 emissions at time t, $lnco2egas_t$ is the natural logarithm of CO_2 emissions from gaseous fuel consumption at time t, $lnco2eliq_t$ is the natural logarithm of CO_2 emissions from liquid fuel consumption at time t, $lngdpk_t$ is natural logarithm of per capita *GDP* at time t, $lninvt_t$ is natural logarithm of Gross Fixed Capital Formation as percentage of *GDP* at time t, $lnlabpr_t$ is natural logarithm of population aged 15 to 64 years as percentage of total population.

We used annual data for this study obtained from the World Development Indicators of the World Bank (World Bank, 2021) ranging from 1970 to 2019. Given the time series nature of the data, it is critical to investigate its characteristics. This is done using the traditional Unit Root test. This is important, since a regression of non-stationary variables on other non-stationary variables gives rise to spurious regression.

Following the results on the time series characteristics of the data, whether *I(0)* or *I(1)*, we will investigate the short and long-run relationships between per capita *GDP* and CO_2 emissions together with other variables of interest using the Bounds Test in an *ARDL* setting (Pesaran et al. 2001). Thus, our model is reformulated to show both the short and long-run dynamics. The generalized *ARDL*(*p*,*q*) model is given below:

$$Y_t = \alpha \quad + \sum_{i=1}^{p} \delta_i Y_{t-i} + \sum_{i=0}^{q} \beta'_i X_{t-i} + \varepsilon_{jt} \quad (4)$$

Where Y_t is the endogenous variable, X_t represents the explanatory variables and are all allowed to be *I(0)* or *I(1)*; the constant term α and the parameters δ and β should be estimated; The optimal lag orders are p and q. The Akaike Information Criterion (*AIC*) is used to ascertain which lag order to use in the Bounds Test. In so doing we get the unrestricted Error Correction Model (Pesaran et al. 2004 called it conditional *ECM*) which is also a conditional *ARDL*(*p*,*q*) presented below for equation 1:

$$\Delta lngdpk_t = \alpha \quad + \delta_1 lngdpk_{t-1} + \delta_2 lnco2e_{t-1} + \delta_3 lnelec_{t-1} + \delta_4 lninvt_{t-1} + \delta_5 lnlabpr_{t-1} + \delta_6 lneleco2_{t-1} + \sum_{i=0}^{q} \beta_{1i} \Delta lngdpk_{t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta lnco2e_{t-i} + \sum_{i=0}^{q} \beta_{3i} \Delta lnelec_{t-i} + \sum_{i=0}^{q} \beta_{4i} \Delta lninvt_{t-i} + \sum_{i=0}^{q} \beta_{5i} \Delta lnlabpr_{t-i} + \sum_{i=0}^{q} \beta_{6i} \Delta lneleco2_{t-i} + \varepsilon_t \quad (5)$$

For the other two models (equations 2 and 3) similar representations are made.

From equation 5, the Bounds test is easily conducted. Indeed, it is equivalent to testing the following hypotheses:

$$\begin{cases} H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0 \\ H_1: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0 \end{cases} \quad (6)$$

From equation 6, the null hypothesis, H_0, tests the absence of a cointegration relationship between the dependent variable and the explanatory variables. The statistics underlying this hypothesis test are the Wald or F-statistics (Pesaran et al 1999). Thus, if we fail to reject H_0 we can conclude that there's no cointegration relationship between the variables thus, they are not cointegrated. However, if we reject the null hypothesis, then, there's a long-run relationship between the sets of variables. In 2001, Pesaran and colleagues proposed a bounds testing methodology that aims to ensure that the error terms in an equation are serially independent. This condition is important to ensure that the model is stable. The asymptotic distribution of both Wald and F-statistics are nonstandard under the null hypothesis of no long-run relationship irrespective of whether the variables are I(0), I(1), or mutually cointegrated. However, Pesaran et al (2001) have provided asymptotic critical values bounds for all classifications of the regressors into I(1) and/or I(0). Thus, we compare the computed F-statistics fall and the lower bound and accept the null hypothesis if it falls below the lower bound. In such a situation we proceed to estimate the short-run dynamics using the Ordinary Least Squares regression technic. For the test, if the F-statistics exceeds the upper bound, we then reject the null hypothesis. If the F-statistics fall between the bounds, the test will be inconclusive. In this case, knowledge of the cointegration rank of the forcing variables (explanatory variables) is required to proceed further (Pesaran et al 1999). All computations were done using the statistical software Stata 17.0.

4. Empirical Results and Discussion

In this section we present and discuss the empirical results. Tables 1 and 2 provide descriptive statistics and pairwise correlation coefficients.

4.1 Descriptive Statistics of the Variables of Interest

It is observed that over the period of analysis, the country's per capita *GDP* reached a maximum of US$ 2,471 (in 1978). Its lowest level stood at US$ 1,132.55 (2011 is the period of the civil war). Investment as percentage of *GDP* stood on average at 15.61% below the regional threshold set at 20%. The highest investment to *GDP* ratio registered stood at 29.66% and it was in 1978. The labor force stood on average at 52.97%. It is also observed that total CO_2 emissions stood on average at 6,557.75*kt*. With the highest emissions being at 11,089*Kt* in 2014. It should be recalled that the optimum CO_2 emissions level in the country stood at 7,755.37*Kt* (N'Zué, 2018).

When the sources of the CO_2 emissions are considered, it is observed that emissions from gaseous fuel consumption stood on average at 1,436.399*Kt* with the maximum emission (4,316.059) registered in 2016.

Table 1. Descriptive statistics of the variables of interest

Variable	Obs	Mean	Std. dev.	Min	Max
gdpk	50	1,600.795	366.143	1,132.548	2,471.015
gfcf	50	15.608	5.950	8.253	29.661
pop1564	50	52.971	0.937	51.861	55.412
co2e	50	6,557.750	2,288.231	2,442.222	11,089.010
co2egast	50	1,436.399	1,621.335	0.000	4,316.059
co2eliqt	50	4,615.819	1,410.428	2,244.204	8,811.801
eleccons	50	176.860	42.098	97.021	274.730

Source: Author's calculations using WDI database (World Bank 2021)

Emissions from liquid fuel consumption stood on average at 4,615.819*Kt* with the highest emission (8,811.801) registered in 1988. The other variable of interest is electric power consumption. It is measured in *kWh* per capita. It is observed that it stood on average at 176.86*kwh* per capita. The highest electric power consumption in the country stood at 274.730*kwh* per capita and it was in 2014.

4.2 Pairwise Correlation Coefficients

Table 2 presents pairwise correlation between the variables. We could infer from this table that the correlation between per capita *GDP* and CO_2 emissions is negative (-0.488) and significant but not strong. The investment variable is positively correlated with CO_2 emissions (0.832). The correlation coefficient is significant. The correlation between per capita *GDP* and CO_2 emissions from gaseous fuel consumption is negative (-0.588) and significant. Another correlation coefficient that is important to consider is the one between the labor force variable and per capita *GDP*. The coefficient is negative (-0.439) and significant. This indicates that the size of the labor force could inhibit the country's economic performance. This could be an indication of low productivity of the labor force. The electric power consumption variable is also negatively correlated with per capita *GDP* (-0.378) but not strong. All these results will be investigated further in the *ARDL* setting.

Table 2. Pairwise correlation coefficients between the variables of interest.

	gdpk	*gfcf*	*pop1564*	*co2e*	*co2egas*	*co2eliqt*	*eleccons*
gdpk	1.000						
gfcf	**0.832***	1.000					
	(0.000)						
pop1564	**-0.439***	0.014	1.000				
	(0.001)	(0.921)					
co2e	**-0.488***	-0.132	**0.719***	1.000			
	(0.000)	(0.360)	**(0.000)**				
co2egast	**-0.588***	-0.164	**0.882***	**0.743***	1.000		
	(0.000)	(0.256)	**(0.000)**	**(0.000)**			
co2eliqt	-0.036	-0.092	-0.122	**0.519***	-0.167	1.000	
	(0.805)	(0.527)	(0.399)	**(0.000)**	(0.245)		
eleccons	**-0.372***	0.061	**0.769***	**0.860***	**0.786***	0.229	1.000
	(0.008)	(0.674)	**(0.000)**	**(0.000)**	**(0.000)**	(0.110)	

Source: Author's calculations using WDI database (World Bank 2021).

4.3 Time Series Characteristics of the Data

The time series characteristics of the data were analyzed via Unit Root tests and the results are presented in Table 3. From the results we have both *I(1)* and *I(0)* variables. Indeed, per capita GDP, labor force, Investment, CO_2 emissions, electricity consumption, electricity consumption and CO_2 emission, $lneleco2egas_t$ and $lneleco2eliq_t$ are stationary after first differencing i.e. *I(1).* Whereas, $lnco2egas_t$, and $lnco2eliq_t$, are stationary i.e. *I(0).* We also created three interaction variables to cater for the interaction between electricity consumption and CO_2 emissions. The Unit Root tests results are presented in Table 3 below.

Table 3. Unit Root Tests Results

Variables	Level		1st Difference		Dec
	ADF	PPerron	ADF	PPerron	
$lngdpk_t$(-2)	-1.483	-1.156	**-4.185***	**-4.239***	***I(1)***
	(0.542)	(0.692)	(0.001)	(0.001)	
$lnlabpr_t$(-2)	0.644	1.935	**-2.764***	**-2.704***	***I(1)***
	(0.989)	(0.998)	(0.004)	(0.073)	
$lninv_t$(-1)	-1.586	-1.45	**-5.838***	**-5.92***	***I(1)***
	(0.490)	(0.558)	(0.000)	(0.000)	
$lnco2e_t$(-1)	-2.249	-2.404	**-8.113***	**-8.216***	***I(1)***
	(0.189)	(0.141)	(0.000)	(0.000)	
$lnco2egas_t$(-1)	**-2.881***	**-12.489***			***I(0)***
	(0.048)	(0.000)			
$lnco2eliq_t$(-1)	**-3.132***	**-3.369***			***I(0)***
	(0.024)	(0.012)			
$lnelec_t$(-1)	-2.000	-1.88	**-8.449***	**-8.336***	***I(1)***
	(0.286)	(0.341)	(0.000)	(0.000)	
$lneleco2e_t$(-1)	-1.968	-1.945	**-7.372***	**-7.363***	***I(1)***
	(0.301)	(0.311)	(0.000)	(0.000)	
$lneleco2egas_t$(-1)	-1.779	**-6.973***	**-6.770***	**-14.301***	***I(1)***
	(0.390)	(0.000)	(0.000)	(0.000)	
$lneleco2eliq_t$(-1)	**-2.942***	-2.853	**-5.230***	**-7.641***	***I(1)***
	(0.040)	(0.051)	(0.000)	(0.000)	

Source: Author's calculations using WDI database (World Bank 2021).

Given the unit roots tests results, we cannot use the traditional Granger and Johansen approached to investigate the long run dynamics. The appropriate approach therefore is to use the Bounds Test proposed by Pesaran, Shin and Smith (2001) to investigate any long run relationship.

4.4 Cointegration Analysis Using Bounds Tests

Table 4 presents the results of the Bounds Test for cointegration. From the stylized facts a break was observed in the trend of per capita *GDP*. That break occurred in 2012. Hence, a dummy variable was generated to account for it. The following tests and the model estimations were done with and without the dummy variable. Let's recall that we would be testing whether there was a long run relationship between per capita *GDP*, CO_2 emissions, electric power consumption, investment, labor force and the interaction between electric power consumption and CO_2 emissions or not. The AIC indicated an optimal lag order of (1,0,1,1,0,0,0,0) for the model with dummy variable indicates. The Bounds Test results give a F-statistics of 11.277 which is greater than the critical value for *I(1)* at the 5% probability level. The decision is therefore to reject the null hypothesis of *No levels relationship*. Thus, per capita *GDP*, CO_2 emissions, electric power consumption, investment, labor force and the interaction between electric power consumption and CO_2 emissions are cointegrated. They therefore move together in the long run.

Table 4. Results of the Bounds Test for Cointegration

Model with dummy variable:	*ARDL*(1,0,1,1,0,0,0,0)	***Model without dummy variable***:	*ARDL*(1,0,1,1,0,0)
H0: No level relationship (No cointegration)			
F-stat	**F = 11.277**	F-stat	**F = 9.366**
Critical Val at 5%	[I(0) I(1)]	Critical Val at 5%	[I(0) I(1)]
k =7	[2.32 3.50]	k =5	[2.62 3.79]
Decision	reject Ho if F > critical value for I(1)	Decision	reject Ho if F > critical value for I(1)
t-stat	**t = -4.821**	t-stat	**t = -3.317**
Critical Val at 5%	[I(0) I(1)]	Critical Val at 5%	[I(0) I(1)]
k =7	[-2.86 -4.57]	k =5	[-2.86 -4.19]
Decision	reject Ho if t < critical value for I(1)	Decision	reject Ho if t < critical value for I(1)

Source: Author's calculations using WDI database (World Bank 2021).

We also considered the model without a dummy variable. The result obtained is like the one with dummy variable. Indeed, the AIC test results for the model without dummy variable indicates an optimal lag order of (1,0,1,1,0,0)**.** The Bounds Test results give a F-statistics of **9.366** which is greater than the critical value for *I(1)* at the 5% probability level. The decision is therefore to reject the null hypothesis of ***No levels relationship***. Thus, per capita *GDP*, CO_2 emissions, electric power consumption, investment, labor force and the interaction between electric power consumption and CO_2 emissions are cointegrated. These variables also move together in the long run.

4.5 Results of the Estimated ARDL Model

Considering the above results, we estimated both short and long run dynamics between per capita *GDP*, CO_2 emissions, electric power consumption, investment, labor force and the interaction between electric power consumption and CO_2 emissions with and without the dummy variable. The results are presented in Tables 5 and 6 below. In Table 5 two models are presented. The first one included electric power consumption and total CO_2 emissions variables, in the second model CO_2 emissions variable is replaced with CO_2 emissions from gaseous fuel consumption.

Table 5. Results of the two *ARDL* models estimated with and without the dummy variable.

Model 1 including electric power consumption and CO_2 emission					***Model 2*** with CO_2 from gaseous fuel consumption				
Model 1 with dummy			***Model 1 without dummy***		***Model 2 with dummy***			***Model 2 without dummy***	
Dependent Variable: Per capita Gross Domestic Product									
ARDL(1,0,1,1,0,0,0,0)			*ARDL*(1,0,0,1,0,0)		*ARDL*(1,0,0,0,0,1,0,0)			*ARDL*(1,0,1,1,0,0)	
ECT(t-1)	-0.215*	(0.000)	-0.161*	(0.002)	*ECT(t-1)*	0.047	(0.537)	-0.401*	(0.001)
					Long Run Dynamics				
$lninv_t$	**0.476***	**(0.000)**	**0.653***	**(0.000)**	$lninv_t$	-0.966	(0.612)	**0.420***	**(0.000)**
$lnlabpr_t$	0.783	(0.761)	3.558	(0.402)	$lnlabpr_t$	49.746	(0.439)	**9.128***	**(0.000)**
$lnelec_t$	**6.655***	**(0.038)**	-2.274	(0.497)	$lnelec_t$	-66.650	(0.553)	-0.707	(0.814)
$lnco2e_t$	**4.551***	**(0.023)**	-0.604	(0.765)	$lnco2egas_t$	-42.054	(0.557)	-0.014	(0.994)
$lneleco2e_t$	**-0.882***	**(0.025)**	0.171	(0.664)	$lneleco2egas_t$	8.059	(0.558)	0.004	(0.990)
dum_t	-0.627	(0.429)			dum_t	0.236	(0.948)		
dum_inv_t	0.424	(0.138)			dum_inv_t	-0.777	(0.680)		
					Short Run Dynamics				
$\Delta lnlabpr_t$					$\Delta lneleco2egas_t$			$\Delta lnlabpr_t$	
D1	**-4.553***	**(0.019)**			D1.	**0.010***	**(0.026)**	D1	**-5.826***	**(0.037)**
$\Delta lnelec_t$					*_cons*	-7.518	(0.533)	$\Delta lnelec_t$		
D1.	**0.232***	**(0.000)**	**0.190***	**(0.001)**				D1.	**0.242***	**(0.003)**
_cons	-6.747	(0.125)	0.119	(0.979)				*_cons*	-10.645	(0.296)
R-squared =	0.769		0.658		R-squared	0.931			0.905	
Breusch-Godfrey LM test for autocorrelation					Breusch-Godfrey LM test for autocorrelation					
H0: no serial correlation					***H0: no serial correlation***					
$chi^2(1)$ =	2.464	(0.116)	$chi^2(1)$ =	0.912	(0.339)	$chi^2(1)$ =	1.996	(0.157)	$chi^2(1)$ =	1.425	(0.232)
White's test for Ho: homoskedasticity					***White's test for Ho: homoskedasticity***					
$chi^2(48)$ =	49.000	(0.433)	$chi^2(34)$ =	43.32	(0.131)	$chi^2(23)$ =	24.000	(0.403)	$chi^2(24)$ =	25.000	(0.405)

Source: Author's calculations using WDI database (World Bank 2021).

The first model analyzed is with and without the dummy variable. With the dummy variable in the model we have an *ARDL*(1,0,1,1,0,0,0,0), the speed of adjustment is negative and significant (-0.215). This is a confirmation of the long run relationship. Similar lung run relationship was found by Rahman and Kashem (2017), Samu et al. (2019) and Gessesse (2020). The coefficient associated with the CO_2 emissions variable (4.551) is positive and significant. This result is in line with that of Bekun et al. (2019). The result indicates that CO_2 emissions positively impacted per capita GDP over the period of analysis and thus, a 1% increase of CO_2 emissions will increase per capita GDP by 4.55%.

It is also observed that electric power consumption has a positive and significant impact on per capita *GDP*. This is in line with Odhiambo (2009), Imran and Siddiqui (2010), Azam et al. (2015) Hossen Hasan (2018), Sarker et al (2019), Dey and Tareque (2020) and Okoye et al. (2021). Indeed, a 1% increase in electric power consumption would result in a 6.65% increase in per capita *GDP*.

The investment variable is positive and significant. If investment is increased by 1%, per capita *GDP* will rise by 0.47%. Unlike the positive relationships, a negative and significant coefficient (-0.882) is associated with electric power consumption and total CO_2 emissions. The dummy variable as well as the labor force variable are not significant. The non-significant dummy variable indicates that there was fundamentally no structural break in the country's growth process in 2012. From the above empirical results, we could infer that there is long run causality running from CO_2 emissions, electric power consumption and investment to per capita *GDP* in the country.

In the short run electric power consumption positively and significantly impact per capita GDP. In terms of causality, there is short run causality going from electric power consumption to per capita GDP. This result is also in line with that of Dey and Tareque (2020). In the short run, it is observed that labor force has a negative and significant impact on per capita GDP. This is an indication of low labor productivity.

Next, we still considered the first model without the dummy variable. It is an *ARDL*(1,0,0,1,0,0). The speed of adjustment is negative and significant (-0.161) as expected. However, only the coefficient associated with the investment variable (0.653) is positive and significant. The remaining variables are not significant.

In the short run, electric power consumption has a positive and significant impact per capita GDP. In terms of causality, it runs from electric power consumption to per capita GDP. Considering Figure 4 below, which is a representation of the cumulative sum of squares (*CUSUM^2*), we retain model 1 with dummy variable.

Model 1 with dummy variable Model 1 without dummy variable

Figure 4. Cumulative Sum of Squares (*CUSUM^2*) of model 1 with and without dummy variable.

Sources: Author's calculation.

In the second model, the CO_2 emissions variable is replaced with CO_2 emissions from gaseous fuel consumption. In this model, whether with or without dummy variable the electric power consumption and the CO_2 emissions from gaseous fuel consumption variable are not significant in the long run. Hence, this model is disregarded.

Table 6 presents the third model in which the CO_2 emissions variable was replaced with CO_2 emissions from liquid fuel consumption. With the dummy variable in the model we have an *ARDL*(1,0,1,1,0,0,0,0), the speed of adjustment is negative and significant (-0.227). The coefficient associated with the CO_2 emissions from liquid fuel consumption variable (4.767) is positive and significant. This result indicates that CO_2 emissions from liquid

fuel consumption positively impacted per capita GDP over the period of analysis and thus, a 1% increase of CO_2 emissions will increase per capita GDP by 4.77%. It is also observed that electric power consumption has a positive and significant impact of per capita GDP (6.709). Indeed, a 1% increase in electric power consumption would result in a 6.71% increase in per capita GDP.

The investment variable is positive and significant. If investment is increased by 1%, per capita *GDP* will rise by 0.47%. Here also, a negative and significant coefficient (-0.908) is associated with the interaction between electric power consumption and CO_2 emissions from liquid fuel consumption. The dummy variables as well as the labor force variable are not significant. From the above empirical results, we could infer that there is long run causality running from CO_2 emissions from liquid fuel consumption, electric power consumption and investment to per capita GDP in the country.

Table 6. Results of the *ARDL* model 3 estimated with and without the dummy variable

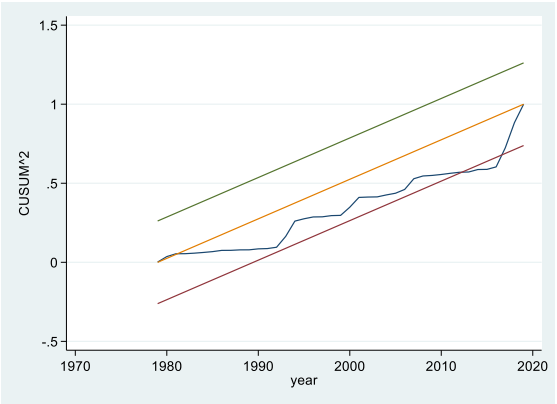
	Model 3 with CO_2 from liquid fuel consumption				
Model 3 with dummy				***Model 3 without dummy***	
ARDL(1,0,1,1,0,0,0,0)				*ARDL*(1,0,0,1,0,0)	
ECT(t-1)	**-0.227***	**(0.000)**		**-0.182***	**(0.000)**
		Long Run Dynamics			
$lninv_t$	**0.476***	**(0.000)**		**0.632***	**(0.000)**
$lnlabpr_t$	0.907	(0.718)		**6.603***	**(0.093)**
$lnelec_t$	**6.709***	**(0.015)**		2.359	(0.483)
$lnco2eliq_t$	**4.767***	**(0.007)**		2.105	(0.327)
$lneleco2eliq_t$	**-0.908***	**(0.009)**		-0.369	(0.373)
dum	-0.263	(0.713)			
dum_inv	0.241	(0.336)			
		Short Run Dynamics			
$lnlabpr_t$					
D1.	**-5.421***	**(0.004)**			
$lnelec_t$			$lnelec_t$		
D1.	**0.228***	**(0.000)**	*D1.*	**0.188***	**(0.000)**
_cons	-7.466	(0.046)	_cons	-6.271	(0.140)
R-squared =	0.792			0.675	
Breusch-Godfrey LM test for autocorrelation					
H0: no serial correlation					
chi^2 (1) =	0.689	(0.406)		0.959	(0.327)
White's test for Ho: homoskedasticity					
$chi^2(48)$ =	49.000	(0.432)	$chi^2(34)$=	43.63	(0.125)

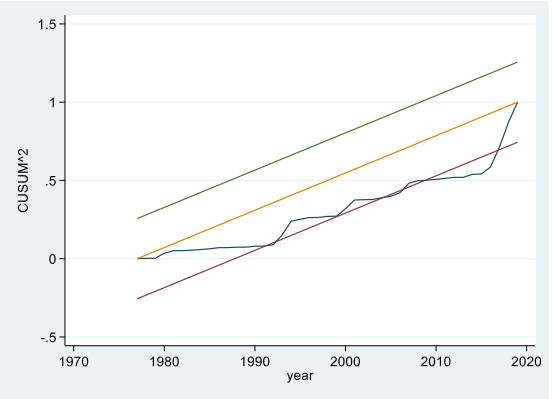
Source: Author's calculations using WDI database (World Bank 2021).

In the short run, electric power consumption positively and significantly impacts per capita *GDP* (0.228). However, it is observed that, labor force has a negative and significant impact on per capita *GDP* (-5.421). In terms of causality, it runs from electric power consumption to per capita *GDP*.

When we consider this model 3 without the dummy variable. We have an *ARDL*(1,0,0,1,0,0). The speed of adjustment is negative and significant (-0.182). In the long run, only the coefficients associated with the investment variable (0.632) and the labor force variable (6.603) are positive and significant. The remaining variables are not significant.

In the short run, electric power consumption has a positive and significant impact per capita *GDP* (0.188). In terms of causality, it runs from electric power consumption to per capita *GDP*. Figure 5 below provides representations of the cumulative sum of squares (*CUSUM^2*). It is clear that model 3 with dummy variable is the dominant model hence, it is retained.





Model 3 with dummy variable Model 3 without dummy variable

Figure 5. Cumulative Sum of Squares (CUSUM^2) of model 3 with and without dummy variable.

Sources: Author's calculation.

5. Conclusion and Policy Implications

The main objective of this paper was to contribute to a better understanding of the impact of electric power consumption together with different sources of CO_2 emissions on economic growth. This included CO_2 emissions from gaseous fuel consumption and CO_2 emissions from liquid fuel consumption. The paper tried first to ascertain whether there was a cointegration relationship (confirmation of a long run dynamic) between per capita *GDP* and CO_2 emissions together with electric power consumption. Then it moved to determine, if any, the short and long run dynamics between per capita *GDP* and CO_2 emissions from gaseous fuel consumption together with electric power consumption; And lastly, the paper ascertained the short and long run dynamics between per capita GDP and CO_2 emissions from liquefied fuel consumption together with electric power consumption. In each case, an interaction variable between electric power consumption and CO_2.emissions was included in the model estimated to ascertain the combine effect on per capita *GDP*.

Annual data from the World Development Indicator Database ranging from 1970 to 2019 were used. The investigation of the time series characteristics of the dataset showed a mixture of *I(1)* and *I(0)* variables over the period of analysis. In light of these results, Pesaran et al's (2001) Bounds Test was used to determine whether short and long run dynamics exist or not between per capita *GDP* and electric power consumption together with CO_2 emissions. Thereafter, three models were estimated. In each model a dummy variable was added to considered the abrupt change that occurred from 2012 going forward in per capita *GDP*. The following results were obtained:

The Bounds Test results led to the rejection of the null hypothesis of ***No levels relationship***. Thus, supporting the existence of a cointegration relationship between per capita *GDP* and the explanatory variables i.e. CO_2 emissions, electric power consumption, investment, labor force and the interaction between electric power consumption and CO_2 emissions. They therefore move together in the long run. Similar results (not presented here) were obtained when CO_2 emissions variable was replaced with CO_2 emissions from gaseous fuel consumption and CO_2 emissions from liquid fuel consumption successively.

In the model with total CO_2 emissions, the long run dynamics show that CO_2 emissions positively impacted per capita *GDP* over the period of analysis. The electric power consumption variable also has a positive and significant impact on per capita *GDP*. As expected, the investment variable's coefficient is positive and significant.

Unlike the positive relationships, a negative and significant coefficient is associated with the interaction between electric power consumption and global CO_2 emissions. Thus, with the current pace of development and its corollary of increasing electric power consumption, if nothing is done to reduce CO_2 emissions, in the long run it will be detrimental to the country's economic growth. The dummy variable and the labor force variable are not significant. The non-significant dummy variable indicates that there was fundamentally no structural break in the country's growth process in 2012. Given the above empirical results, it could be inferred that there is long run causality running from CO_2 emissions, electric power consumption and investment to per capita GDP in the country.

In the short run electric power consumption positively and significantly impact per capita GDP. However, it is observed that labor force has a negative and significant impact on per capita GDP. This is an indication of low productivity of the labor force. Policy measures would be needed to improve the skills of the labor force and ensure that employment opportunities exist to make use of this increasing labor force. In terms of causality, it runs from electric power consumption to per capita *GDP*.

The empirical results for the model using CO_2 emissions from liquid fuel consumption are similar to that of the model using global CO_2 emissions. The reason being that 70.38% of CO_2 emissions emanate from liquid fuel consumption. Only 21.9% emanate from gaseous fuel consumption. Thus, in the model using CO_2 emissions from gaseous fuel consumption, the relevant variables are not significant. This model is therefore not retained.

It is clear from this research that although CO_2 emissions from gaseous fuel consumption are on the rise in the country, they are yet to contribute significantly to per capita *GDP*. It is, so far CO_2 emissions resulting from liquid fuel consumption that contribute the most to per capita *GDP*.

Data Availability

The data that support the findings of this study are available from the corresponding author (NFF), upon reasonable request.

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Notes

Note 1. https://www.sciencemag.org/news/2021/07/europe-s-deadly-floods-leave-scientists-stunned.

Note 2. https://www.theguardian.com/environment/2021/jul/16/climate-scientists-shocked-by-scale-of-floods-in-germany

Note 3. Gaseous fuel means a fuel which is neither solid nor liquid, and includes but is not limited to natural gas, propane, landfill gas, waste gas, and anaerobic digester gas, extracted from https://www.lawinsider.com/dictionary/gaseous-fuel.