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The Impact of the Energy Transition on Economic Growth: Empirical Analysis of the Congolese Case

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Abstract In a global context marked by climatic uncertainties, due to the use of fossil fuels, Congo has embarked on a new energy strategy for several decades aimed at developing renewable energy sources. This article analyzes the impact of the energy transition on economic growth in Congo-Brazzaville. To study the impact, we used the ARDL model as well as Granger causality tests on data from the period from 1990 to 2024. Our results show that there is a strong cointegration between our variables and confirm the neutrality hypothesis for the case of Congo. Our results also confirm the causal link between economic growth and the energy transition.

Keywords energy transition ; economic growth ; renewable energy consumption ; ARDL model ; Granger causality.

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Introduction

The energy transition is at the center of international discussions and public policies of countries. Although climate change is not a new phenomenon, international organizations and states are now concerned about its situation (Dufour, 2019). Developing and emerging countries must maintain their economic growth while alternatively reducing greenhouse gas emissions in order to promote better interoperability among the three sectors of development.

Energy needs include electricity, heat, and transportation. To meet these needs, global energy demand has more than doubled from 1970 to 2010 (from 5,000 to 12,000 Mtoe). It is expected to continue to grow in the coming decades, due to global demographic dynamism (seven billion people in 2010, nine billion by 2050) and the development of emerging economies. The energy scenarios from the International Energy Agency (IEA) all predict an increase in demand, concentrated at over 90% in non-OECD countries and limited only by the varying commitment of policies to reduce greenhouse gas emissions. Under the scenario known as 'new policies', which assumes that countries will comply with the Cancun commitments, the IEA forecasts an increase in energy demand of 'only' 40% for the period 2009-2035. Only wealthy countries see their consumption decreasing in absolute terms. Moreover, others besides the IEA ("Energy for a sustainable world 1988 Goldemberg, Reddy, Johanson, Williams") have constructed scenarios that foresee lower energy demand. Currently, this demand is met to over 80% by fossil fuels.

However, these are not limitless. Estimates of reserves are nonetheless subject to discussion : discrepancies in the estimation of key parameters (depletion of known deposits, technological advancements, new discoveries, etc.) lead to very diverse scenarios for future production. Furthermore, new resources are no longer accessible under the same safety and technical feasibility conditions as before, which requires increasingly significant investments and rising operating costs. Lastly, the proven or potential impacts of their exploration and exploitation on the environment and public health raise opposition. This list of constraints must include a reference to the variable and uncertain global geopolitical context. The fact that a small number of states hold the majority of global reserves, excluding unconventional sources, raises questions about access to the resource and, consequently, supply security. This imbalance is the same for many raw materials, metals, and strategic minerals, some of which are vital for the development of certain Renewable Energies (RE). Furthermore, the exploitation of hydrocarbons Unconventional resources in the world are reshaping the geopolitical landscape. According to scenarios from the IEA, gas consumption could grow by 44% between 2008 and 2035, and fossil resources could account for over 40% of the global energy mix by 2050.

Africa has the potential to create a new model of ecological development; this will only be possible with considerable infrastructure work. The installation of dams remains very limited: despite Ethiopia building what will become the largest dam in Africa, the Renaissance Dam on the Blue Nile, other projects are still on hold, particularly the gigantic Grand Inga project on the Congo River. A true never-ending story that has been anticipated for nearly a century, with a theoretical potential of 44 gigawatts annually, surpassing the Three Gorges Dam in China (18 gigawatts), with the possibility of supplying electricity to a large part of central and southern Africa. The implementation of energy infrastructure projects has always stirred corrupt appetites across the continent (Nkoa, 2016). Furthermore, Rodolphe Greggio (2016) believes that the African continent is fortunate not to depend on electricity from nuclear origin. Its share of production does not exceed 0.4% of the global total : there is currently only one nuclear power plant (in Cape Town) in South Africa, and ambitions in this sector are almost non-existent in Africa : It cannot be ruled out that South Africa will abandon its civil nuclear program, nor that Egypt will give up becoming a civil nuclear power. On the other hand, other nations interested in this energy source (Algeria, Angola, Morocco, Nigeria) are showing skepticism and even discouragement. It is in the field of renewable energies that Africa's electrical potential is expected. The continent produces only 3% of the world's hydropower and 1% of renewable energies (wind, geothermal, solar, industrial biomass).

The Congo, which has an average sunshine level of 12 hours per day, could very well help develop solar energy, due to its privileged geographical position at the heart of Africa and its overlap with the equator line. After the mixed results of the Djoué and Moukoukoulou hydroelectric plants, which did not really meet the country's needs. The exploitation of natural gas in Pointe-Noire enabled the construction of a power plant with a capacity of 300 Megawatts (MW), expandable to 450 MW, inaugurated in 2011, which cost 596 million dollars to increase and diversify Congo's energy potential, has not been enough either. In 2016, the Republic of Congo ranked 139th. The country ranks 143rd in annual production with 1.696 billion kWh and has a power capacity of 591.5 MW. Its electrification rate remains at 45% in cities and 5% in rural areas. The country has invested in solar energy infrastructure to move away from the load shedding experienced in the 2010s. Investments in energy equipment have been made, but sparingly. As a result, public spending on electric energy had not exceeded 0.2% of total public spending. The inadequacy of maintenance has led to significant deterioration of equipment. The country was then plunged into darkness and the hum of generators. The state is now committed to the energy battle, prioritizing renewable energies, even though the total electricity capacity remains low due to the obsolescence of installations.

Notwithstanding its energy dependence, particularly on imported energy, Congo has always maintained a general level of consumption in line with its level of development as the energy mix is dominated by hydrocarbons for transportation and coal for electricity. However, even though Congo is not a direct contributor to global CO_2 emissions, despite its strong dependence on fossil fuels, it is possible for the country to engage in the fight against climate change. Additionally, a crucial factor in the population's precariousness is the lack of access to energy. This is compounded by sustainability challenges, particularly in rural areas where poor rural households still use traditional biomass for cooking and heating. Deforestation is closely linked to energy precariousness in Congo, as elsewhere. In response to the demands for sustainable development and the evolution of the global energy context, Congo has adopted an energy strategy aimed at diversifying energy sources while ensuring competitive energy in terms of costs, availability of products, and their security and sustainability.

The objective of this article is to analyze the impact of the energy transition on economic growth. To analyze its impacts, a model known as the ARDL model is used as indicated in the literature.

1. Methodology

1.1. Theoretical Framework of the Model

Given the need to design effective energy policies, the causal link between the energy transition and economic growth could be a decisive factor. In recent years, the debate on the causal link between renewable energy consumption and economic growth, closely followed by advancements in econometric theory, energy economics, and environmental economics, has resulted in a considerable amount of scientific literature. However, despite all this research, the state of knowledge remains uncertain and controversial. Indeed, the study by John Kraft, A. K. (1978), in which the authors examined the causality of the relationship between energy consumption and economic growth for the United States of America, represents the pioneering study that served as a basis for a multitude of empirical research using different econometric methodologies and variables. However, there is no clear literature when it comes to whether renewable energy consumption results from, or is a prerequisite for economic growth. Indeed, according to Mehrara (2007), the results depend on the methodology used, the country, and the period studied, but also on the specific characteristics of the country in question such as the energy situation, energy policies, institutional arrangements, political and economic history, as well as culture and various other variables. A large part of the studies conducted use the Granger causality test to examine this relationship. The VAR model developed by Sims (1980) and causality tests based on this model are also methodologies used to test the causality between the two variables in many empirical studies. Indeed, four possible hypotheses regarding the direction of the causal link between renewable energy consumption and economic growth are possible :

- The hypothesis of neutrality or absence of causality : this hypothesis argues that there is no causal relationship between GDP growth and energy consumption. This implies that energy consumption is not correlated with GDP growth and that, therefore, energy shortages and conservative policies on energy use do not affect economic growth.
- The conservation hypothesis : according to this hypothesis, there is a unidirectional causality from GDP growth to energy consumption. This hypothesis implies that GDP growth leads to energy consumption. It also suggests that an economy operating within such a relationship is less dependent on energy; therefore, any conservation policy regarding energy consumption will have little to no negative effect on economic growth.
- The growth hypothesis : this hypothesis implies that there is a unidirectional causality going from energy consumption to GDP. This means that energy consumption drives GDP growth. The growth hypothesis suggests that the abundant availability of energy sources at a reasonable price fosters economic growth. In this sense, if an increase in energy consumption can contribute to sustaining economic growth, a reduction in energy consumption may have negative effects on growth.

- The feedback or bidirectional causality hypothesis : According to this hypothesis, there is a bidirectional causality between GDP and energy consumption. Energy consumption stimulates the increase of GDP, and this same growth stimulates energy consumption.

The conclusions of the literature on the relationship between energy consumption and economic growth therefore support four possible conclusions regarding the direction of the causal link. Recently, other studies have also focused on the relationship between renewable energy consumption and economic growth. Indeed, Khobai et al. (2018) examined the causal link between renewable energy consumption and economic growth in South Africa for the period 1990-2014. The authors used the ARDL model to explore the long-term relationship between the variables and the vector error correction model to determine the direction of causality. The authors also incorporated carbon dioxide emissions, capital formation, and trade openness as additional variables to create a multidimensional framework. The results of the study validated the existence of a long-term relationship between the variables. Furthermore, a unidirectional causality from renewable energy consumption to economic growth was confirmed for the long term. On the other hand, short-term results suggest a unidirectional causality going from economic growth to renewable energy consumption. The results then confirm that all variables are cointegrated and support the validity of the long-term growth hypothesis and the short-term conservation hypothesis. Al-mulali et al. (2013) also studied the long-term causal relationship between renewable energy consumption and economic growth in different countries. Indeed, the authors classified the different countries studied into four categories: low-income countries, lower-middle-income countries, upper-middle-income countries, and high-income countries. However, the results of the study are mixed from one country to another. The results revealed that the long-term bidirectional relationship between The variables are more significant in high-income countries. Indeed, it was found that 79% of countries showed a positive bidirectional relationship, in the long term, between renewable energy consumption and economic growth, thus confirming the feedback hypothesis. However, 19% of countries showed no long-term relationship between the variables, thus confirming the neutrality hypothesis. Given that renewable energy consumption plays an important role in GDP growth for most of the studied countries, the authors then emphasized the importance of investments in this sector, highlighting its role in enhancing energy security, due to its contribution to reducing imported fossil fuels.

The authors also emphasize the role of renewable energy in job creation. Cardoso Marques et al. (2012) applied panel data techniques to analyze the role of different energy sources in the economic growth of 24 European countries for the period (1990-2007). The authors empirically tested the distinct effects of energy consumption, by source, on economic growth. The results reveal that the higher the energy dependency, the greater the growth difficulties will be. However, this energy dependency could be offset by the development of renewable energies. The results of the study therefore support that economic growth does not seem to improve with the transition to renewable energies. Indeed, at first glance, the deployment of renewable energies has everything to be a huge success, both in the fight against global warming as well as in reducing energy dependence. Renewable energy sources could also solve the problem of fossil fuel depletion and create jobs and wealth by producing energy locally. However, the study's results suggest that the high costs of promoting renewable energy sources are likely to weigh excessively on the economy, particularly by increasing electricity tariffs and production costs, which induces a counterproductive economic effect. Mohamed Safouane et al. (2014) examine the relationship between renewable energy consumption, international trade, and production based on a sample of 11 African countries covering the period 1980-2008. The results of the study suggest that there is a bidirectional causality between production and international trade in both the short and long term. These empirical results indicate that international trade has a positive impact on the real GDP of the sample. They confirm that international trade is beneficial for developing countries, particularly due to technology transfer. On the other hand, the results demonstrate that there is no causal link between international trade and renewable energy consumption in the long term. This means that the opening of trade has no direct effect, either in the short or long term. On renewable energy consumption. However, the authors confirm that an indirect effect may exist in the short term and more likely in the long term, particularly through technology transfer. The results also show that renewable energy consumption and foreign trade have a statistically significant positive impact on real GDP. Indeed, for the model with exports, a 1% increase in renewable energy consumption increases production by 0.03%, and a 1% increase in exports increases production by 0.19%. For the model with imports, a 1% increase in renewable energy consumption increases production by 0.05%, and a 1% increase in imports increases production by 0.21%.

The authors' recommendations regarding energy policy mainly concern the design of appropriate tax incentives to encourage the use of renewable energy instead of non-renewable energy. Montassar Kahia et al. (2017) also study the short-term and long-term relationships as well as the direction of Granger causality between energy consumption from non-renewable and renewable sources and economic growth in the MENA region countries for the period 1980-2012, including capital and labor as explanatory variables. The empirical results support the existence of a long-term relationship between economic growth, the consumption of renewable and non-renewable energies, labor, and capital.

The results of Granger causality confirm the feedback hypothesis between the two types of energy used and economic growth. This suggests that both energy sources are vital for economic growth. Apergis et al. (2014), for their part, examine the link between renewable energy and economic growth in 80 countries, using the causality test by Canning and Pedroni (2008). The results of the study indicate that there is a positive long-term causality between renewable energies and GDP for the sample studied. The empirical results clearly show the interdependence between renewable energy consumption and economic growth. They indicate that renewable energy is important for economic growth and that the latter also encourages, in turn, the deployment of renewable energy sources. Kabiru Maji et al. (2019) evaluate the impact of renewable energies on the economic growth of 15 West African countries over the period 1995-2014. The results of the study demonstrated that renewable energy consumption slows down the economic growth of these countries. Indeed, the authors attribute these results to the fact that biomass, generally impure and highly polluting, is the most widespread source of energy in these countries, unlike solar or wind energy, which are much less used in West Africa. The study therefore recommends increasing the share of other renewable energy sources such as solar, wind, and geothermal. Saad et al. (2018) analyze and compare the short- and long-term causality between renewable energy consumption and economic growth in 12 countries of the European Union, using a vector error correction model and the Granger causality test for a period from 1990 to 2014. The results of the study indicate the presence of a unidirectional causality going from economic growth to renewable energy consumption in the short term. However, in the long term, the results of the study support the existence of a bidirectional relationship between the variables in question and thus confirm the feedback hypothesis between the variables in the long term. Bhattacharya et al. (2016) also study the effects of renewable energy consumption on economic growth between 1991 and 2012 on a sample of 38 majors renewable energy-consuming countries, chosen based on the Renewable Energy Country Attractiveness Index developed by Ernst & Young Global Limited. The results of the study indicate that renewable energy consumption has a positive and significant impact on the economic output of 57% of the selected countries. Indeed, the authors were able to define three groups of countries. In the first group, renewable energy sources are considered an important driver of economic growth.

These include Austria, Bulgaria, Canada, Chile, China, the Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Kenya, the Republic of Korea, Morocco, the Netherlands, Norway, Peru, Poland, Portugal, Romania, Spain, and the United Kingdom. In most of these countries, a significant shift towards renewable energy occurred during the study period, leading to the creation of several jobs. In the second group, the authors found that renewable energy sources had a negative effect on economic growth. It concerns: India, Ukraine, the United States, and Israel. Finally, for eleven countries, namely Australia, Belgium, Brazil, Ireland, Japan, Mexico, Slovenia, South Africa, Sweden, Thailand, and Turkey, the authors could not determine whether renewable energy sources would be a significant driver or an obstacle to economic growth. Bhattacharya et al. (2016) estimate that these results are due to the fact that these countries have not been able to effectively utilize renewable energy sources in the production process, which therefore has practically no impact on economic production. Alper and Oguz (2016) examine, using the ARDL approach, the causal link between economic growth, renewable energy consumption, capital, and labor for the new EU member countries for the period 1990-2009. The results of the study confirm that the consumption of renewable energy has positive effects on the economic growth of all the countries studied. However, the impact on economic growth is statistically significant only for Bulgaria, Estonia, Poland, and Slovenia. On the other hand, no causal link was found, and thus the neutrality hypothesis has been confirmed for Cyprus, Estonia, Hungary, Poland, and Slovenia. For the Czech Republic, the conservation hypothesis, which states that there is a unidirectional causality from economic growth to renewable energy consumption, has been confirmed, while the causality from renewable energy consumption to economic growth has also been confirmed for Bulgaria, thus the growth hypothesis is confirmed for this country.

Ozcan et al. (2019) analyze the causal link between renewable energy consumption and economic growth in 17 emerging countries over a period from 1990 to 2016. The study results demonstrated that the neutrality hypothesis holds for all the countries studied, except for Poland, which confirmed the growth hypothesis. The authors then conclude that energy-saving policies have no harmful influence on the growth rates of these 16 emerging economies. However, for Poland, energy-saving policies may have negative effects on the country's economic performance level.

According to the authors, the absence of causality does not necessarily imply that renewable energies are not a crucial contribution to economic growth. This indicates, however, that the level of investment in the renewable energy sector is still not sufficient to stimulate the economic growth rates of these economies and that there is likely an unmet threshold beyond which renewable energy consumption will begin to stimulate economic growth. Regarding the Moroccan case, El-Karimi and El Ghini (2020) examined the causal link between renewable energy consumption and economic growth in Morocco by incorporating capital and labor as the main factors of the production function.

The authors used the Toda and Yamamoto (1995) causality test on annual data covering the period 1980-2016. The results obtained reveal that capital significantly affects economic growth, while labor has no significant impact on growth. On the other hand, the results show that there is no significant causal relationship between renewable energy consumption and economic growth. Therefore, the results support the neutrality hypothesis and can be explained by an uneven and insufficient exploitation of renewable energies in Morocco. Bouyghrissi et al. (2020) also analyzed the link and relationship between renewable and non-renewable energy consumption, CO_2 emissions, and economic growth in Morocco over a period from 1990 to 2014 using the ARDL approach and the Granger causality test. The empirical results confirmed that renewable energies in Morocco were beginning to have positive effects on the economic dimension of sustainable development and that there is a causality flowing from renewable energy consumption to economic growth and from economic growth to CO_2 emissions. However, the authors believe that the Moroccan government and private companies must seek innovative methods to finance renewable energy projects. Khanniba et al. (2020) studied the causal relationship between electricity production from renewable sources, CO_2 emissions, and economic growth in Morocco. In this regard, the study used the ARDL approach and the Toda Yamamoto (1995) causality test on data from the period 1990 to 2015. The results reveal the existence of a balance between the variables, both in the short and long term. Indeed, in the short term, CO_2 emissions, electricity production from renewable sources, and the workforce have a negative impact on GDP. Gross fixed capital formation also has a negative impact on economic growth over a one-year period but becomes positive after two years. In the long term, GDP is mainly driven by CO_2 emissions, labor, and electricity production from renewable sources. These results therefore support the growth hypothesis. To the best of our knowledge, none of the studies concerning the case of Congo have integrated trade openness as an explanatory variable, despite its important contribution to economic growth and the development of the renewable energy sector. We therefore estimate that it would be necessary to consider this variable in the present research to have a multidimensional research framework.

1.1. Material and Method

1.1.1. Data : Nature and Source

The data that are the subject of our study are annual and taken from the World Bank databases (WDI, 2025). These annual data cover the period from 1990 to 2024.

Table 1 : below provides information on the variables used.

Variables	Description	Data source
CO_2	CO_2 emissions (metric tons per capita)	WDI
LGDPIB	The natural logarithm of GDP per capita	WDI
LDOUVC	The natural logarithm of the degree of trade openness	WDI
LPE	The natural logarithm of electricity production from hydroelectric sources	WDI
CORRUPTION	Assessment of corruption within the political system,	ICRG
CREN	Renewable energy consumption	WDI
FBCF	Gross fixed capital formation	WDI

Source : author (2025), based on data from WDI and ICRG,

1.1.2. Econometric Modeling

In order to test the long-term relationship, also known as co-integration, between GDP, renewable electricity production, CO_2 emissions, and trade openness for Congo from 1990 to 2024, our study is primarily based on the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to determine the order of the variables. The second step involves studying the long-term equilibrium relationship between the variables using the ARDL approach. Finally, the Granger causality test is used to examine the direction of the causal relationship between the variables. Indeed, determining the order of the variables is a necessary preliminary step before proceeding with the ARDL analysis, which only accepts variables integrated of order I (0) and I (1). Unit root tests are therefore used to avoid the inclusion of I (2) variables. In our study, two types of unit root tests are used, namely the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. Then, in order to determine the co-integration in the short and long term between economic growth and renewable electricity production, the autoregressive distributed lag (ARDL) model, recently developed by Pesaran et al. (2001), is employed. Indeed, this approach allows for better results when the study involves a small sample, which is our case. On the other hand, the ARDL method is distinguished by the fact that it can be applied to non-stationary time series without the constraint of the same order of integration. Indeed, the cointegration test can be conducted simultaneously on variables integrated of order 1 (I (1)) and on variables integrated of order 0 (I (0)). The general form of the ARDL approach to the equations to be estimated is as follows :

$$(1)\; DY_{i,t} = B_{i,o} + \sum_{i=1}^{P} B_{1i}\, DY_{i,t-i} + \sum_{i=D}^{t} B_{2i}\, X_{t-i} + \varphi_{i,1} Y_{i,t} + \varphi_{i,2} X_{t-1} + \varepsilon_{i,1t}$$

$$DY_{i,t} = \sum_{i=1}^{P} \beta_{1i}\, DY_{i,t-i} + \sum_{i=D}^{r} \beta_{2i} X_{t-i} + \mu_1 ECT_{i,t-1} + \varepsilon_{i,2t}$$

The variables Y_{it} $(i = 1,2,3)$ respectively represent the dependent variables. The parameters $\varepsilon_{i,1\ et\ E_{i,2}}$ reflect the residuals of each equation. The β_1 represent the constants of each equation. D is the first difference operator and (p,r) represent the number of lags. To test the long-term relationship ; also called cointegration, between economic growth, renewable energy generation, CO_2 emissions, and trade openness for the case of Congo, the following linear logarithmic forms are proposed, where : GDP represents real GDP, CREN : is the consumption of renewable energies. LCO_2 : represents CO_2 emissions per capita, DOUVC : represents the trade openness ratio, and: error term, β_i : the parameters represent the long-term elasticity of CO_2 emissions, GDP, DOUVC, CREN, PEH, CORR, and FBCF.

$$LogCO_{2_t} = \alpha + \beta_1 LogPIB_i + \beta_2 LogDOVC_i + \beta_3 LogCREN_i + \beta_4\, LogPEH_t + \beta_5 LogCORR_t + \beta_6 LogFBCF_i + \varepsilon_t$$

$$LogPIB_t = \alpha + \beta_1 LogCO_{2_i} + \beta_2 LogDOVC_i + \beta_3 LogCREN_i + \beta_4\, LogPEH_t + \beta_5 LogCORR_t + \beta_6 LogFBCF_i + \varepsilon_t$$

2. Results and Discussion

2.1. Descriptive Statistics

Before delving into statistical analysis, it is essential to create a descriptive statistics table for each of the variables. This step is crucial to gain an overview of the characteristics of our data and to understand the trends and distributions. In the descriptive statistics table below, we will present the main statistical measures for each variable. These measures will include the mean, standard deviation, median, minimum, and maximums valus. This approach will allow us to obtain essential information about the central tendency, dispersion, and shape of each distribution.

Table 2: Descriptive Statistics

	CO_2	LGDP	LDOUV	LPE	CORRUPT	CREN	FBCF
Mean	1,122883	7,645011	19,89730	4,115125	2,307143	67,31810	3,32E+09
Médian	1,127966	7,646136	20,00007	4,406550	2,000000	67,70000	2,94E+09
Maximum	1,431611	7,819508	20,28148	4,605170	4,000000	80,20000	9,70E+09
Minimum	0,802014	7,424813	19,03379	3,105571	1,500000	54,50000	1,16E+09
Std, Dev,	0,150422	0,112039	0,325081	0,544865	0,857200	6,238341	2,14E+09
Skewness	0,015395	-0,519529	-1,303009	-0,806992	0,743834	0,075146	1,470335
Kurtosis	2,521456	2,600933	3,948158	2,175182	2,265406	2,715678	4,601758
Jarque-Bera	0,335348	1,806722	11,21507	4,791014	4,014472	0,150831	16,35255
Probability	0,845630	0,405206	0,003670	0,091126	0,134360	0,927358	0,000281
Sum	39,30089	267,5754	696,4054	144,0294	80,75000	2356,133	1,16E+11
Sum Sq, Dev,	0,769315	0,426796	3,593048	10,09386	24,98294	1323,174	1,55E+20
Observations	35	35	35	35	35	35	35

Source: author (2025), based on data from WDI and ICRG,

2.2. Unit Root Tests for the Variables

Our ARDL analysis thus follows four steps: the first examines the stationary properties of each variable using the unit root test which helps to define the order of integration of the variables. The Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) stationarity tests are used in this regard. The second step is to check for the existence of a long-term relationship between the variables using the bounds testing approach also known as the ARDL Bound Test ; the third aims to estimate the short and long-term parameters and to test the stability of the model ; while the fourth defines the direction of causality between the variables using the Granger causality test. The results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationarity tests are presented in Table (3). They indicate that all series are non-stationary at level but stationary at first difference. The majority is integrated of order (1), except for the variables related to hydroelectric power production, CO_2 emissions, and the gross domestic product, which are integrated of order (0).

After determining the integration order of the different variables as well as the optimal lag of the model, we use the ARDL or Black Box approach for cointegration to determine the long-term relationship between the variables. We employ the 'Bound Test' for this purpose, which aims to calculate an F-statistic (table 6). This tests the null hypothesis which implies no cointegration H0: 1 = 2 = 3 = 0 against the alternative hypothesis, H1: 1≠2≠3≠0, which implies the existence of a long-term relationship between the studied variables.

Table 3 : Results of the ADF and PP stationarity test at the significance level of 5% (i.e., 0.05)

Variables	Type of test	With constant	With constant and with trend	Without constant and trend	T-statistic	Decision
CO_2	ADF	Yes	Yes	Yes	-6.162878	I(1)
	PP	Yes	No	No	-2.909993	I(0)
	KPSS	Yes	Yes	/	0.076270	I(0)
GDP	ADF	Yes	Yes	Yes	-4.904013	I(1)
	PP	Yes	Yes	Yes	-4.902883	I(0)

	KPSS	Yes	Yes	/	0.119519	I(0)
DOUV	ADF	Yes	Yes	Yes	-7.444426	I(1)
	PP	Yes	Yes	Yes	-12.87525	I(1)
	KPSS	Yes	No	/	0.261452	I(1)
PEH	ADF	Yes	Yes	Yes	-6.466399	I(1)
	PP	No	No	Yes	-1.959796	I(0)
	KPSS	Yes	No	/	0.437585	I(1)
CORRUPTION	ADF	Yes	Yes	Yes	-3.604567	I(1)
	PP	Yes	Yes	Yes	-3.789588	I(1)
	KPSS	No	Yes	/	0.080535	I(0)
CREN	ADF	Yes	Yes	Yes	-6.143062	I(1)
	PP	Yes	Yes	Yes	-6.314236	I(1)
	KPSS	Yes	Yes	/	0.136775	I(0)
FBCF	ADF	Yes	Yes	Yes	-4.389710	I(1)
	PP	Yes	Yes	Yes	-4.408080	I(1)
	KPSS	Yes	Yes	/	0.098881	I(0)

Source: developed by the author (at the threshold of 5%)

2.3. Pesaran et al. (2001) Cointegration Test

The cointegration test at the bounds of Pesaran et al. (2001) was adapted for our series, also, let us recall that there are two steps to follow to apply the Pesaran cointegration test :

- Determine the optimal lag first (AIC) ;
- Use the Fisher test to test for cointegration between the series.

2.3.1. Determination of the optimal lag number

The estimation of an ARDL model involves specifying the optimal number of lags, which minimizes the Akaike information criteria. The figure below allows us to determine the appropriate lag number after estimating the ARDL model for each lag.

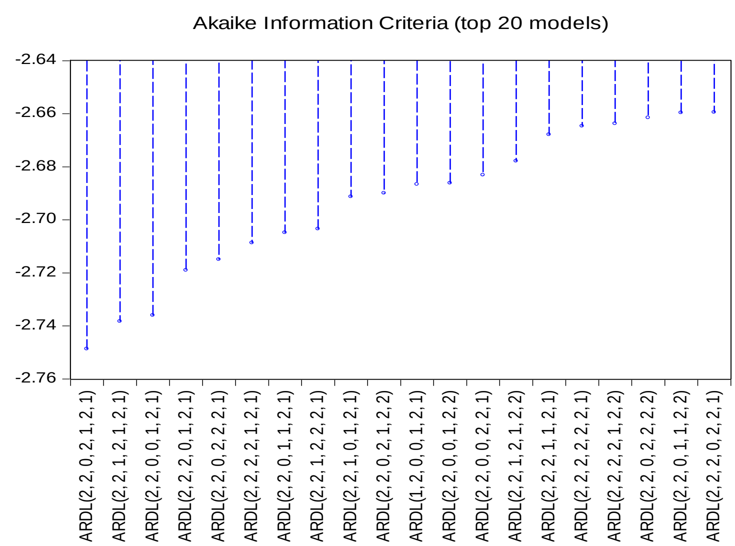

Figure 1: Estimate result of the Akaike information criteria (AIC)

As can be seen in the figure above, the ARDL model (2, 2, 0, 2, 1, 2, 1) is the most optimal among the 20 others presented, as it offers the smallest value of the Akaike Information Criterion (AIC). Furthermore, regarding the tests that help diagnose the estimated ARDL model, there is an absence of autocorrelation of the errors and the problem of heteroscedasticity, the errors are normally distributed, and the model has been well specified.

Table 4 : Tests on the residuals of the ARDL regression. Case of CO_2

Test hypothesis	Tests	Values (probability)
Autocorrelation	Breusch-Pagan-Godfrey	1,357576-Prob (0,2941)
Heteroscedasticity	Breusch-Pagan-Godfrey	0,970431-Prob (0,5318)
Normality	Jarque-Bera	1,542228-Prob (0,462498)
Specification	Ramsey (Fisher)	2,470059-Prob (0.1400)

Source : author (2025), based on data from WDI and ICRG with Eviews9,

Table 5 : Tests on the residuals of the ARDL regression. Case of GDP

Test hypothesis	Tests	Values (probability)
Autocorrelation	Breusch-Pagan-Godfrey	1,560891-Prob (0,2444)
Heteroscedasticity	Breusch-Pagan-Godfrey	0,496530-Prob (0,9139)
Normality	Jarque-Bera	0,442731-Prob (0,801424)
Specification	Ramsey (Fisher)	0,925729-Prob (0,3512)

Source : author (2025), based on data from WDI and ICRG with Eviews9,

The statistical test used to diagnose and properly analyze the estimated ARDL model, namely the Breusch-Godfrey (LM) serial correlation test, confirms the existence of serial correlation in the regression. Indeed, when the probability associated with the F-LM statistic is greater than 0.05, it means that there is an absence of autocorrelation. This is verified in our case because the two probabilities associated with the F-LM statistic are simply equal to 0.24 and 0.29, which is greater than 5%. Similarly, for the ARCH heteroskedasticity detection test, which supports that the probability must be greater than 0.05 in order to confirm the absence of heteroskedasticity. Our results indicate probabilities of 0.91 and 0.53. This simply indicates the absence of this phenomenon. Thus, the last two tests allowed us to observe that the distributions of the variables are normal. The results obtained strongly confirm the absence of autocorrelation and heteroscedasticity. We can therefore conclude that the estimated ARDL model for the studied period is validated and could be the subject of economic analysis and reflection. We can then proceed to evaluate the cointegration test at the bounds. For all these tests, the null hypothesis is accepted. Thus, the statistical validity of our model is confirmed. The dynamics of energy transition in the Republic of Congo, from 1990 to 2024, is explained by 94% by the ARDL model (2, 2, 0, 2, 1, 2, 1) estimated. Therefore, to confirm our results, we test the stability of the model created by the CUSUM of squares method, the result of which appears in the following graph :

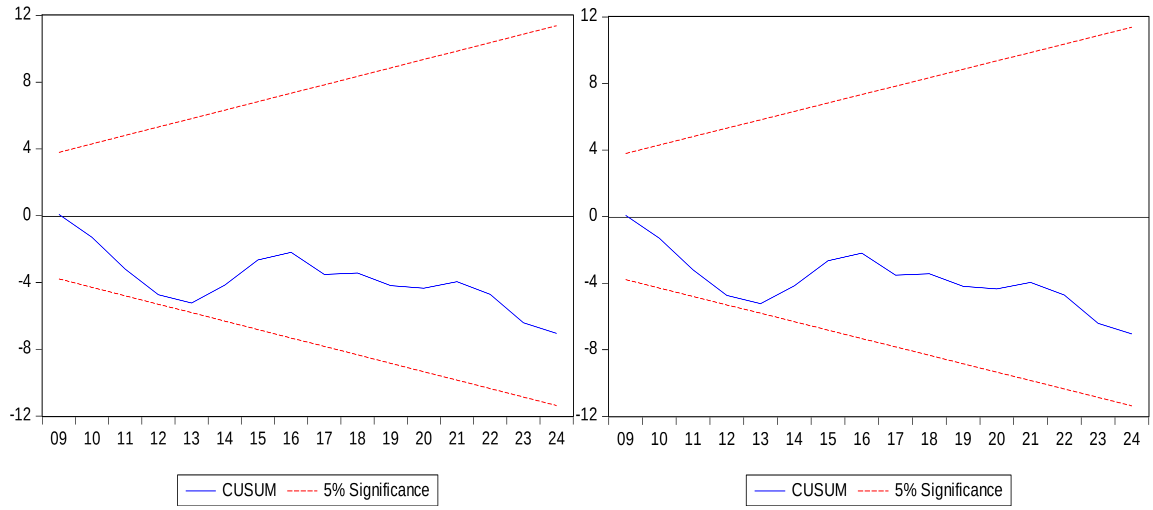

Figure 2 : CUSUM stability tests of the CO_2 variable

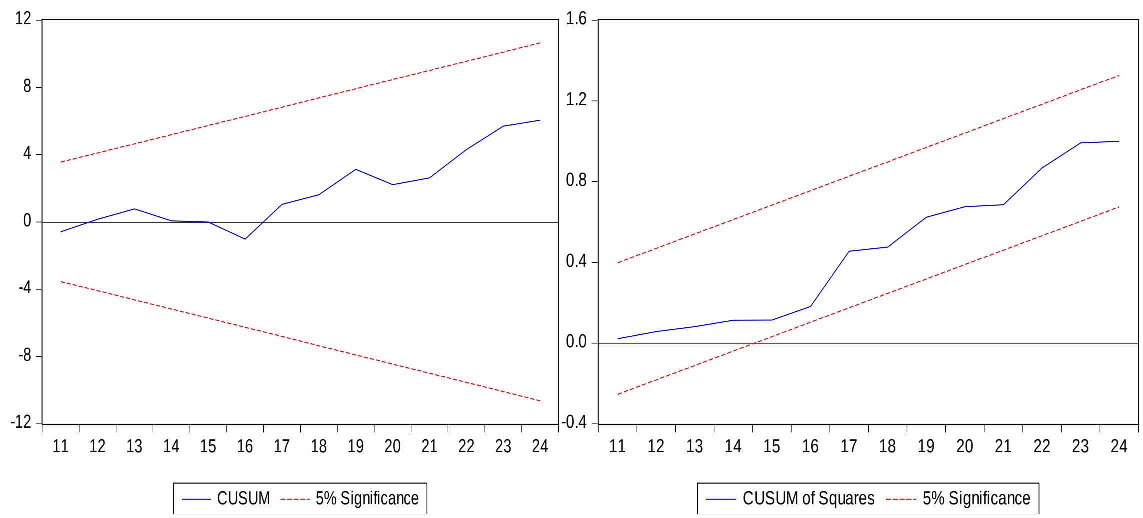

Figure 3 : CUSUM stability tests of the GDP variable

2.3.2. Estimation of the ARDL model

The coefficients of determination of the two regressions studied are 94.00 and 98.27 respectively, which means that the explanatory variables do have an impact on the dependent variable. Indeed, this is confirmed by the results obtained from the DW test exceeding 2, which confirms that all the chosen variables adequately explain our dependent variable in the regression. In terms of long-term impact, we observe that the majority of results are significant at the various significance thresholds of 10%, 5%, and 1%.

Once we have estimated the model, we move on to the next step to determine whether the variables benefit from a long-term relationship. To achieve this, we use the ARDL Bounds test to examine the existence of a long-term relationship. According to this test, it is observed that a long-term equilibrium relationship exists; in other words, the variables are cointegrated in the long term. Indeed, if the calculated F statistic is greater than the critical value of the upper bound I(1), the null hypothesis is rejected. If the F statistic is lower than the lower critical value I(0), the null hypothesis cannot be rejected. When it lies between I(0) and I(1), the results of cointegration are then considered inconclusive. The variables are said to be cointegrated if the null hypothesis is rejected, which means there exists a long-term relationship between the studied variables. We assign GDP and CO_2 emissions as the dependent variables. Our results indicate that the F-statistic is equal to 7.89 for GDP and 8.67 for CO_2 emissions, which we compare to the lower and upper critical values of the different significance levels. We therefore reject the null hypothesis of absence of co-integration and conclude the existence of a long-term relationship between the model's variables. Indeed, when

GDP is defined as the dependent variable, the variables are co-integrated at the 10% and 5% levels. When CO_2 emissions are defined as the dependent variable, the variables are co-integrated at the 2.5%, 5%, and 10% levels.

Table 6 : Result of the ARDL Bound Test

F-Statistics = 8,676397 (CO_2)		
Meaning	I0 Bound	I1 Bound
10%	1,99	2,94
5%	2,27	3,28
2,5%	2,55	3,61
1%	2,88	3,99

Source : author (2025), based on data from WDI and ICRG with Eviews9.

Table 7 : Result of the ARDL Bound Test

F-Statistics =7,897044 (GDP)		
Meaning	I0 Bound	I1 Bound
10%	1,99	2,94
5%	2,27	3,28
2,5%	2,55	3,61
1%	2,88	3,99

Source : author (2025), based on data from WDI and ICRG with Eviews9.

2.4. The Results of the Short-Term Relationship Estimation

The adjustment coefficient or strength of return is statistically significant, negative, and between 0 and 1 (-0.696242) in absolute value. They are also statistically significant because their probabilities are equal to (P-value = 0.00). This guarantees a mechanism of error correction and thus the existence of a long-term equilibrium relationship (co-integration) between the model variables.

In the case of CO_2 : An increase of 1% in GDP, trade openness, and corruption leads to an increase of 1.48%, 0.36%, and 0.10% in CO_2 emissions, respectively. However, the impact of hydroelectric power generation, renewable energy consumption, and gross fixed capital formation (GFCF) on CO_2 emissions is negative. Indeed, an increase of 1% in these variables would result, respectively in the short term, in a decrease of 0.21%, 0.0057%, and 0.00% in CO_2 emissions.

GDP Case : An increase of 1% in CO_2 emissions, gross fixed capital formation (GFCF), consumption of renewable energy, and hydropower production leads to increases of 0.29%, 0.00%, 0.0023%, and 0.072% of GDP, respectively. However, the impact of trade openness on GDP is negative. Indeed, a 1% increase in trade openness would cause a short-term decrease of 0.28% in GDP. Furthermore, the effect of corruption remains positive and not significant. It does not impact GDP in the short term.

Table 8 : ARDL model and estimated coefficients of the variables (short term). Case of CO_2

Variables	Coefficient	Std, Error	t-Statistic	Prob,
D(CO_2 (-1))	-0,264543	0,079775	-3,316094	0,0044
D(LGDPIB)	1,487625	0,223262	6,663131	0,0000

D(LGDPIB(-1))	1,256270	0,206311	6,089199	0,0000
D(LDOUV)	0,362754	0,099100	3,660474	0,0021
D(LPE)	-0,213432	0,065445	-3,261262	0,0049
D(LPE(-1))	-0,148942	0,072010	-2,068362	0,0552
D(CORRUPTION)	0,103199	0,034081	3,028078	0,0080
D(CREN)	-0,005794	0,001865	-3,106673	0,0068
D(CREN(-1))	-0,018672	0,002672	-6,988094	0,0000
D(FBCF)	-0,000000	0,000000	-6,720128	0,0000
CointEq(-1)	-0,696242	0,061495	-11,32191	0,0000

Cointeq = CO_2 - (1,6430*LGDP + 0,4080*LDOUV -0,1478*LPE -0,0947 *CORRUPTION + 0,0340*CREN -0,0000*FBCF -20,7504)

Source: author (2025), based on data from WDI and ICRG with Eviews9.

Table 9 : ARDL Model and Estimated Coefficients of the Variables (Short Term). Case of GDP

Variables	Coefficient	Std, Error	t-Statistic	Prob.
D(LGDP(-1))	-0,467024	0,097516	-4,789218	0,0003
D(CO_2)	0,297017	0,037838	7,849672	0,0000
D(CO_2 (-1))	0,145049	0,036320	3,993634	0,0013
D(LDOUV)	-0,286841	0,034530	-8,307110	0,0000
D(LDOUV(-1))	-0,096727	0,031707	-3,050682	0,0086
D(FBCF)	0,000000	0,000000	9,094650	0,0000
D(CORRUPTION)	0,014534	0,015701	0,925700	0,3703
D(CREN)	0,002374	0,000818	2,901938	0,0116
D(CREN(-1))	0,009160	0,001307	7,006902	0,0000
D(LPE)	0,072113	0,029546	2,440714	0,0285
D(LPE(-1))	0,057471	0,028912	1,987755	0,0668
CointEq(-1)	-0,789875	0,077410	-10,20376	0,0000

Cointeq = LGDP - (0,1514* CO_2 -0,1028*LDOUV + 0,0000*FBCF + 0,0671*CORRUPTION -0,0142*CEREN + 0,0983*LPE + 9,7905)

Source: author (2025), based on data from WDI and ICRG with Eviews9.

2.5. The results of the estimation of the long-term relationship

The estimated long-term coefficients or elasticities are presented in the table below. The effects of gross domestic product per capita on CO_2 emissions are positive in both the short and long term. The long-term results indicate that a 1% increase in GDP leads to a 1.64% increase in CO_2 emissions.

In the case of CO_2 emissions: a 1% increase in GDP, trade openness, and renewable energy consumption would respectively cause an increase of 1.64%, 0.40%, and 0.034% in CO_2 emissions. However, the impact of Gross Fixed Capital Formation (GFCF) on CO_2 emissions is negative. Indeed, a 1% increase in GFCF will lead to a long-term decrease of 0.00% in CO_2 emissions. Furthermore, the effect of energy production from hydroelectric sources and corruption remains negative and not significant. These two variables have no long-term impact on CO_2 emissions.

Case of GDP: In this case, it was found that three explanatory variables, namely energy production from hydroelectric sources, corruption, and gross fixed capital formation (GFCF), indeed have a positive effect on the dependent variable GDP. However, an increase of 1% in energy production from hydroelectric sources, corruption, and GFCF could lead to respective increases in GDP of 0.098%, 0.006%, and 0.00%. These results are statistically significant at the 5% level. Furthermore, the impact of trade openness and renewable energy consumption on GDP is negative. Indeed, an increase of 1% in trade openness and renewable energy consumption would lead to a long-term decrease of 0.10% and 0.014% in GDP. Therefore, the effect of emissions from...

$C0_2$ is positive and not significant. Therefore, $C0_2$ emissions have no long-term impact on GDP.

Table 10 : ARDL model and estimated coefficients of the variables (Long term). Case of CO_2

Variables	Coefficient	Std, Error	t-Statistic	Prob,
LGDPIB	1,643013	0,593604	2,767861	0,0137
LDOUV	0,408018	0,104786	3,893823	0,0013
LPE	-0,147768	0,088353	-1,672459	0,1139
CORRUPTION	-0,094704	0,079746	-1,187576	0,2523
CREN	0,034018	0,010966	3,102035	0,0069
FBCF	-0,000000	0,000000	-2,916844	0,0101
C	-20,75041	6,206448	-3,343363	0,0041

Source : author (2025), based on data from WDI and ICRG using Eviews 9.

Table 11 : ARDL Model and Estimated Coefficients of the Variables (Long term). Case of GDP

Variable	Coefficient	Std, Error	t-Statistic	Prob,
CO_2	0,151354	0,116341	1,300955	0,2143
LDOUV	-0,102822	0,049786	-2,065290	0,0579
FBCF	0,000000	0,000000	8,836990	0,0000
CORRUPTION	0,067070	0,027146	2,470717	0,0269
CREN	-0,014186	0,003163	-4,484764	0,0005
LPE	0,098289	0,031702	3,100429	0,0078
C	9,790512	0,916956	10,677191	0,0000

Source : author (2025), based on data from WDI and ICRG using Eviews 9.

2.6. Causality Between Variables

The results of the causality test developed by Nobel Prize-winning economist Granger demonstrate the existence of a unidirectional causality going from economic growth to energy transition, as the probability associated with the Fisher statistic after the Wald test is below the significance threshold.

Table 12 : Granger causality test

Null hypothesis	Obs	F-Statistic	Prob.
The energy transition does not cause economic growth	33	0,164075	0,8495
Economic growth causes the energy transition	33	4,070789	0,0285

Source : author (2025), based on data from WDI and ICRG using Eviews 9.

2.7. Discussion of Results

The results of our ARDL model demonstrated the existence of a long-term relationship among our variables, namely economic growth, trade openness, renewable energy consumption, gross fixed capital formation (GFCF), hydroelectric power production, and corruption. The Granger causality test then allowed us to determine the direction of this cointegration. Indeed, the results of the test indicated that there is a unidirectional causality running from economic growth (GDP) to energy transition (CO_2 emissions). This means that an increase in CO_2 emissions leads to an increase in GDP, but an increase in CO_2 does not systematically result in an increase in GDP. Therefore, policies aimed at reducing CO_2 emissions will not necessarily have a negative impact on the economic growth of Congo. Indeed, our results align with those of Khobai et al. (2018) who examined the causal link between renewable energy consumption and economic growth in South Africa for the period 1990-2014. The authors used the ARDL model to explore the long-term relationship between the variables and the vector error correction model to determine the direction of causality. The authors also incorporated carbon dioxide emissions, capital formation, and trade openness as additional variables to form a multidimensional framework. The results of the study validated the existence of a long-term relationship between the variables. On the other hand, the results demonstrate that there is no causal link between energy transition and long-term economic growth. This means that the energy transition has no direct effect on economic growth in the long term. However, the authors confirm that an indirect effect may exist in the short term. The results also show that CO_2 emissions have no long-term impact on GDP in Congo, confirming, for our study, the neutrality hypothesis and aligning with the findings of Mounir El-Karimi and EI Ghini (2020) regarding the Moroccan case. Indeed, we can explain this result by the fact that the energy transition is not yet sufficiently deployed to impact economic growth. Our results align with those of Bhattacharya et al. (2016), who explained that these countries have not been able to effectively utilize renewable energy sources in the production process, which therefore has virtually no impact on economic output.

Regarding the results of our ARDL test, the estimated long-term coefficients or elasticities are presented in the table below. The effects of GDP per capita on CO_2 emissions are positive in both the short and long term. Long-term results show that a 1% increase in GDP leads to a 1.64% increase in CO_2 emissions. Additionally, a 1% increase in GDP, trade openness, and the consumption of renewable energy would respectively cause an increase of 1.64%, 0.40%, and 0.034% in CO_2 emissions. However, the impact of gross fixed capital formation (GFCF) on CO_2 emissions is negative. Indeed, a 1% increase in GFCF will result in a long-term decrease of 0.00% in CO_2 emissions. Furthermore, the effect of energy production from hydroelectric sources and corruption remains negative and not significant. These two variables do not have any long-term impact on CO_2 emissions. As for GDP, the results showed that the three explanatory variables, namely, energy production from hydroelectric sources, corruption, and gross fixed capital formation (GFCF), do have a positive effect on the dependent variable GDP. However, an increase of 1% in energy production from hydroelectric sources, corruption, and GFCF could lead to respective increases in GDP of 0.098%, 0.006%, and 0.00%. These results are statistically significant at the 5% level. Furthermore, the impact of trade openness and renewable energy consumption on GDP is negative. Indeed, an increase of 1% in trade openness and renewable energy consumption would lead, in the long term, to a decrease of 0.10% and 0.014% in GDP. Consequently, the effect of CO_2 emissions is positive and not significant. So CO_2 emissions have no long-term impact on GDP. As for the short term, the results are not the same as in the long term, except that the impact of energy production from hydropower sources, renewable energy consumption, and gross fixed capital formation on CO_2 emissions is negative. Indeed, a 1% increase in these variables would respectively cause a decrease of 0.21%, 0.0057%, and 0.00% in CO_2 emissions in the short term. These results align with those of Khanniba et al. (2020), who studied the causal link between electricity production from renewable sources, CO_2 emissions, and economic growth in Morocco. In this regard, the study used the ARDL approach and the Toda and Yamamoto (1995) causality test on data from the period 1990 to 2015. The results reveal the existence of a balance between the variables, in the short and long term. Indeed, in the short term, CO_2 emissions, electricity production from renewable sources, and the active population have a negative impact on GDP. Gross fixed capital formation also has a negative impact on economic growth over a one-year period but becomes positive after two years. In the long term, GDP is primarily caused by CO_2 emissions, the workforce, and electricity production from renewable sources.

Conclusion

In this article, we study the relationship between economic transition and economic growth in Congo-Brazzaville. To analyze the impact of such an energy transition on economic growth, we used the ARDL method as well as the Granger causality test on data from the period ranging from 1990 to 2024.

The results of our study confirm the neutrality hypothesis for the case of Congo. This means that the energy transition does not impact economic growth, at least for now. Indeed, these results align with those of Al-mulali et al. (2013) for certain countries, those of Alper and Oguz (2016) also for certain countries, those of Ozcan et al. (2019) for all the countries studied, and those of Mounir El-Karimi and EI Ghini (2020), who also focused on the case of Morocco. These authors explained the neutrality hypothesis by the fact that the renewable energy sector, particularly the renewable electricity production sector, is not sufficiently developed to affect economic growth. Indeed, despite the progress made in renewable electricity production, the sector is not yet adequately developed, and the country still heavily relies on hydroelectric energy sources.

Congo is a country that does not yet have the necessary technologies and know-how to take advantage of the great potential of renewable energy and to significantly increase its clean energy production. Our recommendations regarding energy policy mainly concern fiscal measures in the renewable energy sector. Indeed, the Congolese government should encourage the use of these energy sources, at the expense of hydroelectric sources, by implementing tax incentives to stimulate investment and consumption of these energy sources, and facilitating the abundance of conventional technologies, for cleaner technologies. On the other hand, and finally to encourage them, it is necessary to establish a conducive environment for investment, through which the country will be able to attract domestic and foreign investments. The formation of a skilled workforce and the development of human capital are also necessary conditions for the deployment of the renewable energy sector in Congo.

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