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Exploring the Relationship Between CO_2 Emissions and Fuel Consumption in Road Transport: Empirical Evidence from Chad

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ABSTRACT

Over the period 2008-2019, this study examines the linear impact of petroleum product (PP) consumption in Chad, PP prices, the vehicle fleet and urbanisation on CO_2 emissions on the one hand, and on the other, it determines the causal links that exist between the various variables studied. This study opts for the augmented Dickey-Fuller and Phillips-Perron tests to verify the stationarity of the variables. The ARDL model is then estimated and diagnostic tests are performed to confirm the validity of the model. To confirm the existence of long-term relationships, the bounds test was applied. Finally, the Toda-Yamamoto causality test was used to capture the influences present between the series under study. The main results show that, in the long term, a 1% increase in gasoline consumption would lead to a 1.03% increase in CO_2 emissions and the linear impact of diesel consumption is positive and insignificant on CO_2 emissions. In the short term, gasoline and diesel consumption have a positive and insignificant impact on CO_2 emissions. In terms of causality, there is a unidirectional causality from gasoline consumption to CO_2 emissions and a bidirectional causality between CO_2 emissions and diesel consumption. This study is the first to simultaneously link CO_2 emissions, PP consumption, PP prices, the vehicle fleet and urbanisation in general, and particularly in the case of Chad. It therefore adds to the literature on the simultaneous relationship between CO_2 emissions, PP consumption, the car fleet and urbanisation in a global and restricted context. This study could guide Chadian oil pollution management decision-makers in adopting policies related to the effects of PP consumption in the road transport sector.

Keywords: CO_2 Emissions, Petroleum Product Consumption, Road Sector, ARDL, Toda-Yamamoto, Chad
JEL Classifications: O13, O38, P28, Q42

1. INTRODUCTION

1.1. Background and History

The transport sector has been an essential means for the movement of people and the supply of goods and services needed in daily life for years (Ağbulut, 2022; Onat et al., 2014; Tamba et al., 2012). It also has an impact on all aspects of human presence, including production, culture, trade, education and defence (Danish et al., 2018). This sector has seen significant growth thanks to energy consumption, particularly that of petroleum products (PP) (Engo, 2019). Global consumption of fossil fuels in the transport sector rose from 88074462 TJ in 2005 to 110471146 TJ in 2019, an increase of 25.43% (AIE, 2021). (AIE, 2021). The transport sector is one of the main end-use consumers of total energy contributing to global emissions. It contributes 29% of total global energy consumption and 65% of global PP (Solaymani, 2019). The largest share of fossil fuel consumption among the various existing sectors puts the transport sector in the lead with a rate of 66%, followed by the industrial and residential sectors with respective rates of 7% and 5% in 2019 (AIE, 2021). Demand for PP in the transport sector has thus become increasingly important over the years. Given that the economic performance of any nation is measured by its energy consumption rate, it follows that this demand plays an important role in a nation's economy (Sapnken, 2018; Carbonnier and Grinevald, 2011) and particularly in the development of the transport sector (Sapnken et al., 2020, 2017; Tamba et al., 2017). From the above, it is clear that global consumption of fossil fuels in general, and PP in particular, is becoming increasingly important in the transport sector.

Chad's overall consumption of fossil fuels between 2010 and 2016 was high, resulting in high greenhouse gas (GHG) emissions (TCNTCC, 2020). In 2010, gross energy consumption of fossil fuels in Chad, excluding biomass, was estimated at 257.01 ktoe[1], of which 91.55 ktoe was for diesel consumption (i.e. 35.62%) and 16.91 ktoe for premium fuel consumption (i.e. 6.58%) (TCNTCC, 2020). In 2016, gross energy consumption of fossil fuels in Chad, excluding biomass, was estimated at 662.86 ktoe, of which 331.87 ktoe was for diesel consumption (50.07%) and 115 ktoe for premium fuel consumption (representing 17.49%) (TCNTCC, 2020). These figures show that diesel and premium oil consumption in Chad has increased significantly over 7 years. In the road transport sector, Chad's consumption of PPs such as gasoline and diesel amounted to 8916m³ in 2007 compared with 130275m³ in 2016, an increase of 121359m³ in 10 years.

GHG emissions in Chad come from the consumption of fuels for the transport sector; to this must be added the consumption of fuels for the production of electricity, the consumption of fuels for domestic use and fugitive emissions in the oil sector (TCNTCC, 2020). Carbon dioxide is the most emitted GHG into the atmosphere (Engo, 2019). Carbon emissions can cause numerous health and environmental problems (Dong et al., 2021). From a health point of view, they can cause serious respiratory problems such as breathlessness, headaches and fatigue, and from an environmental point of view, they can cause climate change and acid rain, which affect the environment. Near-real-time data show that global carbon dioxide (CO_2) emissions rose by 4.8% in 2021 to 34.9 $GtCO_2$, following record declines in 2020 (Liu et al., 2022). Worldwide, transport as a whole was responsible for 23% of total CO_2 emissions from fuel combustion, and road transport was responsible for 20% in 2014 (Santos, 2017). Even the work of Solaymani (2019) supports the estimates for this sector, with around 24% of global CO_2 emissions also due to fuel combustion. Generally speaking, the land transport sector is recognised worldwide as one of the biggest emitters of GHGs (TCNTCC, 2020). Land transport is still largely fuelled by fossil fuels and is therefore the source of significant GHG emissions, particularly CO_2, and atmospheric pollutants (Ehrenberger et al., 2021).

1.2. Related Studies and Identification of Gaps

The relationship between transport, energy and sustainable development has been the subject of much debate in the literature. Generally speaking, the overriding concern is with oil consumption, including air pollution and GHG emissions (Danish et al., 2018). For example, in the BRICS economy, Arora and Kaur (2020) found unidirectional causality from fuel consumption to environmental degradation. In the USA, Umar et al. (2021) find that, in the long term, fossil fuel energy consumption leads to CO_2 emissions from the transport sector in the United States at different levels of frequency. In a study in Turkey, Gokmenoglu and Sadeghieh (2019) show that in the long term, fuel consumption has a positive and elastic impact on carbon emissions of 2.82%. The work of Mensah et al. (2019) studies the causal link between economic growth, fossil fuel consumption, carbon emissions and the price of oil. They conclude that there is a two-way causal link between fossil fuel consumption and CO_2 emissions in the long term and short term for all the panels. In India, Pakistan and Bangladesh, Uzair Ali et al. (2022) argue that fossil fuel consumption and population density have a positive impact on long-term CO_2 emissions. These authors also found that there is no causality between fossil fuel consumption and CO_2 emissions and that there is a short-term causality between population density and fossil fuel consumption and that CO_2 emissions influence population density. Pakistan, Danish et al. (2018) indicate a significant impact of transport sector energy consumption on CO emissions. Furthermore, the impact of urbanisation on CO_2 emissions from the transport sector is statistically insignificant. Lotfalipour et al. (2010) conclude that there is no Granger causality between total fossil fuel consumption and long-term carbon emissions. Hossain (2011) reports that there is no long-term causality between income, energy consumption and CO emissions. Also, Böhringer et al. (2021) argue that national CO_2 emissions could be reduced through a uniform economy-wide emissions pricing policy, and that CO_2 revenues could be recycled in Germany. Malik et al. (2020) analysed oil prices, revenues and their impact on CO_2 emissions in Pakistan. They believe that oil prices have boosted CO_2 emissions in the short run. Long-term, however, the link is in the reverse direction, with oil prices lowering CO_2 emissions. Oil prices, emissions, and energy policy in the GCC area were examined by Alkathery and Chaudhuri (2021) in the year 2021. They draw the conclusion that worldwide clean energy output, pollution, and oil prices are all linked. The UAE (United Arab Emirates), Bahrain, Oman, and Qatar, Mahmood et al. (2022) assert that urbanization has a favorable impact on CO_2 emissions in these countries. According to Meng et al. (2021), both urbanization and industrialization lead to higher carbon emissions. They also contend that urbanization causes emissions to rise more quickly than industrial development. Using a semi-parametric method, Abdallh and Abugamos (2017) investigated a related concept for the MENA (Middle East and North Africa) area and indicated that emissions rise with urbanization and growing wages. According to Majeed et al. (2021), urbanization has deteriorated the ecology in the Gulf Cooperation Council (GCC) area while oil abundance has improved. Gambhir et al. (2015) indicate that passenger cars and heavy goods vehicles account for the majority of CO_2 reduction potential in the future, but that, using central cost assumptions, alternative powertrains are significantly more cost-effective for trucks than for passenger cars. The impact of several parameters that affect fuel usage and CO_2 emissions in the lab and on the road is examined by Fontaras et al. (2017). It is once more proved that elements like traffic circumstances and vehicle configuration play a significant role. Additionally, the gap might be continuously evaluated using quality controls of the CO_2 emissions certification process along with in-use consumption monitoring. González

1 Ktep stands for kilotonnes of oil equivalent. The tonne of oil equivalent (toe) represents the quantity of energy contained in one tonne of crude oil, or 41.868 gigajoules (GJ).

Palencia et al. (2012) report that battery electric vehicles offer the greatest reductions in energy consumption and CO_2 emissions.

To sum up, the above-mentioned studies generally focus on the impact of fossil fuel consumption, oil prices, urbanisation and the car fleet on CO_2 emissions, either individually or grouped together, and the causal links that exist between the various variables under study. Furthermore, the results of these studies are not conclusive. Diesel and petrol are the main sources of CO_2 emissions in Chad (TCNTCC, 2020). CO_2 emissions in Chad are growing and have accelerated significantly since 2011, the year in which the Djarmaya refinery, Chad's only refinery, came on stream (TCNTCC, 2020). This growth can certainly be explained by the increased consumption of PP in Chad and the fall in PP prices. It is crucial to investigate the link between CO_2 emissions, PP use in the road transport sector, and PP pricing given the larger consumption in this sector and its low price. In addition, Chad has a population estimated at nearly 15 million in 2018 (CDN, 2021). The average annual population growth rate rose from 2.4% for the period 1985-2000 to 3.9% for the period 2000-2015 (TCNTCC, 2020). This population is expected to reach 19.34 million in 2025 and 44.21 million in 2050 according to the trend scenario (TCNTCC, 2020). In view of the projected increase in Chad's population, it is therefore becoming necessary to control it in order to take care of local pollution. In addition, the road transport sector in Chad is constantly growing, given the large number of vehicles registered each year. Given the high number of obsolete vehicles, these are the biggest emitters of GHGs. (TCNTCC, 2020). It is therefore interesting to use the vehicle fleet as an explanatory variable for CO_2 emissions.

1.3. Aims of the Study, Contributions and Novelty

On the basis of the above, the primary objective of this study is to examine, over the period 2008-2019, the linear impact of PP consumption, prices, the vehicle fleet and urbanisation on CO_2 emissions. The secondary objective is to determine the causal links between the various variables studied. This work adds to the body of knowledge in various ways: (i) To our knowledge, it is a new attempt to simultaneously highlight the short- and long-term effects of PP consumption, crude oil prices, the vehicle fleet and urbanisation on CO_2 emissions in Chad; (ii) it includes an analysis of the causality between CO_2 emissions, PP demand, crude oil prices, the vehicle fleet and urbanisation in Chad, which has not been covered to date; (iii) this study is intended for Chadian political leaders to formulate policies on the consumption of PP in the road transport sector in order to reduce CO_2 emissions and guarantee sustainable development. Using Chad's time series, this study is the first to simultaneously link CO_2 emissions, PP consumption, PP prices, the vehicle fleet and urbanisation in Chad. It could guide Chadian oil pollution management decision-makers in adopting policies related to the effects of PP consumption in the road transport sector.

1.4. Organisation of Work

The remainder of the study is organised as follows: Section 2 provides a brief overview of CO_2 emissions in Chad. Section 3 describes the data and methodology used. In Section 4, the results are presented and Section 5 is reserved for discussion of the results, while Section 6 concludes the study with some suggestions for policy measures.

2. BRIEF OVERVIEW OF GHG EMISSIONS IN CHAD

Global GHG emissions have risen from 38,669 to 48,117 megatonnes of carbon dioxide equivalent (Mt CO2-eq.), an increase of 23.6%. (World Resources Institute, 2022). This has led to an increase in average global surface temperature of 1.2°C (Organisation Météorologique Mondiale, 2021). Globally reaching zero net emissions by 2050 calls for immediate action and contributions from each country (Akeresola and Gayawan, 2021).

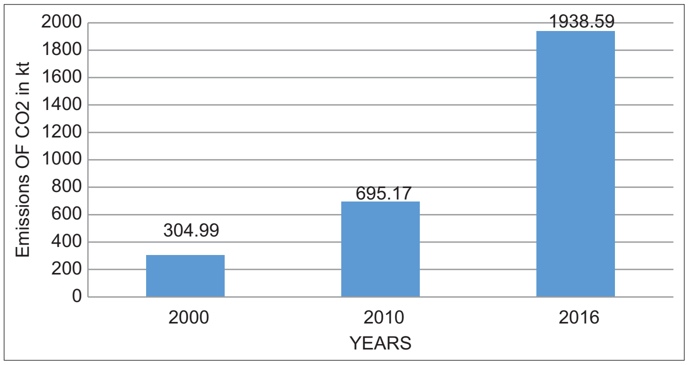
Africa has seen the worst consequences of global warming (Bewket, 2012). In Tanzania, warmer weather and less rain caused Mount Kilimanjaro's glaciers to melt by 49% between 1976 and 2002, leading to the drying up of most of the rivers in the region (Josephine, 2007). By 2033, Mount Kilimanjaro will no longer have any ice on it, according to projections, if the rise in GHG emissions is not stopped. According to Change (2008), Tunisia is the nation most likely to see a drop in yearly rainfall by 2030 and an increase of 2.1°C in its average temperature by 2050. As a result, there will be a great chance of water deficits, which would hurt the citizens.

Africa contributes the least to the world's total GHG emissions (Adzawla et al., 2019; Bewket, 2012). However, anthropogenic GHG emissions are steadily increasing in Africa. Between 1990 and 2011, the total GHG emissions in East Africa rose by 42% (Leimbach et al., 2018). Between 1990 and 2014, GHG emissions in West Africa increased by 17%, with Nigeria accounting for over 46% of these emissions (Akeresola and Gayawan, 2021). According to projections, sub-Saharan African GHG emissions would rise by up to 50% by 2050 and double across the continent (van der Zwaan et al., 2018). Given that GHGs have a lengthy atmospheric lifespan of several thousand years, Africa is working to reduce its GHG emissions (Akeresola and Gayawan, 2021). The commitment of financial and technological resources, however, is what restricts attempts to reduce GHG emissions in emerging economies (Adzawla et al., 2019).

In Chad, several sectors are responsible for GHG emissions, notably the energy sector, the agricultural sector, forests and waste from 2010 to 2018. GHG emissions rose by 50%, from 49,320 kt of CO_2 eq.$_2$ in 2010 to 74,090 kt of CO eq.$_2$ in 2018. (CDN, 2021). GHG emissions come mainly from fuel consumption for electricity generation, fuel consumption in the transport sector, fuel consumption for domestic use and fugitive emissions in the oil sector. Figure 1 shows that CO_2 emissions in Chad have been rising year on year. Between 2000 and 2010, CO_2 emissions rose from 304.99 ktoe to 695.17 ktoe, more than doubling. In 2016, CO_2 emissions have almost tripled compared with 2010.

Taking 2016 as the base year, CO_2 emissions are largely dominated by diesel combustion. Emissions from petrol combustion are in second place, and are mainly emitted by the land transport

Figure 1: Evolution of CO_2 emissions in Chad (TCNTCC, 2020)



sector (TCNTCC, 2020). GHG emissions from the energy sector for the 2010 reference year are estimated at 695.17 ktoe. These emissions are significantly lower than those for 2016, which amounted to 1938.59 ktoe (TCNTCC, 2020). This increase in emissions is mainly due to electricity generation, oil production activities and the transport sector. Given the almost negligible emissions of CH_4 and N_2O, CO_2 accounts for 100% of GHG emissions in Chad's energy sector (TCNTCC, 2020). In 2016, the number of vehicles registered over the last 10 years was 24,5601 (all vehicles combined), broken down as follows: 172486 motorbikes; 43942 light diesel vehicles; 19480 light petrol vehicles and 9693 heavy goods vehicles such as lorries, tractors and semi-trailers (TCNTCC, 2020). TCNTCC (2020) shows that fuel consumption for land transport over the period 2007-2016 is estimated at 30 L/month for motorbikes on average; 100 L/month for light goods vehicles using petrol on average; 100 L/month for light goods vehicles using diesel on average and 150 L/month for heavy goods vehicles using diesel on average. Light goods vehicles running on diesel were in first place in terms of fuel consumption over the period 2007-2016, followed by motorbikes. Light goods vehicles come third in terms of petrol consumption. Finally, heavy goods vehicles running on diesel come last in terms of energy consumption. The growth in the vehicle fleet and the resulting rise in fuel consumption could therefore trigger an increase in energy demand and, consequently, a likely rise in CO_2

3. DATA AND METHODOLOGY

3.1. Variables and Data

The work of Danish et al. (2018) uses energy consumption in the transport sector and urbanisation to model the impact of the latter on greenhouse gas emissions. CO_2. In addition, the recent study by Mahmood et al. (2022) uses the price of oil and urbanisation in its model to study the impact of the latter on the emissions of CO_2 emissions in the Gulf Cooperation Council (GCC) countries. Based on the studies mentioned above and drawing on the work of Solís and Sheinbaum (2013)and those of Alkathery and Chaudhuri (2021) and Majeed et al. (2021)This research focuses on the relationship between emissions of CO_2 emissions, PP consumption (Gasoline and Gasoil), the vehicle fleet, the price of oil (Gasoline and Gasoil) and urbanisation in Chad and proposes the following theoretical models:

$$CO_{2t} = f\left(CSU_t, PSU_t, PAU_t, URB_t\right) \tag{1}$$

$$CO_{2t} = f\left(CGA_t, PGA_t, PAU_t, URB_t\right) \tag{2}$$

Where CO_{2t} represents the emissions of CO_2, CSU_t and CGA_t represent gasoline and diesel consumption respectively, PSU_t and PGA_t represent the price of gasoline and diesel respectively, PAU_t is the number of cars on the road and URB_t is urbanisation. All variables were transformed into natural logarithm following Ahmed et al. (2016) in Eqs. (1) and (2) to obtain trustworthy and consistent empirical findings (Shahbaz et al., 2016). The natural logarithm thus makes it possible to smooth the different variables and make interpretations in the form of elasticities. Empirical models between CO_2 emissions and all the other variables are as follows:

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnCSU_t + \alpha_2 lnPSU_t + \alpha_3 lnPAU_t + \alpha_4 lnURB_t + \varepsilon_t \tag{3}$$

$$lnCO_{2t} = \beta_0 + \beta_1 lnCGA_t + \beta_2 lnPGA_t + \beta_3 lnPAU_t + \beta_4 lnURB_t + \varepsilon'_t \tag{4}$$

Where $lnCO_2$ is the natural logarithm of emissions of CO_2, $lnCSU_t$ and $lnCGA_t$ represent respectively the natural logarithm of the consumption of gasoline and the natural logarithm of the consumption of diesel, $lnPSU_t$ and $lnPGA_t$ represent the price of gasoline and diesel respectively $lnPAU_t$ is the natural logarithm of the car fleet and $lnURB_t$ is the natural logarithm of urbanisation. α_0 and β_0 are the respective constants of Eqs. (3) and (4), ε_t and the respective error terms in Eqs. (3) and (4). We have used urban population growth as a proxy for urbanisation, and the vehicle fleet used here takes into account all passenger cars, vans, buses, rigids, tractors, semi-trailers, trailers and motorbikes. Data on CO_2 emissions come from the World Bank database (Banque Mondiale, 2022a) and are expressed in kilotonnes. Data on PP consumption and prices come from the Société de Raffinage au Tchad in N'Djamena, supplemented by data from ARSAT (2022) and are expressed respectively in thousands of litres and in local currency. Data on vehicle fleet was collected from the Ministry of Transport and Road Safety, and the data on urban population growth in Chad as a proxy for urbanisation comes from the World Bank database (Banque Mondiale, 2022b) and are expressed as an annual percentage. The study period from 2008 to 2019 was chosen because of the official structure of Chad's data, which is uniform over the aforementioned season for all the variables used in this study.

3.2. Stationarity Tests

The nature of the series is crucial to approve before running a time series model such as the one contained in this study. Consequently, the augmented Dickey-Fuller and Phillips-Perron stationarity tests were used. The augmented Dickey-Fuller test was chosen because of the autocorrelation problem from which the ARDL model generally suffers, and the Phillips-Perron test was also adopted because of the heteroskedastic errors that can creep into the ARDL model.

3.3. Co-integration Analysis

In this study, we choose the ARDL model for several reasons: (i) ARDL takes into account the endogeneity problem by including delays for the model's dependent and independent variables; (ii) ARDL can be used as long as the variables are stationary in level, in first differences, or a mix of the two, unlike Johansen's Co-integration, which mandates that all variables must be integrated of the same order; (iii) ARDL can be applied to a small sample size; (iv) ARDL makes it possible to simultaneously estimate the long-term and short-term dynamics of the variables under study. The method of Pesaran et al. (2001) was preferred for several reasons: (i) our series are integrated at different orders I(0) and I(1); (ii) it allows us to combine short-term dynamics and long-term effects by referring to the error correction model. In this research, we use the ARDL model to study the dynamic relationship between CO_2 emissions, the consumption of PP (gasoline and diesel), the car fleet, the price of PP (gasoline and diesel) and urbanisation. This model is represented by Equation (5) below:

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=1}^{t}\beta_i \Delta lnCO_{2t-i} + \sum_{i=1}^{t}\rho_i \Delta lnCPP_{t-i} + \sum_{i=1}^{t}\varphi_i \Delta lnPRX_{t-i} + \sum_{i=1}^{t}\omega_i \Delta lnPAU_{t-i} + \sum_{i=1}^{t}\Phi_i \Delta lnURB_{2t-i} + \lambda_1 lnCO_{2t-i} + \lambda_2 lnCPP_{t-i} + \lambda_3 lnPRX_{t-i} + \lambda_4 lnPAU_{t-i} + \lambda_5 lnURB_{t-i} + \varepsilon_t \quad (5)$$

With Δ being the first difference operator; α_0 the constant; β_i, ρ_i, φ_i, ω_i and Φ_i represent short-term effects; $\lambda_1 \ldots \lambda_5$ λ_1 represent the long-term dynamics of the model and ε_t the error term; $lnCPP_{t-i}$ represents the logarithm of the PP consumption type vector and $lnPRX_{t-i}$ represents the logarithm of the PP price type vector. The Wald restriction test is used to assess co-integration or the long-term relationship. The diagnostic of the coefficient of the Wald restriction test is applied to the long-run variable's parameters to determine the F-test's result. The cointegration hypothesis are as follows:

H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5$ (No co-integration);

H_0: $\lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5$ (Presence of Co-integration);

The null hypothesis will be rejected if the estimated F-stat value exceeds the upper bound value, implying that co-integration exists. This indicates that the independent and dependent variables have a lasting connection. The null hypothesis is not rejected when the F-stat value is smaller than the lower limit value, which shows that the dependent and independent variables do not have a long-term connection since they do not exhibit co-integration. Finally, if the F-stat is between the lower and higher boundaries, the outcome will be deemed inconclusive. The short-run models are shown in Equation (6) below, where θ_i is the pace at which the long-run equilibrium will adapt following the short-run shock or the error correction term.

$$\Delta lnCO_{2t} = \beta_0 + \sum_{i=1}^{t}\beta_i \Delta lnCO_{2t-i} + \sum_{i=1}^{t}\rho_i \Delta lnCPP_{t-i} + \sum_{i=1}^{t}\varphi_i \Delta lnPRX_{t-i} + \sum_{i=1}^{t}\omega_i \Delta lnPAU_{t-i} + \sum_{i=1}^{t}\Phi_i \Delta lnURB_{2t-i} + \theta_i ECT_{t-i} + \varepsilon_t \quad (6)$$

The error correction term is ECT_{t-i}. After short-term shocks (which might influence individual series), it functions to restore equilibrium at speed θ_i. Its coefficient must have a negative sign and be statistically significant.

3.4. Diagnosis and Model Stability

Model validation is linked to the various diagnostic tests carried out after estimation of the ARDL model. To do this, serial independence, the Breusch-Godfrey LM serial correlation test and the normality test are used. Additionally, the model is subjected to the Ramsey Reset test and the ARCH test to look for heteroscedasticity and model misspecification, respectively. Using the CUSUM of squares (Brown et al., 1975), one may determine if the model is beginning to take on an autoregressive structure. This test is used to ensure the stability of the model parameters.

3.5. Granger Causality Test in the Toda-Yamamoto Sense

A number of criticisms of traditional causality tests (principally Granger's) have confirmed the effectiveness of Granger's causality test in the sense of Toda and Yamamoto (1995) based on a modified Wald test (MWALD). This test is used in this study because our variables are integrated at different orders I(0) and I(1).

The modified Wald test (MWALD), according to Wolde-Rufael (2005, 2004), solves the issues with the standard Granger causality test by disregarding any potential co-integration between series. Toda and Yamamoto's (1995) method minimizes the risks associated with any inaccurate identification of the sequence of integration of the series by fitting a VAR model to the levels of the variables (Amiri and Ventelou, 2012). The Granger causality test procedure proposed by Toda and Yamamoto (1995) is as follows: (i) find the maximum order of integration of the series under study d_{max} using stationarity tests; (2) determine the optimal lag of the sub-study level VAR (k) or autoregressive polynomial (AR) using the information criteria (AIC, SC and HQ); (iii) estimate an augmented level VAR of order $k + d_{max}$ (iv) Check the robustness of the VAR(k+d_{max}) using available diagnostic measures; (v) a Wald test is performed on q initial parameters and provides an asymptotic chi-squared distribution with q degrees of freedom. The following models are therefore expressed and translate the Granger causality relations in the Toda-Yamamoto sense:

Model 1: Carbon emissions (CO_2) and gasoline fuel consumption (CSU)

$$lnCO_{2t} = \alpha_0 + \sum_{i=1}^{k}\beta_{1i} lnCO_{2t-i} + \sum_{j=k+1}^{d\max}\beta_{2j} lnCO_{2t-j} + \sum_{i=1}^{k}\lambda_{1i} lnCSU_{t-i} + \sum_{j=k+1}^{d\max}\lambda_{2j} lnCSU_{t-j} + \sum_{i=1}^{k}\Phi_{1i} lnPAU_{t-i} + \sum_{j=k+1}^{d\max}\Phi_{2j} lnPAU_{t-j} + \sum_{i=1}^{k}\varphi_{1i} lnPSU_{t-i} + \sum_{j=k+1}^{d\max}\varphi_{2j} lnPSU_{t-j} + \sum_{i=1}^{k}\rho_{1i} lnURB_{t-i} + \sum_{j=k+1}^{d\max}\rho_{2j} lnURB_{t-j} + \varepsilon_{1t} \quad (7)$$

Model 2: Gasoline fuel consumption (CSU) and carbon emissions (CO_2)

$$lnCSU_t = \alpha_1 + \sum_{i=1}^{k}\beta_{1i}lnCO_{2t-i} + \sum_{j=k+1}^{d\max}\beta_{2j}lnCO_{2t-j} + \sum_{i=1}^{k}\lambda_{1i}lnCSU_{t-i} + \sum_{j=k+1}^{d\max}\lambda_{2j}lnCSU_{t-j} + \sum_{i=1}^{k}\Phi_{1i}lnPAU_{t-i} + \sum_{j=k+1}^{d\max}\Phi_{2j}lnPAU_{t-j} + \sum_{i=1}^{k}\varphi_{1i}lnPSU_{t-i} + \sum_{j=k+1}^{d\max}\varphi_{2j}lnPSU_{t-j} + \sum_{i=1}^{k}\rho_{1i}lnURB_{t-i} + \sum_{j=k+1}^{d\max}\rho_{2j}lnURB_{t-j} + \varepsilon_{2t} \quad (8)$$

Model 3: Carbon emissions (CO_2) and diesel consumption (CGA)

$$lnCO_{2t} = \alpha_0 + \sum_{i=1}^{k}\beta_{1i}lnCO_{2t-i} + \sum_{j=k+1}^{d\max}\beta_{2j}lnCO_{2t-j} + \sum_{i=1}^{k}\lambda_{1i}lnCGA_{t-i} + \sum_{j=k+1}^{d\max}\lambda_{2j}lnCGA_{t-j} + \sum_{i=1}^{k}\Phi_{1i}lnPAU_{t-i} + \sum_{j=k+1}^{d\max}\Phi_{2j}lnPAU_{t-j} + \sum_{i=1}^{k}\varphi_{1i}lnPGA_{t-i} + \sum_{j=k+1}^{d\max}\varphi_{2j}lnPGA_{t-j} + \sum_{i=1}^{k}\rho_{1i}lnURB_{t-i} + \sum_{j=k+1}^{d\max}\rho_{2j}lnURB_{t-j} + \varepsilon_{1t} \quad (9)$$

Model 4: Diesel consumption (CGA) and carbon emissions (CO_2)

$$lnCGA_t = \alpha_1 + \sum_{i=1}^{k}\beta_{1i}lnCO_{2t-i} + \sum_{j=k+1}^{d\max}\beta_{2j}lnCO_{2t-j} + \sum_{i=1}^{k}\lambda_{1i}lnCGA_{t-i} + \sum_{j=k+1}^{d\max}\lambda_{2j}lnCGA_{t-j} + \sum_{i=1}^{k}\Phi_{1i}lnPAU_{t-i} + \sum_{j=k+1}^{d\max}\Phi_{2j}lnPAU_{t-j} + \sum_{i=1}^{k}\varphi_{1i}lnPGA_{t-i} + \sum_{j=k+1}^{d\max}\varphi_{2j}lnPGA_{t-j} + \sum_{i=1}^{k}\rho_{1i}lnURB_{t-i} + \sum_{j=k+1}^{d\max}\rho_{2j}lnURB_{t-j} + \varepsilon_{2t} \quad (10)$$

CO_2 emissions cause the consumption of gasoline and diesel if $\lambda_{1i} \neq 0, \forall i = 1,2,\ldots,k$ respectively in Eqs. (7) and (9). Similarly, the consumption of gasoline and diesel causes CO_2 emissions if $\beta_{1i} \neq 0, \forall i = 1,2,\ldots,k$ respectively in Eqs. (8) and (10). There is bidirectional causality between CO_2 emissions and the consumption of gasoline and diesel if $\lambda_{1i} \neq 0$ and $\beta_{1i} \neq 0, \forall i = 1,2,\ldots,k$ in Eqs. (7), (8), (9) and (10) respectively. Finally, there is no causality between CO_2 emissions and the consumption of gasoline and diesel if $\lambda_{1i} = \beta_{1i} = 0, \forall i = 1,2,\ldots,k$ in Eqs. (7), (8), (9) and (10) respectively. The same causal inference can be made with the other models.We could include many more models by making each of the variables (in turn) the subject of their respective equations. Although this is possible, the results are not always interesting, or worse still, they are not interpretable. So we model and test only those equations that are interesting and interpretable.

4. RESULTS

4.1. Stationarity

The results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests contained in Table 1 confirm that CO_2 emissions and diesel consumption are stationary at level I(0). Gasoline consumption, its price, the price of diesel and the number of cars on the road are stationary at level I(1). Finally, urbanisation is stationary either at level I(0) with the ADF test, or at first difference I(1) with the PP test. In general, none of the variables is stationary at second difference I(2), which meets the requirements of the ARDL boundary co-integration test.

4.2. Estimation of the ARDL Model and Robustness Tests

Eqs. (3) and (4) have an optimal delay order of 1 with the SIC criterion as the delay selection criterion. The models selected are therefore ARDL(1,1,1,1,0) for Equation (3) and ARDL(1,1,1,1,1) for Equation (4).

The ARDL(1,1,1,1,0) and ARDL(1,1,1,1,1) have a R^2 of 0.98, indicating a strong relationship between CO_2 emissions and the other exogenous variables in Eqs. (3) and (4). The models used in Eqs. (3) and (4) are confirmed to be valid by the Durbin-Watson (DW) statistic of 2.90 (vs 2.10). According to the Fisher statistic, all of the variables are jointly significant in the chosen models at the 1% level. With regard to the tests used to diagnose the estimated ARDL model, the model is well specified, the errors are not autocorrelated, there is no heteroscedasticity and the errors follow a normal distribution. The null hypothesis is accepted for all these tests (P-value > 5%). Our model is therefore statistically validated (Table 2). In addition to these various tests, the model's graphical stability is tested using the cumulative sum of squares of the recursive residuals (CUSUM squared). In Figure 2, the CUSUM squared visual representation is shown. The rule states that the model parameters are stable and consistent if the plots stay under the 5% critical limit.

4.3. Co-integration Test

The results of the Co-integration test at the bounds contained in Table 3 confirm the existence of a Co-integration relationship between the series studied (the value of F-stat is > that of the upper bound); This makes it possible to estimate the long-term effects of gasoline consumption, its price, the car fleet and urbanisation on CO_2 emissions on the one hand, and to estimate the long-term effects of diesel consumption, the price of diesel, the car fleet and urbanisation on CO_2 emissions on the other.

4.4. Long-term and Short-term Dynamics

Table 4 presents the long-term results of gasoline consumption, its price, the vehicle fleet and urbanisation on CO_2 emissions in Chad**.** A 1% increase in gasoline consumption would lead to a 1.03% increase in CO_2 emissions**.** Additionally, a 1% increase

Figure 2: Plots cumulative sum of squares recursive residuals (a) ARDL(1,1,1,1,0) (b) ARDL(1,1,1,1,1)

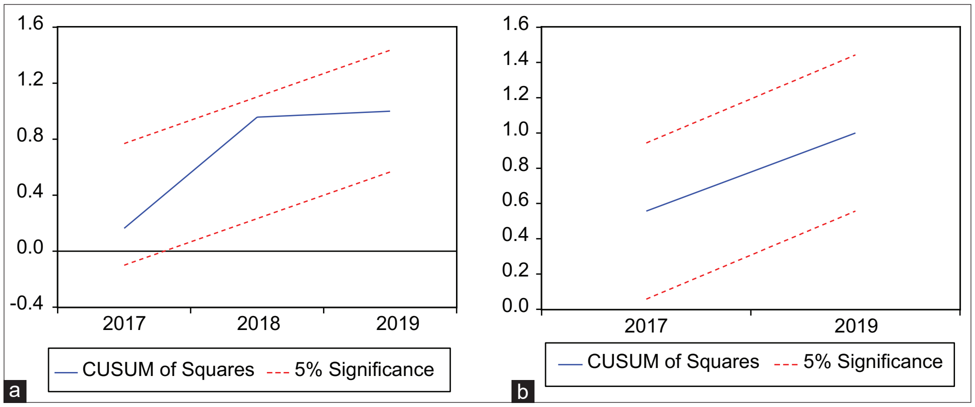


Table 1: Stationarity of variables

Variables	Level		Difference 1 ère		Decision
	ADF	PP	ADF	PP	
ln CO_2	−3.38** (0.03)	−4.50*** (0.00)	–	–	I (0)
ln CSU	1.62 (0.96)	1.40 (0.94)	−1.81** (0.04)	−1.81** (0.04)	I (1)
ln CGA	−3.01** (0.04)	−3.01 (0.04)	–	–	I (0)
ln PSU	−0.42 (0.50)	−0.68 (0.39)	−4.36*** (0.00)	−4.49*** (0.00)	I (1)
ln PGA	−0.94 (0.28)	−0.65 (0.41)	−4.67*** (0.00)	−4.64*** (0.00)	I (1)
ln PAU	−0.76 (0.36)	−1.64 (0.11)	−3.08*** (0.00)	−4.31*** (0.00)	I (1)
ln URB	−3.53** (0.03)	1.79 (0.97)	–	−1.96 (0.04)	I (0) or I (1)

ln CO_2 : CO_2 emissions in logarithm; ln CSU: Gasoline consumption in logarithm; ln CGA: Diesel consumption in logarithm; ln PSU: Gasoline price in logarithm; ln PGA: Diesel price in logarithm; ln PAU: Car fleet in logarithm; ln URB: Urbanisation in logarithm; ***Significance at 1%; **Significance at 5%; (.) : Probability

Table 2: Robustness tests

	ARDL (1,1,1,1,0)		ARDL (1,1,1,1,1)	
	Coefficient	P-value	Coefficient	P-value
R^2	0.99		0.99	
R^2 adjusted	0.98		0.98	
DW-statistic	2.90			
Ramsey Reset test	0.48	0.67	11.05	0.057
Serial correlation	0.78	0.46	2.07	0.49
Heteroskedasticity	0.65	0.44	0.08	0.78
Normality	0.29	0.86	5.46	0.064

Table 3: Co-integration test results

Models	F-statistics	Critical values	
		1%	5%
		I (0) I (1)	I (0) I (1)
F (CO_2/CSU, PSU, PAU, URB)	27.39	3.07 4.44	2.26 3.48
F (CO_2/CSU, PSU, PAU, URB)	31.33	3.07 4.44	2.26 3.48

in the number of automobiles on the road would result in an increase in CO_2 emissions of 0.36%. The price of gasoline and urbanisation remain insignificant. Table 5 presents the long-term results of diesel consumption, the price of diesel, the vehicle fleet and urbanisation on CO_2 emissions in Chad**.** The linear impact of diesel consumption and urbanisation is positive and insignificant. In addition, the linear impact of the price of diesel and the number of vehicles is negative and insignificant.

Table 6 below shows the short-term results of gasoline consumption, gasoline price, car fleet and urbanisation on CO_2 emissions. The error correction term (ECT) is negative and significant, which allows us to say that the error correction model is valid. In fact, gasoline consumption has a negative and insignificant impact on CO_2 emissions. However, a 1% increase in the price of gasoline and in the number of cars on the road would result in an increase in CO_2 emissions of 1.32% and 0.11% respectively.

Table 7 below presents the short-term results of diesel consumption, the price of diesel, the car fleet and urbanisation on CO_2 emissions. ECT is negative and significant, which allows us to say that the error correction model is valid. In fact, diesel consumption has a positive and insignificant effect on CO_2 emissions. A 1% increase in the price of diesel, the number of cars on the road and urbanisation would increase CO_2 emissions by 2.08%, 0.24% and 5.41% respectively.

Table 4: Long-term results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LCSU	1.032130	0.255539	4.039035	0.0273**
LPSU	−0.788356	0.409104	−1.927031	0.1496
LPAU	0.366880	0.123391	−2.973317	0.0589*
LURB	−2.666882	3.881973	−0.686991	0.5414

**Significance at 5%; *Significance at 10%

Table 5: Long-term results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LCGA	1.330279	1.235509	1.076705	0.3942
LPGA	−4.607556	9.953909	−0.462889	0.6889
LPAU	−0.509080	0.568267	−0.895847	0.4649
LURB	11.71130	37.89655	0.309034	0.7865

4.5. Granger Causality Test in the Toda-Yamamoto Sense

Once the long-term and short-term results had been estimated, we carried out a Granger causality test in the Toda-Yamamoto sense. Table 8 presents the results of the Granger causality test in the Toda-Yamamoto sense between the variables of CO_2 emissions, gasoline consumption, gasoline price, car fleet and urbanisation. The results show two bidirectional causalities: a bidirectional causality between gasoline consumption and gasoline price, and a bidirectional causality between CO_2 emissions and gasoline price; and five unidirectional causalities: a unidirectional causality running from gasoline consumption to CO_2 emissions, a unidirectional causality running from CO_2 emissions to the vehicle fleet, a unidirectional causality running from CO_2 emissions to urbanisation, a unidirectional causality running from gasoline consumption to the vehicle fleet and a unidirectional causality running from urbanisation to the vehicle fleet. Table 9 presents the same results, but only for CO_2 emissions, diesel consumption, diesel price, vehicle fleet and urbanisation. It shows three bidirectional causalities: a bidirectional causality between CO_2 emissions and diesel consumption, a bidirectional causality between CO_2 emissions and the price of diesel, a bidirectional causality between the price of diesel and urbanisation; and six unidirectional causalities: a unidirectional causality running from the vehicle fleet to CO_2 emissions, a unidirectional causality running from CO_2 emissions to urbanisation, a unidirectional causality running from diesel consumption to urbanisation, a unidirectional causality running from diesel consumption to the price of diesel, a unidirectional causality running from the vehicle fleet to diesel consumption and finally, a unidirectional causality running from the vehicle fleet to urbanisation.

Table 6: Short-term results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (LCSU)	−0.044877	0.035809	−1.253213	0.2989
D (LPSU)	1.326800	0.071525	18.55006	0.0003***
D (LPAU)	0.116668	0.026959	4.327613	0.0227**
ECT	−0.530343	0.029668	17.87600	0.0004***

***Significance at 1%; **Significance at 5%

Table 7: Short-term results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D (LCGA)	0.102556	0.037594	2.727982	0.1122
D (LPGA)	2.083778	0.082962	25.11736	0.0016***
D (LPAU)	0.245617	0.028566	8.598376	0.0133**
D (LURB)	5.415729	0.556560	9.730721	0.0104**
ECT	−0.196371	0.009057	21.68079	0.0021

***Significance at 1%; **Significance at 5%

Table 8: Results of the Toda-Yamamoto causality test

Dependent variables	Explanatory variables					Decisions
	ln CO_2	ln CSU	ln PSU	ln PAU	ln URB	
ln CO_2		5.71***	9.89***	0.75	0.22	CSU→CO_2 PSU→CO_2
ln CSU	0.02		28.30***	0.63	0.02	PSU→CSU
ln PSU	11.44***	3.63*		2.09	0.00	CO_2→PSU CSU→PSU
ln PAU	3.16*	5.14**	0.22		6.07**	CO_2→PAU, CSU→PAU URB→PAU
ln URB	12.48***	2.11	10.75***	0.04		CO_2→URB PSU→URB

(.) : Probability (P-value); ***Significance at 1%; **Significance at 5%; *Significance at 10%.
The symbol→represents unidirectional causality

Table 9: Toda-Yamamoto causality results

Dependent variables	Explanatory variables					Decisions
	ln CO_2	ln CGA	ln PGA	ln PAU	ln URB	
ln CO_2		6.17***	8.72***	3.21*	0.09	CGA→CO_2 PGA→CO_2 PAU→CO_2
ln CGA	21.90***		1.75	9.03***	1.20	CO_2→CGA PAU→CGA
ln PGA	45.82***	9.45***		1.89	13.45***	CO_2→PGA CGA→PGA URB→PGA
ln PAU	2.26	2.48	0.34		0.93	
ln URB	21.45***	3.05*	13.22***	5.15**		CO_2→URB CGA→URB PGA→URB PAU→URB

(.) : Probability (P-value); ***Significance at 1%; **Significance at 5%; *Significance at 10%.
The symbol→represents unidirectional causality

5. DISCUSSION OF RESULTS AND POLICY IMPLICATIONS

5.1. Discussions

An increase in gasoline consumption would lead to an increase in CO_2 emissions in the long term (Uzair Ali et al., 2022; Umar et al., 2021). Moreover, there is a unidirectional causality from gasoline consumption to CO_2 emissions$_2$ (Arora and Kaur, 2020). That said, the consumption of gasoline could boost CO_2 emissions in Chad, or the more gasoline is consumed, the more CO_2 emissions increase in the long term. The question of reducing CO_2 emissions would therefore become crucial. Chad could therefore seek to reduce its CO_2 emissions by consuming less gasoline and turning more to alternative energies. This is in line with the work of Nnaji et al. (2013). Fossil fuel consumption can be reduced by implementing new energy efficiency measures and improving existing ones, all of which will save energy in the long term (Umar et al., 2021) or the introduction of policies to reduce fuel consumption by petrol-powered vehicles would be useful for considerably reducing CO_2 emissions$_2$ (Solís and Sheinbaum, 2013). It can also be achieved by controlling the rapid growth of modes of transport without high-quality fuel (Danish et al., 2018). We can refer here to the frelated fuels widely used in Chad when we know that fossil fuels power the vast majority of road vehicles in Chad. It should be noted that the long-term consumption of diesel does not seem to affect CO_2 emissions. This situation can be explained by the price of premium petrol, which was generally lower than that of diesel over the study period. The population of Chad would prefer to consume gasoline over diesel, which is more expensive. As a result, the higher consumption of gasoline diesel could lead to an increase in CO_2 emissions. The causality between CO_2 emissions and diesel consumption shows that there is a bidirectional causality between CO_2 emissions and diesel consumption. (Mensah et al., 2019; Chandran and Tang, 2013). In fact, fossil fuel consumption and CO_2 emissions are interdependent, i.e. CO_2 emissions cause diesel consumption (Gokmenoglu and Sadeghieh, 2019) and diesel consumption causes CO_2 emissions$_2$ (Khobai and Le Roux, 2017; Kivyiro and Arminen, 2014). Clearly, higher diesel consumption would lead to higher CO_2 emissions and vice versa. This result would make it possible to set up tools to control diesel consumption in the transport sector in Chad and to use these tools as a solution for reducing CO_2 emissions. (Mensah et al., 2019; Chandran and Tang, 2013). However, Chad can use the vehicle fleet and price as tools to control fossil fuel consumption. In fact, the causality results show that, on the one hand, there is a unidirectional causality from the vehicle fleet to diesel consumption and, on the other hand, a bidirectional relationship between gasoline fuel consumption and the price of gasoline fuel. It should be noted that Chad has significant renewable energy potential. From the north to the south of the country, the sun shines from 2,750 to 3,250 h a year. This gives an average of 4 to 6 kw/h per square metre per day (Mbainaissem Peurdoum, n.d.).

The price of gasoline and diesel is significant in the short term at the 1% threshold. In other words, an increase in the price of gasoline and diesel would lead to an increase in emissions in the short term (Malik et al., 2020). In other words, in the short term, the prices of gasoline and diesel accelerate CO_2 emissions. The more PP prices rise in the short term, the more CO_2 emissions will increase. Controlling and regulating these prices, combined with a reduction in the use of fossil fuels, could make the negative effects on the environment reversible. (Sadorsky, 2009). This could involve, for example, modifying national PP prices in line with changes in international prices to bring about a change in consumer behaviour (Mahmood et al., 2022). This scenario could reduce CO_2 emissions in the short term. Moreover, the work of Li et al. (2020) show that prices could play a very important role in reducing CO_2 emissions. This trend is totally called into question in the long term, where the price of gasoline and diesel remain insignificant. This suggests that, in the long term, CO_2 emissions are not influenced by any increase in the price of gasoline and diesel, and that Chad should be looking at other causes of CO_2 emissions. This result can be based on the implications of causality, which stipulate that the consumption of PP (gasoline and diesel) and urbanisation influence prices. In other words, if PP (gasoline and diesel) prices do not influence CO_2 emissions in the long term, the reason could be the level of PP consumption and the level of urbanisation.

The car fleet is significant in the short term in equations (3) and (4). A 1% increase in the number of cars on the road would lead to a 0.11% increase in CO_2 emissions for equation (3) and a 0.24% increase in CO_2 emissions for equation (4). These results show that whatever the petroleum product used (gasoline or diesel), the level of the vehicle fleet would lead to an increase in CO_2 emissions in the short term. A similar situation is observed in the long term where, in equation (3), a 1% increase in the number of cars on the road would increase CO_2 emissions by 0.36%. However, in equation (4), the car fleet has no significant impact on CO_2 emissions. These long-term results show that the fleet of cars using gasoline diesel would increase CO_2 emissions in the long term, while the fleet of cars using diesel remains insignificant in the long term, even though the causality results show that the fleet of cars using diesel influences CO_2 emissions. Moreover, in China, the work of Gambhir et al. (2015) show that growth in road transport has led to a considerable increase in CO_2 emissions over the last few decades. These findings are supported by those of Fontaras et al. (2017) who state that factors such as vehicle configuration and traffic conditions have a major influence on CO_2 emissions. It is clear that a policy aimed at reducing CO_2 emissions through an adequate vehicle fleet must be put in place as a matter of urgency.

Finally, urbanisation has no significant impact on CO_2 emissions in the short and long term in equation (3). This result is similar to the work of Danish et al. (2018) in Pakistan. On the other hand, the causality results of the same model show us that CO_2 emissions influence urbanisation. This means that particular attention should be paid to the speed of CO_2 emissions so that urbanisation does not necessarily contribute to its increase, as reported in the literature. For equation (4), urbanisation is also insignificant for CO_2 emissions in the long term, and significant in the short term. Thus, in the short term, a 1% increase in urbanisation would lead to a 5.41% increase in CO_2 emissions. This being the case, the more the population grows, the more CO_2 emissions increase. But in the long term, this population growth is insignificant. This result is certainly due to the influence of the vehicle fleet and diesel consumption observed in the related causality results. Three quarters of Chad's territory is desert (CDN, 2021). Moreover, with a population of around 16.6 million in 2019, the country has a population density of around 12.9 inhabitants per square kilometre, despite a population growth rate of around 3% in 2019 (WATHI, 2021). The country also has a rural population of around 78% and an urban population of almost 21.9%, concentrated mainly in the city of N'Djamena (WATHI, 2021). From the above, it is clear that population growth in Chad cannot have a significant impact on CO_2 emissions.

5.2. Implications for Policy

In order to meet the requirements for reducing CO_2 emissions as set out in this study, the following recommendations are made to the Chadian government:

i). Cleaning up the consumption of PP, reducing CO_2 emissions and consistently developing the use of clean energy sources such as hydroelectricity, wind and solar power are just some of the measures that should be adopted to reduce the amount of carbon emitted.
ii). The best way to significantly reduce CO_2 emissions in cities could be to impose a carbon tax on activities that consume a lot of PP. The money raised by this tax should then be used to promote the use of greener energies in these cities.
iii). Putting in place an effective policy would make it easy for industrial and residential consumers to install renewable energy sources such as solar power and others within their premises. This policy should be developed in consultation with leading financial institutions. In any case, it would reduce the amount of fossil fuels purchased by the government.
iv). When oil prices are rising, it would be a good idea to inject the revenue from the sale of oil into cleaner technologies and production processes. This would help to control the environmental consequences of rising oil prices. These environmentally-friendly technologies and production processes also need to be well understood at the time of the agreements between the beneficiary country and the host country, so that the conditions for implementation can be properly defined.
v). To urgently reduce the number of cars in its area that threaten environmental sustainability. The ageing fleet, which is in the majority, could be converted into a new fleet that complies with environmental regulations.
vi). Promote a green public transport programme in towns and cities to reduce dependence on private vehicles and engines, which run mainly on diesel and gasoline diesel in Chad. The promotion of fuel-efficient or hybrid vehicles could also be investigated.

6. CONCLUSION

The primary objective of this study is to analyse the linear impact of PP consumption (gasoline and diesel), PP prices (gasoline and diesel), the vehicle fleet and urbanisation on CO_2 emissions. The secondary objective is to determine the causal links between the various sub-study variables in Chad over the period from 2008 to 2019. To achieve this objective, we performed the Dickey-Fuller augmented and Phillips-Perron stationarity tests; the Co-integration test of Pesaran et al. (2001) enabled us to confirm the long-term relationships of the different variables. We went on to analyse the short- and long-term dynamics of PP consumption, PP prices, the car fleet and urbanisation on CO_2 emissions, and the existing causality between CO_2 emissions, PP consumption, prices, the car fleet and urbanisation. Granger causality in the Toda-Yamamoto sense is used to determine and analyse the various influences between the different variables.

Our results show that, in the short term, only the price of diesel and the number of cars on the road have a significant impact on CO_2 emissions in Equation (3) and that the price of diesel, the number of cars on the road and urbanisation have a significant impact on CO_2 emissions in Equation (4). In the long term, gasoline fuel consumption and the car fleet have a significant impact on CO_2 emissions, while the price of gasoline fuel and urbanisation are insignificant in Equation (3) and in Equation (4), no variable has a significant impact on CO_2 emissions. The Granger causality test in the Toda-Yamamoto sense revealed a variety of causalities. In Equation (3), the causality results indicate that there is bidirectional causality between the consumption of gasoline and the price of gasoline and bidirectional causality between CO_2 emissions and the price of gasoline. Also, there are five unidirectional causalities, namely a unidirectional causality from gasoline consumption to CO_2 emissions, a unidirectional causality from CO_2 emissions to the car fleet, a unidirectional causality from CO_2 emissions to urbanisation, a unidirectional causality from gasoline consumption to the car fleet and a unidirectional causality from urbanisation to the car fleet. In Equation (4), the causality results show that there are three bidirectional causalities, namely a bidirectional causality between CO_2 emissions and diesel consumption, a bidirectional causality between CO_2 emissions and the price of diesel, and a bidirectional causality between the price of diesel and urbanisation.

There are also six unidirectional causalities, including a unidirectional causality between the vehicle fleet and CO_2 emissions, a unidirectional causality between CO_2 emissions and urbanisation, and a unidirectional causality between diesel consumption and urbanisation, unidirectional causality from diesel consumption to the price of diesel, unidirectional causality from the vehicle fleet to diesel consumption and, finally, unidirectional causality from the vehicle fleet to urbanisation. In Chad, CO_2 emissions have been increasing year on year, and are dominated by diesel and gasoline gas emitted by the land transport sector. The road transport sector in Chad is growing rapidly, and its vehicles, many of which are obsolete, are the biggest emitters of greenhouse gases. The country has been experiencing high consumption of these two PPs (diesel and gasoline) for over a decade, and air pollution through CO_2 emissions is constantly increasing.

However, this study has a number of limitations. It relied primarily on the consumption of gasoline and diesel fuel in the road transport sector to understand the dynamics of CO_2 emissions in Chad. Future work could take into account other existing petroleum products that are used in other known transport sectors in order to understand all the assets involved in CO_2 emissions. Finally, this study examined symmetrical relationships and linear causality between the selected variables. Further studies could investigate the asymmetric relationships and non-linear causal links of the variables used in this study.

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