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An Analysis of the Driving Factors Related to Energy Consumption in the Road Transport Sector of the City of Douala, Cameroon

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Abstract: The city of Douala in Cameroon is facing great challenges in terms of its demographic growth, economic development and urbanization, especially in relation to environmental and economic factors. However, there has been significant growth in its road transport sector, which has led to an excessive demand for the consumption of fossil fuels and an increase in greenhouse gas emissions in recent decades within this sector. However, no concrete policy has yet been put in place to improve the energy efficiency of the transport sector. This work aims to identify the driving factors and determine their contributions to the variation in energy consumption. In this study, a decomposition analysis via the Logarithmic Mean Divisia Index (LMDI) method is used for the period of 2010–2019 to quantify the respective effects of the driving factors on the variation in energy consumption. Based on the study of the literature, we classified four main driving factors in the road transport sector that contributes to the total variation in energy consumption, such as vehicle energy intensity, vehicle intensity, gross domestic product (GDP) by capita, and population scale, with each contributing 13.06%, 31.30%, 12.85%, and 42.76%, respectively. In particular, we note that the energy intensity coefficient of the vehicles from 2013 to 2016 and that of the intensity of the vehicles coefficient from 2010 to 2011 and 2012 to 2013 are the two factors that have, nevertheless, led to a slight decrease in the variation in energy consumption. This implies that an improvement in these two factors would contribute to enhancing the energy efficiency of the road transport sector of the city of Douala. It will therefore be necessary to put in place several energy-saving strategies that would lead to a rationalization of energy consumption in order to reduce greenhouse gas emissions by road transports. Policymakers should take this study into account to achieve a balance between energy consumption and economic growth to better integrate the notion of sustainable road transport.

Keywords: decomposition analysis; driving factors; energy consumption; LMDI method; road transport

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1. Introduction

The transport sector is a system that involves high energy consumption [1]. It plays a major and a very important role in the economic activity of a country [2]. Improved resource accessibility, employment growth, market reach, and mobility behavior are all influenced by the transport sector [2–4]. However, the structure and volume of the transport system can greatly vary depending on the socio-economic development of the country. These variations are associated with increased energy consumption and negative environmental impacts, such as greenhouse gas emissions and toxic air pollutants that affect the climate and also the health of populations [1–3,5].

The road transport sector of the city of Douala provides transportation services for both people and goods. For services that transport people, four main forms of passenger transport coexist: taxis, motorcycle taxis, buses, and minibuses. Since the early 2000s, we have seen a robust growth in the number of motorcycle taxis flooding the city. According to a study conducted by the Sustainable Urban Mobility Plan (SUMP) of Douala, motorcycle taxis are the largest means of transportation for people in Douala, with an estimated two million trips per day in 2018 [6]. Although there is a mass transit system, its performance is not optimal to meet the growing demand for mobility. The transportation of goods is provided by trucks. The lack of structuring in this sector is noted, as demonstrated by the work of Bissai et al. [7], who analyzed the sustainable energy metrics in road transport within the city of Douala. The main results of this work showed that the energy intensity of road transport constantly increased (9.93 to 15.9 toe/M€) between 2010 and 2019, thus reflecting the energy-intensive nature of the road sector; in addition, the energy efficiency of motorization varied between 20 and 22% during the period 2010–2019. This implies that there is a great potential for improving the energy efficiency of the road sector in Douala. The need to reduce greenhouse gas emissions for sustainable development constitutes considerations on a planetary scale [8].

An observation is obvious from the overall reading of the situation regarding road transport in the city of Douala: the significant increase in its fleet of vehicles at least in the last two decades. The rise in motorcycle taxis for the transportation of people, fossil fuel industrialization and the phenomenon of rural exodus have all added significant weight from an economic point of view in the EMCCA zone (Economic and Monetary Community of Central African States). All these specific observations in the city of Douala make this city a focal point in our study. Although each city has its specificity, it is necessary to become aware of the global challenges in sustainable city design, which requires balancing the economic, social, and environmental points of view to meet the expectations of sustainable development.

For our study, we analyzed the impacts of the energy intensity of vehicles, the GDP per capita, and the population of the city of Douala, which is the economic heart of Cameroon. We chose four main driving factors for three reasons:

- The growth in road transportation activity leads to an increase in the number of vehicles and energy consumption, more specifically fossil fuels (resulting in negative externalities on the environment). It is therefore necessary to design sustainable transportation planning that can reduce energy consumption and reduce greenhouse gas emissions and thus save energy. This implies a comprehensive understanding of the fleet of vehicles in circulation, for which it is important to analyze two aspects: First, the aspect of "vehicle energy intensity", to analyze the performance of the vehicle fleet and to rationalize energy consumption. The second aspect refers to "vehicle intensity" in order to analyze the structure of the transport system;
- The development of countries and cities around the world is due to technological advances and growth of industries which ultimately lead to economic advancement. In such an environment, we observe the flow of urban mobility. Hence, it is important to highlight the "economic growth" aspect in order to analyze its contribution to the variation in energy consumption;
- The growing demand for urban mobility has a strong correlation with the evolution of population and urbanization. This implies knowledge of the "population effect" in terms of its contribution to the variation in energy consumption. After these three remarks were noted, followed by a review of the literature, we chose four driving factors behind the increase in energy consumption involved in road transport.

We therefore base our work on two main questions: How can we plan a sustainable transport system based on an analysis of the determining factors of energy consumption? What is the contribution of analyzing a breakdown of energy based on the knowledge of the determining factors behind road transport energy consumption? We established two hypotheses in our study:

Research hypothesis 1: The analysis of the driving factors of the energy consumption of road transport can be a preliminary element for energy-saving planning;

Research hypothesis 2: The design of sustainable energy transport presupposes a good mastery of the rational management of energy consumption.

Our work has two specific objectives: to illustrate a set of analytical methodologies for understanding the concept of sustainable transport and to describe some suggestions for improving energy efficiency in the road transport sector.

This article contributes to the process of implementing an energy efficiency policy with an aim to achieve a balance between energy consumption and economic growth in the road transport sector in a global context. The challenge is to reduce greenhouse gas emissions by reducing energy intensity. It is important and necessary to analyze the energy consumption of a system beforehand. We are therefore interested in this theme to provide some elements of reform within a framework of the implementation of a sustainable energy road transport policy in the city of Douala.

In Cameroon, the transport sector accounts for a very large share of energy consumption, with petroleum products being the main source. Foreign trade statistics reveal a net increase in imports of petroleum products from 1.026 million tonnes in 2018 to 1.62 million tonnes in 2020, an increase of around 59%, thus reflecting significant growth in energy consumption of petroleum products in the transport sector [9]. Road transport plays the most important role in the movement of people and goods, meeting about 90% of the domestic demand for passenger transport and almost 75% of the demand for goods transport and monopolizing more than 85% of national transport demand [10].

In many reviews, it has been mentioned that the use of fuels in the transport sector increases dramatically with economic activity, population growth, rapid industrialization, and even urban spatial configuration [1,3,11,12]. This phenomenon is observable in the major cities of the country, in particular that of Douala, and also in the EMCCA zone (Economic and Monetary Community of Central African States), given its highest economic and demographic weight. However, the industrial development of the big cities in Cameroon along with the phenomenon of rural exodus places the city of Douala at the center of the major challenges of sustainable development. Eco-development and the reduction in greenhouse gas emissions are major challenges for the city. The transport sector, which consumes a lot of fuel and is responsible for the harmful effects on the environment, requires great attention.

The choice of the road transport sector is explained by its strong involvement in the economic and environmental dimensions of sustainable development. Petroleum products such as gasoline and diesel are the main fuels utilized in the road transport sector. To to better analyze our study goals, recognizing a set of determining factors is one of the main steps in order to identify the different causes responsible for the growth of energy consumption in road transport. This will allow us to recommend appropriate solutions to improve energy efficiency and make transport sustainable.

Many factors can be presented, such as the types of fuels used by the vehicles, the weight of the vehicles, the age of the vehicles, the speed of the vehicle, the distances traveled, the traffic conditions and the modal mix [13]. As part of our study, we highlight the economic, technological, and demographic factors. The objective of our study is to make a diagnosis of the impact of these factors on the energy consumption of road transport in the city of Douala during the period 2010–2019.

The determination of the impacts of these factors during the period of study could allow us to recommend an energy-saving policy in the transport sector. In our study, we conduct a decomposition analysis of the energy consumption of the road transport sector in the city of Douala, the economic capital of Cameroon, through the LMDI method to discuss the impacts of the various factors. Reducing polluting emissions from road transport is a major focus for the development of sustainable transport around the world. The notion of sustainable transport refers to a transport system that meets the current needs without compromising the ability of future generations to meet theirs [14]. The implementation of a comprehensive energy policy aimed at developing strategies to improve the energy efficiency of the transport sector and at carrying out surveys on the main driving factors causing variations in energy consumption is the main pathway to achieving sustainable transport [15,16].

The rest of this paper is structured as follows: Section 2 provides a brief overview of the literature review of the works on the main factors affecting the transport sector. Section 3 presents a brief description of the energy consumption of road transport in the city of Douala. Section 4 presents the data, the main factors influencing the energy consumption of road transport, and the methodology of the decomposition analysis through the LMDI method. Section 5 presents the empirical results and discusses them by proposing some policy options aimed at rationalizing the energy consumption of road transport. Section 6 concludes the paper.

2. Literature Review

Energy consumption in the transport sector and its emissions of polluting gases are frequently discussed in the literature [17]. The rapid increase in motorization caused by a lack of transport policy planning threatens energy security and the state of the environment, and leads to rapid traffic congestion [18]. The relationship between economic activity, transport activity, and energy in the transport sector is one of the important relationships that requires effective diagnostic analysis for an understanding of energy use in the road sector transportation [19]. Indeed, for an estimation of energy consumption in the transport sector, the evaluation using top-down and bottom-up approaches of factors such as economic, demographic, technological, and urban is necessary.

Many studies concerning the identification of the determinants of energy consumption in the transport sector have been carried out previously using the method of decomposition analysis. For sustainable transport planning, the need to study the determinants of energy consumption in the transport sector is highlighted in most studies. In order to study the energy consumption of transport, majority of works have used the decomposition method which is very popular and effective in the analysis of the factors influencing the energy consumption of transport [20]. The LMDI method is the most used in works beyond the transport system.

Su et al. [21] used the LMDI method to analyze the factors influencing electricity demand in Beijing. The results of their work showed that the consumption of electric power would increase if the economy and urbanization in Beijing continued to develop, and it advocated that an optimization of the structure of the industry, the improvement in the efficient use of electrical energy, and the adoption of clean energy can reduce Beijing's electrical energy consumption. Jiang et al. [22] used the LMDI decomposition analysis to estimate carbon emissions from the road passenger and freight transportation sectors in the United States from 2008 to 2017. The results of their work concluded that energy intensity and passenger transport intensity are key to reducing emissions from road passenger transport, and changing the structure of transport causes emissions to shift between different modes of passenger transport. Tippichai [23] uses the decomposition method to analyze energy consumption in Thailand from 1990 to 2020. The results of his study showed that the value added by economic sectors is the important factor in the demand for additional energy, while energy intensity is the most important factor for the reduction in consumption of energy. Wang et al. [24] conducted a decomposition analysis of CO_2 emissions in northeast China, highlighting investment factors. The results of their work indicate that investment-related factors have a significant impact on carbon emissions. In their work, Huang et al. [25] conducted a research on the characteristics of energy-related CO_2 emissions, the decoupling relationship, and the decomposition of the LMDI factor in Qinghai. The results of their work concluded that the structural effect of energy consumption was the main factor limiting carbon emissions, followed by the energy intensity effect, while economic growth and population size were the important factors facilitating increased carbon emissions.

Akyürek [26] conducted an LMDI decomposition analysis of the energy consumption in the Turkish manufacturing industry for the period 2005–2014. The results of his work show that the effects of intensity and activity have the same evolutionary pace. He finds that the energy intensity of the manufacturing industry followed a slightly decreasing trajectory (0.288 ktoe/USD in 2005 and 0.219 ktoe/USD in 2014) during the period, thus reflecting the contribution of changes in activity, energy efficient technologies, and other energy efficiency efforts. Kim [27] conducted an LMDI decomposition analysis of energy consumption in Korea's manufacturing sector.

The results of his work showed that energy consumption due to the intensity effect in the petroleum and chemical industries has increased and suggests that, to combat climate change in this sector, it will be important to carry out industrial restructuring and industry-specific energy saving policies.

Yang et al. [28] analyzes the driving forces of China's CO_2 emissions from energy consumption using the Kaya–LMDI methods; according to the results of their work, economic activity is the largest driving force promoting carbon emissions, while on the contrary, energy intensity is the biggest suppressor. They recommend that optimizing the industrial structure, improving the structure of energy and import–export trade, and intensifying the development of clean energy can effectively limit the growth of carbon emissions. Zhu et al. [29] researched the drivers of carbon emission of the road transport industry in six Asia-Pacific countries from 1990 to 2016 using the LMDI decomposition method. The results of their work showed that the effect of economic production and the effect of population size have positive influences on the carbon emissions of the road transport industry, and the effect of production economic remains the most important determining factor. The energy intensity effect and the transport intensity effect have different influences on the carbon emission of the road transport industry for these six Asia-Pacific countries. Moreover, they mention that the effect of the carbon emission coefficient has a relatively weak influence.

Li et al. [30] analyzed the relationship between development and CO_2 emissions in the transport sector of China. They extended their work to 30 provinces and used the LMDI method to explore the effect of several factors on the state of decoupling. The results of their work showed that underdeveloped provinces were more likely to have a low state of decoupling than developed and coastal provinces and that income level was the main influential factor limiting the development of decoupling in the sector of transport. Population scale had a very small negative role in the development of decoupling. In addition, the effects of CO_2 emissions efficiency, transportation intensity, and industry structure varied across the provinces. Fang et al. [31] analyzed the energy consumption of transport in three major regions of China. They used the Logarithmic Mean Divisia Index (LMDI) technique to identify the nature of the factors affecting the evolution of transport energy consumption. The results of their work showed that the GDP effect and the transport structure effect promote the increase in energy consumption in different regions and subsequently the energy intensity effect exerts an inhibiting effect in the central and eastern regions, while favoring an increase in energy consumption in the western region. The effect of the share of passenger and freight transport on energy consumption is not significant. The increase in energy consumption due to economic development and transport structure effects will continue for some time.

The work of Olanrewaju [32] analyzes energy consumption in the South African industry using the LMDI approach. The results of his studies have shown that saving techniques and industrial policies have had no impact on the country's industrial energy and established that to achieve energy savings, it is important to implement well-formulated policies, if not carried out yet. On the other hand, if the formulated policies are implemented, then there is a need to revise the existing policies. Wang et al. [33] conducted a decomposition analysis of carbon emission factors related to energy consumption in the Guangdong province from 1990 to 2014. The results of their work showed that the impacts and influences of various factors on carbon emissions are different with different stages of development and they add that the effect of economic growth and the effect of population size are the two most important driving factors of the increase in greenhouse gas emissions. The energy intensity effect played a dominant role in reducing carbon emissions. The energy structure effect and the technical progress effect had different but relatively minor effects on carbon emissions during the five different stages of development. In their work, Liang et al. [34] analyze the factors affecting the increase in CO_2 emissions from the transportation sector in China using an LMDI decomposition analysis. The results of their work showed that economic development explains most of the increase in CO_2 emissions from the transport sector, while energy efficiency explains most of the suppression of the CO_2 emissions. They also show that the pull effects of the consumption of natural gas, electricity, and other clean energies on the increase in CO_2 emissions compensate for the inhibiting effects of traditional fossil fuels. Transport development plays an obvious role in promoting CO_2 emissions, while the effects of population size are relatively smaller compared to those of transport development.

Achour et al. [35] use the LMDI method to decompose the influencing factors of energy consumption in the transport sector in Tunisia. The results of their studies indicate that the overall effect of economic output, transport intensity, population scale, and transport structure on energy consumption is positive, while the effect of overall energy intensity is negative. Jiang [36] used the decomposition method to identify the factors driving the evolution of transport energy consumption. In this work, they showed that the impact of transport activity is the most important significant factor that contributes to a growth in energy consumption and energy intensity has a dominant major role in reducing energy consumption. Zhang et al. [37] highlighted the decoupling index with the LMDI decomposition method to analyze the contribution of factors that influence energy-related CO_2 emissions in China over the period 1996–2010. The results of their research showed that economic growth is the main major driver of the increase in carbon emissions in recent decades; on the other hand, the reduction in energy intensity and the cleaning of the structure of final energy consumption have had a significant impact on reducing carbon emissions.

Qipeng et al. [38] used the decomposition methodology of the LMDI method to identify the main drivers of regional transport energy consumption in China. Their results showed that the impacts of the effects of scale and technique weaken, while, on the other hand, the effect of structure increase on energy consumption. The method of decomposition analysis, as we can see, is widely used in energy studies. We have presented a body of work that has referred to this analysis technique. However, there are several decomposition analysis models which will be presented in Section 4 of the document devoted to the methodology.

3. Energy Consumption of Road Transport in the City of Douala

The transport activity of the city of Douala is essentially that of road transport and depends exclusively on petroleum products (gasoline and diesel). The annual statistical data for energy consumption (gasoline and diesel) expressed in ktoe (kilo ton oil equivalent) as well as the growth rate expressed as a percentage (%) over the period 2010–2019 are presented in Table 1. Figure 1a presents the annual evolution of total energy consumption and the growth rate. During this period, the consumption of fossil fuels by road transport increased considerably from 66.108 Ktoe in 2010 to 180.336 Ktoe in 2019, with an average annual growth rate of 11.58%.

Table 1. Annual evolution of gasoline, diesel consumption and growth rate of road transport in Douala, 2010–2019.

Years	Fuel Type	Fuel Consumption (Ktoe)	Annual Growth Rate (%)
2010	Gasoline	40.123	7.77
	Diesel	25.985	
2011	Gasoline	52.104	15.91
	Diesel	24.528	

Table 1. *Cont.*

Years	Fuel Type	Fuel Consumption (Ktoe)	Annual Growth Rate (%)
2012	Gasoline	72.723	28.38
	Diesel	25.659	
2013	Gasoline	85.437	15.73
	Diesel	28.425	
2014	Gasoline	85.835	2.19
	Diesel	30.523	
2015	Gasoline	93.174	9.83
	Diesel	34.622	
2016	Gasoline	99.813	7.14
	Diesel	37.115	
2017	Gasoline	107.234	7.1
	Diesel	39.421	
2018	Gasoline	117.905	9.34
	Diesel	42.459	
2019	Gasoline	135.104	12.45
	Diesel	45.232	

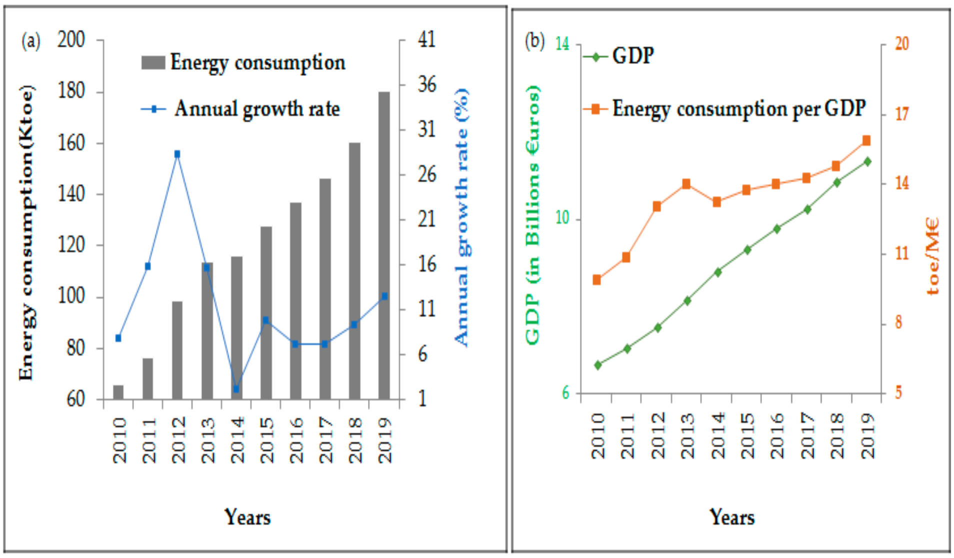


Figure 1. (**a**) Evolution of energy consumption and annual growth rate, and (**b**) GDP and energy consumption per GDP.

Energy consumption of the road transport sector is strongly associated with several factors, such as economic activity, population growth, road vehicle fleet, road network, motorization, fuel costs and market planning transportation. Energy efficiency of the road transport system leads to reduced energy consumption, reduced greenhouse gas emissions, financial savings and energy security. The energy intensity of fuel consumption in the city of Douala generally increases with GDP over the study period. Figure 1b shows the evolution of GDP expressed in billions euros and energy consumption per GDP expressed in tonnes of oil equivalent per million euros (toe/MEUR). During the study period, there is a general increase in the energy intensity of energy consumption; this can be explained by a critical situation in the rational management of energy consumption in road transport, reflecting an energy-intensive road sector. A production system whose energy intensity is constantly increasing requires a rigorous analysis of the management of energy consumption in order to define and determine the main causes of this increase in energy intensity [39–42].

4. Data and Methodology

4.1. Source of Data

In this work, we used several sets of statistical data from many establishments for the period 2010 to 2019. These data were obtained from the Ministry of Transport (MINTRANS), the Ministry of Water and Energy, the Cameroon Petroleum Depot Company (CPDC), and the National Institute of Statistics (NIS). In order to better analyze our study aims, we used integrated data on population, road fuel consumption expressed in ktoe, and gross domestic product expressed in euro.

4.2. Data

In this section, we present and discuss potential factors that have an impact on the variation in road transport energy consumption.

4.2.1. The Energy Intensity of Vehicles

The energy efficiency of vehicles is linked to the energy consumption of road transport. Figure 2a shows a general increase in vehicle energy intensity between 2010 and 2019. This may reflect that the growth of road vehicles has led to a significant increase in traffic fuel consumption, as shown in Figure 1b, illustrating the evolution of the energy intensity of fuel consumption. However, the evolution of the energy intensity of vehicles in Figure 2a shows a slight decrease from 2013 to 2016. This can be explained by a number of taxes imposed on the road transport sector, increasing fuel prices and some observed fuel shortages.

4.2.2. Vehicle Intensity

Fuel consumption related to road transport depends on the use of road vehicles. Figure 2b shows us the evolution of the intensity of road vehicles in the city of Douala and we observe an increasing trend from 2010 to 2019. This tells us that the demand for road vehicles per unit of GDP has grown. The increase in vehicle intensity reflects the fact that the economic growth of the city of Douala required a large number of road vehicles during the study period. Indeed, the high intensity of vehicles can be correlated with the increase in fuel consumption. Table 2 shows a robust growth in automobile flow in the city of Douala, with an average annual growth rate of 9.5%. The rapid growth in car fleet is explained by a sharp increase in taxis and motorcycle taxis, both modes occupying a very important place in the mobility of goods and people; in addition to this, the purchase of private vehicles for non-profit services is also another important factor.

Table 2. Size and distribution of the road vehicle fleet.

Road Vehicles Fleet	Years		Average Annual Growth Rate (%)
	2010	2019	
Cars	9702	18,892	8.41
Motorcycles	20,800	52,000	10.87
Bus	500	810	4.23
Trucks	770	1075	4.49
Total vehicles	31,772	72,777	9.5

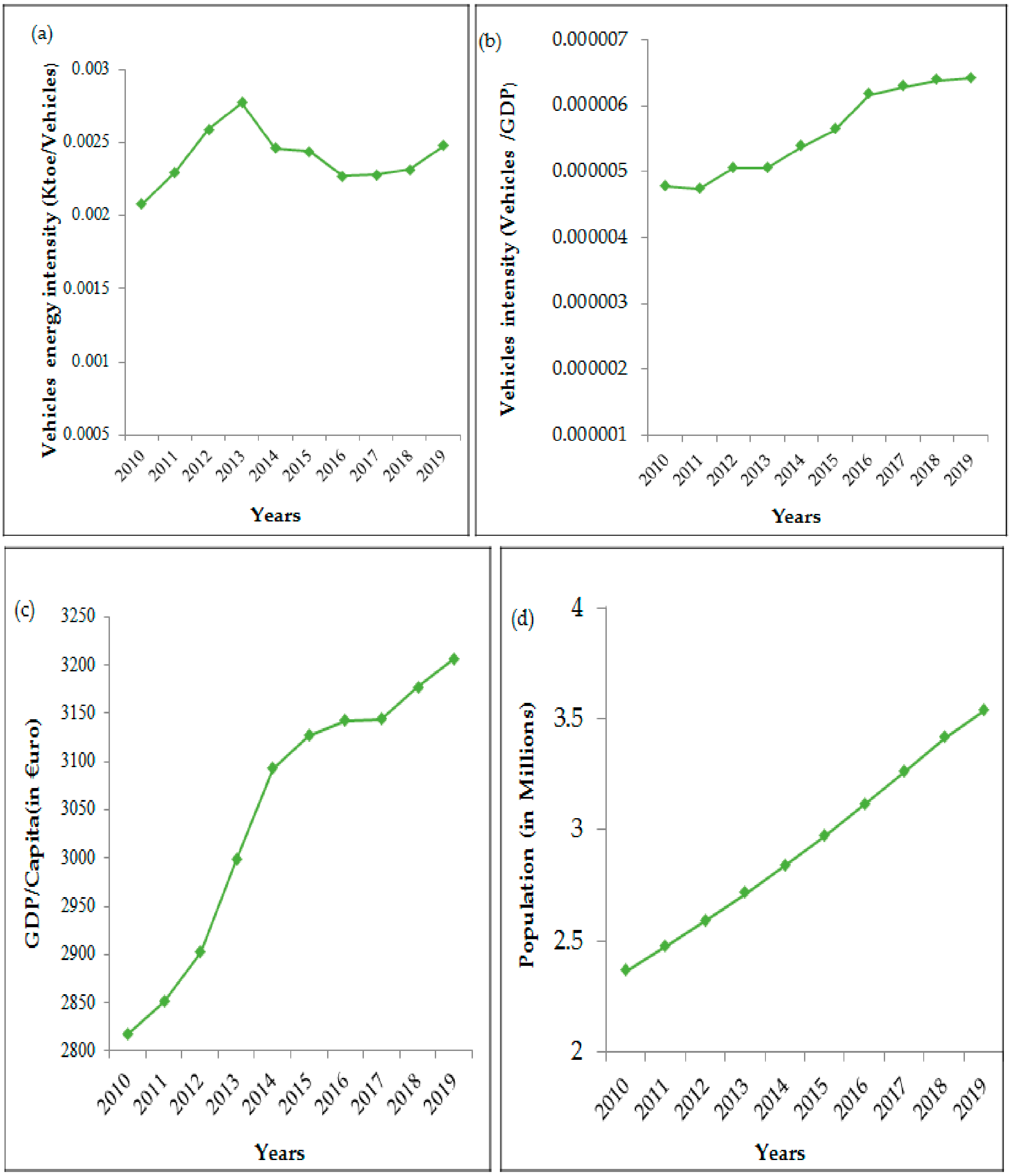


Figure 2. Evolution of driving factors of energy consumption in the road transport sector in Douala: (**a**) vehicle energy intensity, (**b**) vehicle intensity, (**c**) GDP per capita, and (**d**) population.

4.2.3. Economic Growth and Motorization

The gross domestic product of the city of Douala experienced a steady growth from 2010 to 2019, with an annual growth rate of 5.85%. Transport energy consumption is strongly linked to economic growth. From 2010 to 2019, both energy consumption and GDP per capita has increased significantly. This generally results in an increasing demand for urban mobility directly due to the growth of economic activity and the improvement in the standard of living. Economic growth is correlated with an increase in motorization. Figure 2c shows the evolution of GDP per capita. This growth in GDP per capita and in the motorization rate can be explained by an increase in purchasing power and industrial development.

4.2.4. Population Growth and Urbanization

The population of the city of Douala increased during the study period. Demographic change correlates with increasing urbanization. Urban density has increased at an average annual growth rate of 4.5%. Figure 2d presents the increase in population of the city of Douala throughout the study period.

4.3. Methodology

The objective of the LMDI method is to break down a quantity [43]. Many decomposition analysis methods have been developed to decompose and determine the contribution of each impacting element to the variation in energy consumption [44]. However, the methods of Laspeyres, Divisia, and the refined techniques of Laspeyres do not allow to highlight and decompose the important factor, called residual, which is the sum of all the interactions of the main effects of the system to be analyzed, thus leading to large errors estimation [13]. In the Arithmetic Mean Divisia Index (AMDI) method, although logarithmic expressions can decompose the residual, this causes calculation problems when values of zero appear in the data set of the study (the case where the denominator is zero). On the other hand, the Logarithmic Mean Divisia Index (LMDI) method highlights the additive and multiplicative decomposition by replacing the arithmetic average weight through the logarithmic function which makes it possible to fully decompose the residual [43]. In this study, we opted for the LMDI method because it allowed us to calculate the different coefficients of the effects of each determining factor with more precision, unlike other methods which are not suitable for performing this calculation.

This method is widely used for sustainable transport studies. In our study, we have included data on population, economic growth per capita (GDP_t), vehicle intensity (VI_t), vehicle energy intensity (VIF_t), and road transport energy (RTE_t) in order to define the main determinants of fuel consumption. To determine the contribution of the main factors influencing the variation in road transport energy consumption, we present a methodology for decomposing road transport energy.

Thus, the energy consumption of road transport for a year *t* (can be translated by the expression $RTE_t)$ [43] is as follows:

$$RTE_t = \sum\nolimits_{it} RTE_{it} \tag{1}$$

where *i* and *t* represent the type of fuel (diesel and gasoline) and the reference year, respectively.

Expression (1) can be written in the following way:

$$RTE = \frac{RTE}{RV} \times \frac{RV}{GDP} \times \frac{GDP}{POP} \times POP \tag{2}$$

The Relation (2) can also be translated using the following:

$$RTE = VFI \times VI \times GDP \times POP \tag{3}$$

in this relationship,

- *VFI* represents the energy intensity of vehicles, defined as the energy demand per vehicle;
- *VI* is the intensity of vehicles translating the demand for vehicles for a unit of *GDP;*
- *GDP* represents the economic growth per inhabitant and makes it possible to better understand the evolution of the motorization rate, and to assess the impact on the use of vehicles and energy consumption;
- *POP* represents the population of the city of Douala, which helps to understand the impact of population growth on energy consumption.

Indeed, the evolution of these different factors reflects their direct and indirect impacts on the evolution of energy consumption [13,36,45,46]. The evolution of energy consumption in the road transport sector (ΔRTE_t) during two periods can be attributed to different indicators, which are as follows:

- The change in the energy intensity of vehicles (VFI_t), with effect coefficient (VFI_{eff});
- The variation in the intensity of vehicles (VI_t), with effect coefficient (VI_{eff});
- Change in economic activity (GDP_t), with effect coefficient (GDP_{eff});
- Population change (POP_t), with effect coefficient (POP_{eff})

After having defined the different variations, the expression of the variation in the energy consumption of the road transport sector can be expressed by the following relation:

$$\Delta RTE_t = RTE(T) - RTE(0) = VFI_{eff} + VI_{eff} + GDP_{eff} + POP_{eff} \tag{4}$$

In general, the effects can be calculated according to the pattern of expression of VI_{eff} :

$$VFI_{eff} = [RTE(T) - RTE(0)]ln[VFI(T)/VFI(0)]/ln[RTE(T)/RTE \tag{5}$$

5. Results and Discussion

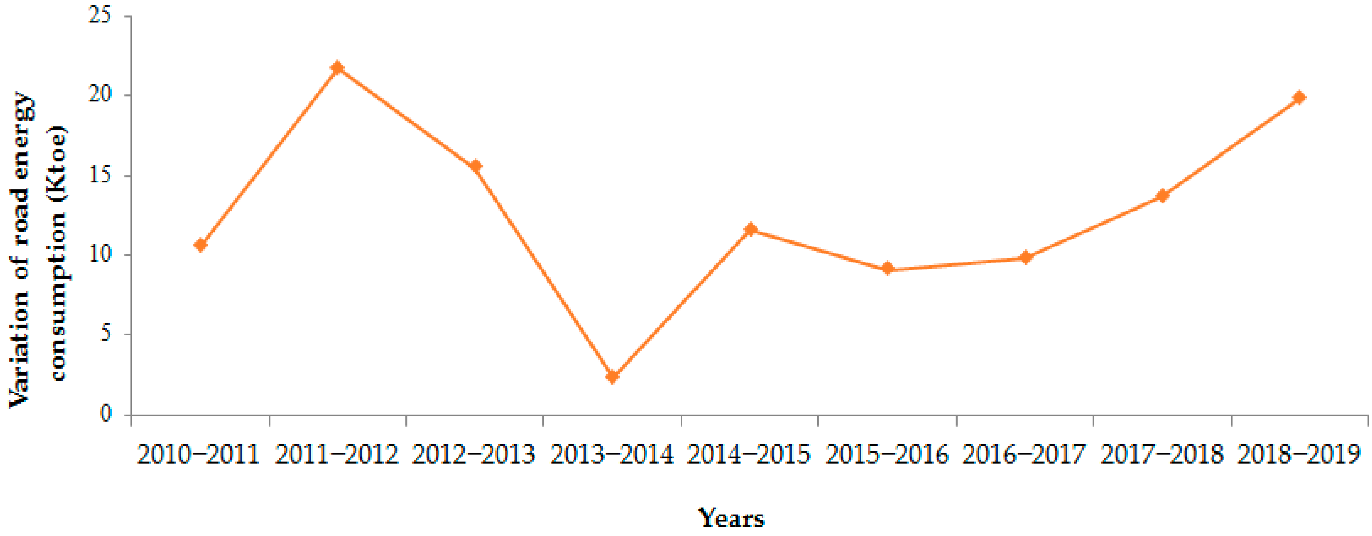
The methodological approach used in the previous section highlights a set of major factors that influence the energy consumption of the road transport sector in the city of Douala. The data collected and processed were limited to the years of 2010 to 2019. The activity of the road transport sector is linked to energy consumption. In this section, we present the contributions of the determinants of energy consumption. The results of our study are presented in Table 3. The variation in energy consumption is positive, with a value of 114.087 Ktoe. Figure 3 shows the trend of this variation and the effect coefficients of the driving factors. The effects of the energy intensity of vehicles and that of the intensity of vehicles coefficients on the total variation in energy consumption have been both positive and negative. The impact of the economic production and population coefficients is positive.

Table 3. Results of energy consumption linked to road transport in Douala.

Year	ΔRTE_t	VIF_{eff}	VI_{eff}	GDP_{eff}	POP_{eff}
2010–2011	10.543	7.067	−0.644	0.848	3.272
2011–2012	21.722	10.415	5.728	1.554	4.025
2012–2013	15.485	7.31	−0.147	3.446	4.877
2013–2014	2.346	−13.816	7.325	3.572	5.265
2014–2015	11.557	−1.045	5.644	1.336	5.622
2015–2016	9.087	−9.612	12.015	0.641	6.087
2016–2017	9.797	0.623	2.526	0.064	6.539
2017–2018	13.696	2.537	2.494	1.628	7.036
2018–2019	19.854	11,431	0.771	1.58	6.072
2010–2019	114.087	14.91	35.712	14.669	48.795

5.1. Effect of Vehicle Energy Intensity

Figure 3b shows the contribution of the energy intensity of the vehicles and the variation in energy consumption coefficients. The vehicle energy intensity coefficient represents 14.91 Ktoe or 13.06% of the total variation in energy consumption. This coefficient is positive, except for the period 2013–2016, where it is negative. In particular, we see that the energy intensity of vehicles coefficient has the same shape as the variation in energy consumption. We can therefore deduce that the variation in energy consumption is strongly linked to the energy intensity of vehicles. The energy intensity of vehicles is one of the main contributors to the increase in the variation in the energy consumption of road transport. From the negative values obtained, we can deduce that a reduction in the energy intensity of vehicles will lead to a reduction in energy consumption and therefore an improvement in the energy efficiency of road transport.



(a)

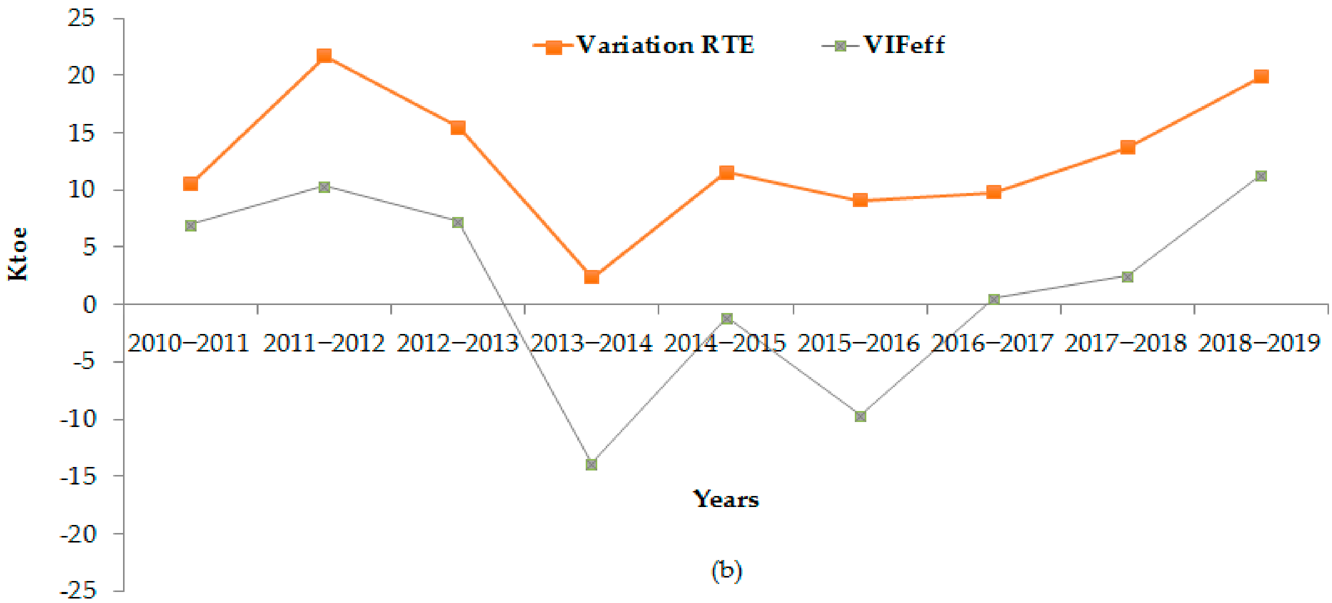
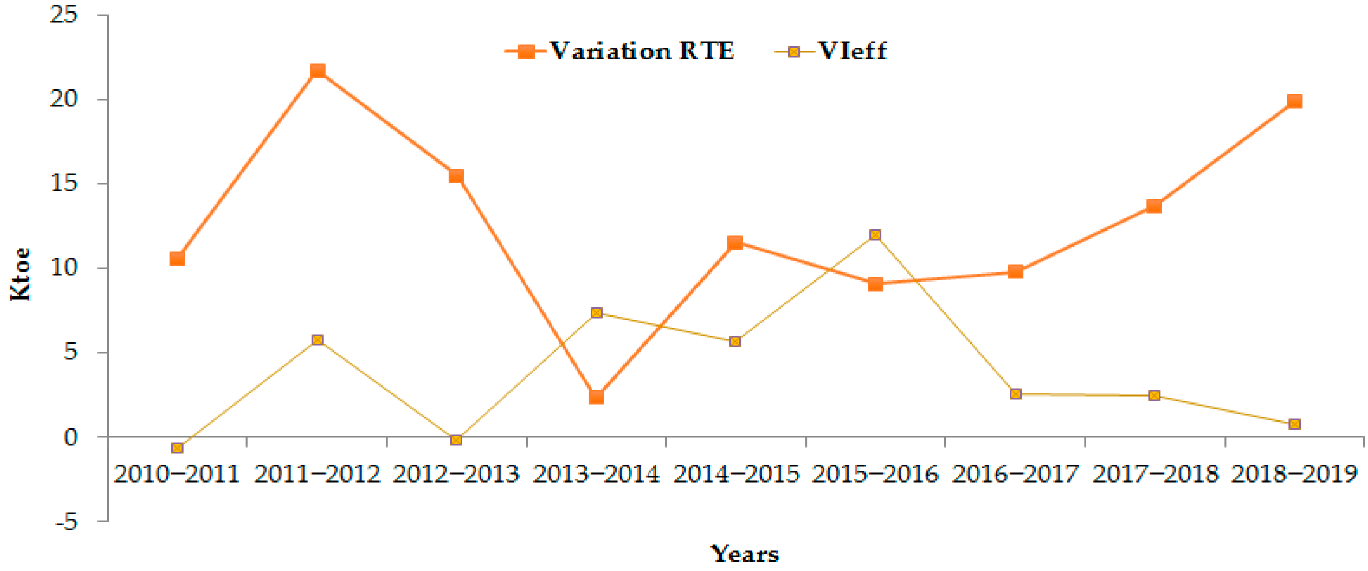
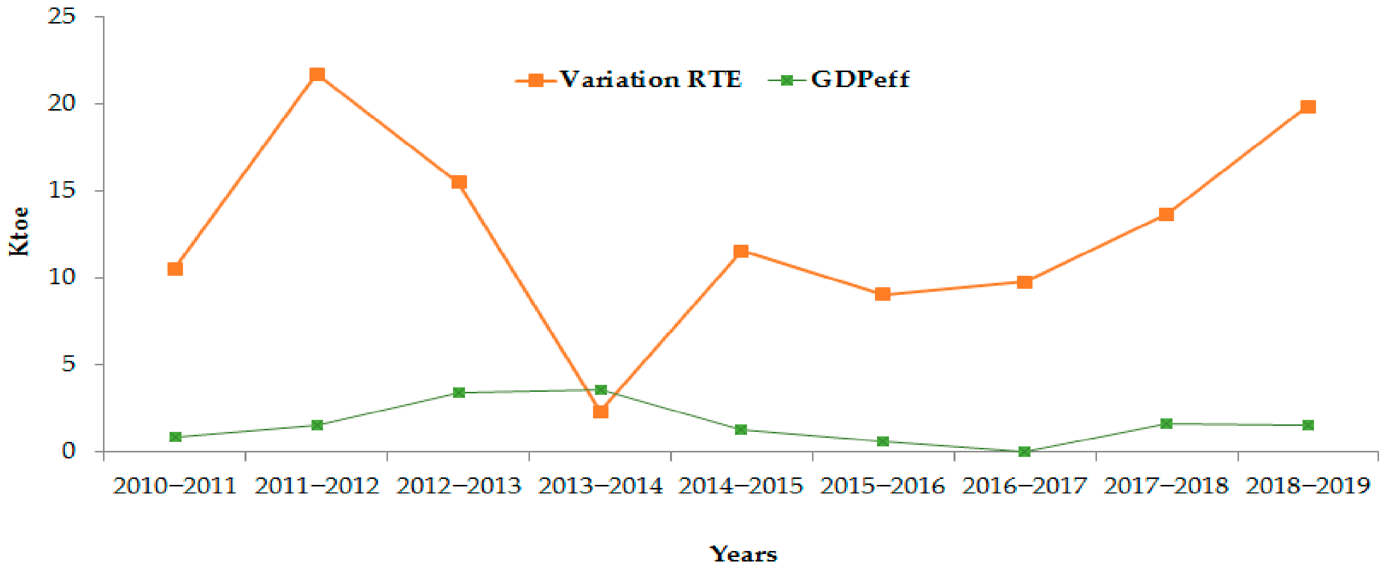


Figure 3. *Cont.*

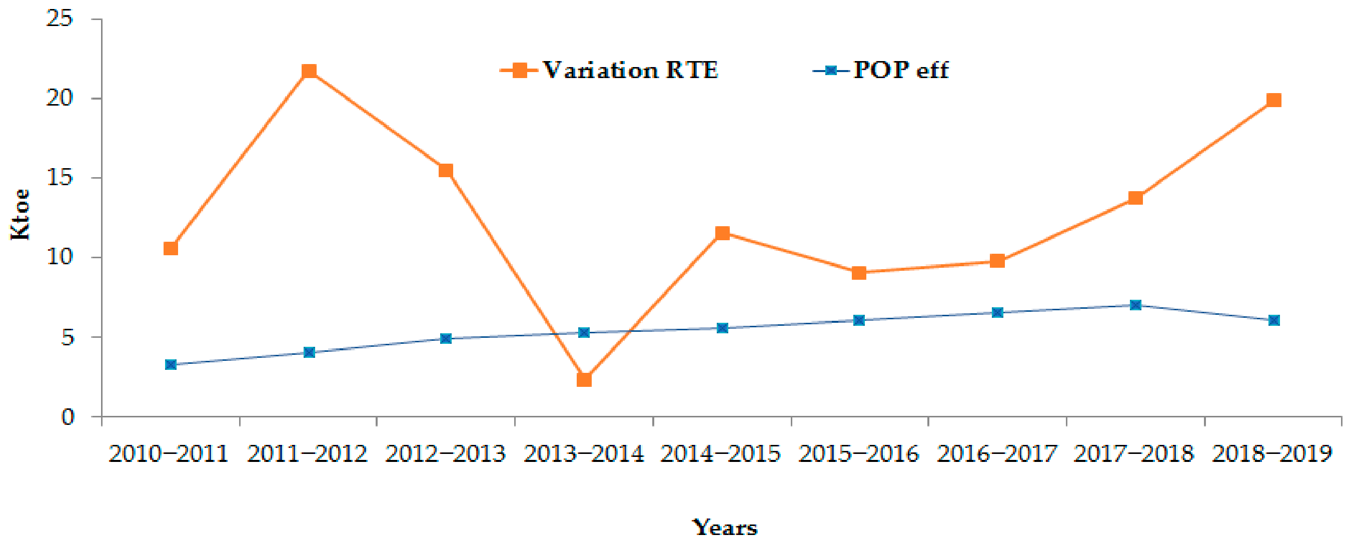


(c)



(d)

Figure 3. *Cont.*



(e)

Figure 3. The variation in energy consumption and the effect coefficients of driving factors in the road transport sector in Douala: (**a**) variation in road energy consumption, (**b**) energy intensity effect coefficient of vehicles, (**c**) vehicle intensity effect coefficient, (**d**) GDP effect coefficient and (**e**) population scale effect coefficient.

5.2. Vehicle Intensity Effect

Figure 3c shows the contribution of the vehicle intensity coefficient. It represents 35.712 Ktoe or 31.30% of the total variation in energy consumption. This coefficient is mostly positive and is negative over two short periods, 2010–2011 and 2012–2013. The positive values obtained from the vehicle intensity coefficient during the study period inform us that it has considerably contributed to the increase in the energy consumption of road transport. This is explained by a significant increase in the use of road vehicles in the city of Douala, in particular that of passenger transport, mostly taxis and motorcycle taxis. As for the negative values obtained, this may explain why a reduction in energy demand requires good structuring of road transport in the city of Douala, in particular by promoting public transport and improving road infrastructure.

5.3. Effect of Economic Growth

Figure 3d shows the impact of the GDP per capita coefficient. This coefficient is positive throughout the study period and represents 14.669 ktoe or 12.85% of the total variation in energy consumption. Over the period of 2015–2018, we can see that this coefficient has the same shape as the variation in energy consumption and can therefore be considered as a major factor contributing to the variation in the energy consumption of road transport. However, between the period of 2011 and 2014, there is an increase in the effect of the GDP per capita coefficient which led to a decrease in energy consumption. On the other hand, the opposite phenomenon occurred during the period between 2014 and 2015, where a decrease in the effect of the GDP per capita coefficient led to an increase in energy consumption. It can therefore be deduced that the effect of GDP per capita is a determining factor in the variation in energy consumption. This was highlighted in Section 2 of our study cited above, in particular by an increase in the rate of motorization, a strong demand for urban mobility and an improvement in living conditions.

5.4. Demographic Effect

Figure 3e presents the contributions of the population and total variation in energy consumption coefficients. The results show that population plays a major role in increasing the energy consumption of the transport sector, representing 48.795 Ktoe or 42.76% of the total variation in energy consumption. This reflects the strong impact of population on energy consumption. This can be explained by the fact that urbanization generally increases with population growth. This means that the increase in population leads to a pressing demand for mobility and therefore more energy consumption.

In our study, we calculated the general contribution of each factor to the total variation in energy consumption of road transport in the city of Douala between 2010 and 2019. At the end of our study, we can conclude that the contributions of energy intensity of the vehicles and the intensity of the vehicles coefficients on the total variation in energy consumption is mostly positive and for certain periods, it is negative. The main cause of this observed change can be explained by the fact that the economic context of Douala is characterized by an instability of the hydrocarbons sector and the increase in the prices of hydrocarbons can influence the different variations observed in these coefficients. The effect of population and GDP per capita on the total change in energy consumption is positive. Thus, the population coefficient with a contribution of 42.76% on the total variation in energy consumption is the main driving factor, followed by the intensity of vehicles with a contribution of 31.30%, the intensity energy of vehicles with a contribution of 13.06% and finally economic production with a contribution of 12.85%.

The results obtained constitute a decision-making tool for the public authorities in the context of the city of Douala where it will be necessary to carry out a planning model aimed at reducing the energy intensity of vehicles and the intensity of vehicles, which could contribute to a reduction in greenhouse gas emissions. These results also provide an opportunity for public authorities to better control the fuel demand.

6. Conclusions

In this study, we examined the energy consumption of road transport and determined the respective contributions of the main factors influencing the total variation in energy consumption in the city of Douala during the period 2010–2019. We used the LMDI decomposition method. This study concludes that the effects of the energy intensity of vehicles and intensity of vehicles coefficients are negative over certain periods. It can thus be deduced that improving the energy intensity of vehicles and the intensity of vehicles can have a major impact on the reduction in energy consumption. As a result, the condition of vehicles in circulation and the structuring of road transport are two driving forces requiring optimization for a good rationalization of energy consumption. In order to control the increase in the energy consumption of road transport, the energy efficiency of road transport must be improved. According to Zhang et al. [37], technological progress is a more effective way to increase the efficiency of energy consumption. Moreover, for Yang et al. [28], technological development and applications of renewable energies can also contribute to energy efficiency.

Mo et al. [47], in a study of the environmental sustainability of road transport in OECD countries (Organization for Economic Co-operation and Development), establish that technological progress and tightening of regulations on economic consumption and vehicle emissions have improved the overall managerial availability performance of these countries from 2000 to 2014. Improving road infrastructure is important because it will reduce the problem of road congestion which is a significant element in the phenomenon of fuel overconsumption. According to the work of Wang et al. [48], the quality of the transport infrastructure is an important indicator that must be taken into account while planning a sustainable transport policy, thereby establishing the fact that a sustainable policy has a direct impact on transport infrastructure. Energy efficiency exerts an indirect influence on industrial agglomeration. Energy efficiency is one of the energy planning tools [49].

Based on the results of our study, in order to reduce CO_2 emissions from road transport in Cameroon, several measures can be highlighted:

- Consider regulatory restrictions for the importation of vehicles;
- Monitor the impact of economic developments on the environment;

- Reduce energy intensity by promoting the conversion of road transport to rail and water transport;
- Check the quality of the fuel in circulation;
- Control the emission standards of vehicles in circulation;
- Promote public transport by limiting the growth of private vehicles which will lead to a reduction in the intensity of vehicles;
- Urban planning and transport.

This study lays the foundation for a conception of energy sustainability in the transport sector where controlling the increase in energy consumption is important in order to achieve energy saving. Policymakers need to take this study into account to develop sustainable transport planning. We can conduct a long-term forecast study on the energy consumption and emissions of road transport vehicles in the city of Douala in order to analyze the different scenarios that could allow us to better control energy consumption to achieve sustainable transport planning.

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