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Analysis of Sustainable Energy Metrics in Douala's Road Transportation Sector, Cameroon

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ABSTRACT: In this study, Douala, Cameroon was used as a case study to analyze the characteristics of sustainable energy for road transport from 2010 to 2019. Douala, being the national capital and entry point to Central Africa, served as a major hub for the movement of people and goods. However, the road transport sector was plagued by a number of problems, including traffic congestion, the use of fossil fuels, air pollution, and global warming associated with road traffic. The objective of this work was to evaluate a set of indicators that would allow monitoring the evolution of trends in the interactions between the energy component and sustainable development. The DPSIR (Driving Force, Pressure, State, Impact, and Response) model was used to select a set of indicators. According to the results, the energy intensity of the fuel used for transport decreased from 9.93 to 15.9 toe/M€. This increase in energy intensity reflected the energy-intensive nature of the road industry. Additionally, from 2010 to 2019, the energy efficiency of road transport vehicles in the city of Douala fluctuated between 20 and 22%. This indicates a significant potential for improving energy efficiency. Therefore, decision-makers need to implement sustainable transport planning to address these issues.

KEYWORDS: Sustainable energy indicator; sustainable development; energy; energy system; sustainable energy road transport

1. Introduction

The phenomenon of urban mobility, which was translated into the movement of people and products by means of transport (road, sea, air, rail) in the stated space, posed a challenge for the growth of cities throughout the world [1]. The city of Douala, the capital and largest metropolis of Cameroon, served as a key hub for mixing movements across the Economic and Monetary Community of Central African States (CEMAC) sub-region due to its physical situation, which also revolved around the problems of air pollution and road transport. The main objective of our study was to examine the indicators of sustainable use of road transport energy in the city of Douala. According to the International Energy Agency (IEA), the transport sector was one of the major sectors of energy consumption and one of the main causes of environmental degradation [2]. The city of Douala experienced a growing demand for mobility, and several causes could be explained, particularly by urbanization associated with the increase in activities. We could also add to this the problem of the demographic explosion experienced by the city of Douala and the phenomenon of rural exodus. By integrating the environmental and social issues associated with it, particularly through energy difficulties, it clearly appeared that the development of road transport was at the heart of both the main tensions and the major challenges of urban development, which therefore implied putting road infrastructure in the face of climate change [3]. It would be necessary to combine an approach with sustainable energy indicators to measure and monitor significant progress in order to deal with these difficulties and carry out an evaluation of projects with futuristic energy sustainability [4]. The construction of relevant indicators was necessary for the development, identification, and monitoring of sustainable energy policies in the road transport sector. Given the level of complexity of this industry, the variety of actors involved, and the lack of a culture of monitoring and evaluating the performance of energy policies in this sector, the concept of sustainable energy indicator was currently a crucial approach for the definition and monitoring of any energy-sustainable road transport policy [5]. Numerous studies had demonstrated the importance and essential value of the indicator tool for putting the idea of sustainable development into practice. In order to highlight their effects on the environmental, economic, and social issues associated with the movement of people and products within the metropolitan area, the works [6, 7] proposed a long-term simulation model of urban mobility from a sustainable development perspective.

Recent research on the concept of indicators emerged from the measurement of human development, well-being, and the idea of sustainable development with all its excesses [8, 9]. With the exception of some research that had contributed to the practice of indicators in disaggregated or sectoral terms that led to a more global vision, the notion of the indicator had long been a component of sustainability in its global aspect. The definition of sustainable energy indicators had also been the subject of further research [10–13]. The work of [11] was based on measuring the sustainability of regional transport in China to have a design of the structure of an energy system. [12] defined a set of sustainable energy indicators to quantify a model, [13], on the other hand, explored an analytical model for developing sustainable energy indicators that were measured against a condition that was specified in light of the circumstances. An indicator was a variable datum that was highlighted to characterize a phenomenon [14]. It had been observed that this term could mean many different things depending on how the many works were evaluated, including "measuring instrument," "statistical measure," "variable," "parameter," "proxy," and "index." In this study, the term "indicator" referred to a sustainability policy [15, 16]. The Sustainable Energy Development Indicator was introduced by the International Atomic Energy Agency (IAEA) in 1999. These parameters were highlighted to assess energy policies for macro-energy systems and technological processes for macro-energy systems, as well as micro-energetics. However, there has not been much development in objective research on the cross-sector indicator strategy. In their research, [17] developed energy indicators for the road transport sector, emphasizing the notions of "energy sustainability" and "transport sustainability," which served as analytical foundations for the implementation of public energy-saving strategies [17]. In order to lay the foundations for approaching the idea of sustainable energy road transport, a review of sustainable energy indicators is necessary.

2. Materials and Methods

2.1. Study zone.

Douala, the capital and largest city of Cameroon, is located at 4.0°N, 9.7°E, on the southeast side of the Wouri estuary, in the middle of the Gulf of Guinea. Like most cities where economic activity is on the rise, Douala has experienced a considerable increase in its population. The population of the city of Douala was 1,931,977 people (11.1% of the population of Cameroon) in 2005, 2,409,459 people (12.0%) in 2011, 3,527,243 people (14.2%) in 2020, and is projected to reach 5,965,650 people (17.6%) in 2035, according to the Preliminary Study on the Local Economy of the City of Douala presented in Figure 1 [18]. This growth rate has translated into a population increase of 1.8 in 2020 compared to 2005 and a projected increase of 3.1 in 2035. Douala serves as an important regional port and plays a significant role in trade within the CEMAC zone. It is also one of the main areas of industrial concentration in Central Africa and serves as the hub of the logistics network. According to the National Institute of Statistics (NIS), the GDP per capita in Douala is estimated to be 1.6 million CFA francs, which is nearly 2.8 times the GDP per capita of Cameroon [18]. A survey conducted by the Groupement inter-patronal du Cameroun (IGCAM) revealed that 55% of transport companies in the country are based in Douala, clearly demonstrating the importance of road transport for the city's economic growth. The population of Douala has been growing at an accelerated rate over the past ten years, increasing from 2,361,000 to 3,536,000 people with an average annual population growth rate of 4.6% between 2010 and 2019, as illustrated in Figure 1.

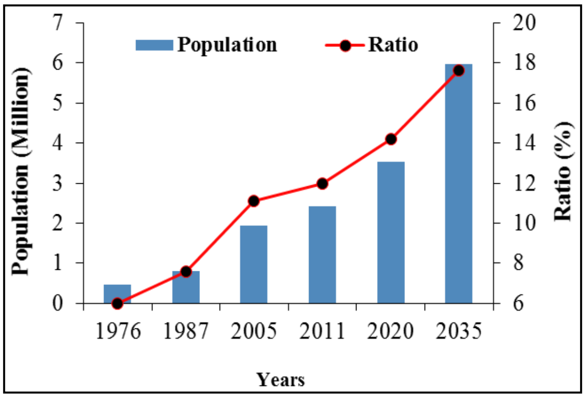

Figure1. Population of the city of Douala and ratio to the population of Cameroon.

2.2. Data source.

The following data was researched using a collection of files from several relevant institutions:

- Energy statistics from the Ministry of Water and Energy were used to calculate the annual road fuel consumption by GDP indicator. It is expressed as one tonne of oil equivalent per million euros (toe/M€).
- Data on the contribution value of the road transport industry per inhabitant are provided by the Ministry of Transport in euros (€) and are the subject of numerous annual publications.
- Statistics published by the World Bank and the Energy Department of the Ministry of Water and Energy provide information on emissions from the road transport sector. Emissions from the road transport sector are indicated in tonnes of CO_2.

- The annual reports drawn up by the Ministry of Transport provide statistics on the road vehicle fleet. The register of registered vehicles is used for their calculation, distinguishing passenger cars, buses and coaches, special vehicles, trucks, vans, trailers, and semi-trailers from each other and from other types of vehicles. These statistics are included in the Ministry of Transport's annual reports.
- Internal Ministry of Transport databases, statistical yearbooks, and annual reports provided the information needed to calculate the length of the road network. Road infrastructure is measured in kilometers (Km).

Cameroon's energy statistics, represented in kilo tons of oil equivalent (Ktoe) [19], were used to calculate the annual fuel consumption by the various machines used in the activities of the road transport sector in the city of Douala, as presented in Table 1. Fuel consumption and demographic change are closely linked. Road transport plays a key role in the economic operations of the city, given its significant impact on trade with nations in the CEMAC sub-region. The transport industry, especially the road sector, is continuously expanding with the growth of the population, similar to other economic activities. Table 2 shows that the Gross Domestic Product (GDP) is growing, and the city's economy is progressing despite the many challenges related to industrial growth. This has a positive effect on the overall economy of the nation, representing an average of 32% of the national GDP between 2010 and 2019 [18].

Table 1. Annual evolution of road transport fuel consumption.

Years	Fuel type	Fuel consumption	
		ktoe	PJ
2010	Gasoline	40.123	1.67
	Diesel	25.985	1.08
2011	Gasoline	52.104	2.18
	Diesel	24.528	1.02
2012	Gasoline	72.723	3.04
	Diesel	25.659	1.07
2013	Gasoline	85.437	3.57
	Diesel	28.425	1.19
2014	Gasoline	85.835	3.59
	Diesel	30.523	1.28
2015	Gasoline	93.174	3.9
	Diesel	34.622	1.45
2016	Gasoline	99.813	4.17
	Diesel	37.115	1.56
2017	Gasoline	107.234	4.48
	Diesel	39.421	1.66
2018	Gasoline	117.905	4.93
	Diesel	42.459	1.78
2019	Gasoline	135.104	5.65
	Diesel	45.232	1.9

Table 2. GDP of the city of Douala from 2010 to 2019.

Years	GDP in Million Euros (M€)
2010	6,652.16
2011	7,048.32
2012	7,514.88
2013	8,129.28
2014	8,778.56
2015	9,294.4
2016	9,779.52
2017	10,246.08
2018	10,841.6
2019	11,340.48

2.3. The concept of energy sustainability.

Energy was a necessary component for socio-economic progress and a higher standard of living. Different energy production and consumption systems might not have been sustainable in the long term in an ever-changing world. The reflections focused on numerous research studies that highlighted methods for evaluating the sustainable energy indicators of various industrial systems, aiming to measure sustainability [20]. The interrelationships between the aspects of energy system sustainability were illustrated in Figure 2.

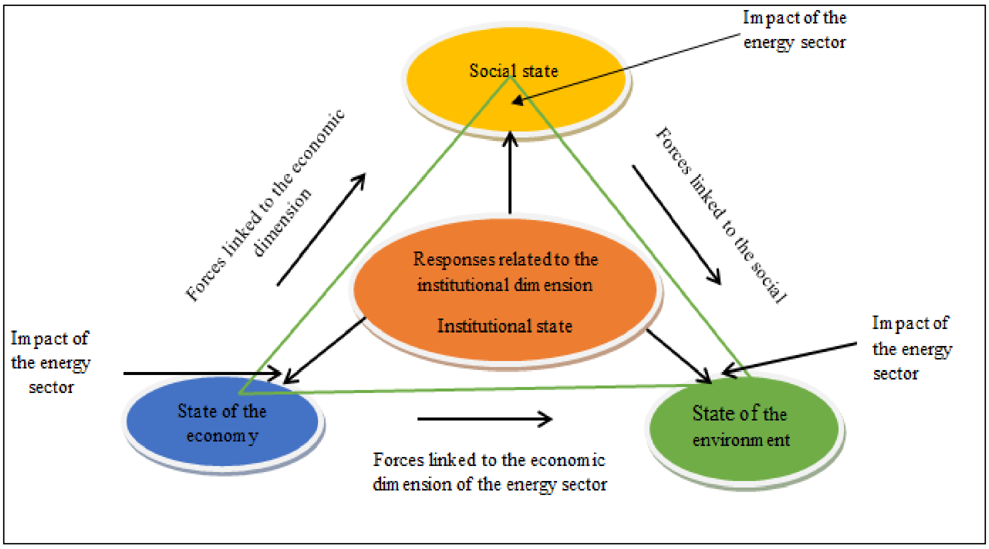

Figure 2. Interrelationships between the sustainability dimensions of the energy system [21].

2.4. Methodology.

The DPSIR method was an approach that aimed to analyze the relationships between factors that had a direct impact on the environment according to a logic of causality [22]. It connected human activities and the environment. This model had been established by the International Energy Agency. In general, the acronym PSR (Pressures-State-Responses), the analysis model, or its improved version Driving Force-Pressure-State-Impact-Response (DPSIR), using a notion such as "human activities exert pressure on the environment and affect the quality and quantity of natural resources (state), had been developed to adapt to change, society integrated a range of sectoral, economic, and even environmental policy measures (societal reactions) and responded retroactively to pressures induced by human activity. The response framework, notably as used by the OECD and the United Nations Commission on Sustainable Development, served as the basis for the DPSIR model (based on an agreement between the States members). The European Environment Agency (EEA) created it as a general tool to help understand the links between human activities and the state of the environment (including its effects on quality of life and public health) as well as compiling reports documenting these various links [22]. Figure 3 displayed the DPSIR model of road mobility. This method included the following five functions or parameters in the analysis:

- "D" Drivers were the directing or driving forces that underlay human behaviors and processes and impacted environmental capital (e.g., energy consumption);
- "P" stood for resource pressures or functions, referring to the pressures caused by human actions and processes on environmental resources (e.g., emissions);

- The third function, "S", referred to the situation and state of the natural resources on which the pressures had an impact (e.g., ozone concentration rate). Indicators of environmental conditions gave a broad view of the state and trends of the environment, rather than the pressures on it.
- "I" referred to the immediate results and impacts of changes in state on the quantity and quality of the environment (e.g., the number of deaths caused by an increase in ozone concentration).
- "R" represented the response that was consistent with societal and political decisions, government actions to refocus development, and respond to environmental issues. The extent to which society reacted to environmental problems was illustrated by indicators of societal responses. Societal responses included both individual and collective actions aimed at reducing, adapting to, or avoiding the negative effects that human activity had on the environment, as well as halting or reversing the degradation that had already taken place. Institutional capital was crucial in creating these responses because it set the parameters for political decision-making.

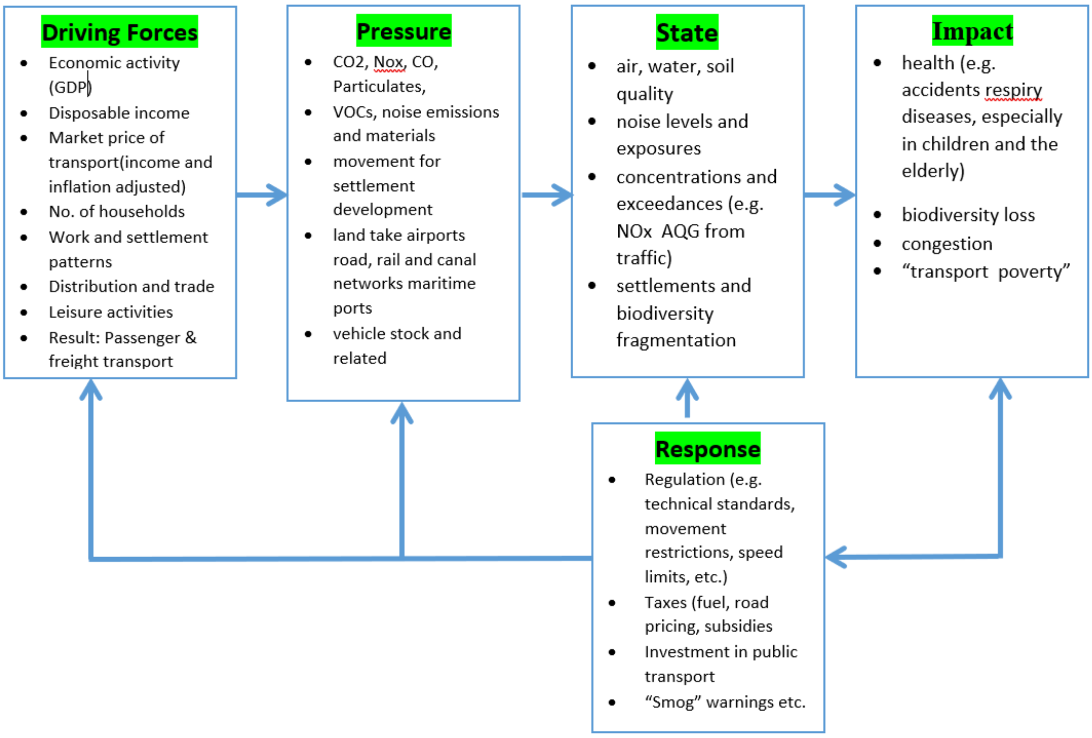

Figure 3. The DPSIR model for the transport sector [23].

2.4.1. Selection of sustainable energy indicators for road transport.

The study used a synthesized model to better reflect the distinctive characteristics of the city. Three key indicators were developed as a result. The following features of the DPSIR scheme led to the creation of this model: (1) Responses and driving forces were closely linked and (2) Since the same element or factor could frequently exist in both components, depending on the central objective, the two components, impact and state, could be combined for methodological reasons. In our survey, eight indicators were identified, and they were grouped into three major groups as shown in Table 3.

Table 3 . Energy-related road transport indicators for the city of Douala.

Types of indicators	Energy indicators	Dimensions
Resource indicators	Energy intensity of road transport	Competitive transportation
	Energy vectors	clean transportation
Impact indicators	Real added value of the road transport sector	Competitive transportation
	CO_2 emissions from road transport	clean transportation
	Road vehicle fleet	Competitive transportation
Response indicators	Motorization rate	fair transport
	road infrastructure	fair transport
	Overall efficiency performance of powertrains	Competitive Transportation

2.4.2. Data analysis.

2.4.2.1. Resource indicators.

The energy resources necessary for road transport activity are represented by structural indicators (pressure indicators). These indicators show how the road transport sector's fuel consumption (both the amount and type of gasoline used) has changed over time. On the one hand, they make it possible to measure and analyze trends in the contribution of the mode of road transport to the use of non-renewable energy sources and the resulting energy dependence. On the other hand, they facilitate the assessment of air pollutant emissions, in particular greenhouse gas emissions. To assess the competitiveness of the road transport industry , these resource or pressure indicators follow the relationships between energy consumption in transport and economic sustainability.

2.4.2.1.1. Share of the different energy vectors in the final energy consumption of road transport.

The energy resources required for road transport activity were represented by structural indicators (pressure indicators). These indicators demonstrated how the fuel consumption of the road transport sector, including the quantity and type of gasoline used, had changed over time. They served two purposes: firstly, to measure and analyze the trends in the road transport mode's contribution to the utilization of non-renewable energy sources and the resulting energy dependence, and secondly, to assess air pollutant emissions, particularly greenhouse gas emissions. These resource or pressure indicators played a crucial role in evaluating the competitiveness of the road transport industry by examining the relationship between energy consumption in transport and economic sustainability.

Table 4 . Lower calorific value of some fuels [24].

Fuel type	Lower calorific value (kJ/kg)
Gasoline	43.80
Diesel	42.70

Let *m be* the mass of the fuel, the quantity of energy *(E)* contained in this fuel in chemical form is given by the following relationship [25] :

$$E = m \times LHV$$

where m is the mass of fuel (kg); PCI the Lower Calorific Value (kJ/kg) and E represent the Energy contained in a ton of raw fuel (ktoe) and in PetaJoule (PJ).

The total energy used in the road transport sector is the sum of the energies used by the various motors.

$$E = \sum_{i=1}^{n} E_i$$

2.4.2.1.2. Energy intensity of road transport.

According to the International Energy Agency, it describes the annual evolution of fuel consumption in relation to GDP. This indicator is expressed in tons of oil equivalent per million euros (toe/M€).

$$EI_{fc} = \frac{E}{GDP}$$

E represents the annual road fuel consumption expressed in toe; GDP the gross domestic product in M€ and EI_{fc} is the energy intensity of fuel consumption (toe/M€).

2.4.2.2. Impact indicators.

Impact indicators answer questions relating to the consequences of transport activities or the management of road transport on the environment and the economy.

2.4.2.2.1. Added value of the road transport sector.

These indicators make it possible to monitor the overall evolution of the transport sector [17]. They give an overview of the evolution of traffic, the length of the network, the characteristics of the fleet and the extent of negative externalities. They measure the interactions between energy consumption in road transport and economic sustainability. This indicator is expressed in €/Capita. The intensity of the added value of the road transport sector per capita is given by:

$$I_{AV} = \frac{AV}{N}$$

Here AV is the added value of the road transport sector expressed in euros (€); N is the number of inhabitants and I_{AV} represents the intensity of added value (€/Capita).

2.4.2.2.2. CO_2 road transport emissions.

These indicators make it possible to quantify and monitor the evolution of CO_2 road transport emissions as well as its contribution to total emissions (all sectors combined). They measure the interactions between energy consumption in road transport and environmental sustainability to provide insight into the dimension of clean transport. The intensity of CO_2 rroad traffic emissions per capita is expressed by the following equation:

$$Ie_{CO_2} = \frac{e_{CO_2}}{N}$$

Where e_{CO_2} ris the amount of emissions from road transport expressed in tonnes, N is the number of inhabitants and Ie_{CO2} the Intensity of CO_2 remissions (tonne CO_2 /capita).

2.4.2.3. Response indicators.

The purpose of these indicators is to highlight societal reactions linked to transport concerns, such as tariff policies, supply of transport services, speed regulation, and control. They also serve as control parameters on which public authorities could take action to promote more sustainable transport, such as improving the basic transport offer and local services.

2.4.2.3.1.Fleet of road vehicles.

It enabled the quantitative tracking of trends in the evolution of the road vehicle fleet, providing an accurate depiction of the volume of private vehicle traffic and, indirectly, public transport usage. Additionally, it facilitated monitoring the changes in the structural characteristics of the fleet and drawing short-term trends from data on new car registrations. This information assisted in assessing the extent and nature of the environmental impacts caused by road transport. This response indicator, also referred to as the driving force indicator, evaluated the socio-economic viability of the transportation industry and contributed to defining fair and competitive aspects of transportation. It offered actionable insights based on fleet characteristics, usage efficiency, and incentives for environmentally friendly modal choices. The intensity of road infrastructure and the motorization rate served as two metrics expressed in the following manner:

2.4.2.3.2.The motorization rate.

Motorization indicates the number of individual vehicles per thousand people [17].

$$\tau_m = \frac{Q}{1000}$$

Q is the number of road vehicle types (cars, buses/coaches, trucks/vans, tractors/special vehicles, motorcycles) and τ_m indicates the motorization rate (vehicles/1000 capita).

2.4.2.3.3.Road infrastructure intensity.

Road infrastructure intensity: In general, these indicators are intended to reflect the degree to which the supply of road infrastructure meets the expectations of energy-sustainable transport. Data on network length plays a fundamental role in achieving energy sustainability in road transport. Any deficiencies or uncontrolled supply of road infrastructure pose a risk of hindering the development of the road sector towards less sustainable solutions. These response indicators measure the actionable factors associated with the characteristics of the road network, particularly in terms of infrastructure length, and help characterize the socio-economic sustainability of road transport. They provide insights into the evolution of network accessibility by reporting the number of kilometers of infrastructure per 1000 capita [17].

$$I_{ir} = \frac{L}{1000}$$

Where L is the Number of kilometers of road infrastructure (Km) and I_{ir} the Intensity of road infrastructure (km/1000 capita).

2.4.2.3.4. Overall efficiency of the road sector.

Energy efficiency designates an operational state of a system in which energy consumption is minimized while providing an identical service. It refers to optimizing energy consumption by striving for the lowest energy intensity (for equal service) or through a "rational use of energy," which involves more efficient processes and tools. The aspect of energy saving aims to reduce waste and unnecessary consumption, making it a crucial element of environmental performance and, in certain situations, even improving service quality. Similar to other modes of transportation such as air, maritime, or rail, the road transport sector utilizes various types of engines or fuels, each with different calorific values [24]. Energy efficiency, defined by the first law of efficiency, represents the ratio of energy contained in useful products of a process to the energy contained in all incoming flows. Gasoline and diesel are commonly used as fuels for road transport vehicles. Weighted average fuel efficiencies can be calculated for each fuel type by multiplying an operating fuel efficiency (η) by a weighting factor (f). The weighting factor is determined by the ratio of energy input for each fuel to the total energy input of the sector. The following expressions are presented [25]:

$$f = \frac{Energy\ input\ of\ a\ fuel}{Total\ Energy\ Input}$$

Gasoline Weighted Fuel Efficiency

$$\eta_{gasoline} = \eta \times f_{gasoline}$$

Weighted Diesel Fuel Efficiency

$$\eta_{diesel} = \eta \times f_{diesel}$$

The relationship between the total average or weighted average energy efficiency (η_0) of the road transport industry for a given year is as follows:

$$\eta_0 = \eta_{gasoline} + \eta_{diesel}$$

The following equation can also be used to represent the overall weighted average energy efficiency:

$$\eta_0 = \sum \eta_i \times f_{ij}$$

Where η_i is The operating efficiency of a fuel, f_{ij} is the weighting factor for the i^{th} fuel used in the j^{th} year, and η_0 is the overall efficiency performance of the road sector (%).

3. Results and discussion

The development of a set of sustainable energy indicators for the road transport sector of the city of Douala is highlighted by the implementation of the methodological approach described in the previous section. The years 2010 to 2019 are the only years for which data has been collected and processed. Energy consumption and the activity of the road transport industry are linked. High activity will inevitably be followed by increased energy consumption, and the reverse is also true.

3.1. The resource indicator.

3.1.1. Share of the different energy vectors in the final energy consumption of road transport.

Figure 4(a) illustrates a notable surge in fuel consumption, which can result in a substantial rise in the utilization of taxis, particularly motorcycle taxis, for urban transportation in the city. Meanwhile, the supply of diesel remains relatively stable. As depicted in Figure 4, these indicators exhibit a significant correlation with motorized road traffic and the observed growth of road transport in terms of value added. Road infrastructures and numerous human activities are intertwined with the utilization of road fuel. Furthermore, they align with the composition of the vehicle fleet and the emissions of atmospheric pollutants.

3.1.2. Energy intensity of road transport.

Industrialization has resulted in an increase in energy intensity, while new technological advancements have contributed to a decrease [26, 27]. Figure 5 depicts the rise in energy intensity of road transport in the city of Douala over a ten-year period due to economic expansion, with values escalating from 9.93 to 15.9 M€ between 2010 and 2019. However, there was a slight decline in 2014, followed by a rebound in 2015 and a continuous increase through 2019. The energy intensity history from 2010 to 2019 demonstrates an overall upward trend. Figure 4(b) displays the upward trend in on-road gasoline consumption between 2010 and 2019. This can be attributed to a significant increase in vehicle traffic and the transportation of goods by road. The expansion indicates that road transport consumes a substantial amount of energy. Considering the economic activities in which the city plays a significant role in Cameroon's GDP, coupled with population growth, it is plausible to expect a growing dependence on fuels within the road sector of the city of Douala over time.

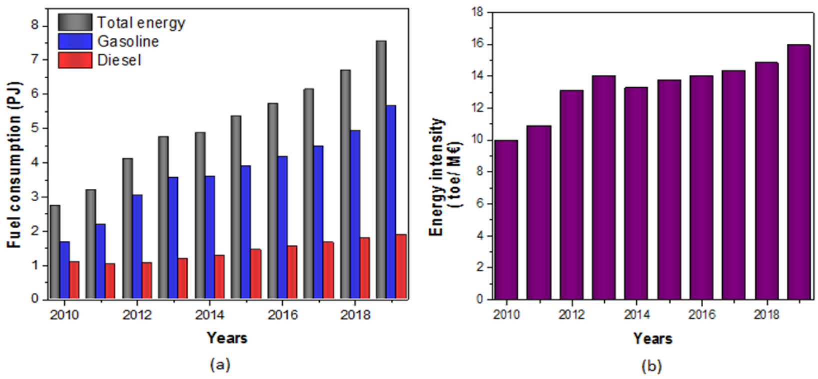

Figure 4. (a) Evolution of the energy intensity of road transport and (b) evolution of the use of different fuels in the transport industry.

3.2. The impact indicator.

3.2.1. Intensity of added value.

Figure 5(a) illustrates a significant increase in energy requirements, indicating the growing weight of energy demands. It also indicates the flourishing road transport industry in the city of Douala, highlighting the need for further study on energy costs as the scale of the city's expanding needs becomes evident.

3.2.2. Intensity of CO_2 road traffic emissions.

In the city of Douala, per capita CO_2 emissions from the transport sector decreased from 0.175 to 0.212 tonnes of CO_2. Figure 7 demonstrates a similar trend, highlighting the strong correlation between fuel consumption and carbon dioxide emissions from vehicle transport. This expansion results in a significant increase in the overall energy intensity, as depicted in Figure 5(b).

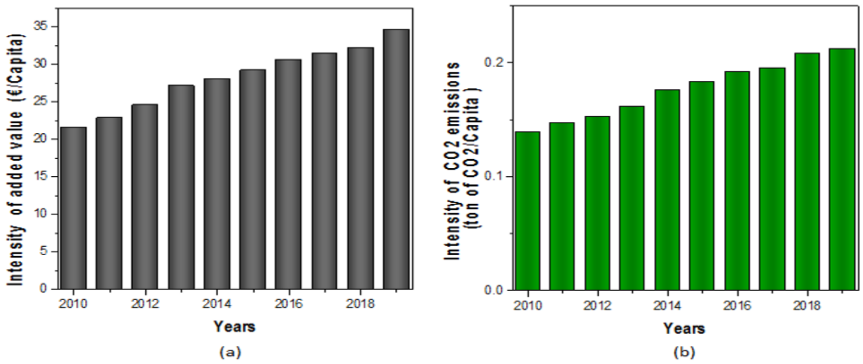

Figure 5. (a) Evolution of the intensity of value added; (b) Evolution of the intensity of CO_2 emissions due to road traffic.

3.3. The response indicator.

3.3.1. Fleet of road vehicles.

Figure 6(a) illustrates that individual vehicles, particularly two-wheelers and cars, predominantly make up the road traffic structure in the city of Douala. However, there is a notable prevalence of motorcycles in passenger transport, reaching the 50,000 mark in 2019. This observation can be attributed to a lack of planning in the urban transport system.

3.3.2. Road transport motorization rate.

As depicted in Figure 6(c), the motorization rate rose from 20.08 to 24.52 cars per 1000 inhabitants between 2010 and 2019. This can be attributed to an increase in energy consumption and specific sectoral externalities typically influenced by the technological characteristics and fuel quality.

3.3.3. Road infrastructure intensity.

Figure 6(d) shows the progression of the number of kilometers of road network per capita for the period from 2010 to 2019. These three stages are as follows:

– In the first period, from 2010 to 2012, the intensity of road infrastructure supply decreased;
– In the second, from 2012 to 2014, the intensity of road infrastructure supply improved somewhat;
– Third , from 2015 to 2019, the intensity of road infrastructure supply decreased significantly.

The decrease in the intensity of road infrastructure in the city of Douala, which does not align with population growth, can explain this trend. The condition of road infrastructure plays a crucial role in enhancing energy efficiency. Monitoring road maintenance becomes necessary as the deterioration of roads increases vehicle fuel consumption, ultimately impacting the energy efficiency of road transport in the city. The city's road infrastructure faces numerous challenges in maintaining the current network and constructing new ones. The network size decreased after 2014, reaching a value of 1800 km in 2019. To address traffic congestion issues, substantial efforts are required to streamline the supply of road infrastructure.

The quality of road infrastructure significantly influences energy efficiency. The link between road infrastructure and energy efficiency lies in the state of the road network since its deterioration leads to increased energy consumption and fuel overconsumption. Our study observed that the reduction in road infrastructure from 2010 to 2012 and from 2015 to 2018 resulted in an increase in energy intensity and a decrease in energy efficiency. Furthermore, the degradation of the road network contributes to road congestion, further exacerbating fuel overconsumption. These issues can be attributed to urban planning failures.

3.3.4. Energy efficiency of engines.

The evolution of engine energy efficiency from 2010 to 2019 is depicted in Figure 6(e). It is evident that the efficiency range falls between 20% and 22%. This observation suggests that there is significant potential for energy savings that can be emphasized. Considering the substantial influence of the city, its impact extends to the entire country. Consequently, it becomes necessary to analyze the typical efficiency of engines used in the city of Douala. The lack of improvement in this variation over the course of ten years highlights the inefficiency of the road transport system in Douala. To gain a deeper understanding of the primary obstacles to mobility in Cameroon, including energy consumption issues and the imperative to achieve energy savings to reduce energy intensity, conducting a comprehensive analysis of the road sector would be fascinating.

The study of sustainable energy indicators for road transport in the city of Douala provides us with all the aforementioned parameters, which necessitate a diagnosis to identify the primary sources directly affecting the efficiency of the city's road sector. Our survey primarily focuses on road traffic data. Figure 6(e) illustrates a decrease in fuel efficiency, while Figure 1(b) displays an increase in energy intensity of fuel consumption. According to previous studies [26, 27, 28], energy intensity should decrease as energy consumption varies, and efficiency should increase with economic growth. However, the observed increase in energy intensity in road transport in the city, coupled with the country's heavy reliance on fossil fuels, may explain the discrepancy.

The characteristics of energy consumption reveal a strong correlation between fuel consumption, GDP, and population, indicating significant energy demand pressure, which often does not account for a fair simplification of the transport system. It was observed that fuel consumption and traffic exhibit a strong positive association. This finding helps us comprehend the energy intensity of fuel consumption depicted in Figure 1(b), which showcases the energy-intensive nature of the road sector with areas of excessive fuel consumption. The growing demand for fuel, disregarding factors such as the efficiency of the road fleet and the rationalization of road infrastructure, contributes to the link between traffic and the energy intensity of fuel consumption.

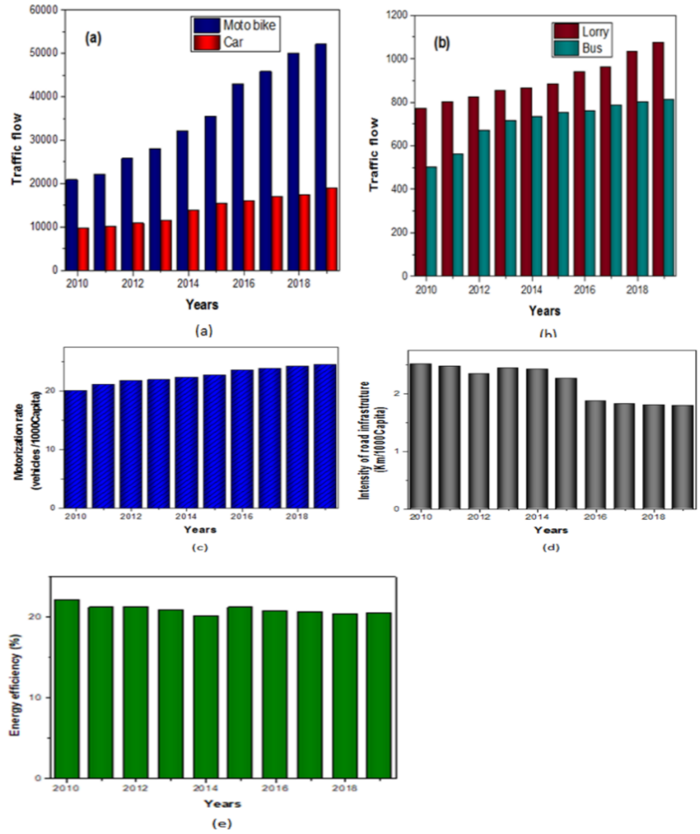

Figure 6. Response indicators. Fleet of road vehicles in the city of Douala: (a) Motorcycles and Cars and (b) Trucks and Buses; (c) Motorization rate due to road traffic; (d) Intensity of road infrastructure; (e) Evolution of the energy efficiency of engines in the road sector.

The surge in traffic is accompanied by an increase in CO_2 emissions. It is evident that the expanding road traffic in the city of Douala will require additional energy over the next 10 to 20 years as mobility demands increase, underscoring the importance of implementing a genuine policy of sustainable transportation. The quality of vehicles and improvements in road conditions will be determining factors in addressing overconsumption. The energy efficiency of motorization, fluctuating between 20% and 22% in Douala, signifies significant potential for enhancing energy efficiency in road transport. Given the various challenges facing the city, particularly in terms of transport needs driven by a rapidly growing population, a sustainable energy strategy is crucial. As a case study, the road transport situation in the city of Douala warrants consideration of these indicators and can serve as a solid foundation and decision-making tool for public authorities. Thus, several strategies should be highlighted, including:

- Regulatory restrictions on vehicle imports to enhance fleet control and reduce fuel consumption.
- Managing the environmental impact of economic developments by promoting renewable energy in road transport through hybrid fuels and achieving a balance between energy consumption and economic growth to integrate the concept of sustainable road transport.
- Ensuring the control of fuel quality in circulation, especially in a city like Douala with industrial activity and associated pollution effects, to reduce greenhouse gas emissions.
- Regulating vehicle emission standards for vehicles in circulation.
- Encouraging mass transportation and limiting the growth of private vehicles to reduce vehicle intensity.

– Emphasizing orderly planning of road infrastructure, which can have a significant impact on reducing energy consumption in road transport.

3.4. Benchmarking of road transport performance.

Although specific studies on the energy efficiency of road transport in large cities of the state have been relatively scarce to date, making direct comparisons with other cities challenging, our study focuses exclusively on the case of Douala as a basis for implementing the concept of sustainable cities. However, it could serve as a potential avenue for future research in other cities with similar characteristics to Douala. Nonetheless, we were able to gather information on the overall efficiency of transport in various countries such as Saudi Arabia, Jordan, Turkey, China, Malaysia, and Norway [25]. The energy performance of the road transport sector in Douala aligns with the general trends observed in the transport sectors of these countries, underscoring the dominant role of road transport in shaping the overall performance of a country's transport sector. The low energy efficiency in Douala, as well as in Cameroon as a whole, can be attributed to various factors, including the poor condition of the roads, illicit trade in petroleum products, aging vehicles, and the substandard quality of fuel. These factors need to be taken into account when assessing energy efficiency in the context of Douala and Cameroon.

4. Conclusion

In our study, we conducted an analysis of sustainable energy indicators for road transport in the city of Douala from 2010 to 2019. We employed the DPSIR framework to establish a set of sustainable energy indicators specific to the context of Douala. The findings of our study led to several conclusions, notably that the energy intensity of the sector increased from 9.93 toe/M€ in 2010 to 15.9 toe/M€ in 2019, indicating a high energy intensity in the road sector. Furthermore, the energy efficiency of the engines ranged from 20% to 22%, suggesting significant potential for improving energy efficiency. The low energy efficiency observed in Douala, as well as in Cameroon overall, can be attributed to various factors such as the poor condition of the roads, illicit trade in petroleum products, aging vehicles, and substandard fuel quality. These factors need to be considered when assessing energy efficiency in Douala and Cameroon. Based on the sustainable energy indicators analyzed, it can be concluded that the primary objective of the study has been achieved. However, further exploration of the factors influencing energy consumption is necessary to reduce energy intensity. Looking ahead, this study can serve as an exploratory path to better understand sustainable cities in the context of road transport. It is essential to consider the specific characteristics of each city at the national, regional, and global levels to facilitate meaningful comparisons with other cities. Such comparisons will contribute to enhancing the effectiveness of environmental management policies, which represent a significant challenge for the development of sustainable cities.

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Competing Interest

The authors declare no conflict interest.

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