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The Comparison between the Total Aggregate Sustainability of Electric Vehicles and Internal Combustion Engine Vehicles, Evidence from Montreal

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Abstract: As an essential service to make society functional, the transportation section draws great attention because of the high emissions in terms of Greenhouse gas. Since the definition of sustainability was introduced, researchers started to evaluate the sustainability of each type of transportation. This paper compares the total aggregate sustainability of Electric Vehicles and Internal Combustion Engine Vehicles in Montreal through a re-designed methodology combining Miller Framework and ELATIC approach together. It assesses sustainability through eight indicators in three dimensions. After the assessment, we find that because of the high proportion of hydro energy used for electricity generation in Quebec, Electric Vehicles perform better than in other provinces in Canada. However, the accessibility should be improved given that many owners of Vehicles complain about the inconvenience. In addition, in our discussion, the limitation of data accuracy and the scope of the research is fully described with some improvement suggestions.

Keywords: Electric Vehicles; Internal-combustion Engine Vehicles; Sustainable Transport; Sustainability; Montreal.

1. Introduction

The environmental impact of transportation is a major issue in all regions of the world today. The primary concern of traffic-related emissions is internal combustion engine vehicles [1]. Therefore, finding an alternative of internal combustion engine vehicles is one of the necessary actions to achieve Canada's climate objectives. Electric vehicles, as the major components of zero-vehicles, can be considered a strong candidate. There are lots of advantages of Electric Vehicles (EVs). One of the essential ones is zero-tailpipe emission. That's why EVs have gained popularity in terms of being environmental-friendly vehicles [2].

According to the Association des véhicules électriques du Québec, Quebec, as the biggest market of EVs in Canada, contributes 46 percent of registered EVs in Canada. The city of Montreal also contributes to this achievement of Quebec. Approximately 7% of the new vehicle purchases by Montrealers are Electric Vehicles in 2021

This study aims to compare the sustainability performance regarding environmental, social and economic aspects of EVs and ICEVs in Montreal. By introducing a systematical assessment of indications called ELASTIC methods, the paper improves the indicator selection part of methodology primarily developed by the University of Calgary for evaluating sustainable transportation named "Miller Framework". Then this paper pays high attention to data related to each chosen indicator. With various types of reliable data and the adoption of the framework, the paper concludes with a summary of key findings and a discussion of the limitation and future improvement. The contributions of this work can be summarized from two categories: 1) by making the comparison, it provides the reasons why the city of Montreal adopted its "Transportation Electrification Strategy from 2021 to 2023". 2) from the data collection, some unavailable data related to transportation in Montreal are calculated from alternative data from reliable sources. These can be used in future research.

2. Methodology

2.1. Indicators Selection

This study applies a systematic framework called "Evaluative and Logical Approach to Sustainable Transport Indicator Compilation" (ELASTIC) to select the indicators instead of the default indicators contained in Miller Framework. Several reasons lie behind this. 1) ELASTIC provides a systematic framework of indicator selection, which not only considers the basic objectives of this paper but the characteristics of the indicators themselves [3]. 2) ELASTIC provides an understandable and precise approach to evaluating the indicators in the same dimension. This makes the comparison simple when the indicators are chosen [3]. 3) Some applications of ELASTIC can be used to guide the indicator selection process, while Miller Framework just provides the default indicators without the reasons and examples [3]. Based on the criteria discussed above and the evaluation process provided by ELASTIC, the sustainability of EVs and ICEVs will be assessed from three dimensions, environmental consideration, social consideration and economic consideration [3].

In this study, each dimension has the different focus. Environmental consideration represents the environmental impact of the energy factors of EVs and ICEVs locally. Energy efficiency, energy consumption and the pollution are analysed. The Social consideration represents how EVs and ICEVS promote human welfare. Two factors are considered within this article, affordability and accessibility. Affordability answers the question of "Is it affordable for people to own one EV or ICEV in Montreal". At the same time, accessibility pays attention to the convenience of driving each type of vehicle in Montreal. Economic consideration represents the contribution of EVs and ICEVs to the vibrant and efficient economy.

2.2. Data Collection

2.2.1. Energy-consumption

One main determinant of sustainable transport is how much fuel it needs to maintain its function [4]. However, no direct data related to the energy-consumption of ICEVs in montreal has been published. Fortunately, Ontario has one related data. Based on the research that has been done about Ontario, one typical ICEV in Canada needs 2.82 gallons of fuel to run 100km [4]. Therefore, this study assumes that one typical ICEV also needs to use the same amount of fuel to run 100km in Quebec. For EVs, one data in Hydro Quebec shows that on average EVs need 16kWh of electricity to run 100km. To make these two data into the same unit-Joules, conversion is required. After the conversion, one Electric Vehicle requires 57600000 Joules per 100km, while one ICEV needs 365300000 Joules of energy.

Some information about this data is worth noticing here. Firstly, the energy consumption of EVs is the average number of all types of Electric Vehicles. Secondly, both data are from passenger vehicles. Thirdly, both data are collected before the pandemic. The data about ICEVs is from 2018, while the data about EVs is from 2019.

2.2.2. Energy Efficiency

Energy efficiency simply reflects how energy is used efficiently [5]. One related data is found. However, because of the lack of data in Montreal, this study uses the average number of the efficiency of energy conversion of passenger vehicles from on-board storage to turning the wheels in Canada as the data for this indicator. Based on the data from the Government of Canada, gasoline vehicles' energy efficiency is 16%, while Electric vehicle is 76%. However, the ICEVs include gasoline-fueled vehicles and diesel-fueled vehicles. Therefore, both should be considered in principle. However, according to data from Statistics Canada, only 1.35% on average of ICEVs registrations are diesel vehicles in Canada from 2017 to 2019. Only a tiny effect will be placed on the overall energy efficiency of the ICEVs. Therefore, 16% will be used for ICEVs in this study. In addition, the data related to Electric vehicles is the average number in terms of all types of EVs (BEV, PHEV and so on). To summarize, the indicators of the energy efficiency of two types of vehicles will use 76% and 16% for EVs and ICEVs, respectively.

2.2.3. Pollution

In terms of the environmental factor of one transportation, one essential indicator is the amount of GHG emission produced, which will cause severe air pollution in the city [6]. Since the introduction of Electric Vehicles, much research has been done in testing GHG emissions of the EVs in their life cycle. Based on their research, they find that GHG emissions of EVs not only depend on the use of vehicles but the source of electricity and the charging method [4]. Therefore, stimulating the different scenarios related to charging methods and electricity power generation methods is required to get the data regarding GHG emissions of EVs. One method developed by the University of Waterloo will be adopted in this study. The study examines CO2 emissions of EVs in Ontario from four scenarios [4]. To make the comparison between EVs and ICEVs more obvious, only scenario one (natural gas power generation systems and charging at any time) is considered. After the calculation, on average, EVs will produce 8.22 kg CO2 emissions per 100km [4]. Comparing this number with the data in the study of Ontario by University of Waterloo, the calculated data is smaller than the number in the study (13.48) [4]. Since the electric power generation system highly relies on hydroelectric power in Quebec (95%), this number is partially accurate. the data for ICEVs should be similar between Ontario and Quebec, which is 26 kg CO2 emissions per 100 km.

2.2.4. Affordability

Like other data, purchase prices also vary from different regions because of some factors. According to the data from the Canadian Automobile Association, the average price of EVs in Quebec is $83510, while the price of ICEVs is $51122. This price gap is demonstrated by Mark Stewart, Chief Operating Officer for Stellantis North America, when he said: "on average, an electric vehicle is 40 to 45% more expensive than a classic internal combustion engine powertrain".

The definition of Maintenance cost is the expense by an individual or one corporation to keep the transportation in operating condition. To focus on the main part of sustainability, this study only pays attention to the fuel cost of each type of vehicle. All data comes from the tool designed by Hydro Quebec. After the adjustment of the conditions, the result is that the fuel cost per 100 kilometres for EVs is $1.85. For ICEVs, the editable condition is fuel consumption per 100 km of the vehicles and the fuel price. Based on the 2023 Fuel Consumption Guide designed by Natural Resources Canada, most cars have 10.7L/100km in the city. Moreover, the fuel price is from Canada Automobile Association—on average $1.60/L in Montreal. Therefore, setting 10.7L/100km and $1.6/L into the tool gets $17.6 per 100 km driving by ICEVs.

The subsidy is also one essential consideration of the affordability of one vehicle. In Canada, there are no subsidies for the ICEVs, but both the federal government and the Quebec government have a subsidy for EVs. Based on the program of the Incentive for Zero-Emission Program (iZEV)of the Government of Canada, two levels of incentives are given for the purchase or lease of electric vehicles: "1) Battery-electric, hydrogen fuel cell and longer-range plug-in hybrid vehicles (an electric range equal to or greater than 50 km.) are eligible for up to $5000. 2) shorter range plug-in hybrid electric vehicles (electric range under 50 km) are eligible for up to $2500". For the Government of Quebec, they also provide an incentive program, which can be summarized in three levels: "1) Up to $7000 on a new all-electric or plug-in electric vehicle. 2)Up to $2000 on a new electric motorcycle. 3) Up to $3500 on purchasing an eligible used all-electric vehicle".

However, do these subsidies really reduce the purchase price of the EV for the public? After researching these two programs and consulting with one dealer in Montreal. The answer is "not really". Upon initial observation, this incentives policy makes a significant decrease in the purchase price of EVs. Because of this considerable reduction, more and more will consider EVs as their first or next car. The highest subsidy that the public from these two programs is $12000 ($7000+$5000). However, only two Plug-in Hybrid Vehicles can get these subsidies based on the program's conditions: 1) Chrysler Pacifica Hybrid. 2)Toyota RAV4 Prime. Therefore, these incentives do not cover all types of EVs. Only Battery Electric Vehicles (BEV) can gain the most subsidies.

2.2.5. Accessibility

Accessibility refers to how easy it will be from a specific origin to reach various activities. In the island of Montreal, because the number of charging stations will definitely be higher than the number of gas stations, it is meaningless only

to compare these two numbers to compare the accessibility of EVs and ICEVs. Unfortunately, there is also no direct data about the accessibility of "fuel stations". However, the accessibility measures the convenience of EVs and INEVs for the public. Therefore, one indirect measurement is applied in this study, which is the percentage of complaints about the convenience of "fuel-stations" for the owners of vehicles in Montreal. For EVs, Renaud-Blondeau et al. do research in terms of the public charging stations on island of Montreal [7]. They design a survey to collect the public's attitudes toward the convenience of EVs [7]. In the result of the survey, 72% of EV owners wish to have more charging stations on the Island of Montreal [7]. For ICEVs, however, no survey had been done related to gas stations in Montreal. As a result, this study estimates one approximate number from the main social media for Montreal. By researching the following keywords on main social media "gas stations, bad, Montreal, low efficient, wait long time", there are approximately 2-4 posts out of 10 related to "lower convenient" on each media. Therefore, the percentage is roughly 30%.

2.2.6. Economics Contribution

The economic contribution of EVs can be reviewed from different perspectives. In this study, the focus is on how one supply chain of EVs and ICEVs supports a vibrant and efficient economy. This study will adopt the employment factor to test the economic contributions of these two types of vehicles. For combustion vehicles, there is no direct data about the number of jobs provided by one supply chain. However, one estimation can be made based on the report of the Canadian Automotive Partnership Council. In total, 125000 direct employments are provided in Canada's automobility industry, excluding Electric Vehicles. In Canada, there are many automakers. In this study, the biggest 10 major automakers are chosen to calculate, including Ford, GM, Toyota, Stellantis, Honda, Hyundai, Nissan, Kia, Subaru and Volkswagan. Through the calculation, the average number of jobs provided by one supply chain of combustion vehicles are 25000 per automaker. For EVs, because this is a new industry, only a few automakers in Canada. One of the biggest is Tesla. 6600 full-time employments were provided by Tesla in 2021.

2.3. Directly Sustainability Analysis of Data

After the data collection, the next step is the analysis of the contribution of each data to sustainable transport. The method used here to do the Sustainability Analysis is developed primarily by Jeon et al. to examine the transportation system sustainability of the Atlanta metropolitan area. Two equations are used to normalize the data from different indicators. For the positive Impact Factor Equation:

$$n_i = \frac{x_i}{Max(all\ x)} \quad (1)$$

For the negative Impact Factor Equation:

$$n_i = \frac{Min(all\ x)}{x_i} \quad (2)$$

Where x is the data of certain transportation, n is the normalized factor, and i represent the interested transportation.

Therefore, after the calculation, the results are summarized in Table 1.

Table 1. Direct analysis between the data of EVs and ICEVs

Indicator	Unit	Desirability	Electric Vehicles	ICEV	Electric Vehicles	ICEV
Total energy use	J/100km	Less is better	57600000	365300000	1	0.1576
Pollution	Kg of CO2/100km	Less is better	8.22kg	26	1	0.51
Energy efficiency	Percentage	More is better	76%	16%	1	0.3026
Purchase price	Canadian Dollar	Less is better	83510	51122	0.7552	1
Operating cost	Canadian Dollar	Less is better	1.85	517.6	1	0.1377
Subsidy	Canadian Dollar	More is better	Vary	0	1	0
Accessibility	Percentage	Less is better	72%	30%	0.429	1
Employment	Number of Jobs	More is better	6600	25000	0.264	1

2.4. Overall Analysis of Sustainable Performance

After the analysis of each indicator, the overall sustainability performance of each type of vehicle should be calculated through the equation described below. Composite Sustainability Index (CSI) captures the overall performance of sustainable transportation.

$$CSI = w_e \sum w_i E_i + w_s \sum w_i S_i + w_n \sum w_i N_i \quad (3)$$

Table 2. Weighting references from two dimensions—methodological quality, objectives of sustainable transport

Weighting related to methodological quality		Weighting related to different objectives of sustainable transport	
Criteria	Weights	Objective	Weights
Measurability	0.22	Livable streets and neighborhoods	0.16
Ease of Availability	0.14	Protection of the environment	0.2
Speed of Availability	0.07	Equity and Social inclusion	0.17
Interpretability	0.34	Health and safety	0.31
Isolatability	0.23	Support of a vibrant and efficient economy	0.17

The weights should be given based on different objectives of sustainable transport and different methodological quality [3]. The relative weights are concluded in Table 2. Combining these two different weighting methods together, this work will use weights described in Table 3 to do the CSI calculation.

Table 3. Weights of the related indicators

Indicator	Units	weights
Total energy use	J/100km	0.3
Pollusion	Kg of CO2/100km	0.4
Energy efficiency	Percentage	0.3
Purchase price	Canadian Dollar	0.2
Operating cost	Canadian Dollar	0.2
Subsidy	Canadian Dollar	0.2
Accessibility	Percentage	0.4
Employment	Number of Jobs	1

3. Result and Discussion

For the environmental factor, there is no doubt that EVs cause less GHG emissions during usage. Therefore, what really matter is the electricity power generation method, which is the main reason that results in the difference between GHG emissions of EVs and ICEVs. Given the 95% of electricity produced by Hydro-energy in Quebec, the overall pollution in the life cycle of EVs is lower from other provinces of Canada. For example, it is not the case in Alberta, with 89% of electricity is produced by fossil fuels [8].

For social consideration, although Electric Vehicles have a relatively higher price than combustion vehicles, the lower fuel cost compensates this in the long run. It is worth noticing that accessibility of Electric Vehicles is worse than ICEVs even though many charging stations are located on the island of Montreal. The main reason behind this is that only a few EV owners have private charging stations. Most depend on public charging stations. Therefore, because the time efficiency of the charging is lower than the gas station, it makes lots of complaints about the charging. Fortunately, the Government of Montreal acts to solve this problem. Based on "Montreal's Transportation Electrification Strategy 2021-2023", the government aims to install 600 new level 2 charging stations by 2023 and 1000 by 2025. For the economics sector, because of the complexity of the technology of Electric Vehicles, more and more job opportunities will make in the future in this field.

4. Conclusion

The evaluation of sustainable transport has received high attention since the concept of sustainability was introduced. Countless researchers have delved into this field to examine the different sustainable transport from different aspects. They all have some remarkable contributions to sustainable development, whereas some limitations also exist in each research. As a result, many improvements can be made in the future. Specifically, addressing the limitations listed above and improving future research should be achieved by taking several steps. Firstly, more accurate and geographically specific data should be efforted on that to ensure consistency and improve the accuracy of the results. Secondly, regular updates to the dataset, particularly for some fast-changing industries like automobiles, are essential actions to increase the quality of the research. This action requires the participation of everyone in the industry. Finally, to have a more comprehensive analysis that enhances the understanding of sustainable transport in one city, the scope of the study should be expanded. Specifically, assessing more indicators can be considered as a good improvement, which will provide additional perspectives in terms of each consideration of sustainability.

This is not the end. This is only the beginning.

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