Analyzing the CO2 Emissions and Fuel Consumption of Light-Duty Vehicles

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Abstract

On-road emissions data for different types of vehicles are needed for estimating the CO2 emissions and fuel consumption which can affect the car-buying behavior of the citizens with the goal of helping to mitigate the consequences of global warming and achieving sustainable development. The Government of Canada presents a dataset that provides model-specific fuel consumption ratings and estimated carbon dioxide emissions for new light-duty vehicles for retail sale in Canada. Citizens can check the vehicles with the best fuel consumption ratings and lowest estimated annual fuel cost to save money and help to enhance the carbon emission issues. The data covers all the vehicle models from 1995 to 2022, including more than 1000 models from more than 50 companies. This paper focuses on the vehicle classes prevalent in the market (such as SUV, Compact, and Two-seater) to analyze their emissions factor and fuel consumption considering the average performance of the vehicle classes during previous years. The output shows that in different vehicle classes, the range of the carbon emissions varies significantly. The new vehicle models presented to the market do not necessarily have a better performance in sustainability aspects and car buyers should pay more attention to the scores of the vehicles considering various environmental indexes.

Keywords
CO2 Emissions, Fuel Consumption, Light-duty Vehicles.

1. Introduction
Nowadays both transportation and energy generation sectors are key actors in the greenhouse gas (GHG) emissions scene, gathering about 14% and 25% of total GHG emissions worldwide, respectively (Pachauri et al. 2014). To reduce vehicle emitted greenhouse gases (GHGs) on a global scale, the scope of consideration should be expanded to include the manufacturing, fuel extraction, refinement, power generation, and end-of-life phases of a vehicle, in addition to the actual operational phase (Kawamoto et al. 2019). Although many cities use green mobility systems such as public bicycle sharing systems, greenhouse gas emissions and fuel consumption have still remained a serious issue for governments (Vishkaei et al. 2020; Vishkaei et al. 2021). Vehicle stock is a key factor in determining oil use and CO2 emissions in the transportation sector and vehicle technologies improve over time because of either government requirements or market competition (Huo et al. 2007). A considerable amount of fuel is consumed by cars each year, resulting in a large amount of exhaust emissions. In 2011, approximately 59% of oil was used for transportation resulted in approximately 22% of anthropogenic carbon dioxide emissions (Zhou et al. 2016). Current energy consumption in the transportation sector accounts for about one quarter of the global energy demand and is expected to double until 2050 (Sierra 2016).

Light Duty Vehicle(s) means a mobile machine that is primarily used to transport passengers and cargo (e.g., cars, vans, SUVs, pickup trucks), with a Gross Vehicle Weight Rating (GVWR) less than or equal to 10,000 pounds. Figure (1) shows the yearly sales of new light-duty commercial vehicles in Europe from 2014 to 2021. In recent years the average sales were around two million units (https://www.statista.com/statistics/1195893/light-duty-vehicles-sales-europe/).

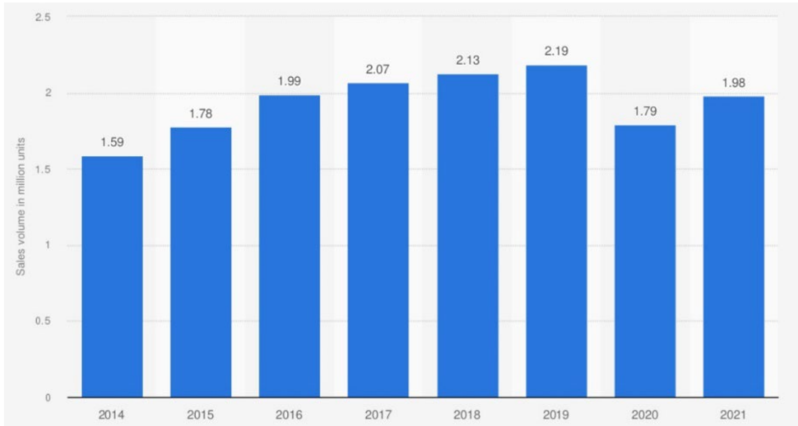

Figure 1. Yearly sales of new light-duty commercial vehicles in Europe from 2014 to 2021 in million units (source: Statista).

These days the world is more concerned about environmental issues and most of people are paying more attention to sustainable development and the Circular Economy (CE). One of the main environmental benefits generated by the CE is reducing CO2 emissions and preventing tons of air pollutants (Maranesi and De Giovanni 2020). One of the major contributors to global emissions, especially the emission of CO2, is the transportation sector and LightDuty Vehicles (LDVs) contribute largely to country's emission inventory (Raymand et al. 2021). Reducing CO2 emissions from road transport is a critical priority in the European Union's policy agenda (Zacharof et al. 2021). European Union requirements regarding vehicle emissions for passenger cars and light commercial vehicles were introduced in 2009 for type approval and in 2011 for all new types, specified as Euro 5, with further requirements (Euro 6) planned from 2014 onwards (Bielaczyc et al. 2014).

The light-duty vehicle (LDV) sector is undergoing many changes, including technological advancements (e.g., vehicle electrifcation, automation), new business models (e.g., ride-hailing), and government regulations and policies (e.g., fuel economy (FE) standards, zero-emission vehicle mandates, infrastructure investments, and incentives to encourage adoption of alternative fuel vehicles). Despite significant uncertainty, these developments, combined with demographic growth, will influence the future LDV feet size and composition, and consequently the oil demand from LDVs (Albrahim et al. 2019). There has been little attention given to the analysis on the temporal variation of exhaust emissions from diesel vehicles during real-world driving. Clearly, there is a need for detailed experimental information on emission characteristics in the condition of real driving (Chong et al. 2020).

Proper management and control of vehicle emissions are urgently required to improve air pollution in cities. In summary, this work will answer the following questions by analyzing a database that includes information regarding various vehicle models covering the years 1995-2022 provided by the government of Canada. The analysis is done using various graphical diagrams and plots by Power BI.

- What are the prevalent vehicle classes in terms of the number of models in the market since 1995?
- What are the prevalent engine types in terms of the number of cylinders in the market since 1995?
- What is the trend of the average fuel consumption rates of different vehicle classes from 1995 to 2022?
- What is the trend of CO2 emission rates of different vehicle classes from 1995 to 2022?
- How can the number of cylinders and the size of the engines affect fuel consumption as well as CO2 emissions?
- Which vehicle classes have a better performance considering fuel consumption and CO2 emission score?

2. Data Analyzing

In this section, the dataset that is provided for light-duty vehicles on a governmental website of Canada (https://open.canada.ca/data/en/dataset/98f1a129-f628-4ce4-b24d-6f16bf24dd64/resource/f2e53a2b-e075-473a-9a9c-5d7bef68d07d) will be analyzed. The dataset includes various models of vehicles that were available in the retail market from more than 50 companies considering different information such as transmission, fuel type, vehicle class, fuel consumption, and CO2 emission. In the first step, we will analyze the share of different vehicle classes of the available models in the market. Figure (2) analyzes the share of different classes from 2017 to 2022 to indicate which of the classes have the highest shares in the number of models that are provided in the market.

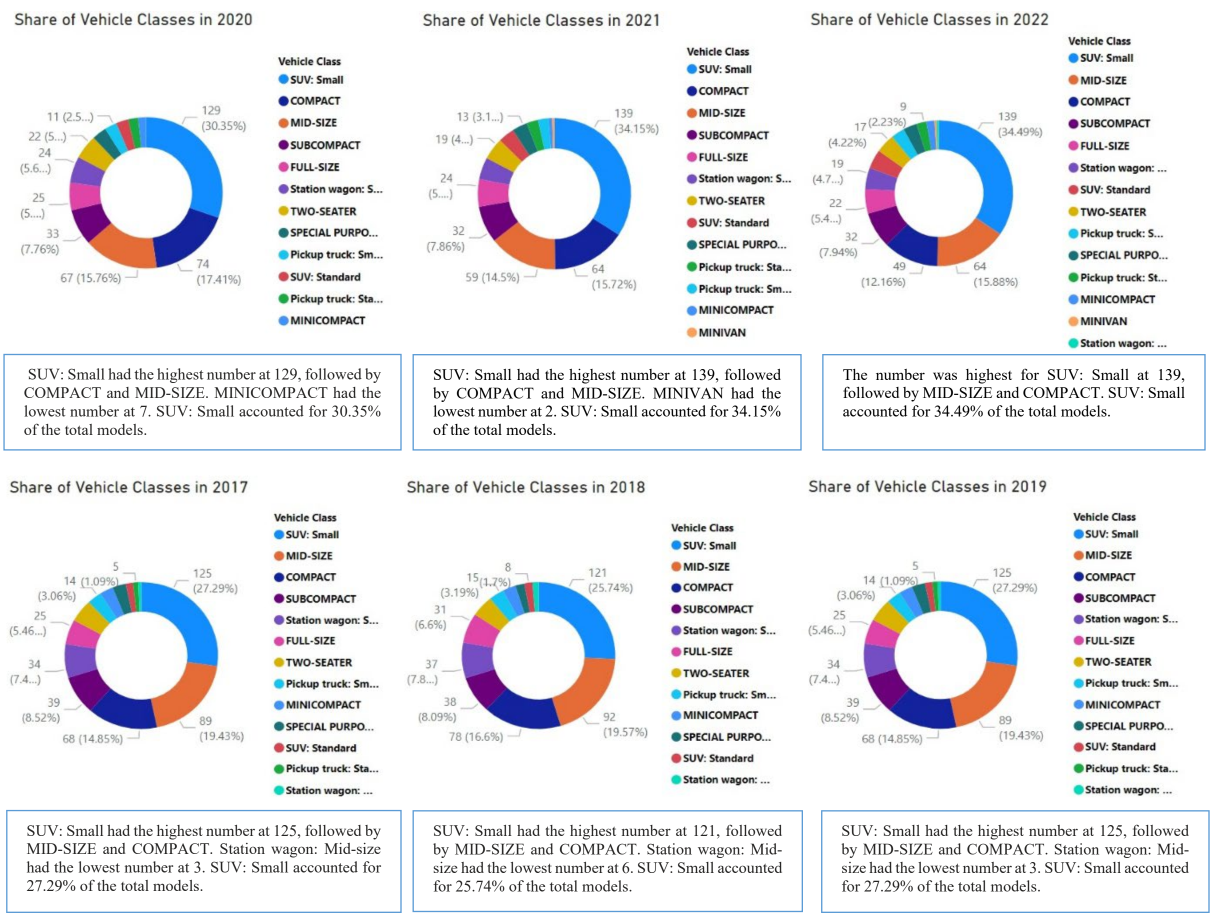

Figure 2. Share of different vehicle classes in terms of models between 2017 and 2022.

Based on Figure (2), SUV: small, Mid-size, Compact, Subcompact, Full-size, Station wagon: small, SUV: standard, and Two seaters vehicles have the most number of models compared to other vehicle classes. Small SUVs have the maximum share and after that Mid-size and Compact classes are following them. These three vehicle classes have more than 50% share of different models that are presented to the market which shows people are more interested in these classes of vehicles. Figure (3) discusses the number of vehicle models in terms of the number of cylinders from 1995 to 2022. The maximum number of vehicle models belongs to 2015 and the minimum number is related to 1998. Companies have always provided more models for four, six, eight, and three-cylinder engine vehicles respectively. The share of the vehicles in terms of different types of engines is brought in Figure (3).

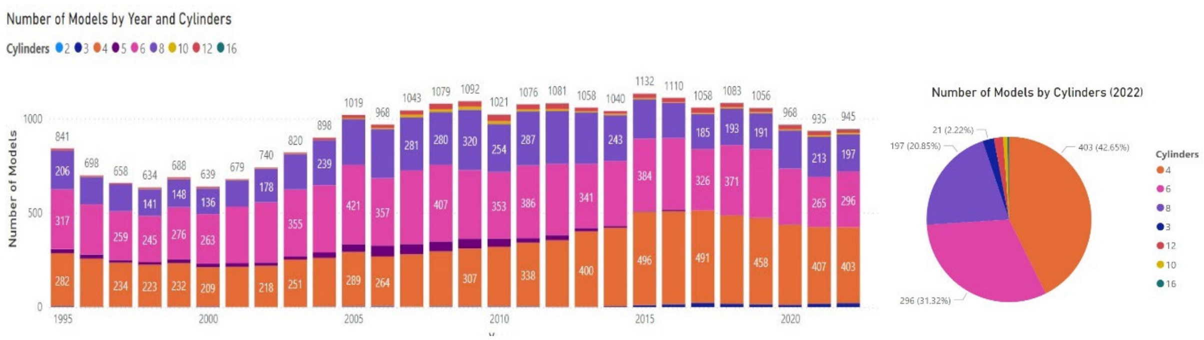

Figure 3. Share of different vehicle models in terms of the number of cylinders between 1995 and 2022.

Figure (4) indicates the number of vehicle models during the previous years (sorted by the number of models in each year) by cylinders.

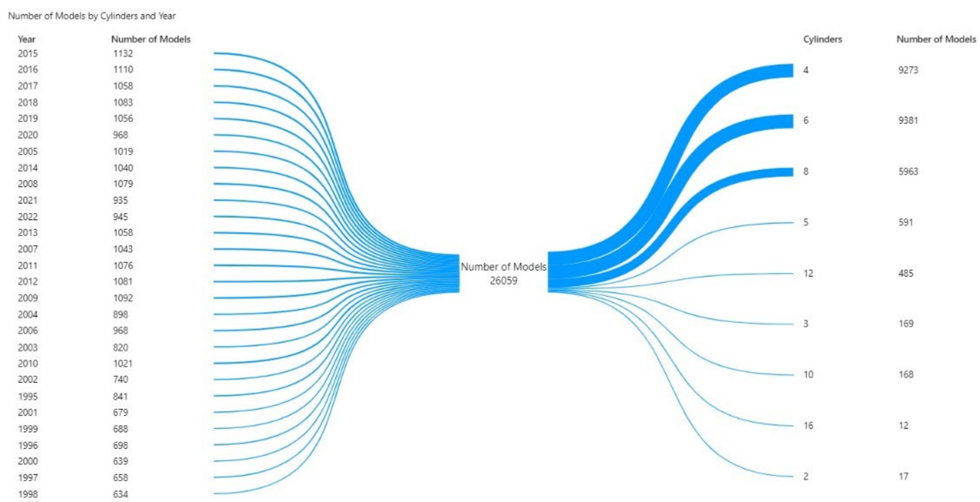

Figure 4. Sorted number of models in terms of year and cylinder.

To calculate the fuel consumption, the consumption rates (liter per 100 kilometers) in the city and highway are considered to calculate the combined rate (55% city, 45% highway). Figure (5) analyzes the fuel consumption of four, six, eight, and three-cylinder engine vehicles from 2011 to 2022 using a violin plot. As is shown in this figure, the mean, median, minimum, and maximum amount of fuel consumption has increased for the new models of vehicles (the models that are provided to the market in the last few years). Except for the vehicles with three-cylinder engines, the variety of the models in other types is reduced. The standard deviation of fuel consumption for vehicle models with eight cylinders is reduced compared to ten years ago which shows the current models in the market are more identical in their performance regarding fuel consumption. All these show that car buyers should be more aware of the performance of different vehicle models.

Figure (6) indicates the average fuel consumption of vehicles with different numbers of cylinders when they are driven in the city, on the highway, and in the combination of them (55% city, 45% highway). For vehicles with more than eight cylinders, the difference in fuel consumption compared to the vehicles with three or four cylinders is significant. The difference is even more remarkable when we compare them in the city.

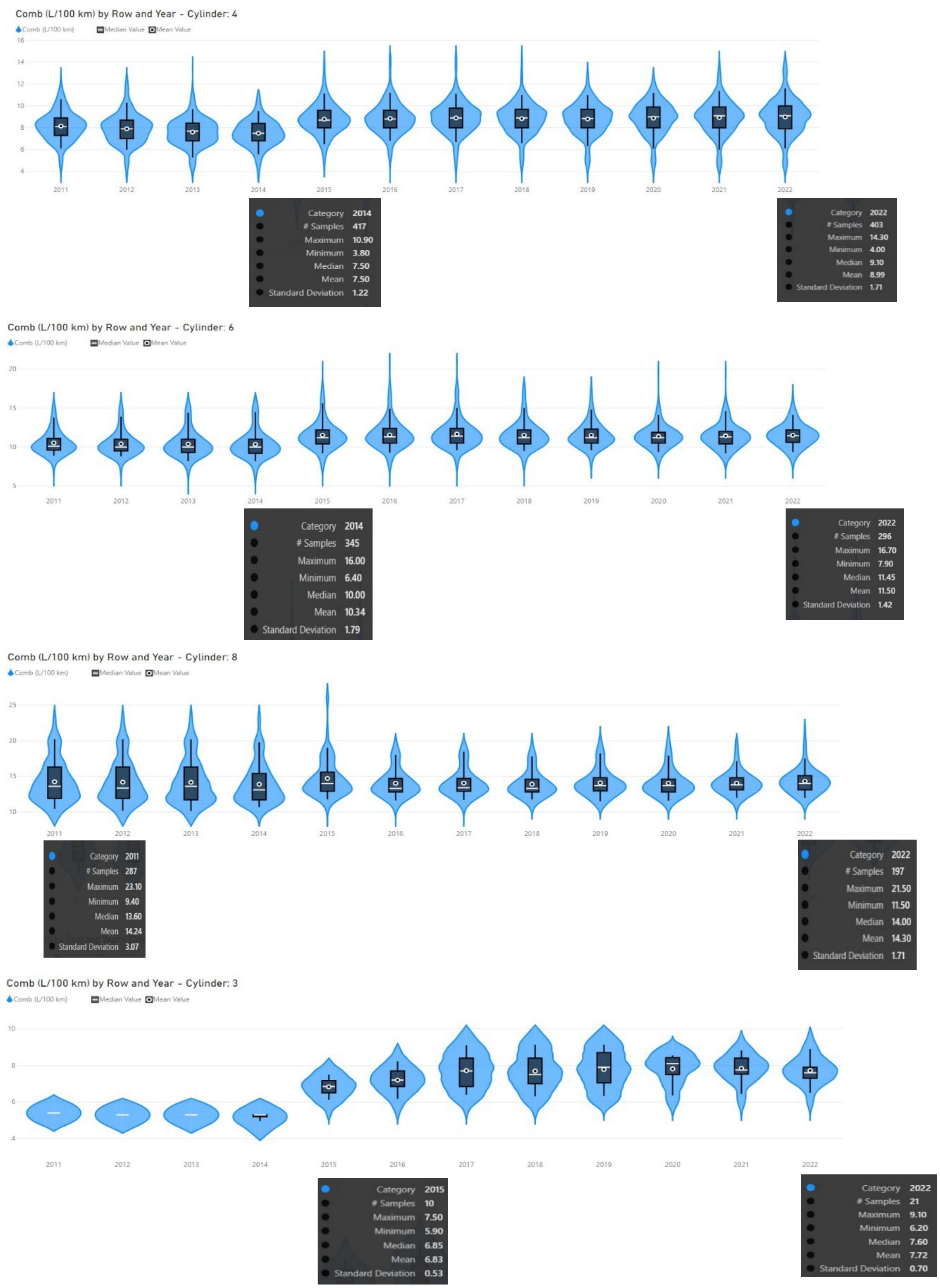

Figure 5. Fuel consumption of four, six, eight, and three-cylinder engines from 2011 to 2022

Figure 6. The average fuel consumption of different vehicle models in the city, highway, and combination of them for vehicles with different cylinder engines in 2022.

Figure (7) analyzes the average combined fuel consumption (*L/100 km*) by Engine Size (*L*) and Cylinders in 2022. It compares vehicle models by categorizing them in terms of the number of cylinders (rows) and engine size (columns) considering three intervals for the average fuel consumption including [0, 8.33], [8.33, 16.6], and [16.66, 25] liter per 100 kilometers. All the models of three-cylinder engine vehicles have an average fuel consumption between zero and 8.33 *L/km* and this is the same for most the four-cylinder vehicles except for some models that have an engine size between 1.4 and 2.5 *L*.

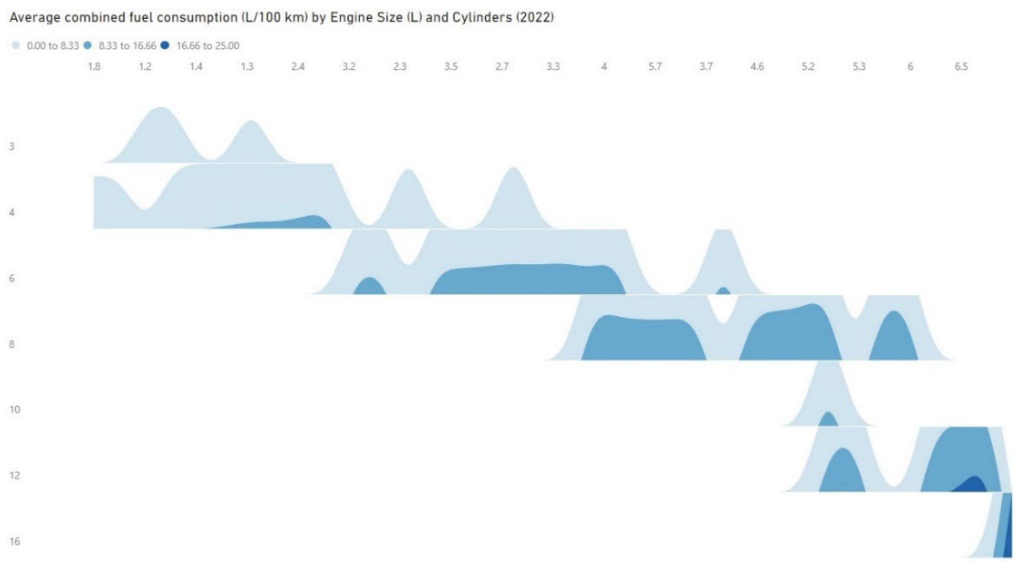

Figure 7. The average combined fuel consumption (*L/100 km*) by Engine Size (*L*) and Cylinders in 2022.

To investigate the tailpipe emissions of carbon dioxide (in grams per kilometer) considering combined rate (city and highway), figure (8) is provided to compare emissions of vehicle models that are presented in the market from 2011 to 2022 considering various types of engines which have more models in the market (3-, 4-, 6-, and 8-cylinder engines). Based on the violin plot, the performance of all types of vehicles with a different number of cylinders has improved over the years and companies could reduce the amount of carbon emission per kilometer in different vehicle models. Based on the carbon emissions (in grams per kilometer) of the vehicle models, the tailpipe emissions of carbon dioxide are rated on a scale from 1 (worst) to 10 (best). Figure (9) analyzes the carbon emission rate of the vehicles by cylinders in 2022. In general, the average CO_2 rate of the vehicle models with three-cylinder engines is lower than the other engine types but all the three-cylinder engine models do not have necessarily a better performance in this indicator compared to others and it depends on the engine size. For instance, the average CO_2 rate score for three-cylinder engines with a 1.2 Liter engine size is equal to the average CO_2 rate score of four-cylinder engine vehicle models with a 1.6 Liter engine size.

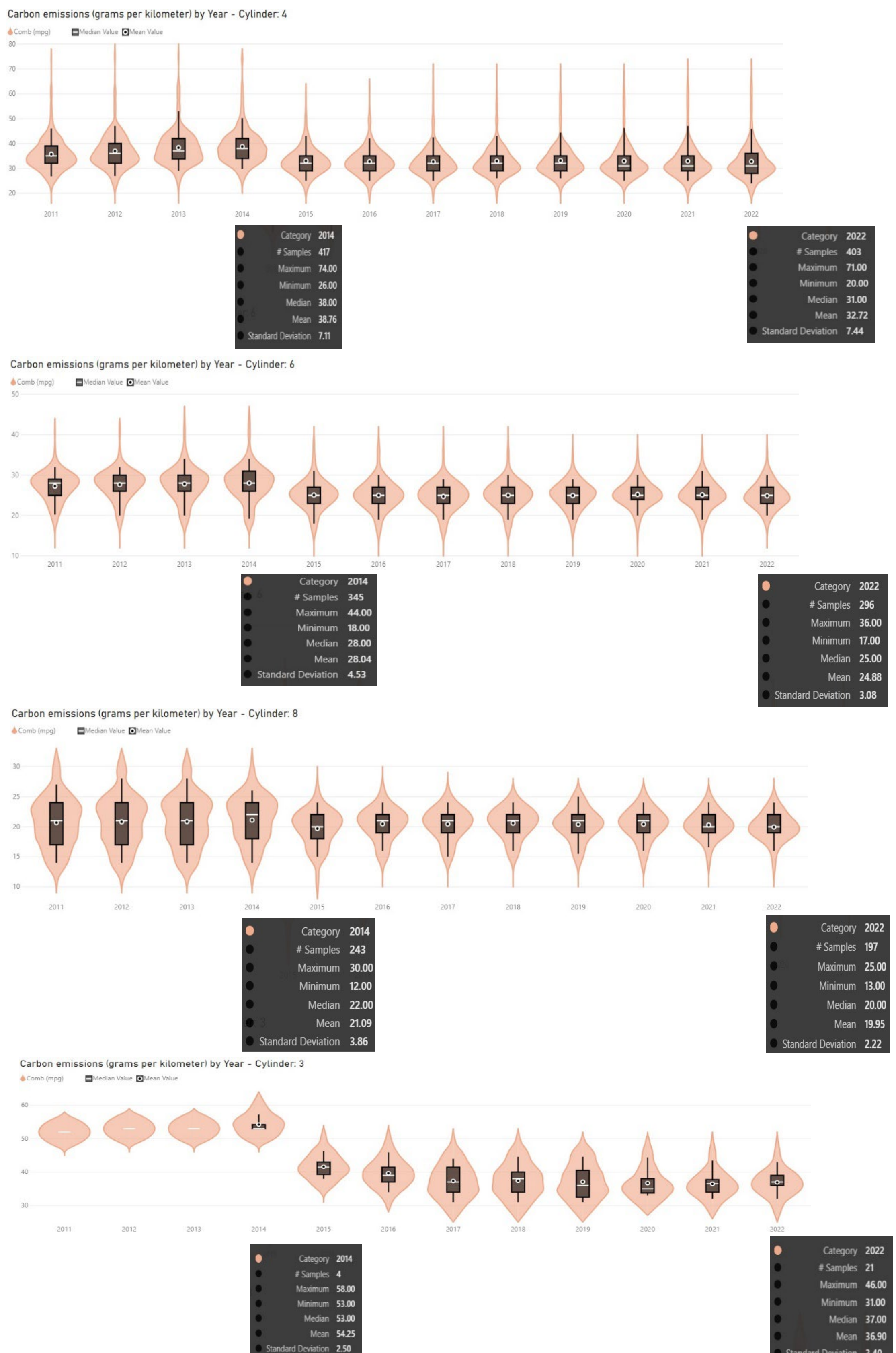

Figure 8. Carbon emissions (gram per kilometer) of four, six, eight, and three cylinder engines from 2011 to 2022.

The engine size is another important factor that can affect the fuel consumption as well as carbon emissions of the vehicles. Car buyers should attention that all three-cylinder vehicles do not have always a better efficiency compared to four-cylinder engine models. This point can be also extracted from figure (10) which shows the average CO2 rating by cylinder and engine size in 2022. Some vehicle models with four-cylinder engines have identical performance compared with some three-cylinder models with the same engine size.

To provide a better comparison regarding the CO2 rating of different vehicle models, figure (11) presents the average CO2 rating (sorted from maximum to minimum) of vehicles by cylinder and engine size. Based on this graph (Mekko Chart), the vehicle models that exist in the market with four cylinders and 1.8 or 1.6 *L* engine size have the maximum average CO2 rating score which equals 7.3. The vehicle models with three cylinders and four cylinders and 1.5 *L* engine size, on average, have similar performance. The difference in the average CO2 rating of twelve-cylinder engine vehicle models is significant between the vehicle models with 6.6 and models with 6 *L* engine size.
Now, focusing on the vehicle classes that have more different models in the market (SUV: small, Mid-size, Compact, Subcompact, Full-size, Station wagon: small, SUV: standard, and Two seaters), figures (12) and (13) compare the proposed vehicle classes in term of the average CO2 rating score and the average combined (city and highway) fuel consumption respectively. The first point from these two graphs is that various models of every class have different performances in consuming fuel and emitting CO2. But among different models of the proposed classes that are available in the market in 2022, the models with 1.8 *L* size engine in the mid-size class and some models with 1.6 *L* engine size from the "Station wagon: small" class have the best performance regarding carbon emissions and fuel consumption.

For different vehicle classes and engine types, figure (14) indicates the engine types of each vehicle class, and sort them based on the CO2 rating score. For instance, the compact class with three cylinders on average has the least carbon emission and fuel consumption.

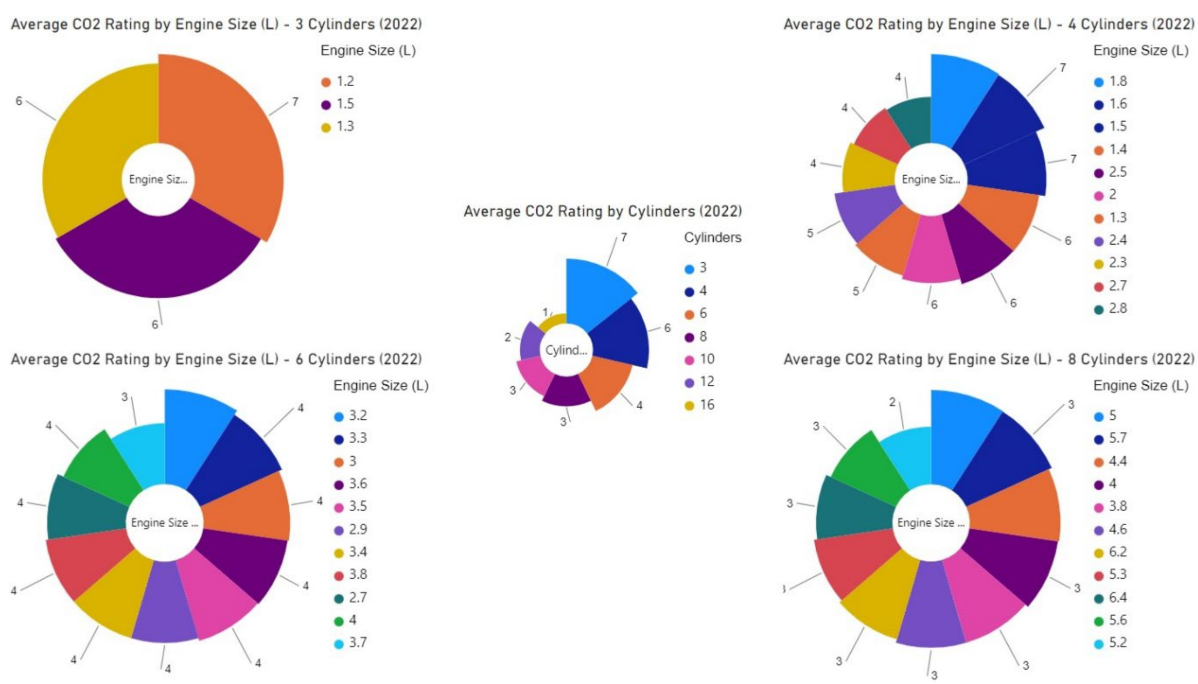

Figure 9. The average carbon emissions rate on a scale from 1 (worst) to 10 (best) by cylinder and engine size in 2022.

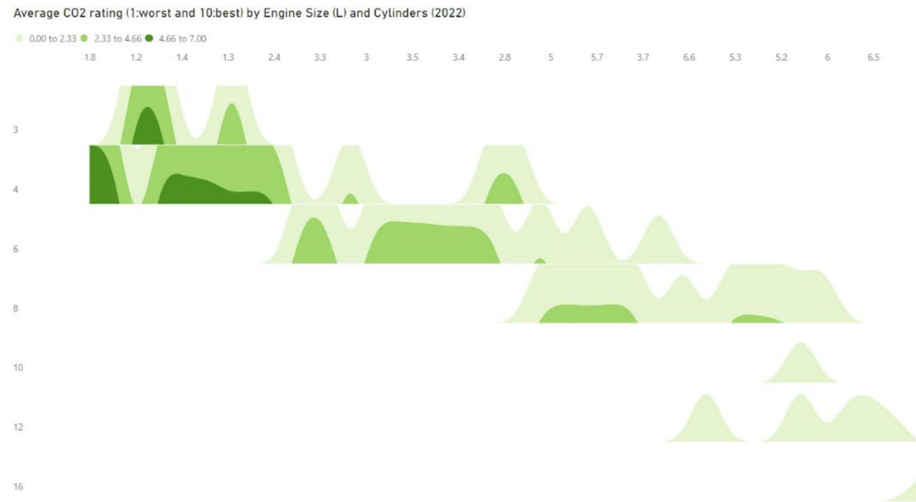

Figure 10. The average CO2 rating by Engine Size (*L*) and Cylinders in 2022.

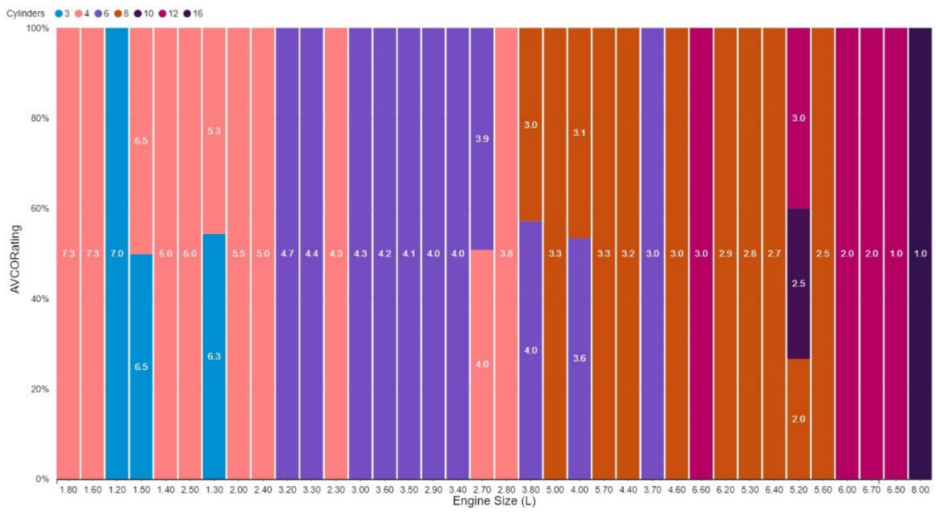

Figure 11. Comparing vehicles by sorting the average CO2 rating considering different Engine Sizes (*L*) and Cylinders for available vehicles in the market in 2022.

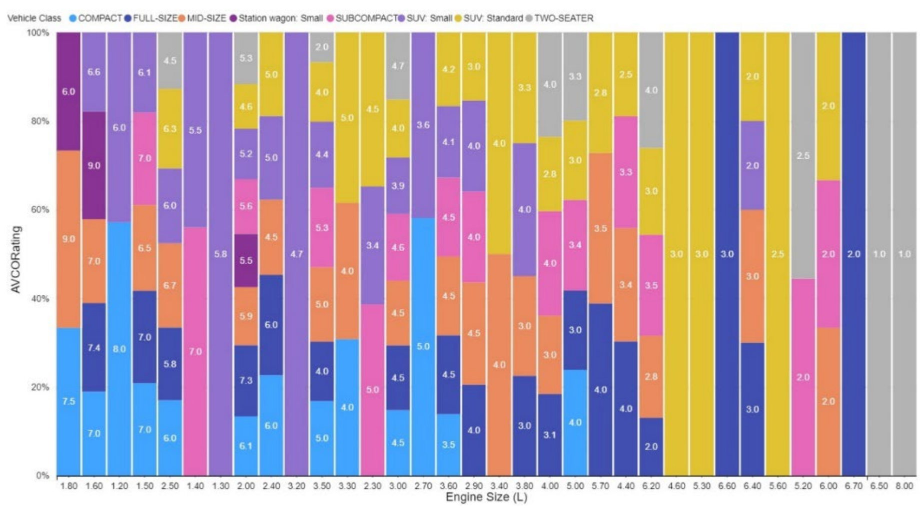

Figure 12. Comparing different vehicle classes in terms of the average CO2 rating score by Engine Size (*L*) for available vehicles in the market in 2022.

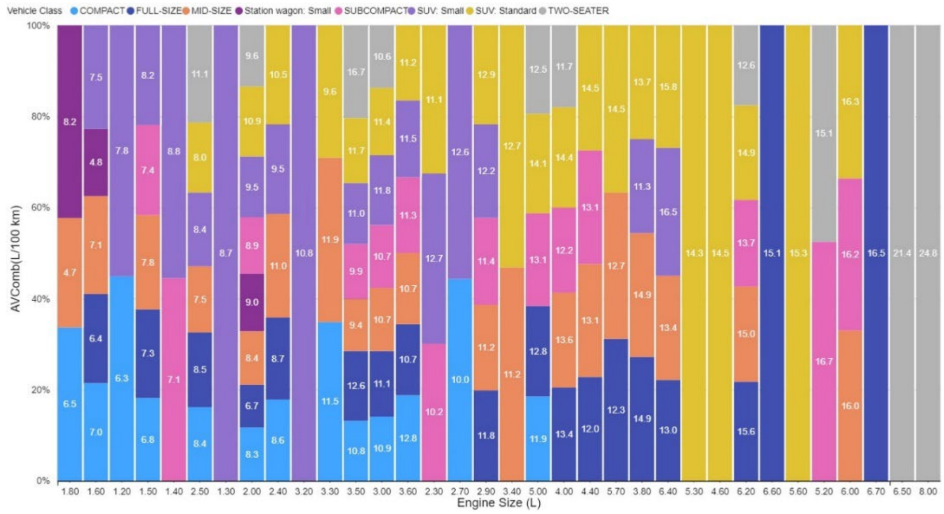

Figure 13. Comparing different vehicle classes in terms of the average fuel consumption (*L/km*) by Engine Size (*L*) for available vehicles in the market in 2022.

As there are many vehicle models that are available in the market each year, providing a database that indicates the amount of CO2 emissions and the fuel consumption can help car buyers to select a vehicle that matches their needs considering the environmental effects. Based on what was analyzed using different types of diagrams and plots, the vehicles with a smaller number of cylinders are not necessarily more environmentally friendly, and the engine size, as well as the vehicle class, should be considered by the buyers. This issue is more remarkable when we are comparing three-cylinder engine vehicles with four-cylinder engine vehicles or vehicles with four cylinders with vehicles with six ones.

Rank	Vehicle Class	Cylinders	AV CO2 Rati...	AV Fuel (L/km)
1	COMPACT	3	8.00	6.35
2	SUBCOMPACT	3	7.00	7.45
3	FULL-SIZE	4	6.86	7.25
4	MID-SIZE	4	6.31	7.98
5	COMPACT	4	6.20	8.16
6	SUV: Small	3	6.17	7.98
7	Station wagon: ...	4	6.11	8.21
8	SUBCOMPACT	4	5.50	9.18
9	SUV: Small	4	5.35	9.30
10	TWO-SEATER	4	5.12	9.92
11	MID-SIZE	3	5.00	9.10
12	SUV: Standard	4	4.88	10.42
13	SUBCOMPACT	6	4.70	10.67
14	MID-SIZE	6	4.57	10.54
15	COMPACT	6	4.44	11.15
16	FULL-SIZE	6	4.28	11.37
17	SUV: Small	6	4.09	11.60
18	SUV: Standard	6	4.00	11.57
19	TWO-SEATER	6	4.00	11.89
20	COMPACT	8	4.00	11.90
21	TWO-SEATER	8	3.50	12.39
22	SUBCOMPACT	8	3.37	13.37
23	FULL-SIZE	8	3.28	13.16
24	MID-SIZE	8	3.13	13.73
25	SUV: Standard	8	2.85	14.55
26	TWO-SEATER	10	2.50	15.13
27	FULL-SIZE	12	2.17	16.30
28	SUV: Small	8	2.00	16.50
29	MID-SIZE	12	2.00	16.00
30	SUBCOMPACT	12	2.00	16.20
31	SUV: Standard	12	2.00	16.30
32	TWO-SEATER	12	1.00	21.40
33	TWO-SEATER	16	1.00	24.80

Figure 14. Sorted Vehicles class with different engine types (in terms of the number of cylinders) based on the CO2 emission rating score and fuel consumption (*L/Km*) for available vehicles in the market in 2022.

2. Conclusion

In this paper, a dataset of different vehicle models that were available in the market in different years from 1995 to 2022 is analyzed to compare various vehicle classes and engine types in terms of fuel consumption and CO2 emissions. The dataset is provided on a government website in Canada to be used by the citizens before deciding to buy a specific vehicle model considering their carbon footprint. After analyzing the dataset using different plots and graphs, the following points can be mentioned as the main outputs of the research.

- The maximum number of vehicle models is related to 2015 and the minimum number of the models is perceived in 1998.
- The vehicle classes that have more than 50% of the market in terms of the number of models include SUVs: small, Mid-size, and Compact classes.
- Companies always provided more models for four, six, eight, and three-cylinder engine vehicles respectively.
- The mean, median, minimum, and maximum amount of fuel consumption has increased for the new models of vehicles (the models that are provided to the market in the last few years) considering four, six, eight, and three-cylinder engine vehicles from 2011 to 2022.
- Except for the four, six, and eight-cylinder engine vehicles the variety of the models in other types is reduced from 2011 to 2022.
- On average the current models of vehicles with eight cylinders are more similar in terms of fuel consumption compared to 10 years ago.
- For vehicles with more than eight cylinders, the difference in fuel consumption in the city and on the highway is more significant compared to the vehicles with three and four cylinders.
- In 2022, all the models of three-cylinder engine vehicles have an average fuel consumption between zero and 8.33 *L/km*. This is the same for most the four-cylinder vehicles except for some models that have an engine size between 1.4 and 2.5 *L*.
- The fuel consumption rate becomes more significant for most of the models with more than six cylinders and with the size of the engine of more than 3.5 liters.
- Regarding the four, six, eight, and three-cylinder engine vehicles, on average the performance in carbon emissions (grams per kilometer) of all types of vehicles with the different numbers of cylinders has improved from 2011 to 2022.
- In 2022, the average CO2 rate of the vehicle models with three-cylinder engines is lower than the other engine types but all the three-cylinder engine models do not have necessarily a better performance in this indicator compared to other vehicle models with a higher number of cylinders.
- Car buyers should consider that all three-cylinder vehicles do not have always a better efficiency compared to four-cylinder engine models. Some vehicle models with four-cylinder engines have identical performance compared with some three-cylinder models with the same engine size in terms of CO2 rating score.
- In 2022, the vehicle models with four cylinders and 1.8 or 1.6 *L* engine size have the maximum average CO2 rating which equals 7.3.
- In 2022, considering vehicle classes SUV: small, Mid-size, Compact, Subcompact, Full-size, Station wagon: small, SUV: standard, and Two seaters, various models of every class have different performances in consuming fuel and emitting CO2. The models with a 1.8 *L* engine size in the mid-size class and some models with a 1.6 *L* engine size from the "Station wagon: small" class have the best performance regarding carbon emissions and fuel consumption. The compact class with three cylinders on average has the least carbon emission and fuel consumption.

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Biography

Behzad Maleki Vishkaei is an Assistant Professor at the Department of Business and Management at Luiss University. Prior to joining Luiss, he was an Assistant Professor at the University of Eyvanekey (Iran), and before that he used to teach as an instructor at several universities in Iran. He cooperated also with different companies as a Strategic Planning and Project Management expert. He holds a Ph.D. in Industrial Engineering from Mazandaran University of Science and Technology (Iran). His research topics focus on Supply Chain Management, Operations Research, Transportation, Digital Transformation, and Smart Cities. He is interested in developing practical models and solutions that can be useful for companies and cities.

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