Monte Carlo Simulation

CO2 emissions in Quebec

Liudmyla Kotusenko, Lourdes Crivelli, Jingyi Zou, Ning Ye

1. Introduction

In September 2019, an outstanding number of people (estimated 500,000) joined Greta Thunberg on her Montreal climate march. After seeing more than a quarter of the city population rallying for a change, we were left wondering what the future greenhouse emissions in Quebec would be like. We have decided to simulate the carbon dioxide emissions generated by private cars and light trucks in Quebec under the current policies and compare them with emissions under alternative policies and changes in consumer attitudes.

2. Database

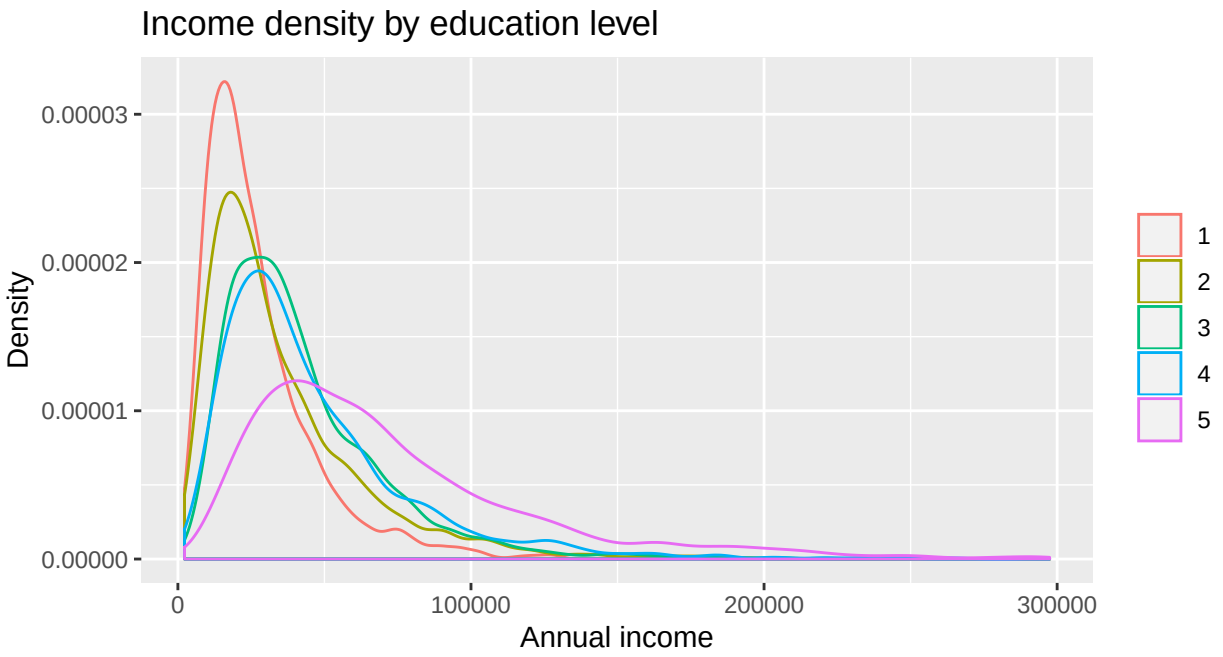
For this study, we built our own database, simulating 10,000 Quebecers aged 18+. For each of those 10,000 people, we generated education level, annual income, distance to work, and type of car owned (or no car). For our scenarios, we also generated a probability to buy an electric/hybrid car or a light truck, based on the characteristics of each scenario.

2.A Consumer Profiles

We collected education and income distribution for Quebec population aged 18+ using the 2016 census microdata by Statistics Canada (StatCan), that can be summarized as follows:

Education level	Group share	Mean annual income, CAD	Annual income standard deviation
No high school	17.5%	26,094	21,747
High School	21.6%	33,819	30,542
Apprenticeship	17.6%	40,311	29,153
College	18.3%	44,437	36,764
University	25.0%	69,022	55,175
Total	100.0%	44,351	40,067

We used the education structure from the table above to randomly generate education levels for our imaginary 10,000 people (a vector of 10,000 values). Then, based on the education level, we randomly generated income for each person (another vector of 10,000 values). For that, we used a log-normal distribution with means and standard deviations from the table above. Since this income is based on 2016 data, we multiplied it by the coefficient of 1.06978 to update it to 2018 levels, assuming income of all education groups grows at the same pace. This coefficient accounts for 4% income growth in 2017 reported by StatCan and assumed 2.8% growth in 2018, which is average growth for 2010-2016. The density plot for generated income per each education level (from 1, the lowest, to 5, the highest) is shown below. We cut somewhat the long tail to make the plot more readable.



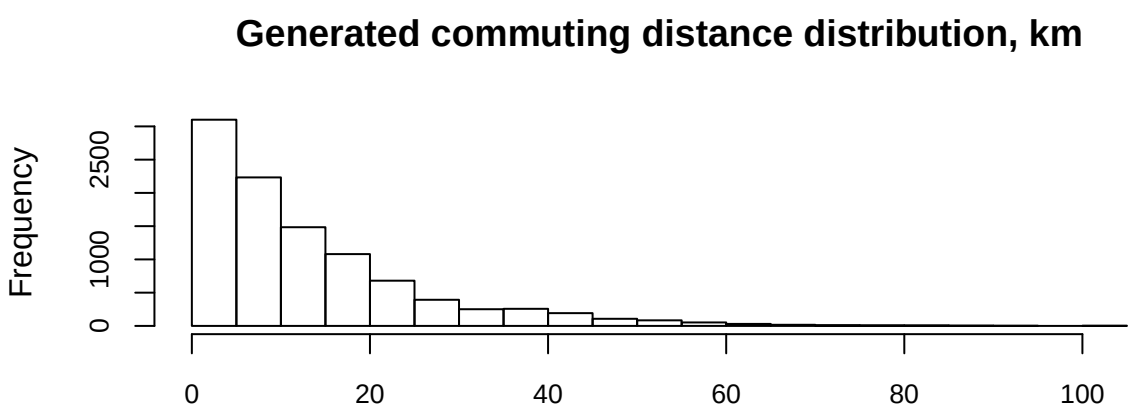
2.B Distance

We used the distribution of distances to work travelled by car, truck or van from 2016 census by StatCan (shown below) to randomly generate distances for each individual. The distance generated was the midpoint of the bins from the StatCan distribution. We split the last bin into 5-km bins (up to 100km) and assumed exponentially declining trend of the share of distances.

Distance to work	Share
Less than 1 km	4.6%
1 to 2.9 km	14.6%
3 to 4.9 km	12.1%
5 to 6.9 km	9.8%
7 to 9.9 km	12.5%
10 to 14.9 km	15.4%
15 to 19.9 km	9.9%
20 to 24.9 Km	6.6%
25 to 29.9 km	4.2%
30 to 34.9 km	2.7%
35 km or more	7.7%

After simulating distances for each person (km), we calculated the total distance travelled in one year per each individual (finalkm) by applying the following formula:

$$finalkm = 2 * 365 * km$$



2.C Car Types and CO_2 emissions

For this project, we consider the following 5 types of vehicles: No Car/ Regular Car (gas) / Light Truck (gas) / Hybrid Car / Electric car.

We could not find car distribution by education level, so we created an artificial distribution based on the following assumptions:

1. The type of car is independent of the distance to work.
2. Car ownership rate in Canada is 87%, so 13% of our 10,000 individuals will have no car [1].
3. We calculated the weighted average share of light trucks in new car sales reported by StatCan in 2010-2018. This share was equal to 50%, so we assume the equal share of cars and light trucks in the private car fleet for 2018. Multiplied by car penetration (87%), these shares reduce to 43.5% for the distribution we will be using to simulate cars.
4. For electric/hybrid cars, we used the real number (52,556) of such cars on the roads [2] and found their share in total registrations provided by Statistics Canada (1%, which turns into 0.87% when multiplied by car penetration, with 50%/50% split for electric/hybrid cars) in 2018. For each education level, we then modified this share to reflect their ownership of the electric/hybrid car as reported in 2018 survey by Angus Reid Institute [3]. According to this survey, people with higher education levels report higher ownership rates of an electric/hybrid car.
5. As education level increases, the average income grows, so we assumed that the proportion of light trucks should grow along with the education level. The table below shows the assumed structure of cars owned per each education level. We used it to randomly generate cars for people with different education levels. For each person, we generated 500 cars (a matrix of 10,000 people * 500 cars).

	No car	Regular car	Light truck	Hybrid car	Electric car
No high school	20.00%	47.77%	31.75%	0.24%	0.24%
High School	16.59%	47.77%	34.96%	0.34%	0.34%
Apprenticeship	13.00%	47.77%	38.49%	0.37%	0.37%
College	13.00%	42.64%	43.50%	0.43%	0.43%
University	5.00%	30.99%	62.65%	0.68%	0.68%
Total	**13.00%**	**42.64%**	**43.50%**	**0.43%**	**0.43%**

We collected CO_2 emissions from NRC Fuel Consumption Guide [4]. For each car type, we took a (weighted) average of CO_2 emissions (in g/km) for the models listed below:

Type of Car	CO_2, g/km	Make / Model Used (average)
No Car	0	Nike
Light Truck	303	Ford F Series / Ram Pickup / GMC Sierra
Regular Car	181	Honda Civic / Toyota Corolla / Hyundai Elantra
Hybrid Car	36	Chevrolet Volt / Toyota Prius
Electric Cars	0	Nissan Leaf / Tesla Model 3 / Chevrolet Bolt EV

To calculate CO_2 emissions, we then multiplied distance travelled per year by CO_2 emissions per km (in g/km) and converted the final amount into thousands of tons of CO_2.

2.D Generating new car purchases

In our scenarios, we look at what happens in 3 years from 2018 given some changes in car prices or consumer preferences. Using StatCan car registrations and new vehicle sales data, we estimate that, on average, about 7% of car owners change their car during a year. We will generate a new car for 21% of people, the expected share to change a car in three years. We assume that the total car fleet does not change over this period, *thus we will be keeping the share of people without a car at the same level (13%) for all scenarios.*

We calculated the individual probability of getting an eco-friendly car based on the following formula:

$$P(eco - friendly) = \frac{W * I * 0.4}{Price}$$

where:

- I is the annual income of an individual
- Price is the price of an electric/hybrid car
- W is the willingness to buy the car of this type

By incorporating income in the formula, we lowered the probability of someone getting a car outside their purchasing power. We used a threshold of 40% income [5]. For the price of an electric/hybrid car, we assumed that the compensation for an electric car is CA$8000, and the compensation for a hybrid car is CA$4000. We used the following prices of electric/hybrid cars in our calculations::

- electric: $45,000*1.15-$8000 = $43,750.
- hybrid: $40,000*1.15-$4000 = $42,000.

The willingness to buy an electric or hybrid vehicle reflects the probability of someone getting an eco-friendly type car given that a person can afford such a purchase. We calculated this variable based on the responses to the following questions from the 2018 survey by Angus Reid Institute:

- *QE5. Suppose you were in the market to buy a new car. If that were the case, how likely do you think you would be to consider a hybrid vehicle?*
- *QE5. Suppose you were in the market to buy a new car. If that were the case, how likely do you think you would be to consider a plug-in electric vehicle?*

For each of the questions, we took the share of answers for "Definitely would consider this" per each education level and corrected them for Quebec (consideration levels for hybrid/electric cars in Quebec are lower than for the whole Canada). We divided those numbers by two to approximately match the share of new hybrid and electric cars "bought" in our simulation (scenario #1) and the expected share of hybrid and electric cars bought in the province in 2019. We assume the sales of hybrid/electric cars in 2019 to be 26,000 (double the sales for the first six months of 2019 presented by Association des véhicules électriques du Québec). The share of hybrid/electric vehicles sold should be about 5.5-5.8% in new car sales (including regular cars and light trucks).

The final values for the willingness to buy an electric/hybrid car per each education level are shown in the table below. The table also contains *the probability to buy a light truck for each education level*. This probability is different from the one we used to simulate our baseline scenario since the share of light trucks in new car sales has been steadily growing since 2015, according to StatCan. In 2018, light trucks accounted for 63% of the new vehicle purchases (or 54.8%, if multiplied by 87% car penetration). To simplify our model, we will keep this share unchanging through the three years, though in real life it is growing. For each education level, we created its own probability to buy a light truck, with higher probabilities for higher education levels.

Education	Hybrid car (willingness to buy)	Electric car (willingness to buy)	Light truck (Prob. to buy)
No high school	3.8%	4.3%	40.0%
High School	3.8%	4.3%	44.0%
Apprenticeship	5.7%	5.6%	48.5%
College	5.7%	5.6%	54.8%
University	9.5%	10.4%	78.9%
Total	**5.9%**	**6.3%**	**54.8%**

For the probability to buy a regular car, we treated it as our lost degree of freedom and allowed it to change to ensure that all the probabilities add up to one. We also assumed that people would rather switch to an electric/hybrid car from a regular car than from a light truck.

3. Scenarios

3.A Baseline CO_2 emissions for 2018 (S0)

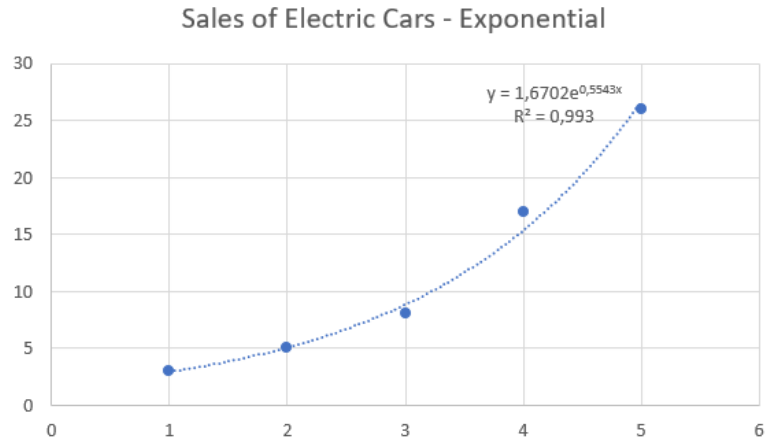
For our baseline, we simulated current cars based on the car distribution for each person and repeated it 500 times. Distances were created once for each person following the distance distribution. The baseline for CO_2 emissions was calculated by multiplying the simulated distance travelled per year by CO_2 emissions per km of the car type. The result has been converted into thousands of tons of CO_2 to facilitate the comparison.

3.B CO_2 emissions in 3 years when 21% of our database change their cars

The following scenarios are all based on the same basic assumption that 21% of the sample will change their cars in 3 years. We randomly pick 21% of the sample and replace their current cars with new cars (which can be the same as before or a new type of car). For each of the scenarios, we run the simulation 500 times per person. With the fixed distance, we calculate the CO_2 emissions for each run and then aggregate those to compare scenarios.

We analyze the following scenarios:

- **Scenario 1 - Under the current policy / prices / consumer preferences**. For our first scenario, we simulate new cars assuming that the current policy, car prices and consumer preferences stay the same as today.
- **Scenario 2 - Electric/hybrid car price goes down by 10%**. We assume that prices for eco-cars go down by 10% due to market competition or additional compensation from the government.
- **Scenario 3 - Electric/hybrid car price goes down by 25%**. In this scenario, we assume a higher price decrease for an electric/hybrid car. We expect lower CO_2 emissions in this scenario than in scenario 2.
- **Scenario 3a - BLACK FRIDAY - Electric/hybrid car price goes down by 40%!** As Black Friday is coming, we make an assumption that the price of electric/hybrid cars is dropping 40% to see if there is any significant change in CO_2 emissions.
- **Scenario 4 - Willingness to buy an electric/hybrid car increases by 20%**. In this scenario we change individuals' willingness to buy such a car directly. The willingness to buy an electric/hybrid car may grow due to an environmental campaign or an increasing number of charging stations.
- **Scenario 5 - Willingness to buy an electric/hybrid car increases by 40%**. In this scenario, CO_2 emissions should be lower than those in scenario 4.
- **Scenario 6 - Willingness (probability) to buy a truck declines by 10%**. The declining willingness to buy a light truck may be caused by increasing tax on buying trucks or by growing environmental consciousness of the consumers.
- **Scenario 7 - Willingness (probability) to buy a truck declines by 20%**. In this scenario, CO_2 emissions should be lower than those in scenario 6.
- **Scenario 8 - Electric/hybrid car price goes down by 10% and the willingness to buy an electric/hybrid car increases by 20%**. For this scenario, we combined the decline in price for electric/hybrid cars and the increased willingness to buy an electric/hybrid car.
- **Scenario 9 - Exponential growth in electric/hybrid car sales over the three years**. We observe a clear exponential trend in eco-car sales in the market. In this scenario, we approximate the exponential trend in eco-friendly car sales as shown by the Association des véhicules électriques du Québec. This would be equivalent to doubling the willingness to buy an electric/hybrid car (component W of the probability to buy an eco-car).

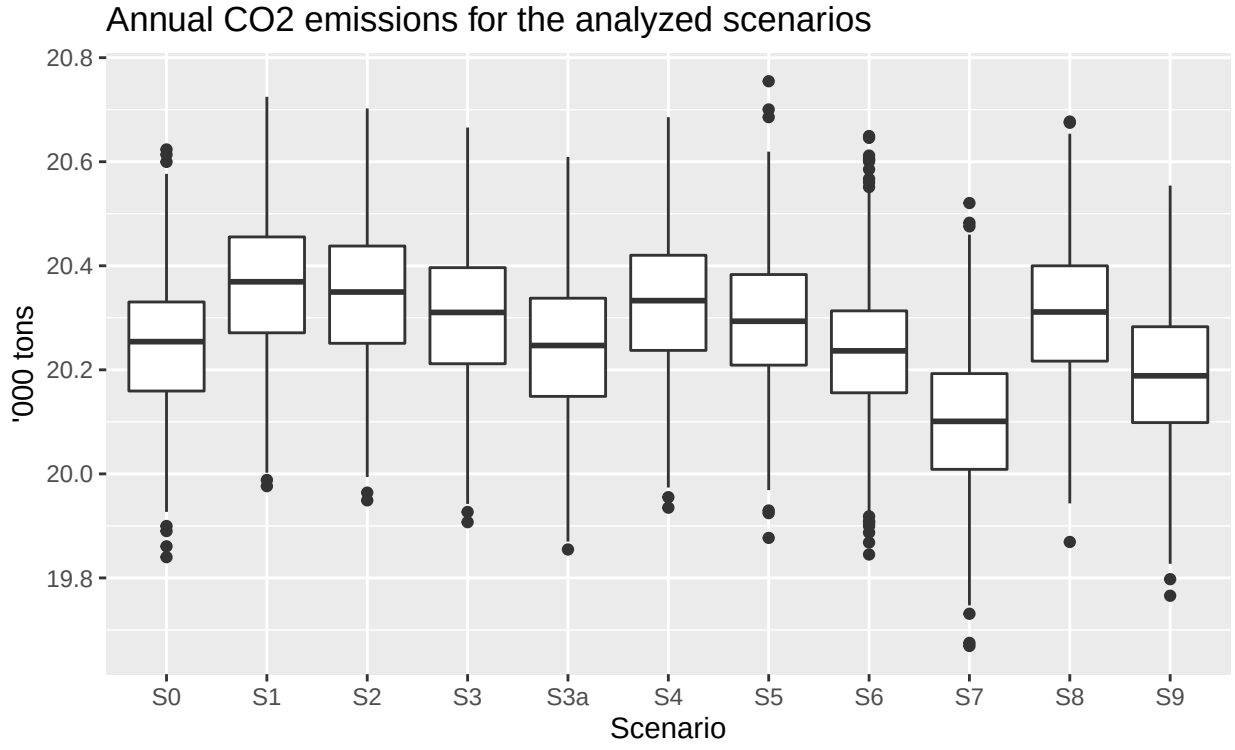


Year	Sales	Prediction Exponential
2015	3	2,91
2016	5	5,06
2017	8	8,81
2018	17	15,34
2019	26 (estimate)	26,69
2020	No Data	46,47
2021	No Data	80,89

Scenario	Price Down Eco-car	Increase in Will to buy Eco-car	Decrease Will to buy light truck
Scenario 1	-	-	-
Scenario 2	10%	-	-
Scenario 3	25%	-	-
Scenario 3a	40%	-	-
Scenario 4	-	20%	-
Scenario 5	-	40%	-
Scenario 6	-	-	10%
Scenario 7	-	-	20%
Scenario 8	10%	20%	-
Scenario 9	-	200%	-

4. Results

Compared to the baseline, scenario 1 demonstrates an increase in CO_2 emissions. This happens due to the growing share of light trucks in the car fleet (an accurate reflection of the increasing light truck sales in Quebec). Even though we keep the share of light trucks purchased in the scenario stable over the 3-year period, their number in the car fleet is growing fast due to their high base. This offsets the positive impact of the increased number of eco-friendly cars. The share of the latter, although growing fast in relative terms, still remains small to have a significant effect on CO_2 emissions.



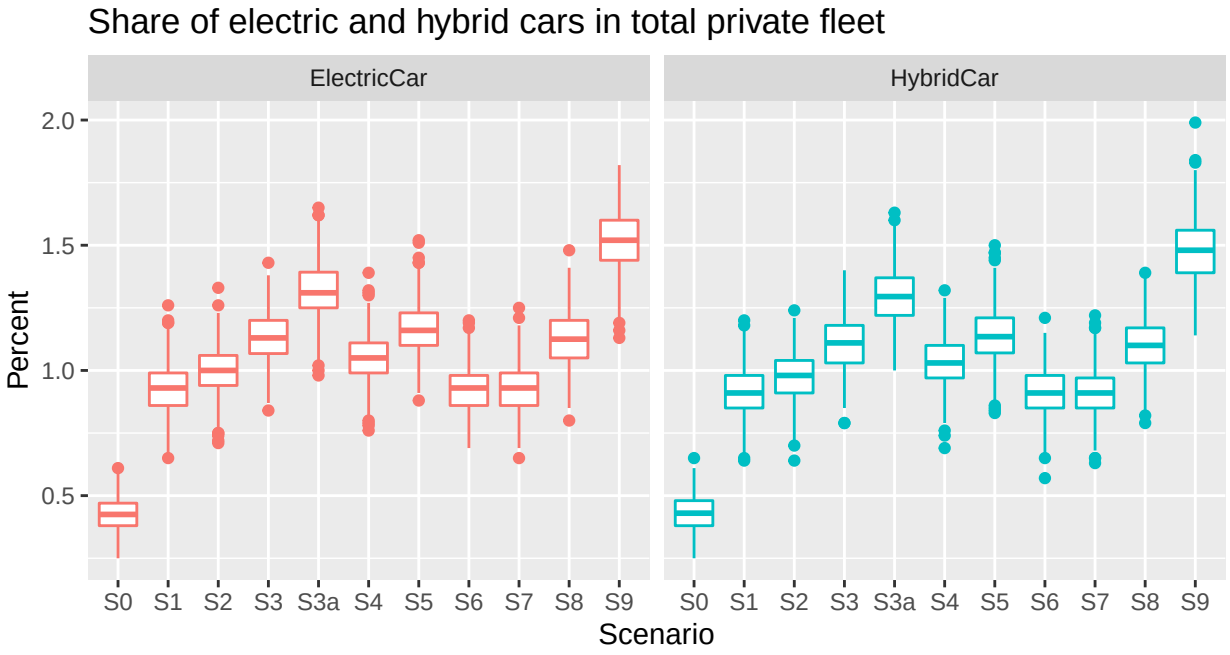
Among the scenarios involving the price change of electric/hybrid cars (S2, S3, S3a, S8), we can see that the scenario 3a, though highly unlikely in reality, produces the lowest CO_2 emissions, which is due to 40% decrease in prices for electric/hybrid cars. Although this is the best scenario among price-changing scenarios, its effect is worse than decreasing the willingness to buy a light truck (scenarios 6 and 7).

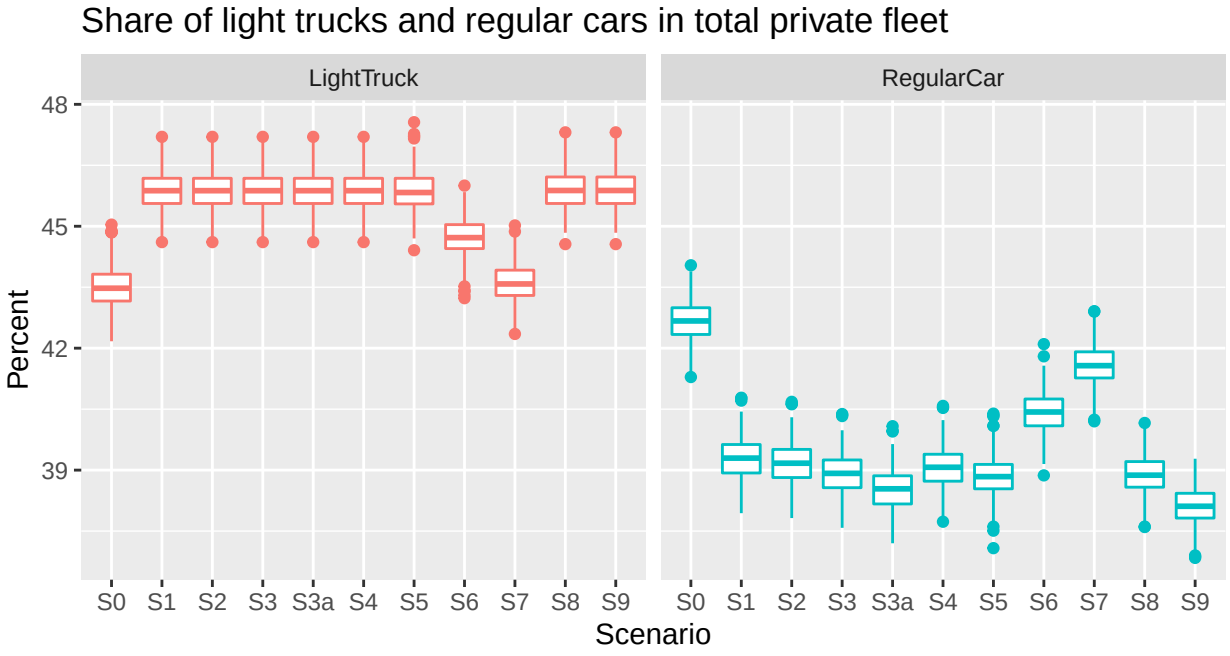
As a result of the price decrease by 10%, 25% and 40% in scenarios 2, 3 and 3a, the share of eco-friendly

cars in total car fleet grows, on average, by 7%, 21% and 42% vs scenario 1 where we assume current policies and unchanged consumer preferences.

When it comes to changing the willingness to buy a car, emissions decline faster when we reduce incentive to buy a light truck by 20% (scenario 7) than when we increase the awareness of and willingness to buy eco-friendly cars (scenarios 4, 5 and 9). Even when doubling the willingness to buy a "green" car in scenario 9, it was unable to compete against a 20% decrease in willingness to buy light trucks.

When it comes to eco-car sales, the scenarios that significantly increased our fleet where 9 and 3a (doubling willingness to buy, an equivalent of the exponential growth of eco-friendly car sales, and Black Friday sale approach). This proves that our model is sensitive to different stimuli, but without contradicting what would be expected from the reality.





5. Conclusions

Our initial theory was that increasing the number of electric/hybrid car purchases would have a meaningful impact on the amount of CO_2 generated. However, none of our scenarios resulted in a significant decrease in CO_2 emissions. Even though some scenarios showed declining CO_2 emissions compared to the baseline (3a, 6, 7 and 9), the reduction in mean emissions was less than 1%. In the remaining scenarios, however, we even observed increasing CO_2 emissions vs the baseline which was due to the growing share of light trucks in the car fleet.

After running several scenarios with price decrease for eco-friendly cars, we realized that the price by itself was not able to revert the CO_2 output. We then opted to change the willingness to buy an eco-car, making sure that our results would be in line with the market trends. Although we more than doubled the fleet of eco-friendly cars, no scenario was able to make a considerable impact on CO_2 emissions.

Instead of trying to push the electric / hybrid sales, the focus should be on reducing the number of people getting a light truck. Increasing taxation, raising awareness of the pollution, introducing market quotas,- these are some examples of policies that could be taken into account. As seen in our results, the best scenario is the one that reduces the willingness to buy a light truck by 20%. Since light truck sales in Quebec are constantly increasing, we would advise to take such an action as soon as possible.

6. References

[1] https://www.cipma.org/2018/04/12/millennial-ownership-of-vehicles-in-canada/

[2]https://www.aveq.ca/actualiteacutes/statistiques-saaq-aveq-sur- lelectromobilite-au-quebec-en-date-du-30-juin-2019-infographie

[3] http://angusreid.org/electric-vehicles/

[4] https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/fuel-consumption-guide/21002

[5] http://www.realcartips.com/carloans/389-loan-based-on-income-credit.shtml

[6]https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/dt-td/Rp-eng.cfm?LANG=E&APATH=3&DETAIL=0&DIM=0&FL=A&FREE=0&GC=0&GID=0&GK=0&GRP=1&PID=110716&PRID=10&PTYPE=109445&S=0&SHOWALL=0&SUB=0&Temporal=2017&THEME=125&VID=0& VNAMEE=&VNAMEF=

Other sources:

[7] http://www.nxtbook.com/dawson/desrosiers/cuvr2017/index.php?startid=58#/60

[8] https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701

[9] https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010000201