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Do Electric Vehicles Make Carbon-Sense in Nova Scotia?
A Well-to-Wheels Analysis Using
Nova Scotia Power's Electricity-Fuel Mix

An analysis of electric vehicles and
their potential impact on Nova Scotia's passenger vehicle emissions

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Glossary

AER	All Electric Range
CO_2e	Carbon dioxide equivalent
CV	Conventional Vehicle
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
G	Gram
GtB	Generation-to-Battery
GHG	Greenhouse gases
HEV	Hybrid Electric Vehicle
kg	Kilogram
km	Kilometre
kWh	Kilowatt-hour
NRCan	Natural Resources Canada
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid-Electric Vehicle
t	Metric tonne
TtW	Tank-to-Wheels
WtB	Well-to-Battery
WtG	Well-to-Generation
WtT	Well-to-Tank
WtW	Well-to-Wheels

1 Introduction

The rising levels of atmospheric greenhouse gases caused by the increased use of fossil fuels for energy services—notably transportation, heating, and the generation of electricity—is acknowledged to be one of the principal drivers of climate change. In the recent past, those jurisdictions attempting to address greenhouse gas emissions have focused primarily on the generation of electricity from fossil-energy sources (primarily coal and to a lesser extent, oil) since the large-scale, stationary production of greenhouse gases was seen as an easier "fix" than mobile ones. This approach to addressing the issue of greenhouse gas emissions may be changing with the advent of the electric vehicle since numerous studies have shown that vehicles propelled by electricity typically have a lower greenhouse gas intensity (expressed as CO_2e/mile or CO_2e/km) than conventional vehicles.

This report considers the effect of introducing plug-in electric vehicles for commuting purposes in Nova Scotia; the results are extrapolated from commuting to annual driving scenarios. The approach taken is different from the EPRI report, *Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions* (EPRI, 2007), which determines annual emissions based on the vehicle's Utility Factor (UF), the distance driven electrically and non-electrically (i.e., with gasoline). In the EPRI report, a variety of UFs were presented for different plug-in hybrid-electric vehicles, notably 0.12 (PHEV 10), 0.49 (PHEV 20), and 0.66 (PHEV 40);[1] rather than employing the EPRI Utility Factor, this report calculates the total emissions (well-to-tank and tank-to-wheels in addition to well-to-generation and generation-to-battery) for each type of vehicle potentially used for passenger transportation in Nova Scotia.

The four different vehicles considered in this report are listed in Table 1.

Table 1: Vehicles examined in this report

Vehicle	Type	Size	Curb weight (lbs)	GVW[2] (lbs)	Number of passengers
Hyundai Elantra[3] (Hyundai Canada, n.d)	Conventional	Mid-Size	2,661 to 2,820	3,792	5
Toyota Prius (Toyota Canada, n.d.)	Hybrid-electric	Mid-Size	3,042	3,980	5
Nissan Leaf (Nissan, 2011)	Plug-in electric	Mid-Size	3,366	4,322	5
Chevy Volt (GM, 2011)	Plug-in hybrid	Compact	3,781	N/A	4

The fuel intensity associated with each vehicle is presented in terms of city driving and highway driving. Highway driving with a gasoline vehicle invariably has better fuel economy than city driving because of the stop-and-start characteristics of city driving; however, the opposite is true for electric vehicles because the electric motor can shutdown when stopped, whereas the gasoline vehicle must continue running. NRCan assumes that the distance an average Canadian

[1] All EVs have an "all electric range", or AER, expressed as the number of miles that a fully-charged vehicle can travel before needing a full recharge. The AER is written as a number after the vehicle type; in the EPRI report, a PHEV 10 indicates that the vehicle has an all-electric range of 10 miles. Examples of production vehicles include the Chevy Volt (PHEV 35; a 35 mile AER) and the Nissan Leaf (PEV 73; a 73 mile AER). As with all vehicles, regardless of energy source, the actual distance travelled will depend on a number of factors, including driving conditions, driving habits, road conditions, and weather conditions, including temperature.

[2] Gross Vehicular Weight

[3] Elantra's Gross Vehicular Weight is for 2012.

vehicle travels has a city-highway ratio of 55:45; the report uses this ratio in determining the combined city-highway driving fuel economy.

1.1 Differences between U.S. and Canadian vehicle fuel-intensity data

Although both the U.S. and Canada rate the fuel intensity of most commercially available vehicles in their respective countries, there are differences in the results obtained. In the U.S., a vehicle's fuel economy (fuel intensity) is based on the U.S. EPA's 5-cycle testing procedure: city driving, highway driving, cold temperature operation, high speed/quick acceleration, and air conditioning (U.S. DOE, 2011). In Canada, a vehicle's fuel consumption (fuel intensity) data is obtained from the Federal Test Procedure (FTP) and consists of city and highway testing cycles (Transport Canada, 2010). Examples of these differences are shown in Table 2, which compares U.S. and Canadian results for five of the best fuel consumption vehicles in Canada (NRCan, 2011). The differences are the ratio (expressed as a percentage) of a vehicle's Canadian fuel consumption and its U.S. fuel economy.

Table 2: Comparison of Canadian fuel consumption with U.S. fuel economy (U.S. DOE, 2011), (NRCan, 2011)

Vehicle	U.S. Fuel Economy Data[4]		Canadian Fuel Consumption Data		Ratio	
	City l/100km	Highway l/100km	City l/100km	Highway l/100km	City	Highway
Hyundai Elantra (Mid-size)	8.1	5.9	6.8	4.9	83.8%	83.3%
Toyota Prius (Mid-size)	4.6	4.9	3.7	4.0	80.2%	81.6%
Honda Civic Hybrid (Compact)	5.9	5.5	4.7	4.3	79.9%	78.6%
Honda Accord Sedan (Full size)	10.2	6.9	8.8	5.8	86.0%	83.8%
Hyundai Sonata (Full size)	9.8	6.7	8.7	5.7	88.8%	84.8%

1.2 Other assumptions

When no Canadian data is available, the report uses data from the EPRI report. When U.S. data is taken from the EPRI report it is converted to metric as required; the conversion factors used are summarized in Table 3.

[4] U.S. fuel economy data converted from standard units (miles per gallon) to litres per 100km using the equation 235.2 ÷ mpg.

Table 3: Conversion factors

From	To	Factor
1 mile	Kilometre	1.609344
1 U.S. gallon	Litres	3.7854
1 Canadian gallon	Litres	4.546

2 Conventional Vehicles

A conventional vehicle (CV) is one that has a gasoline engine and operates exclusively on gasoline.

2.1 Estimating emissions per kilometre

The greenhouse gas emissions associated with a CV are considered to come from two sources: the extraction, production, and distribution of the gasoline (referred to as well-to-tank emissions) and the consumption of gasoline while driving (referred to as tank-to-wheels emissions). The well-to-wheels emissions per kilometre are the sum of the well-to-tank and tank-to-wheels emissions (equation 1).

$$GHG_{WtW/km} = GHG_{WtT/km} + GHG_{TtW/km} \tag{1}$$

With the emissions per kilometre known, the total emissions over a given distance can be obtained using equation 2.

$$GHG_{Total} = Distance \times GHG_{WtW/km} \tag{2}$$

The greenhouse gas emissions per kilometre and the total greenhouse gas emissions can be obtained using equations 1 and 2 with the respective fuel economies for city-driving, highway-driving, and combined city-highway driving.

2.1.1 Well-to-tank emissions

At a minimum, to obtain the well-to-tank emissions, it is necessary to know the sources of the crude oil, the method of transporting them, the quality of the crude, the refining process, how the refined gasoline is distributed, and the source of electricity to operate the filling-station's fuel pumps. Since this data is not easily attainable in Nova Scotia, EPRI values are used instead.

The EPRI report estimates that in the United States, a CV with a fuel economy of 24.6 miles/gallon (10.5 km/litre) emits 100g CO_2e/mile (62.1g CO_2e/km). The emissions associated with other vehicles depend upon their fuel economy and the ratio shown in equation 3 (reworked from the non-metric version in the EPRI report).

$$GHG_{WtT/km} = \frac{10.5}{Fuel\ Economy} \times 62.1 \tag{3}$$

Well-to-tank emissions are determined from the fuel economy and can be calculated for either city or highway driving.[5]

EPA fuel economy is expressed as miles per gallon, whereas NRCan fuel consumption data is given in terms of litres-consumed per 100 kilometres. The reciprocal of fuel consumption is used as the fuel economy for Canadian vehicles (i.e., kilometres per litre).

2.1.2 Tank-to-wheels emissions

The source of the tank-to-wheels emissions is the combustion of gasoline to propel the vehicle. When one U.S. gallon of gasoline is combusted, it yields approximately 9260g of CO_2e (carbon-dioxide equivalent), of which about 95% are attributable to CO_2 and the remainder being a mixture of methane (CH_4), nitrous oxide (N_2O), and hydro fluorocarbons (HFCs) (EPA, 2011). The metric equivalent is 2446g CO_2e/litre.

As with well-to-tank emissions, tank-to-wheels emissions depend upon the vehicle's fuel economy; the method to obtain the estimated tank-to-wheels emissions is shown in equation 4 (from the EPRI report).

$$GHG_{TtW/km} = \frac{2446}{Fuel\ Economy} \tag{4}$$

Tank-to-wheels emissions are determined from the fuel economy and can be calculated for either city or highway driving.

2.2 Hyundai Elantra

The Hyundai Elantra with manual transmission is the most fuel-efficient mid-sized CV in Canada, its fuel consumption and fuel economy are shown in Table 4. Like other CVs, the Elantra has better highway than city fuel economy (km/litre) and hence has lower emissions for highway driving (151.7g CO_2e/km$_{Highway}$) than for city (210.5g CO_2e/km$_{City}$).

Table 4: Hyundai Elantra fuel consumption and emissions (NRCan, 2011)

Driving characteristics	Fuel consumption (litres/100 km)	Fuel economy (km/litre)	Well-to-tank emissions (gCO_2e/km)	Tank-to-wheels emissions (gCO_2e/km)	Total emissions (gCO_2e/km)
City	6.8	14.7	44.2	166.3	210.5
Highway	4.9	20.4	31.8	119.9	151.7
Combined	5.9	16.8	38.6	145.4	184.1

3 Hybrid Electric Vehicles

A hybrid electric vehicle (HEV), like a CV, operates exclusively on gasoline; however, it uses a combination of gasoline and electricity generated on-board for propulsion. Electricity is

[5] The EPRI report expects well-to-tank emissions to fall from 100g CO_2e/mile in 2010 to 75g CO_2e/mile in 2050; this is due to improvements in gasoline vehicle's fuel economy of 0.5% per year. With no indication of Nova Scotia's 2010 or 2020 well-to-tank emissions, the emissions are assumed to be constant over this period (62.1g CO_2e/km)

generated from the gasoline engine powering a generator (typically the electric motor run in reverse) and from regenerative braking (a generator is connected to the wheels and when braking is required, the generator is enacted, causing the vehicle to slow down). On-board batteries store any electricity that is generated. HEVs that use the electric drive for start-stop city driving have an advantage over gasoline vehicles in that when idling, the electric motor is turned off, whereas a gasoline vehicle remains running when idling. Broadly speaking, there are two classes of HEV, partial hybrid and full hybrid.

A partial hybrid (often simply referred to as a "hybrid") uses a gasoline engine for most propulsion, although the electric motor is used for rapid acceleration; for example, when passing another vehicle or climbing a hill (U.S. DOE, 2011).

A full hybrid uses a gasoline engine for generating electricity only; all other propulsion is done using the electric motor. Full hybrids have better fuel economy and hence have lower emissions than gasoline vehicles or partial hybrid vehicles (U.S. DOE, 2011).

With the exception of some electricity produced from regenerative braking, a HEV, like a CV, uses gasoline for propulsion; accordingly, equations 1 through 4 are employed in determining the emissions associated with a HEV.

3.1 Toyota Prius Hybrid

The Prius is Toyota's full hybrid version and is the best selling HEV in Canada (Toyota, 2011). Since the Prius uses its electric drive when in low-speed, start-stop city driving, it has better fuel economy (km/litre) than when used in highway conditions; as a result, emissions associated with city driving (114.6g CO_2e/km_{City}) are less than those for highway driving (123.8g $CO_2e/km_{Highway}$).

Table 5: Toyota Prius Hybrid fuel consumption and emissions (NRCan, 2011)

Driving characteristics	Fuel consumption (litres/100 km)	Fuel economy (km/litre)	Well-to-tank emissions (gCO_2e/km)	Tank-to-wheels emissions (gCO_2e/km)	Total emissions (gCO_2e/km)
City	3.7	27.0	24.0	90.5	114.6
Highway	4	25.0	26.0	97.8	123.8
Combined	3.8	26.1	24.9	93.8	118.7

4 Plug-in Electric Vehicles

A plug-in electric vehicle (PEV) is one that operates exclusively on electricity. The electricity it uses is stored in a battery (equivalent to the CV's tank) and charged with electricity from a generation source.

4.1 Estimating emissions per kilometre

Any greenhouse gas emissions associated with a PEV are assumed to come from the supplier of the electricity and are referred to as the well-to-battery emissions (equivalent to the well-to-tank emissions in a CV). Since the vehicle is electric, there are no battery-to-wheels emissions; any emissions are from well-to-battery.

The well-to-battery emissions per kilometre depend upon:

- The emissions associated with the upstream production and transportation of energy sources from the well (e.g., mine) to the place of generation; these emissions can include fugitive emissions of, for example, methane from coal mines or natural gas pipelines.
- The vehicle's charging efficiency, expressed in terms of the AC kWh consumed per kilometer in the charging process and the efficiency of the charging process (the conversion efficiency).
- The electricity supplier's emissions intensity, expressed in grams CO_2e emitted per kWh.

One approach to finding the well-to-battery emissions per kilometre is to first estimate the total emissions associated with the supply chain of every fuel source used by the electricity supplier (well-to-generation) and the total emissions from the electricity supplier's generating facilities (generation-to-battery); from this, the emissions intensity (gCO_2e/kWh) can be obtained, as shown in equation (5.

$$Emissions\ intensity_{WtB} = \frac{\sum Supply\ chain\ emissions + \sum Generation\ emissions}{Total\ electricity\ generated} \tag{5}$$

With this, the well-to-battery emissions per kilometer can be determined from the product of the emissions intensity and the vehicle's electricity consumption per kilometer using equation 6.

$$GHG_{WtB/km} = \frac{Electricity\ consumed\ per\ km}{Conversion\ Efficiency} \times Emissions\ intensity_{WtB} \tag{6}$$

Given the number of possible emissions associated with different supply chains, well-to-generation emissions are often omitted from calculations of well-to-battery emissions; for example, the EPRI report makes no mention of them. Some effort has been made to address this issue (for example, see (Weisser, 2007) and (Samaras & Meisterling, 2008)); U.S. EPA is presently developing a method to determine well-to-generation emissions (EPA, n.d.).

4.2 Nissan Leaf

The Nissan Leaf is a PEV with an EPA estimated 73 mile (117.5 km) range on a single charge (that is, it is a PEV 73); its city and highway electric fuel economy are shown in Table 6. At the time of writing, the Leaf had not been evaluated by NRCan, meaning that the Leaf data for Canada had to be estimated from EPA data: its Canadian range is estimated to be 160 km (from EPA LA4 city testing (Nissan Canada, n.d.)), and its estimated city, highway, and combined fuel consumptions are shown in Table 6. The well-to-battery emissions (i.e., well-to-generation and generation-to-battery) per kilometre are specific to the electricity supplier.

Table 6: Nissan Leaf fuel economy and estimated fuel consumption

Driving characteristics	Fuel economy (U.S. DOE, 2011)			Estimated fuel consumption[6]
	kWh/100mile	kWh/100km	kWh/km	kWh/km
City	32	19.9	0.199	0.167
Highway	37	23.0	0.230	0.192
Combined	34.3	21.3	0.213	0.178

Assuming that the Leaf's electrical consumption includes the conversion efficiency (none is specified), the well-to-battery emissions are simply the fuel consumption (0.167 kWh/km$_{City}$ or 0.192 kWh/km$_{Highway}$) divided by the electricity supplier's emissions (g CO_2e/kWh). Since this can vary by supplier, Figure 1 shows the expected emissions per kilometre for electricity suppliers with well-to-battery emissions intensities ranging from a low of 100g CO_2e/kWh to 1,000g CO_2e/kWh. "Highway" refers to a Leaf being driven under highway conditions, while "City" refers to driving a Leaf in city conditions.

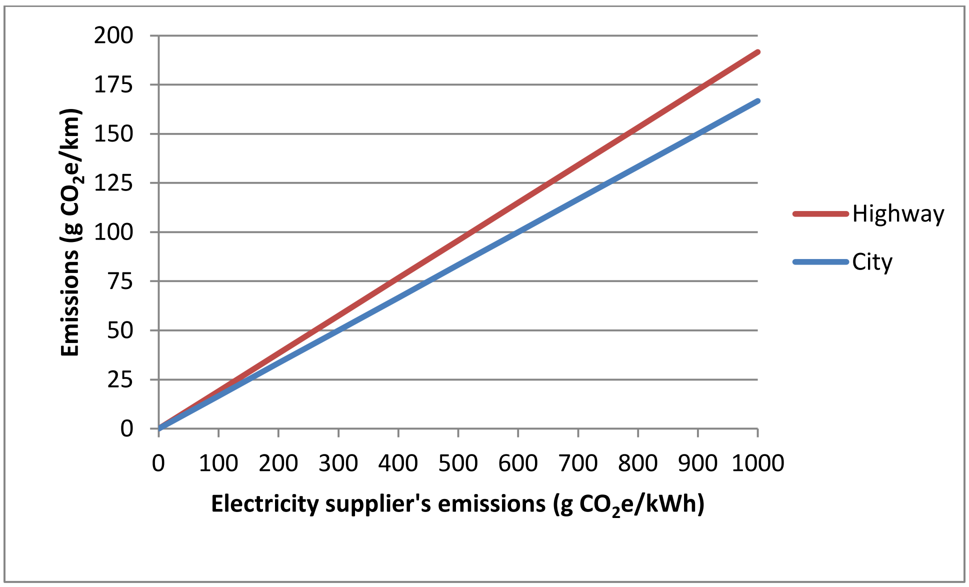

Figure 1: Nissan Leaf – emissions vary depending upon supplier's emissions intensity

In the case of the Nissan Leaf, the CO_2e emissions per kilometre range from 16.7g CO_2e/km$_{City}$ or 19.2g CO_2e/km$_{Highway}$ for an electricity supplier with an emissions intensity of 100g CO_2e/kWh to 166.7g CO_2e/km$_{City}$ or 191.5g CO_2e/km$_{Highway}$ for a supplier with an intensity of 1,000g CO_2e/kWh.

[6] The multiplier used to obtain the Leaf's Canadian fuel consumption was 0.838 for city and 0.833 for highway (from the median values in Table 2, 83.8% and 83.3%). These were applied directly to the Leaf's fuel economy. The Leaf's combined Canadian value was obtained from the weighted average (55:45) of the city and highway multipliers.

5 Plug-in Hybrid-Electric Vehicles

A plug-in hybrid-electric vehicle (PHEV) is one that can operate as an EV or as a CV. The EPRI report assumes that when driven, the PHEV operates exclusively as an EV (i.e., exhausting its battery) before operating as a CV. The greenhouse gas emissions associated with a PHEV come from two sources, depending upon the distance driven: first, well-to-battery (when operating as an electric vehicle), and second, well-to-wheels (when operating as a conventional vehicle). The following algorithm (equationEquation 7) obtains the total greenhouse gas emissions for a PHEV and depends upon the distance driven and the AER.

$$
\begin{aligned}
&IF\ Distance \leq All\ Electric\ Range\ THEN\\
&\qquad GHG_{Electricity} = Distance \times GHG_{WtB/km}\\
&\qquad GHG_{Gasoline} = 0\\
&ELSE\\
&\qquad GHG_{Electricity} = All\ Electric\ Range \times GHG_{WtB/km}\\
&\qquad GHG_{Gasoline} = \left(Distance - All\ Electric\ Range\right) \times GHG_{WtW/km}\\
&END\\
&GHG_{Total} = GHG_{Electricity} + GHG_{Gasoline}
\end{aligned}
$$

Equation 7

In the algorithm shown in equationEquation 7, the well-to-battery's and well-to-wheel's emissions are obtained separately, depending upon the vehicle's gasoline fuel economy, its electricity consumption, and the emissions intensity of the electricity supplier.

5.1 Chevy Volt

The Chevy Volt is a PHEV; it has both a gasoline fuel economy and an electricity fuel economy. Its gasoline fuel economy is shown in Table 7. The Volt's Canadian gasoline fuel consumption is estimated to be 17.7 km/litre$_{City}$ and 20.4 km/litre$_{Highway}$, also listed in Table 7.

Table 7: Chevy Volt gasoline fuel economy and estimated fuel consumption

Driving characteristics	**Fuel economy** (U.S. DOE, 2011)			**Estimated fuel consumption**[7]
	miles/gallon	**litres/100km**	**km/litre**	**km/litre**
City	35	6.7	14.9	17.7
Highway	40	5.9	17.0	20.4
Combined	37.3	6.3	15.8	18.9

When operating as a gasoline vehicle, the Volt's total well-to-wheels emissions depend upon whether it is being driving in the city or on the highway and are the sum of its well-to-tank emissions (equation 3) and tank-to-wheels emissions (equation 4) as shown in equation 8. The

[7] The multiplier used to obtain the Volt's Canadian fuel consumption (gasoline) was 0.838 for city and 0.833 for highway (from the median values in Table 2, 83.8% and 83.3%). These were applied directly to the Volt's fuel economy. The Volt's combined Canadian value was obtained from the weighted average (55:45) of the city and highway multipliers.

well-to-wheels emissions will depend upon whether the Volt is driven in the city or on the highway.

$$GHG_{WtW/km} = \frac{10.5}{Fuel\ economy} \times 62.1 + \frac{2446}{Fuel\ economy} \quad (8)$$

The Volt's electricity consumption also depends upon whether the vehicle is used for city or highway driving, as shown in Table 8.

Table 8: Chevy Volt electric fuel economy and estimated fuel consumption

Driving characteristics	**Electric fuel economy** (U.S. DOE, 2011)			**Estimated fuel consumption**[8]
	kWh/100mile	**kWh/100km**	**kWh/km**	**kWh/km**
City	35.7	22.2	0.222	0.186
Highway	37.4	23.2	0.232	0.194
Combined	36.5	22.7	0.227	0.189

When operating as an electric vehicle, the Volt's emissions, like those of the Nissan Leaf, depend upon the electricity supplier's emissions intensity; its CO_2e emissions per kilometre are shown in Figure 2.

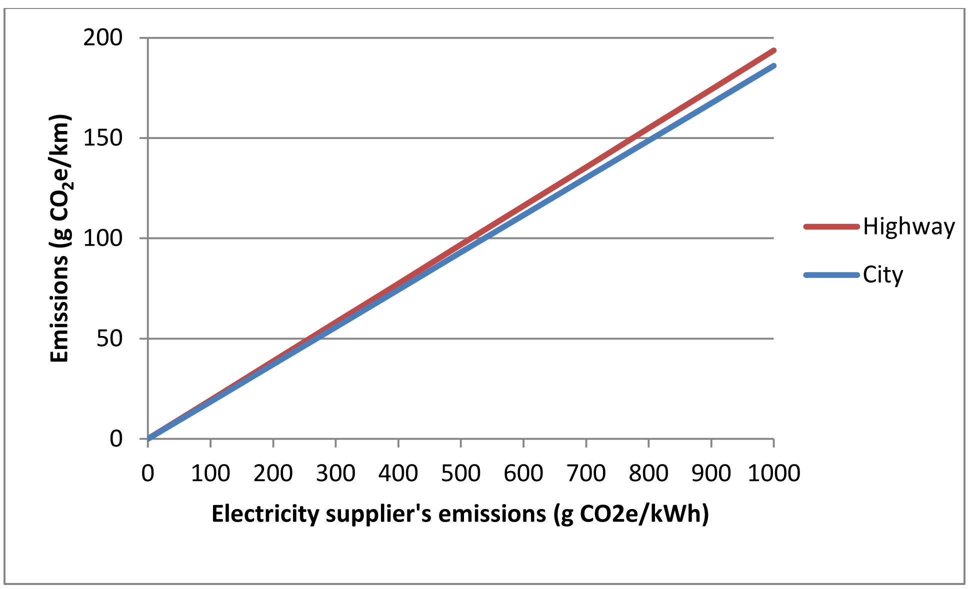

Figure 2: Chevy Volt – emissions vary depending upon supplier's emissions intensity

At low emissions intensities, there is little difference between driving a Volt in city or highway conditions. Even at higher emissions intensities, such as 1,000g CO_2e/kWh, there is little difference between the Volt's city and highway emissions, which are 186.0 and 193.6g CO_2e/km, respectively.

[8] See previous footnote.

6 Emissions comparison

The volume of greenhouse gases emitted by any of the vehicles described above depends upon a variety of factors, including distance travelled, the fuel sources used by the vehicle, and the efficiencies associated with getting the fuel source to the vehicle's wheels. This section examines the total CO_2e emissions for all four vehicles for commuting distances up to 160 kilometers (the AER of the Leaf) and when driven up to 25,000 kilometers per year in city, highway, and combined city-highway driving conditions.[9,10]

Since the emissions associated with the Leaf and Volt depend upon the emissions intensity of the electricity supplier, the results presented show the effect of three electricity supplier intensities (100g CO_2e/kWh, 500g CO_2e/kWh, and 1,000g CO_2e/kWh) on the total emissions for the distance travelled. To distinguish the different vehicles and intensities, the vehicle's name, Leaf or Volt, is given, followed by the intensity value; for example, Leaf 500.

6.1 City-driving conditions

Figure 3 shows the total emissions for the Elantra, Prius, Leaf, and Volt for distances up to 160 kilometres under city-driving conditions.

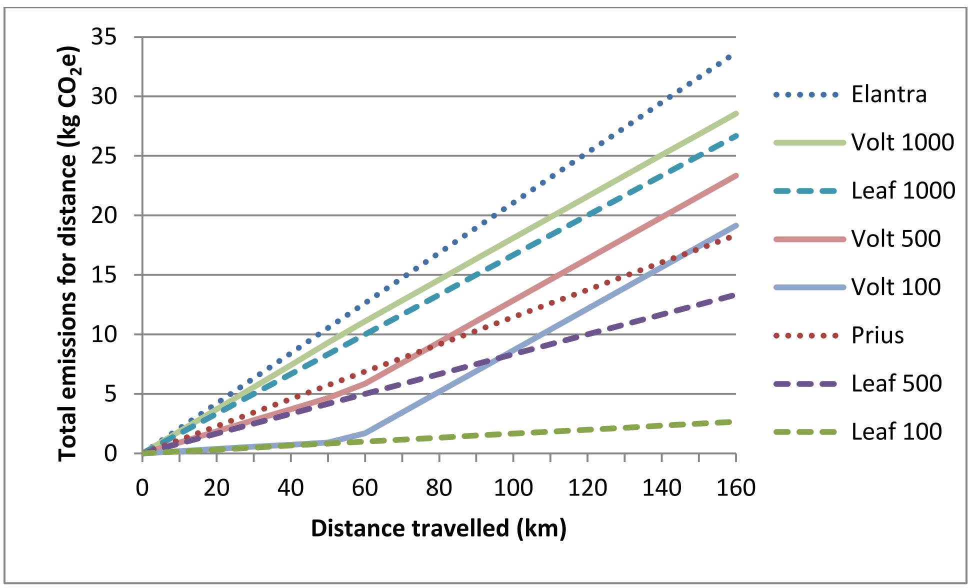

Figure 3: Emissions vs. distance travelled: City driving conditions

The Elantra emits more emissions than any of the electric vehicles. The Volt 1000's emissions intensity while operating as an electric vehicle are essentially the same as when it operates as a gasoline vehicle. The difference in the Volt's electricity and gasoline emissions are more pronounced at lower electricity emissions intensities.

[9] The Leaf's estimated AER for Canada is 100 miles or 160.1 km; the AER is assumed to be 160 km or 100 miles. This assumption is used throughout the remainder of the report.

[10] The remainder of the report refers to metric units rather than U.S. units.

While operating as purely electric vehicles up to the Volt's AER of 56 kilometres, the Leaf and the Volt have roughly the same level of emissions for electricity supplier emission intensities of 100 and 500 CO_2e/kWh. However, the two start to diverge after the 56 kilometre mark when the Volt begins operating as a purely gasoline vehicle. Since the Volt 100 operating on gasoline has higher emissions per kilometer than does the Leaf 500, the Volt 100's emissions exceed those of the Leaf 500 around the 90 kilometer mark. On the other hand, regardless of the electricity supplier's emissions intensity, as soon as the Volt operates as a gasoline vehicle its fuel economy and emissions are the same, although the total emissions (the running sum of the well-to-battery and well-to-wheels emissions) are different.

The emissions associated with the Prius are less than that of the Elantra, Leaf 1000, Volt 500, and Volt 1000. They are the same as those of the Volt 500 up to about 56 kilometers, at which point, the Volt operates as a purely gasoline vehicle and has markedly higher emissions as the distance increases. Its emissions are marginally better than those of the Volt 100 at 160 kilometers.

The Leaf 100 has the lowest of all vehicles' emissions up to its maximum range of 160 kilometers.

6.2 Highway-driving conditions

The emissions for all four vehicles Elantra, Prius, Volt, and Leaf operating under highway-driving conditions are shown in Figure 4.

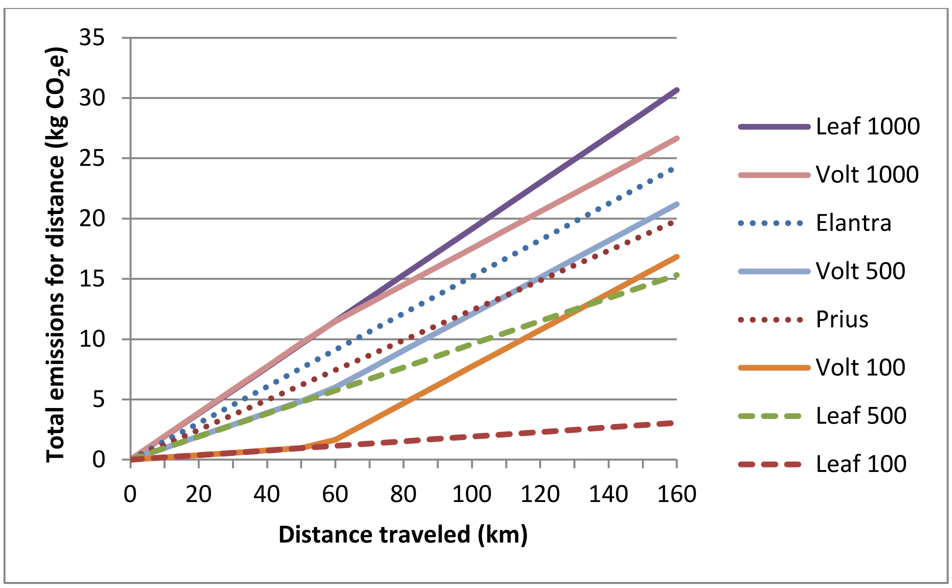

Figure 4: Emissions vs. distance travelled: Highway driving conditions

Since the emissions associated with highway-driving are better for the Elantra than either the Leaf 1000 or Volt 1000, its emissions are considerably lower. Interestingly, when the Volt 1000 is operating as a gasoline vehicle (beyond its AER of 56 kilometers) it has better emissions than does the Leaf 1000 because of the superior fuel economy.

At distances less than about 110 kilometers, the Prius has higher emissions than the Volt 500; however, because the Prius has better gasoline fuel economy than the Volt, the Volt's emissions surpass those of the Prius beyond 110 kilometers.

Up to about 56 kilometres, the Leaf 100 and Volt 100 exhibit similar levels of emissions; however, beyond this point when the Volt operates as a gasoline vehicle, its emissions deteriorate and eventually surpass those of the Leaf 500. As with city-driving, the Leaf 100 has the lowest overall emissions.

6.3 Combined city-highway driving conditions

The city-highway ratio for combined city-highway driving in Canada is assumed to be 55% city and 45% highway. The results of driving the different vehicles under combined-driving conditions up to 160 kilometers are shown in Figure 5.

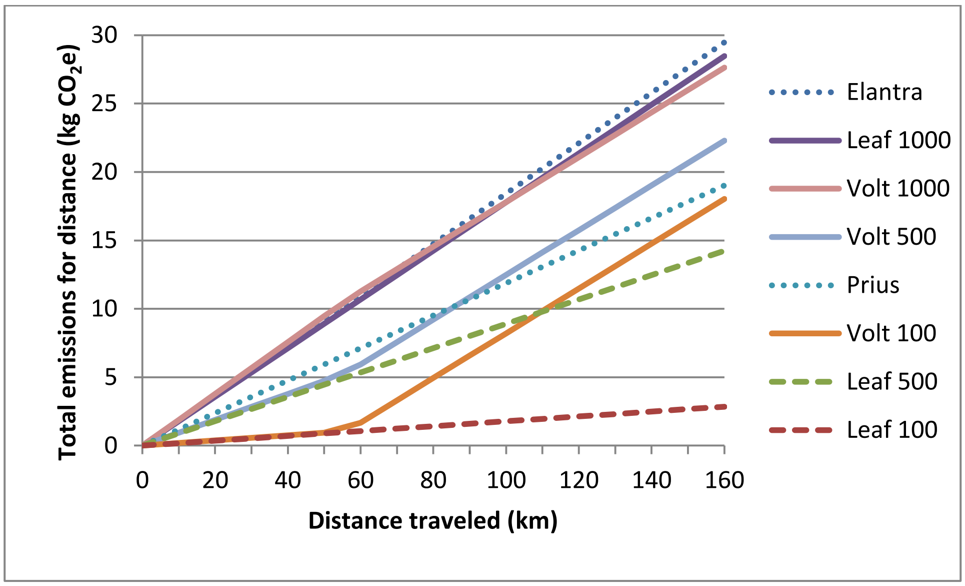

Figure 5: Emissions vs. distance travelled: Combined city-highway driving conditions

Up to about 80 kilometers, the emissions associated with the Elantra, Leaf 1000, and Volt 1000 are similar; by 160 kilometers, the Volt 1000 is marginally lower than the Leaf 1000 which is, in turn, lower than the Elantra. The Volt 500 has lower emissions than the Prius until it begins to operate as a gasoline vehicle (at its AER of 56 kilometers); by 80 kilometers, the Prius exhibits lower emissions. As before, the Leaf 100 and Volt 100 have similar emissions up to the Volt's AER, at which point the Volt operates as a gasoline vehicle and the Volt 100's emissions increase to the point where they are almost the same as those of the Prius at 160 kilometers. The Leaf 100 has the lowest emissions overall.

7 Electric vehicles and Nova Scotia

This section considers the potential reduction in greenhouse gas emissions from different combinations of passenger vehicle driving distances given Nova Scotia Power's present and projected emissions intensity (for 2015 and 2020).

7.1 Commuters in Nova Scotia

In 2006, there were about 433,000 Nova Scotians who were considered employed; this total includes those who worked at home, worked outside Canada, had no fixed workplace address, or had a specific (or "usual") place of work (StatsCan, 2011). Of these, about 403,000 worked outside of the home at some location in the province, over 90% of which used a form of private vehicle (car, truck, or van) to travel to and from work. The mode of transport and the number of commuters utilizing that mode are shown in Figure 6.

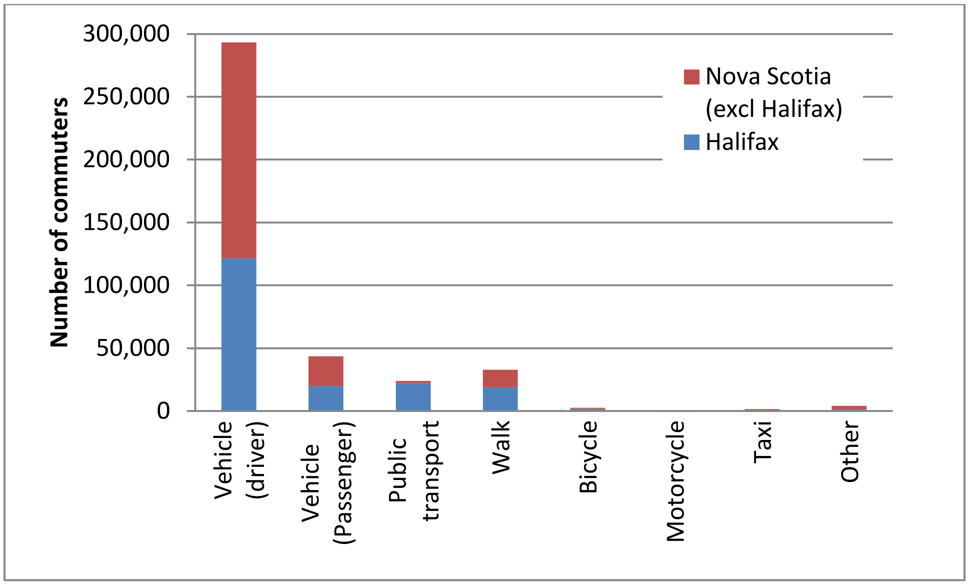

Figure 6: Transportation mode and number of commuters in Nova Scotia (StatsCan, 2011)

The overwhelming mode of choice for travelling to work in the province is the private vehicle, followed by walking and public transport. Shorter distances to work and the availability of public transport mean that walking, public transport, and bicycling are done predominantly in the Halifax Regional Municipality (StatsCan, 2011).

Of the about 293,000 private vehicles driven, there is no easy way of determining the vehicle type (i.e., car, truck, or van) as registrations of motor vehicles are classified by weight. For example, in 2006, there were approximately 525,200 vehicles weighing less than 4,500kg and 342,000 "passenger automobiles" (Nova Scotia Finance, 2007).

Similarly, information on the distance from a commuter's home to their place of work is restricted to those who have a "usual place of work" and the distances provided refer to a range of one-way, straight-line distances with no indication of the mode being used. The number of commuters and straight-line distances are shown in Figure 7.

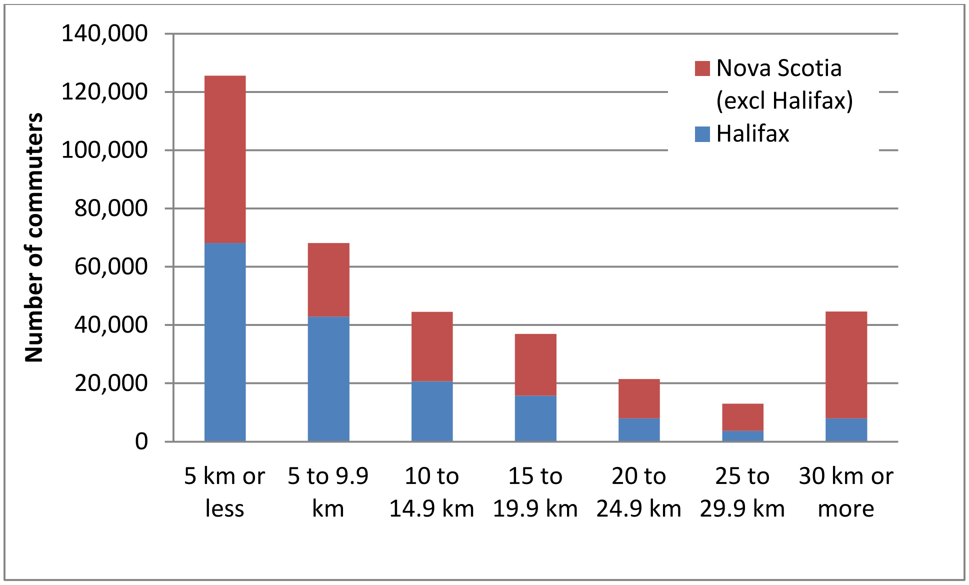

Figure 7: Total commuters by commuter distance (StatsCan, 2011)

The median, straight-line distance for commuters to their usual places of work in Nova Scotia is 8.4km (StatsCan, 2011) and for those in Halifax, it is 6.5km (StatsCan, 2011).

7.2 Nova Scotia Power

The following analysis considers the emissions intensity of the provincial electrical supplier, Nova Scotia Power (NSP), and its probable effect on the emissions associated with the different electric vehicles under consideration. NSP's present emissions intensity is approximately 828g CO_2e per kWh (NSPI, 2011). Table 9 shows NSP's emissions intensity for 2010 and the estimated emissions intensities for 2015 and 2020; the emissions caps are "hard" in that NSP is not permitted to exceed them in the specified years.

Table 9: NSP's current and projected emission intensities
('*f*' forecast, see footnote 11; '*e*' estimate) (NSPI, 2010)

Year	Greenhouse gas cap (Mt)	Total generation (GWh)	Emissions intensity (g CO_2e/kWh)	WtB emissions intensity (g CO_2e/kWh)
2010	9.7	12,146	828	911*e*
2011*f*	9.52	12,444	765	842*e*
2012*f*	9.34	12,471	749	824*e*
2013*f*	9.16	12,382	740	814*e*
2014*f*	8.98	12,255	733	806*e*
2015*f*	8.8	12,138	725	798*e*
2016*f*	8.54	11,994	712	783*e*
2017*f*	8.28	11,844	699	769*e*
2018*f*	8.02	11,704	685	754*e*
2019*f*	7.76	11,560	671	738*e*
2020*f*	7.5	11,394	658	724*e*

The emissions intensities from the emissions caps in Table 9 are generation-to-battery; that is, the supply chain emissions are not included. At the time of writing, NSP's well-to-generation emissions were not available; accordingly, the supply-chain emissions intensity were estimated to be 10% of the of the generation-to-battery's emissions intensity. The choice of 10% was based upon the observation that some of NSP's fossil-generation fuel-sources are sourced locally, meaning the any transportation-related emissions would be small. Although much of NSP's coal is imported from the United States and South America and is subject to transportation emissions, the choice of 10% reflects some well-to-generation research which suggests that such emissions are in this range (Samaras & Meisterling, 2008).

Figure 8 shows the expected emissions under city-driving conditions for the two gasoline vehicles and the two electric vehicles in each of the three years (2010, 2015, and 2020). In all three years, there is a marked decline in emissions for the electric vehicles, although the Leaf is always better than the Volt when considered in the same year. The Elantra always has the highest emissions while the Prius's emissions are about 5% lower than those of the Leaf 2020.

[11] NSP's emissions intensity for 2010 was 799g CO_2e/kWh (emissions cap divided by total generation); however, its actual emissions intensity was 828g CO_2e/kWh (NSPI, 2011).

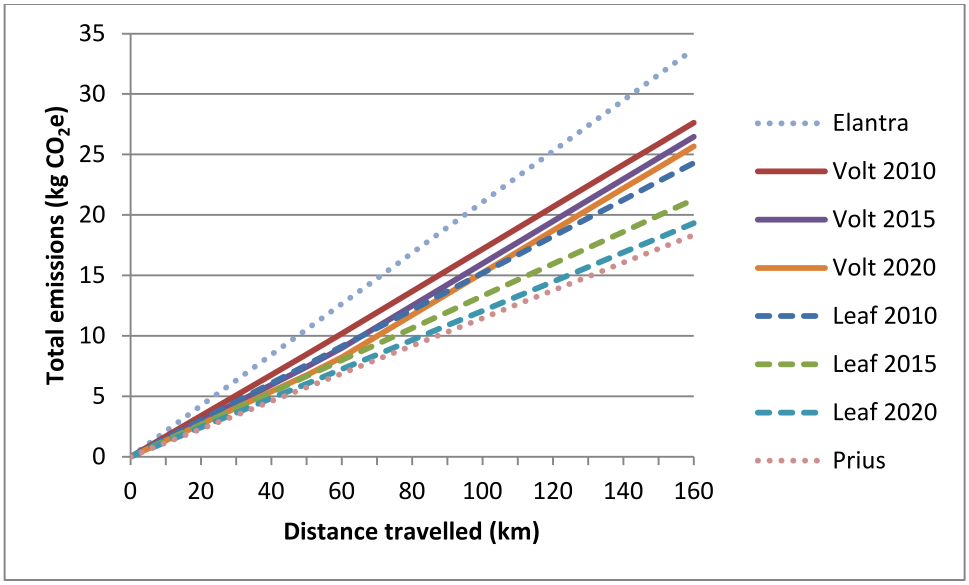

Figure 8: City-driving emissions for Nova Scotia (various distances)

Combined city-highway driving conditions have lower emissions for each distance than does city-driving alone; this is shown in Figure 9. As before, the Leaf always has lower emissions than the Volt for each year considered. The Prius's emissions are noticeably better than those of all other vehicles.

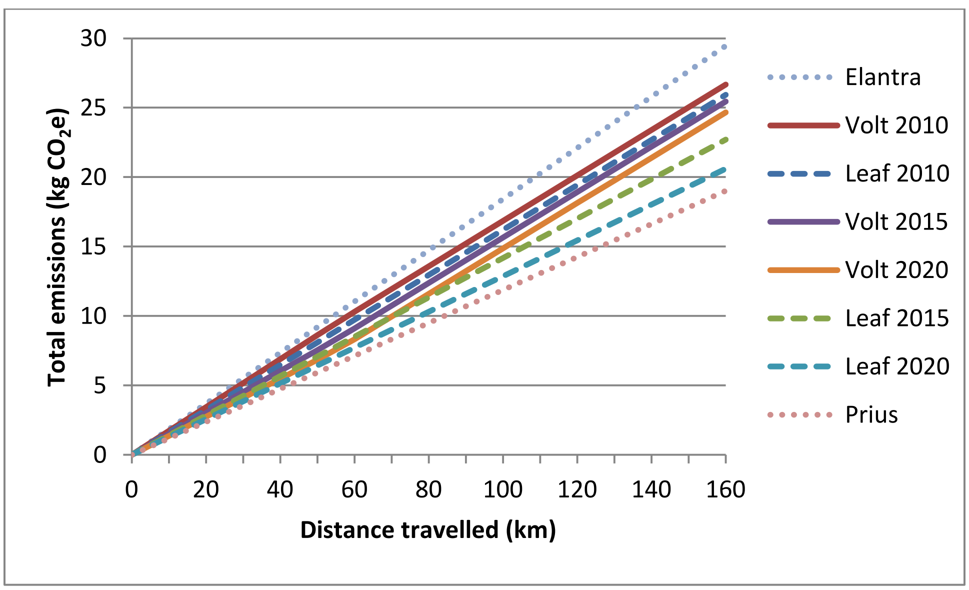

Figure 9: Combined city-highway emissions for Nova Scotia (various distances)

7.3 Commuting emissions

This section examines the projected emissions for the Elantra, Prius, Leaf, and Volt in 2010, 2015, and 2020 if they are used for commuting purposes in Nova Scotia. Two different commuting scenarios are considered: city-driving and combined city-highway driving.

Before the total commuting-related emissions associated with each vehicle can be estimated, it is necessary to determine the roundtrip commuting distance. Table 10 takes the straight-line distance used by Statistics Canada and compensates for the straight-line distance by assuming that the average trip length is 30% longer; with this value, the round-trip distance can be obtained. The table also includes the annual commuting distance, assuming the vehicles are used for 49 weeks or 245 days each year (two-weeks of vacation and five statutory holidays (StatutoryHolidays.com, 2011)).

Table 10: Estimated roundtrip commuting distances for Nova Scotia and Halifax

Jurisdiction	Straight-line distance (km)	30% increase (km)	Round-trip distance (km)	Annual distance (km)
Nova Scotia	8.4	10.9	21.8	5,341
Halifax	6.5	8.5	16.9	4,141

The round-trip distances from Table 10 are now used to determine the emissions from the different vehicles if they were used under city-driving and combined city-highway driving conditions.

7.3.1 City-driving conditions

The daily, round-trip commuting-related CO_2e emissions from all four vehicles over the three years in question are shown in Figure 10 for both commuting distances (21.8 km, for Nova Scotia, and 16.9 km, for Halifax). In all cases, the vehicles were assumed to operate under city-driving conditions.

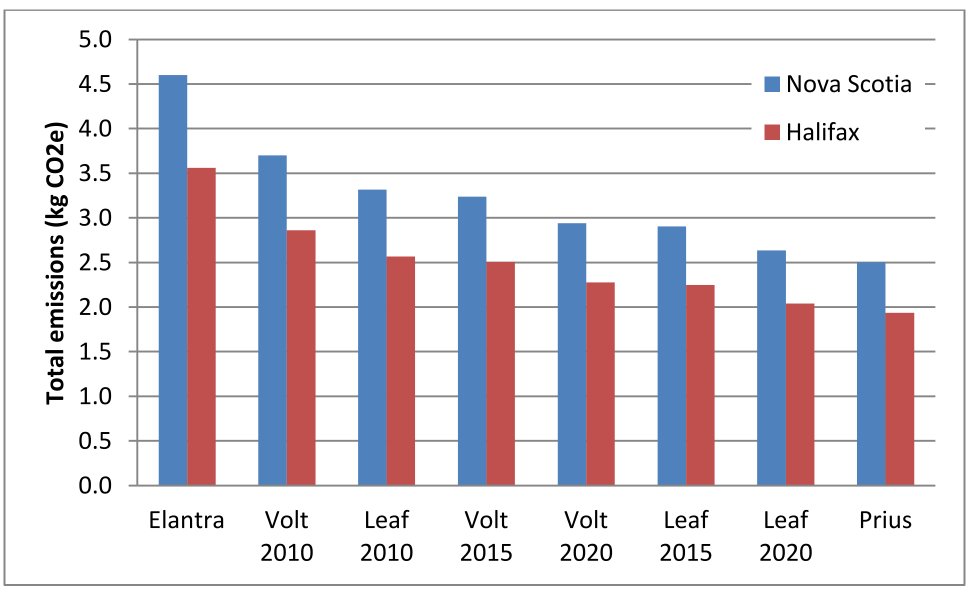

Figure 10: Daily, roundtrip commuting-related emissions for different vehicles and years

Not surprisingly, as NSP's emissions intensity decreases, the emissions associated with the electric vehicles improves. The Prius, operating in these conditions, has emissions marginally better than the Leaf 2020's.

The changes in emissions between 2010 and 2020 for the PEVs in 2020 when compared with the Prius, Elantra and PEVs in 2010 are shown in Table 11 (the ratios are the same for both Nova Scotia and Halifax city-driving). The most significant changes occur in 2020 between the Leaf and all other vehicles; the Leaf's emissions are reduced by 25% or more than those it exhibited in 2010. By 2020, the Leaf's emissions are about 5% greater than those of the Prius.

Table 11: Changes in emissions between 2010 and 2020 for various vehicles

Vehicle	Volt 2020	Leaf 2020
Prius	14.8%	5.0%
Elantra	-36.9%	-74.6%
Volt 2010	-20.5%	-40.4%
Leaf 2010	-12.8%	-25.8%

The annual commuting emissions for the vehicles are shown in Figure 11 (245 commuting days; 21.8km/day or 5,241km/year for Nova Scotia; 16.9km/day or 4,141km/year for Halifax). The decline in annual emissions is perhaps best illustrated by the switch from the gasoline Elantra (1,127 kg Nova Scotia and 872 kg Halifax) to the Leaf 2020 (646 kg Nova Scotia and 500 kg Halifax).

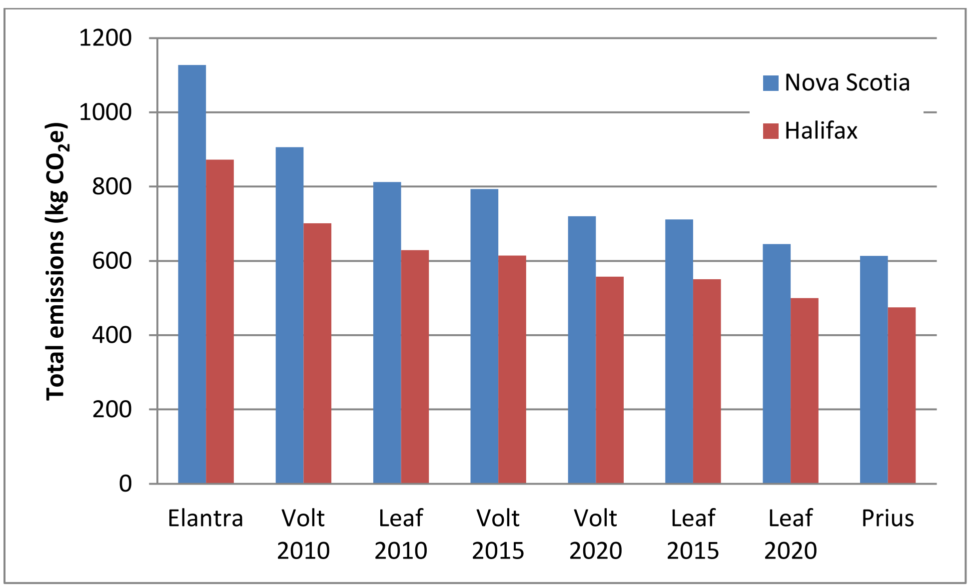

Figure 11: Annual commuting-related emissions for different vehicles and years

7.3.2 Combined city-highway driving conditions

Combined city-highway driving, as with city driving, compared the commuting-related emissions of all four vehicles, the three years, and two commuting distances (21.8 km, for Nova Scotia, and 16.9 km, for Halifax). The results of the daily driving are shown Figure 12.

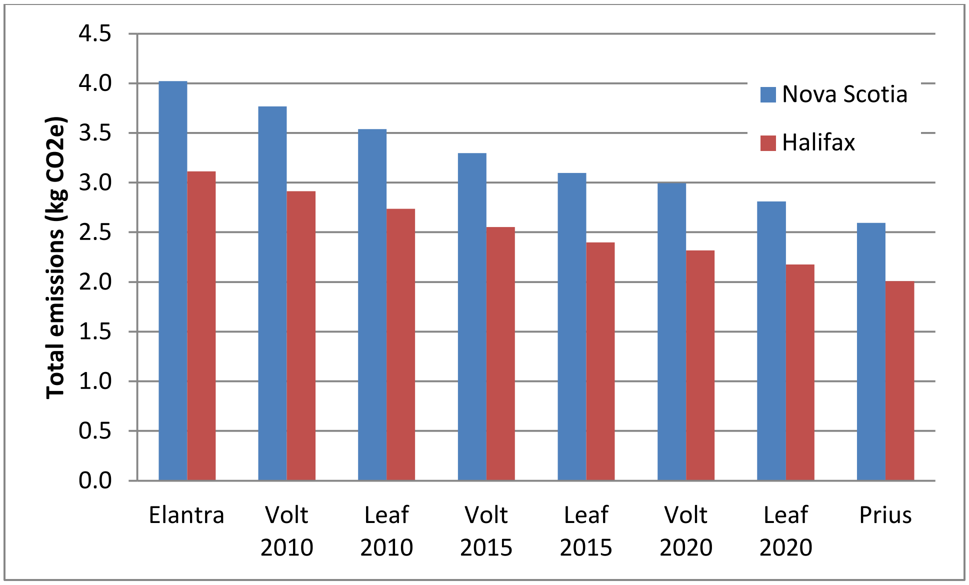

Figure 12: Daily, roundtrip commuting-related emissions for different vehicles and years

The Elantra's superior highway-driving fuel economy (when compared to its city-driving fuel economy) means that, unlike the other vehicles, it experiences a decline in emissions, as shown in Table 12; for example, combined city-highway driving for the Elantra for Nova Scotia commuting is 4.02kg $CO_2e_{Combined}$ and 4.60kg CO_2e_{City} for city-only. On the other hand, the Leaf 2020 produces lower emissions when driven in Halifax under city conditions than it does when driven Nova Scotia under combined city-highway conditions (2.81 kg $CO_2e_{Combined}$ as compared with 2.04 kg CO_2e_{City}).

Table 12: Daily emissions (kg CO_2e) for selected years, vehicles, and commuting distances (City vs. Combined)

Driving conditions	Commuting distance	Volt 2010	Elantra	Leaf 2020	Prius
City-only	Nova Scotia	3.70	4.60	2.64	2.50
	Halifax	2.86	3.56	2.04	1.94
Combined City-highway	Nova Scotia	3.77	4.02	2.81	2.59
	Halifax	2.92	3.11	2.18	2.01

Figure 13 shows the annual emissions expected from the vehicles operating under combined city-highway conditions for both commuting distances (245 commuting days; 21.8km/day or 5,241km/year for Nova Scotia; 16.9km/day or 4,141km/year for Halifax). As discussed above, with the exception of the Elantra, all vehicles exhibit an increase in annual emissions because of their superior city-driving capabilities.

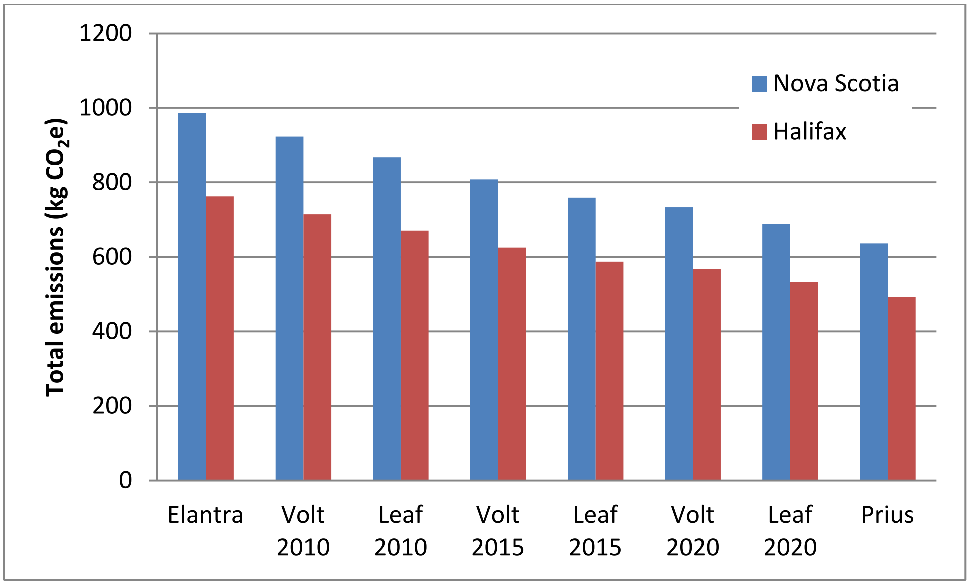

Figure 13: Annual commuting-related emissions for different vehicles

7.4 Average annual vehicle emissions

From Table 10, it is clear that commuting is responsible for about one quarter to one-third of the average 16,551 km Nova Scotians drove in 2008 (NRCan, 2010). In order to gain a better understanding of the possible annual emissions associated with passenger vehicle usage for both commuting and non-commuting purposes, this section examines five different annual driving distances (5,000 km, 10,000 km, 15,000 km, 20,000 km, and 25,000 km) on the four vehicles under consideration. The method employed determines the emissions associated with daily driving distances and then scales them to annual emissions and distances; given the distances involved, combined city-highway fuel consumption is assumed (that is, 55% city and 45% highway). The average daily driving distances are shown in Table 13; vehicles are assumed to operate six days-a-week.

Table 13: Annual and daily driving distances

Annual distance (km)	Daily distance (km)
5,000	16.0
10,000	32.1
15,000	48.1
20,000	64.1
25,000	80.1

The emissions are then determined for daily driving distances using the data and formulas described previously. The daily results are extrapolated to annual (again, assuming the vehicles are operated six days-a-week); Figure 14 shows the estimated annual emissions for each of the distances.

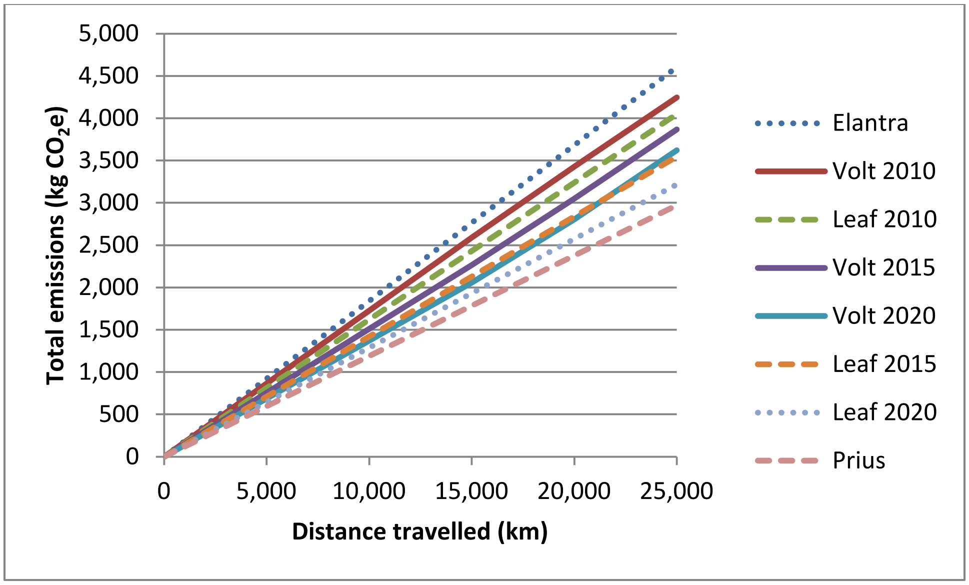

Figure 14: Estimated emissions for various annual driving distances

Not surprisingly, as distances increase, emissions do as well, although the emissions of the PEVs are offset as NSP's emissions intensity improves (that is, declines) over the decade. The changes in emissions by distance and over the decade are shown in Figure 15. For example, a Leaf driven 25,000 km a year in 2020 would have over a 20% reduction in greenhouse gas emissions compared with 2010.

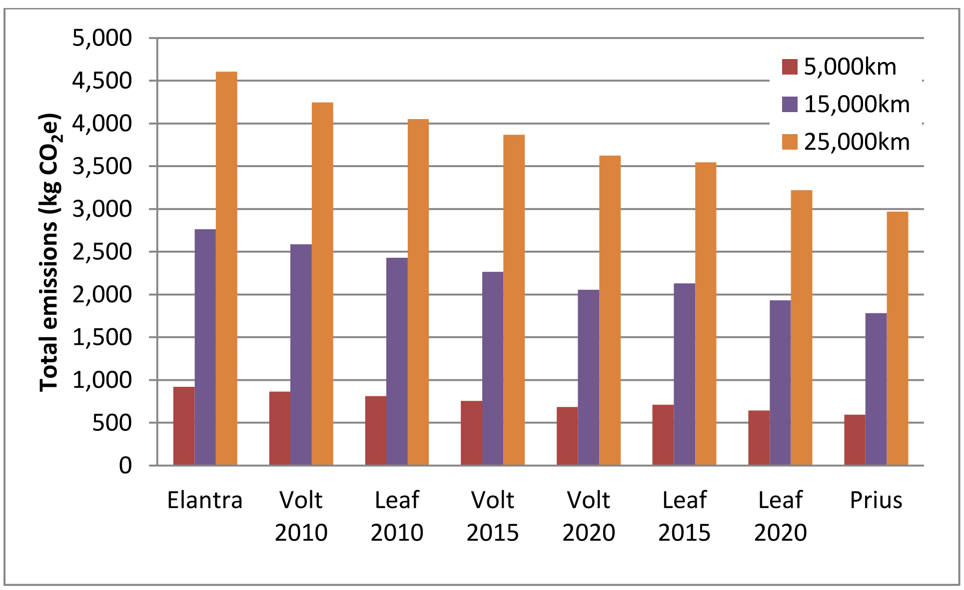

Figure 15: Improvements in emissions between 2010 and 2020

8 Discussion

This report has considered the effects on greenhouse gas emissions from passenger-vehicles with the introduction of plug-in electric vehicles in Nova Scotia. The results suggest that over the next decade, adopting a mid-sized electric vehicle such as the Prius or Leaf would result in considerable reductions in vehicular emissions. These results were predicated on a number of assumptions, some of which are discussed in this section.

At the time of writing, neither the Leaf nor the Volt had undergone Transport Canada's Federal Test Procedure to determine their city and highway fuel consumption. The values employed in this report were the U.S. EPA fuel economy test results for the Leaf and Volt scaled by the median value for five of the best fuel consumption vehicles in Canada. When Canadian fuel consumption data is available for these vehicles, it would be advisable to revisit the calculations and results found in this report.

The emissions associated with NSP's well-to-generation were estimated at 10%. As with Canadian fuel consumption data, when more detailed information becomes available for the emissions intensities of NSP's supply chains, they should be included in the calculations.

The technologies used in both the conventional and electric vehicles (CVs and EVs) were assumed to remain static, meaning that the tank-to-wheels emissions found for the 2011 model year will be the same as in 2020. While this is undoubtedly true, it is reasonable to assume in both CVs and EVs, that a new technology improvement found for, say, the Leaf would soon be adopted for the Prius (and vice versa). For example, although the Prius is a third generation HEV and the Leaf is a first-generation PEV, the experiences gained from the development of the Prius, such as in battery and control technologies, are well-known and can easily influence the design of other EVs. Similarly, new technologies for CVs, such as the Elantra, are transferable to PHEVs such as the Volt.

One can argue that the well-to-tank emissions for CVs and HEVs should increase because of increasing reliance on synthetic crude oil from Alberta's tar sands. This is a common misunderstanding by many people living in Nova Scotia as the province gets only a small fraction of its crude oil from Canada and all of that from Newfoundland (Hughes, 2010). Having said this, supplies of conventional light-sweet crude are declining, being replaced by heavier, sour crudes which are more difficult to refine. Furthermore, assuming that emissions from crude oil refining will increase because of changes in feedstock fails to acknowledge the increasing use of NGLs (natural gas liquids) as a replacement for supplies of light-sweet crude, something that will probably keep refining-related emissions closer to their current levels. Any possible increase in greenhouse gas emissions associated with this refining has not been taken into account in this report since Nova Scotia's actual well-to-tank emissions are not publically available and were therefore based on the EPRI numbers for the United States and the EPRI report assumes that improvements in gasoline technologies will decrease the well-to-tank emissions (this assumption was not used in this report, instead a compromise was adopted, keeping well-to-tank emissions constant over the decade).

The cumulative decadal emissions are important to consider, given the lifetime of CO_2e emissions in the atmosphere (IPCC, 2001). Figure 16 compares the cumulative emissions for the Elantra, Leaf, and Prius for combined city-highway driving starting in 2011 for Nova Scotia's annual driving distance of 16,551 km (that is, all three vehicles are purchased in 2011 and subject to identical driving activities each year over the decade). For example, it shows that in

2020 the cumulative emissions for the Elantra are about 55% higher than those of the Prius and more than 31% greater than those of the Leaf.

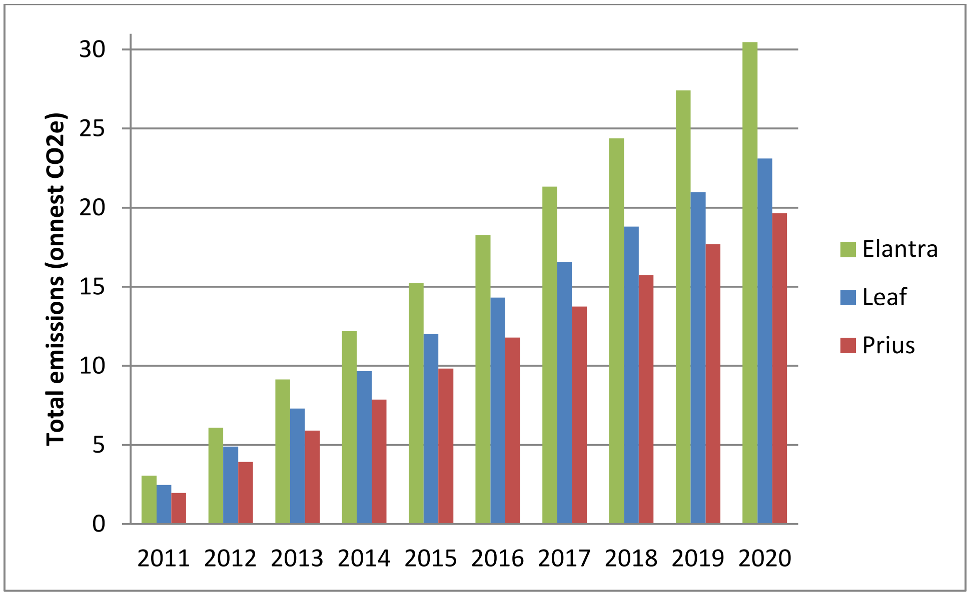

Figure 16: Cumulative emissions for Prius and Leaf purchased in 2011 and driven Nova Scotia's average annual distance

9 Summary

This report has considered four different passenger automobiles available (or soon to be available) representing a range of technologies; notably, conventional vehicles (Elantra), hybrid-electric vehicles (Prius), hybrid plug-in electric vehicles (Volt), and plug-in electric vehicles (Leaf). All vehicles ultimately rely on some form of carbon-based fuel for their propulsion: both conventional and hybrid vehicles rely on gasoline and plug-in electricity generated from fossil sources. In Nova Scotia Power's present and planned fuel mix, plug-in electric vehicles (both hybrid and non-hybrid) exhibit a range of greenhouse gas emissions, initially falling between conventional and hybrid-electric vehicles at the start of the decade and approaching that of hybrid electric vehicles by the end of the decade. When compared with existing conventional and hybrid vehicles, plug-in electric vehicles exhibit the greatest change in emissions as Nova Scotia Power decreases its carbon intensity in accordance with provincial legislation.

In summary, given the assumptions made in this report with respect to well-to-wheels and well-to-battery emissions, electric vehicles in general and plug-in vehicles in particular do make carbon sense in Nova Scotia when compared with existing conventional (i.e., gasoline) vehicles used in existing and expected driving conditions and given NSP's greenhouse gas emission caps. By the end of the decade, they will be approaching the levels of greenhouse gases emitted by today's lowest carbon-intensity full-hybrid vehicles. Should more accurate data become available, these conclusions may need revising.

It should also be noted that this report has focused on greenhouse gas emissions only; other issues that will need to be addressed when considering the future of personal transportation in Nova Scotia include energy security (price volatility and supply of both oil products and electricity), smart-metering technologies, changing demographics, urban design, and transportation policy.

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Appendix: Data for selected graphs

Data for Figure 10: Daily, roundtrip commuting-related emissions for different vehicles and years (kg CO_2e)

Daily	Roundtrip distance (km)	Elantra	Volt 2010	Leaf 2010	Volt 2015	Volt 2020	Leaf 2015	Leaf 2020	Prius
Nova Scotia	21.8	4.60	3.70	3.32	3.24	2.94	2.90	2.64	2.50
Halifax	16.9	3.56	2.86	2.57	2.51	2.27	2.25	2.04	1.94

Data for Figure 11: Annual commuting-related emissions for different vehicles and years (kg CO_2e)

Annual	Roundtrip distance (km)	Elantra	Volt 2010	Leaf 2010	Volt 2015	Volt 2020	Leaf 2015	Leaf 2020	Prius
Nova Scotia	21.8	1127	906	812	794	720	711	646	613
Halifax	16.9	872	701	629	614	557	550	500	475

Data for Figure 12: Daily, roundtrip commuting-related emissions for different vehicles and years (kg CO_2e)

Daily	Roundtrip distance (km)	Elantra	Volt 2010	Leaf 2010	Volt 2015	Leaf 2015	Volt 2020	Leaf 2020	Prius
Nova Scotia	21.8	4.02	3.77	3.54	3.30	3.10	2.99	2.81	2.59
Halifax	16.9	3.11	2.92	2.74	2.55	2.40	2.32	2.18	2.01

Data for Figure 13: Annual commuting-related emissions for different vehicles and years (kg CO_2e)

Annual	Roundtrip distance (km)	Elantra	Volt 2010	Leaf 2010	Volt 2015	Leaf 2015	Volt 2020	Leaf 2020	Prius
Nova Scotia	21.8	986	923	867	808	759	733	689	636
Halifax	16.9	763	714	671	625	587	568	533	492

Data for Figure 14: Estimated emissions for various annual driving distances (kg CO_2e)

Annual distance (km)	Elantra	Volt 2010	Leaf 2010	Volt 2015	Volt 2020	Leaf 2015	Leaf 2020	Prius
5,000	921	862	810	755	685	709	644	594
10,000	1,842	1,725	1,620	1,510	1,371	1,419	1,287	1,188
15,000	2,763	2,587	2,430	2,265	2,056	2,128	1,931	1,782
20,000	3,684	3,428	3,240	3,051	2,806	2,837	2,575	2,376
25,000	4,604	4,245	4,050	3,869	3,623	3,546	3,219	2,970