

EVS27

Barcelona, Spain, November 17-20, 2013

Electric vehicles – a ‘one-size-fits-all’ solution for emission reduction from transportation?

Hajo Ribberink¹, Evgueniy Entchev

¹(corresponding author) Natural Resources Canada, 1 Haanel Dr., Ottawa, ON, Canada,
Hajo.Ribberink@nrcan.gc.ca

Abstract

Electric vehicles are broadly considered to have a great potential for reducing emissions from transportation and are sometimes presented as a ‘one-size-fits-all’ solution. A simulation study was performed to forecast least emitting options for single vehicles as well as for total light duty vehicle fleets in the Canadian provinces of Québec, Ontario and Alberta for the year 2025. The study used the Plug-in Electric Vehicle – Charge Impact Model (PEV-CIM), a software tool developed by Natural Resources Canada for evaluating the impact of PEVs on the electricity grid, on fuel costs, and on emissions.

Simulation results from PEV-CIM indicate that battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) offer a great potential to drastically reduce GHG emissions in the provinces of Québec and Ontario thanks to the low emission intensity of their electrical grids. However, the slow turnover of the light duty vehicle fleet limits the overall emission reduction of the provincial fleets for the year 2025 to only 5 – 12%. Power generation in the province of Alberta is dominated by the use of coal and natural gas. Its GHG emission intensity is higher than the threshold of 720 gCO₂eq per kWh at which the emissions of BEVs and PHEVs are equal to those of hybrid electric vehicles (HEVs). For this province, HEVs will give the lowest emissions.

Electric vehicles do reduce GHG emissions compared to gasoline vehicles. However, a ‘one-size-fits-all’ does not exist as local conditions greatly influence which type of electric vehicle (HEV, PHEV, or BEV) is the best option. Besides, short term solutions may differ from those for the long term.

Keywords: emissions, simulation, optimization, vehicle performance, Canada

1 Introduction

The transportation sector is one of the major sources of greenhouse gas (GHG) emissions. CO₂ emissions of the sector represent 23%

(globally) and 30% (OECD) of overall CO₂ emissions from fossil fuel combustion [1]. It is clear that a significant overall reduction of GHG emissions can not be realized without a substantial emission reduction of the transportation sector.

Electric vehicles (EVs) are broadly considered to have a great potential for reducing emissions from transportation. However, the question arises whether electric vehicles are a ‘one-size-fits-all’ solution for emission reduction from transportation. This question is addressed in this paper by looking at the emission reduction potential of EVs in 3 distinct regions in Canada: the provinces of Québec, Ontario and Alberta. In a simulation study, the optimum solution for minimizing GHG emissions from light duty vehicles was determined for each of these provinces for the year 2025.

2 Simulation method and inputs

2.1 Simulation method

GHG emissions of Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Hybrid Electric Vehicles (HEVs) and Conventional Vehicles (CVs) applied in each of the three provinces were determined using the PEV-CIM software tool.

PEV-CIM (the *Plug-in Electric Vehicle – Charge Impact Model*) is a free software tool developed by Natural Resources Canada [2], aimed at evaluating the impact of PEVs on the electricity grid, on fuel costs, and on emissions.

PEV-CIM generally utilizes inputs related to the performance of a PEV and its drive pattern to calculate the amount of grid power necessary to recharge its batteries. The specific impact on the electricity grid of PEV battery recharging is then determined for a selected charge pattern. After

that, GHG emissions for simulated vehicles are calculated based upon the grid electricity used and any fuel consumed.

For this study, PEV-CIM was used in ‘Emission mode’, which allows the comparison of the GHG emissions of BEVs, PHEVs, HEVs, and CVs. Simulation results were obtained and compared on the level of single vehicles as well as for total provincial fleets to find the optimum emission reduction solutions for each province.

2.2 Provincial characteristics

Canada is a large country with significant regional variation. Major differences in geography have resulted in the application of different technologies for power generation (hydro power in Québec, coal and natural gas based generation in Alberta). Besides, substantial differences exist in the composition of provincial vehicle fleets. Table 1 presents the provincial characteristics related to the light duty vehicle fleet and the electricity generation system used in this study. The provinces of Québec, Ontario and Alberta were selected for this study, because they display the full range of variation in Canada.

2.3 Vehicle performance data

Accurate performance data measured in a consistent way is indispensable for any simulation study in which the performance of different types of vehicles (BEVs, PHEVs, HEVs, and CVs) is compared. In this study, vehicle performance data from the US Environmental Protection Agency (EPA) was used [3].

The EPA provides vehicle performance data for all light duty vehicles on the market in the USA.

Table 1: Provincial characteristics related to the light duty vehicle fleet and the electricity grid ([4-7])

	Québec	Ontario	Alberta
Forecasts for 2025			
Population (millions)	8.306	15.573	4.170
Vehicle fleet (millions)	5.497	9.725	3.475
Electricity generation capacity (GW)	43.5	35.0	12.9
Average GHG emission intensity * (kg CO ₂ eq/kWh _{delivered})	0.029	0.178	1.006
Vehicle fleet compositions			
Passenger cars (%)	65	50	35
Light trucks (%)	35	50	65
Average daily driving distance (km)	40.6	44.4	44.2

* Emission calculations for electricity and gasoline are based on a full fuel cycle approach.

These vehicle performance estimates are based upon the measured vehicle performance under standard industry test cycles. Testing results have been corrected using a standard correction method to better match real-world driving performance.

The EPA classifies light-duty vehicles as either ‘cars’ (covering all vehicle classes from two-seaters to large sedans and station wagons) or ‘trucks’ (SUVs, vans and pick-up trucks) [3]. For greater clarity, these vehicle segments will be indicated as ‘passenger cars’ and ‘light trucks’ in this study. Most HEVs, PHEVs, and BEVs currently on the market have been introduced in the passenger car segment, with a smaller number being light trucks. Instead of using specific vehicles as representative for their type and segment, this study used *average* performance figures for HEVs, PHEVs, and BEVs over all vehicle classes per vehicle segments (see Table 2). This approach reflects the expected future situation in which HEVs and PHEVs and BEVs have substantially penetrated all vehicle segments and classes.

The average performance figures for the different vehicle types were derived from the estimated average performance of model year 2013 CVs [8, 9] and correlations between the fuel economy of 2013 HEVs, PHEVs and BEVs, and conventional versions of the same model [3]:

- The model year 2013 EPA data set contains 16 passenger cars that are available in both HEV and CV versions, and seven light truck HEV/CV models. In each vehicle segment, the HEV versions need an average 26% less fuel than their CV alternatives.
- The five 2013 models that come in both a BEV and a CV version were examined in a similar way. There was an average ratio of 2.60 between BEV electricity consumption (in kWh/100 km) and gasoline consumption of the CV version (in Litres/100 km).
- The number of model year 2013 PHEVs on the market was insufficient to determine a representative average performance. Instead, the average PHEV performance in electric mode was assumed to be equal to the average BEV performance. Likewise, the average gasoline consumption of HEVs was used for the average PHEV performance in charge sustaining mode.

Table 2: Average vehicle performance based on EPA data for combined city and highway driving [3]

Vehicle type	Fuel type	Passenger cars	Light trucks
		Litres / 100 km	Litres / 100 km
CV	Gasoline	8.53	11.46
HEV	Gasoline	6.34	8.52
PHEV	Gasoline	6.34	8.52
		kWh / 100 km	kWh / 100 km
PHEV	Electricity	22.2	29.8
BEV	Electricity	22.2	29.8

2.4 Vehicle penetration scenarios

When HEVs were introduced to the market, they first appeared in the passenger car segment. HEV versions of light trucks followed a number of years later. A similar approach is currently seen with the introduction of BEVs and PHEVs. Different scenarios for the penetration of HEVs and of BEVs and PHEVs were therefore used in the simulations of the total provincial fleets (see Figure 1). The scenarios are similar to the medium penetration scenario in [10], but with different starting years reflecting the differences in the introduction of advanced vehicle options in the various market segments.

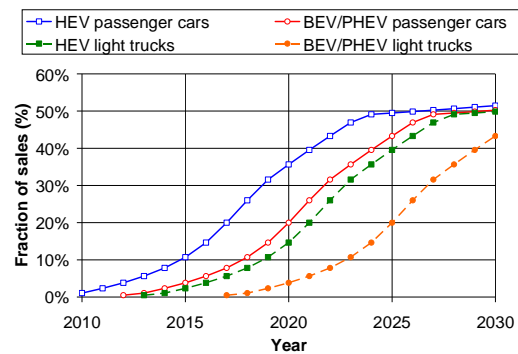


Figure 1: Scenarios of penetration rates of HEVs or BEVs/PHEVs as fraction of total light duty vehicle sales.

3 Simulation Results

3.1 Single vehicle simulations

Annual GHG emissions for all vehicle types and segments were calculated using the average

performance per vehicle type and segment (Table 2) and the daily driving distances per province (Table 1). PHEVs were assumed to have a nominal electric range of 40 km. However, following the SAE J2841 method for calculating the fraction of electric kilometres for PHEVs [11], only an average 18.4 kilometres could be driven electrically daily. BEVs were assumed to have a sufficient battery range for all driving. Both PHEVs and BEVs were assumed to be fully charged overnight. Table 3 presents the results of the GHG emissions simulations for the three provinces.

Figure 2 presents the results of the single vehicle emissions from Table 3 relative to the CV emissions (per province). It is clear that electric drive has the potential to greatly reduce GHG emissions in Québec and Ontario, but currently not in Alberta due to its high emission intensity of the electricity grid.

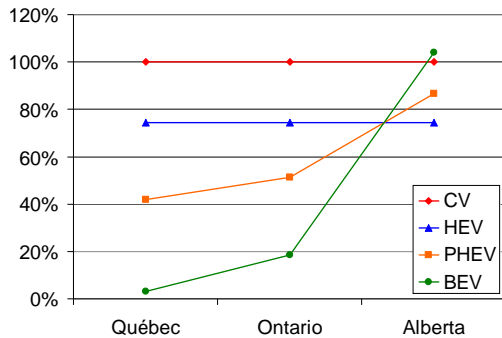


Figure 2: Emissions of the average HEV, PHEV and BEV relative to the average CV emissions (per province).

Figure 3 extends the simulation results for the various provinces to a more general correlation between the emission intensity of all possible grid mixes and the resulting vehicle type with least emissions. For grid emission intensities greater than 720 gCO₂eq/kWh_{delivered}, HEVs

provide transportation with least emissions. For cleaner grids, BEVs or PHEVs in electric mode have the lowest emissions. The grid emission intensities for Québec, Ontario and Alberta from Table 1 are also displayed in Figure 3.

3.2 Simulations for total fleets

Simulations were run to forecast the emissions in 2025 of the provincial fleets using the fleet composition and daily driving data from Table 1, the vehicle performances from Table 2 and the penetration scenarios presented in Figure 1. The fleet emission results are presented in Table 4, and in Figure 4 relative to the emissions of the provincial fleet of CVs.

Table 4: GHG emissions (in Mt CO₂eq/year) for total provincial light duty vehicle fleet scenarios in 2025.

Vehicle types	Québec	Ontario	Alberta
CVs only	23.62	47.79	17.75
CVs + HEVs	22.25	45.25	16.89
CVs + PHEVs	21.91	45.30	17.54
CVs + BEVs	20.75	43.62	17.81

Figure 4 displays a similar trend for fleet emissions as Figure 2 presents for the single vehicles. Again, the results vary by province. Electric vehicles do not achieve significant emission reductions compared to conventional vehicles in Alberta. HEVs present the lowest emission option for this province. The impact of cleaner vehicles on total fleet emissions in Ontario and Québec in 2025 is noticeable, but still limited due to the slow turnover of the vehicle fleet (see Figure 5). For each scenario, the majority of the light duty vehicle fleet in 2025 will still be CVs. The earlier introduction of HEVs (see Figure 1) resulted in a fleet with HEVs in Ontario having a similar emission reduction as a fleet with PHEVs, while PHEVs on a per vehicle basis have more than double the emission reduction of HEVs (see Figure 2).

Table 3: Annual GHG emissions (tonnes CO₂eq/year) for the average CV, HEV, PHEV and BEV in 2025

Vehicle type	Passenger car			Light truck		
	Québec	Ontario	Alberta	Québec	Ontario	Alberta
CV	3.83	4.19	4.17	5.15	5.64	5.61
HEV	2.85	3.12	3.10	3.83	4.19	4.17
PHEV	1.61	2.15	3.62	2.17	2.88	4.86
BEV	0.12	0.77	4.34	0.15	1.04	5.83

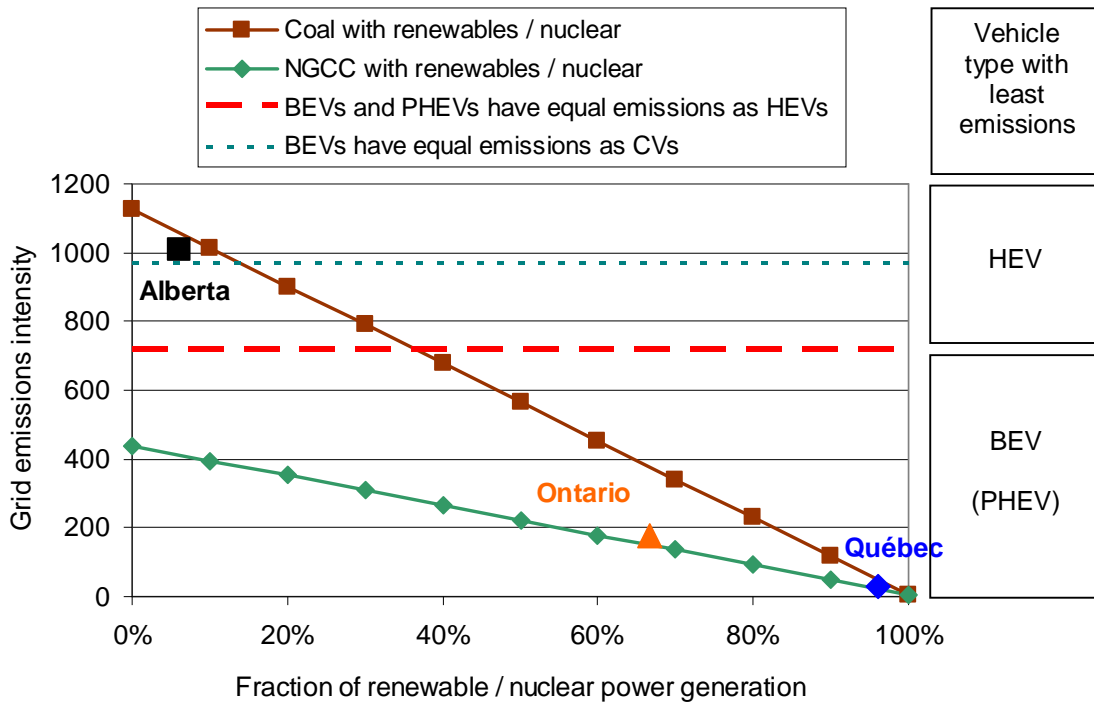


Figure 3: GHG emission intensity (in $\text{gCO}_2\text{eq/kWh}_{\text{delivered}}$) of electricity grids with varying fractions of renewable power generation replacing coal fired electricity generation or natural gas fired combined cycle (NGCC) power plants. The emission intensity of the grid greatly influences which vehicle type will cause the least emissions per kilometre (right hand side of figure).

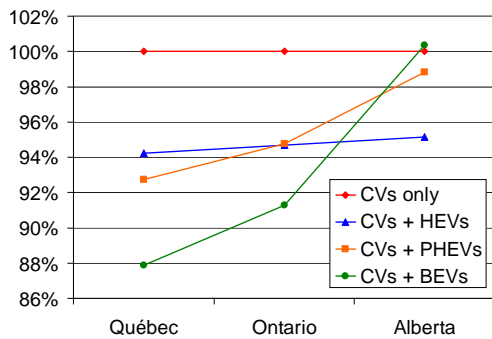


Figure 4: Emissions of provincial fleets with HEVs, PHEVs, or BEVs in 2025 relative to the emissions of a fleet consisting of CVs only.

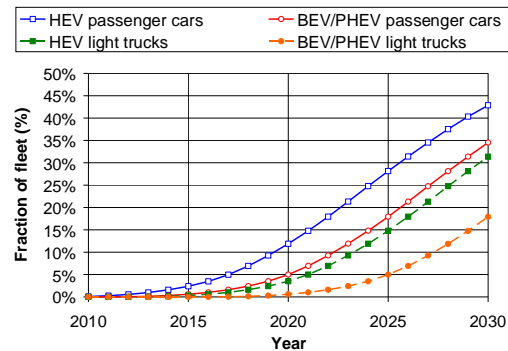


Figure 5: HEVs and BEVs/PHEVs as fraction of the total light duty vehicle fleet for penetration scenarios presented in Figure 1.

4 Discussion

Simulations of future vehicle fleets in three Canadian provinces have shown a large variety in emission reductions from HEVs, PHEVs, and BEVs. Local conditions like the emissions intensity of the electrical grid and the composition of the provincial fleet strongly

influence the emission reduction potential per vehicle and the penetration rate of advanced vehicles in the provincial fleets.

Fleets with BEVs represent the lowest emission solution for Québec and Ontario in 2025, while HEVs would then be the preferred option for Alberta.

The results of this study differ from previous work (for instance [10], [12]), which indicate that PHEVs/BEVs will always be cleaner than CVs regardless of the source of electricity. This seemingly conflicting result is caused by the difference in approach for vehicle performance figures. The current study used performance figures that were averages for *all* vehicle classes per vehicle segment, while the previous studies applied numbers representative of the more efficient passenger car vehicle classes (compact, mid-size).

PHEVs and BEVs could in the future also become the least emitting vehicles in Alberta, if the emission intensity of its electricity grid will be reduced significantly by the introduction of more renewable power generation or other measures to reduce emissions from electricity production.

5 Conclusion

Electric vehicles do result in emission reduction compared to conventional gasoline-only vehicles. However, a 'one-size-fits-all' does not exist! Local conditions greatly influence which type of electric vehicle (HEV, PHEV, or BEV) will be the best option to reduce emissions from transportation. Besides, short term solutions may also differ from those for the long term.

Acknowledgments

Funding for this work was provided by Natural Resources Canada through the Program of Energy Research and Development.

References

- [1] OECD/International Transport Forum, Reducing Transport Greenhouse Gas Emissions: Trends & Data 2010, <http://www.internationaltransportforum.org>, accessed on 2013-02-11.
- [2] Natural Resources Canada, The Plug-in Electric Vehicle – Charge Impact Model (PEV-CIM), <http://canmetenergy.nrcan.gc.ca/software-tools/PHEV-CIM/3049>, accessed on 2013-05-29.
- [3] US Environmental Protection Agency, <http://www.fueleconomy.gov>, accessed on 2013-02-11.
- [4] Statistics Canada, *Population projections for Canada, Provinces and Territories 2005-2031*. Catalogue no. 91-520-X, Ottawa, Canada, 2005.
- [5] Natural Resources Canada, *Canada's Energy Outlook: The Reference Case 2006*. ISBN 0-662-43440-4, Ottawa, Canada, 2006.
- [6] DesRosiers Automotive Consultants Inc, *DesRosiers Automotive Yearbook 2007*, ISBN 0841-9957, Richmond Hill, Canada, 2007.
- [7] Statistics Canada, *Canadian Vehicle Survey 2009*. Catalogue no. 53-223-X, Ottawa, Canada, 2010.
- [8] University of Michigan - Transportation Research Institute, http://www.umich.edu/~umtriswt/EDI_sales_weighted-mpg.html, accessed on 2013-01-31.
- [9] Center for Climate and Energy Solutions, *Federal Vehicle Standards*, <http://www.c2es.org/federal/executive/vehicle-standards>, accessed on 2013-01-31.
- [10] EPRI/NRDC, *Environmental Assessment of Plug-In Hybrid Electric Vehicles. Volume 1: Nationwide Greenhouse Gas Emissions*, Palo Alto, CA, USA, 2007.
- [11] SAE International, *SAE J2841 Standard: Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data*, Warrendale, PA, USA, 2009.
- [12] Hajo Ribberink, Chris Shum, Evgeniy Entchev, *The Impact of PHEV Charging on the Future Electricity Grid and on GHG Emissions in Canada*. Proceedings of EV2010VÉ Conference, Vancouver, September 13-16, 2010.

Authors



Hajo Ribberink has a M.Sc. degree in Applied Physics. He uses modelling and simulation to assess new and innovative technologies for the production or use of electricity and/or heat. He leads CanmetENERGY's research in the field of electric vehicles and was the main developer of the Plug-in Electric Vehicle – Charge Impact Model (PEV-CIM).



Dr. E. Entchev holds B. Eng. degree in nuclear engineering, M. Sc. degree in applied mathematics and a doctorate on optimization of large energy systems. His research interests are in the field of improving the efficiency and sustainability of energy systems. He has more than 140 publications and is a co-author of two books.