Modelling the GHG emissions intensity of plug-in electric vehicles using short-term and long-term perspectives

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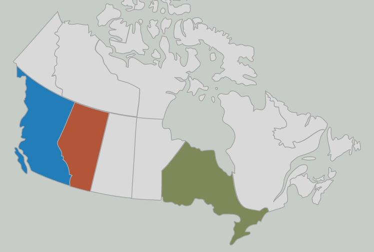
Background

Plug-in electric vehicles (PEVs) are expected to play a key role in achieving long-term climate goals. However, their greenhouse gas (GHG) emission reduction potential depends on factors that can vary by region and over time (e.g. electricity supply mix). Despite these dynamics, many earlier studies have quantified PEV emission impacts from only a short-term, static perspective.

In this study, we model the source-to-wheels emissions intensity (gCO_2e/km) of PEVs from both short- and long-term perspectives. Our analysis looks at three Canadian provinces, covering a range of power systems, policies, and consumers: British Columbia (BC) , Alberta, and Ontario (Fig. 1)



Data

We collected consumer data using the 2013 Canadian Plug-in Electric Vehicle Survey, (CPEVS) a three-part, mixed-mode survey of 1,754 new car buyers across Canada (Fig. 1). The survey included:

- **Vehicle Design Game** (Fig. 2) where respondents designed their preferred next new vehicle as a conventional (CV), hybrid (HEV), plug-in hybrid (PHEV) or battery electric vehicle (BEV).
- **Driving Diary** (Fig. 3) where respondents recorded driving activities and access to potential charging at home and other destinations over a three-day period.

Over one-third of respondents designed a PEV in the design game (i.e. expressed interest in purchasing a PEV as their next vehicle) (Fig. 4). This study focuses on this "Early Mainstream" PEV buyer market segment. We use data from their driving diaries to model activity profiles (including recharge access for the "Early Mainstream" market) (Fig. 5).

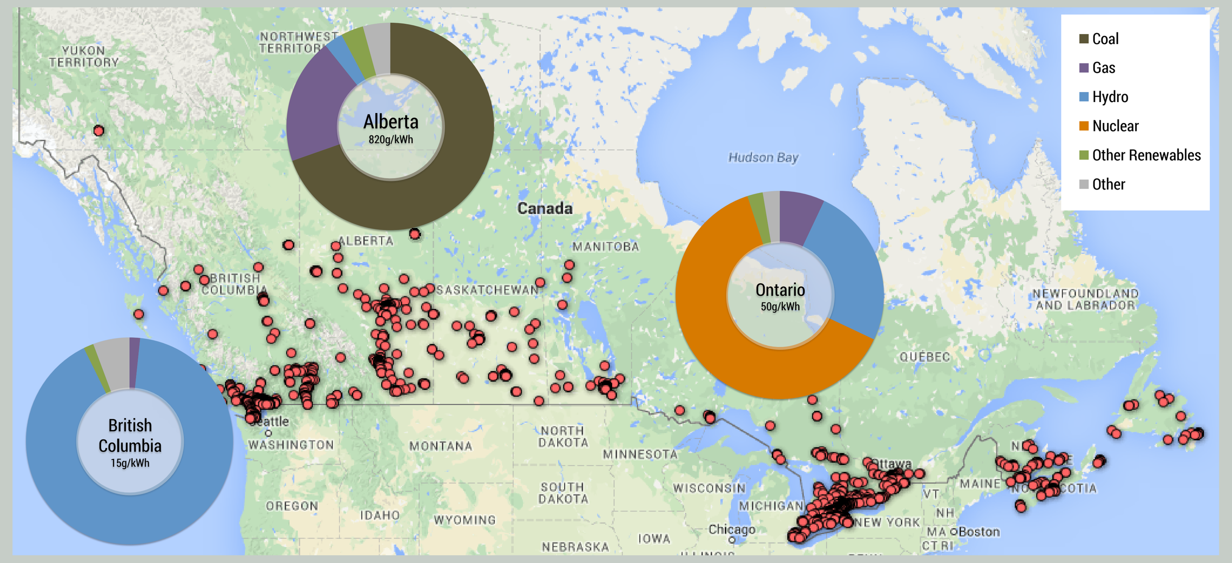


Figure 1 - Respondents from the Canadian Plug-in Electric Vehicle Survey (CPEVS) and 2014 generation mix and annual average GHG emissions intensity of power generation in British Columbia, Alberta, and Ontario

Short-term (static) model

We model three scenarios of PEV usage by "Early Mainstream" respondents to illustrate the impact of varying recharge access rates and PEV type on GHG emissions:

Scenario 1. User Informed: representing survey respondents' selected PEV designs, driving behaviour, and present recharge access.

Scenario 2. User Informed + Enhanced (L2) Workplace Access: same as Scenario 1, but with enhanced workplace recharge access (i.e. assuming Level 2 access is available at all workplaces).

Scenario 3. BEV-240 + Enhanced (L2) Home and Work Access: using respondents' driving data, but assuming each "Early Mainstream" respondent is driving a BEV with 240km of range, and that Level 2 recharge access is universally available at all homes and workplaces.

We estimate GHG emissions from gasoline use using a "well-to-wheels" (WtW) approach, which includes emissions from fuel production, transportation, and use. We derive hourly average and marginal emissions factors for each region using recent historical hourly electricity generation and trade data (Fig. 6).

The three scenarios produce very different time-of-day demand profiles for PEVs (Fig. 7). Scenario 1 and 2 have a moderate evening peak (upon arrival at home), with Scenario 2 resulting in an additional peak in the morning as vehicles arrive at work (due to enhanced workplace access). Scenario 3 has a morning peak and even larger evening peak due to enhanced home recharge access (with Level 2), and increased demand for electrified vehicle km (due to universal BEV usage).

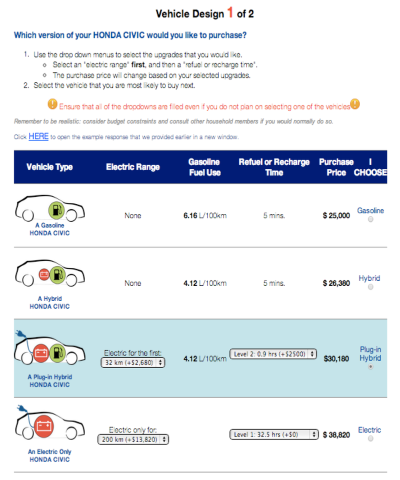


Figure 2 - Vehicle design game from CPEVS

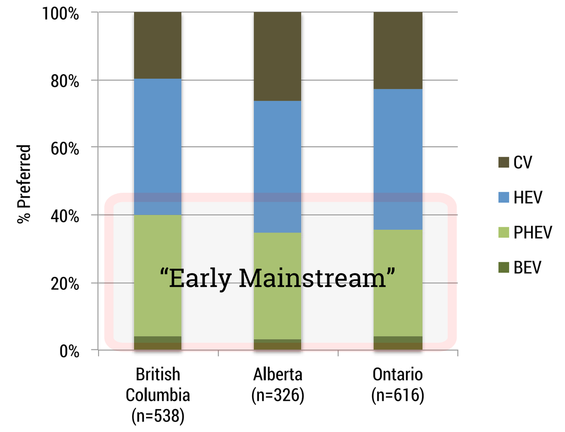


Figure 4 - Respondent vehicle design by province. Respondents who designed a PEV (PHEV or BEV) are classified as the "Early Mainstream"

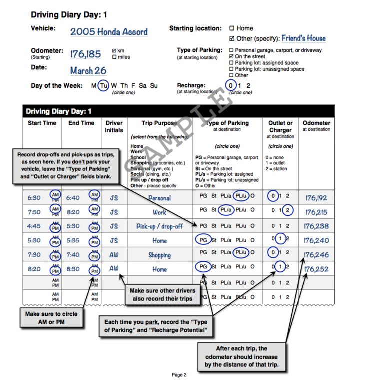


Figure 3 - Vehicle driving diary from CPEVS

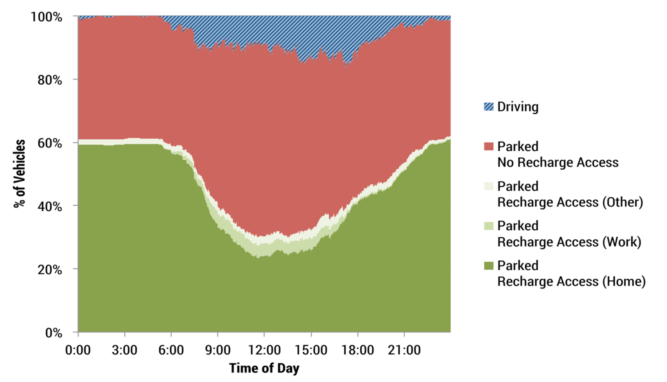


Figure 5 - Driving activity and recharge access by time of day for the BC "Early Mainstream" subsample

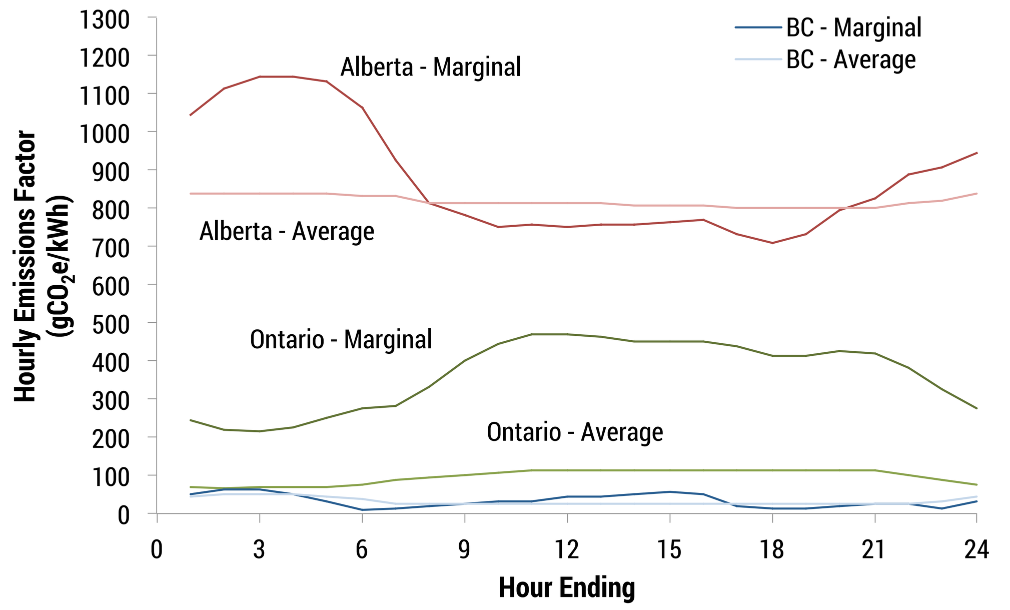


Figure 6 - Marginal hourly and average hourly GHG emissions factors for electricity supply using recent electricity generation and trade data

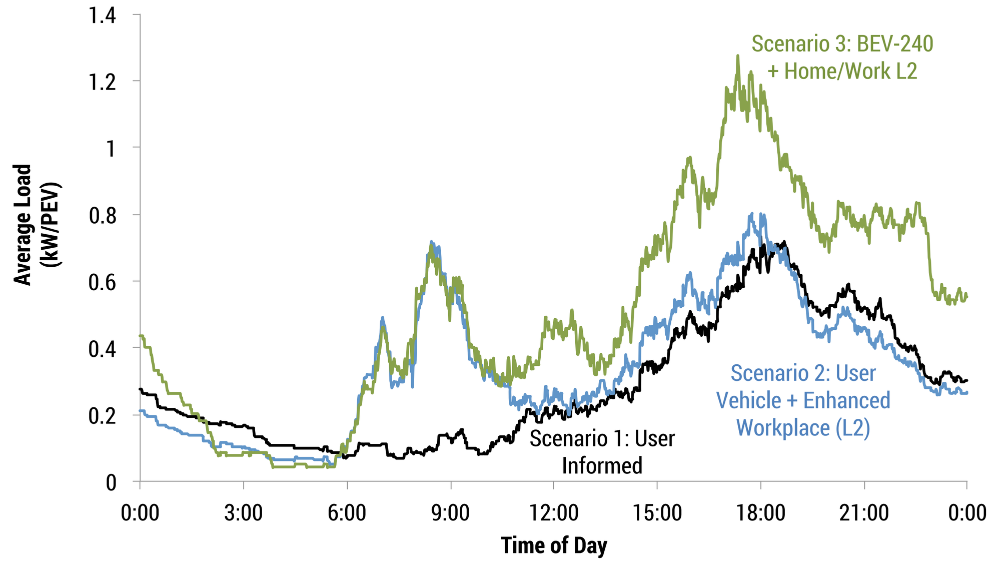


Figure 7 - Electricity demand profiles under three scenarios in BC

Long-term (dynamic) model

We use insights from the short-term perspective to inform a long-term dynamic energy-economy model (CIMS) that considers changes to the electricity grid mix and vehicle fleet over several decades. CIMS is a hybrid energy-economy model which integrates aspects of technology-specific "bottom-up" models, and full economy "top-down" models such as macroeconomic feedbacks and behavioural realism. CIMS represents the uptake of new technologies through a market share (*MS*) algorithm that considers the key factors that affect purchase decisions (Eq. 1) including: capital costs (*CC*), maintenance costs (*MC*), energy costs (*EC*), intangible (*i*) or non-financial costs (e.g. preferences and constraints), and private discount rates (*r*).

$$MS_j = \frac{\left[CC_j * \frac{r}{1-(1+r)^{-n}} + MC_j + EC_j + i_j\right]^{-v}}{\sum_{k=1}^{K}\left\{\left[CC_k * \frac{r}{1-(1+r)^{-n}} + MC_k + EC_k + i_k\right]^{-v}\right\}}$$

Equation 1

We model three policy scenarios in CIMS to explore their effects on the personal transportation and electricity sectors, and resulting fleet-average PEV emissions intensity:

1. **Reference (Current Policies)**: existing federal and provincial climate policies (as of August 2015) affecting the transportation and electricity sectors, including federal and provincial (Ontario) regulations to phase-out coal, BC's low carbon fuel standard and carbon tax, as well as provincial incentives on the purchase of PEVs in BC and Ontario;
2. **Carbon Tax**: escalating, economy-wide carbon tax starting in 2016 at $25/tonne and increasing to $250/tonne by 2050 (based on the IEA World Energy Outlook "450 Scenario" and potentially in-line with current carbon pricing strategies);
3. **Strong Standards (ZEV mandate and Clean electricity)**: standards that require the deployment of zero-emissions electricity and zero-emissions vehicles over the medium term (2025), including a minimum PEV share of new vehicles of 12.75% in 2025 (9.25% PHEV; 3.5% BEV) based on California's ZEV program and potentially in-line with Quebec's mandate.

Results summary

Short-term

Over the short term, fleet-wide emissions intensity of PEVs varies substantially between regions, with the greatest reduction potential, relative to conventional gasoline vehicles, in British Columbia (78-99%), followed by Ontario (58-92%) and Alberta (34-41%) (Fig. 8).

Long-term

Over the longer term, the emissions intensity of electricity decreases at least one-third by 2050 even under current policies (Fig. 9). Fleet average PEV emissions are 23-40% (British Columbia), 51-68% (Alberta), and 25-40% (Ontario) below 2015 levels by 2050.

Policy implications

1. To maximize emission reductions from passenger vehicles over time, PEV market penetration needs to be complemented with reductions in electricity generation emissions.
2. Despite the large temporal and regional variations, PEVs offer substantial GHG emissions benefits compared to conventional vehicles in all contexts explored.
3. Policy makers seeking to achieve deep GHG cuts may want to support PEV adoption, even in jurisdictions that presently use relatively high carbon electricity.

Results

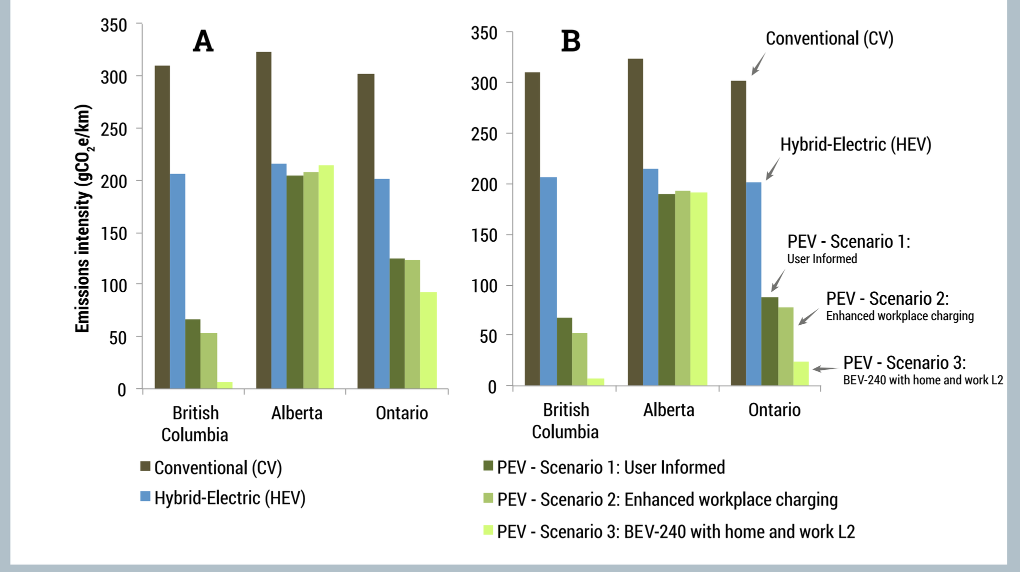


Figure 8 - Short-term GHG emissions intensity using (A) hourly marginal and (B) hourly average emissions factors for electricity

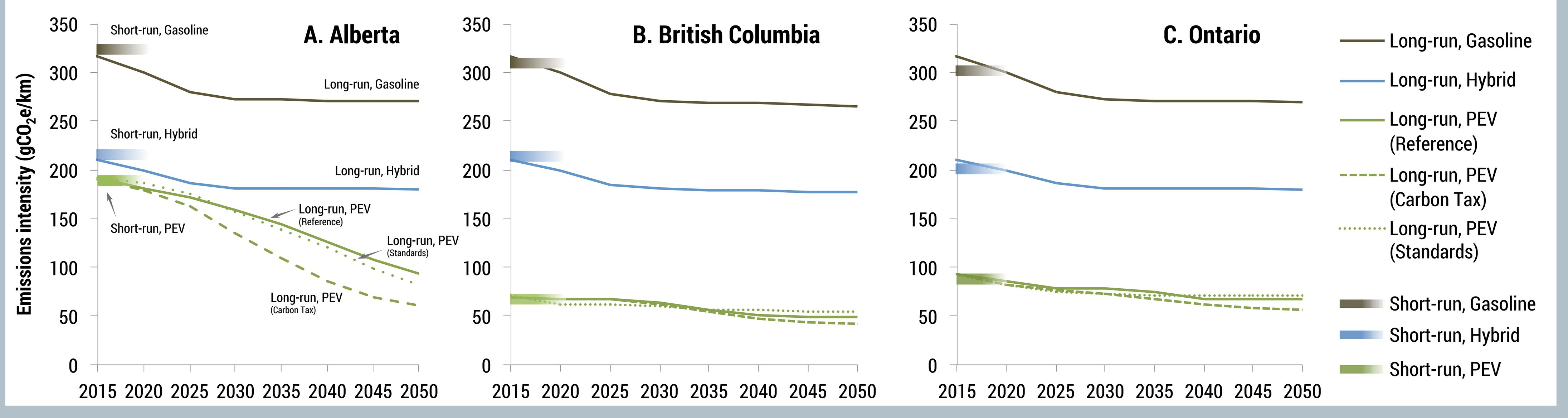


Figure 9 - Fleet-average short-term (Scenario 1) and long-term GHG emissions intensity of vehicles in (A) Alberta, (B) British Columbia and (C) Ontario

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