MODELING INCREASED ELECTRIC VEHICLE CHARGING DEMAND IN QUEBEC

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The UNIVERSITY of VERMONT
TRANSPORTATION RESEARCH CENTER

JCCTRP
Joint Clean Climate Transport Research Partnership
Partenariat de recherche conjoint sur le climat et les transports

Energy Modelling Initiative
Bringing the Tools to Support Canada's Energy Transition

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SUMMARY

The interactions between electric vehicle charging and renewable power generation are an important consideration for any jurisdiction seeking to use increased electric vehicle penetration as strategy to reduce greenhouse (GHG) emission in the transportation sector. This paper describes a model for developing highly-resolved, time-of-day specific charging demand from travel survey data that is consistent with real-world driving patterns and applied to Quebec. Since vehicle charging timing is dependent on electric vehicle supply equipment (EVSE) availability, three EVSE scenarios are considered: 1) home-only, 2) home and workplace only, 3) universal EVSE. The modeling described here provides a valuable approach for understanding the interactions between power grid operation and demand profiles while exploring a range of assumptions about EVSE availability and charging behaviors. All EVSE scenarios result in increased peak demand that could decrease electricity net export and then, contribute to an increase of generation by non-renewable generating sources. This indicates that pricing or other mechanisms that influence charging decisions could result in lower cost and lower emissions outcomes. Results are discussed in light of the renewable energy resources available in Quebec and emerging low-carbon transportation policies.

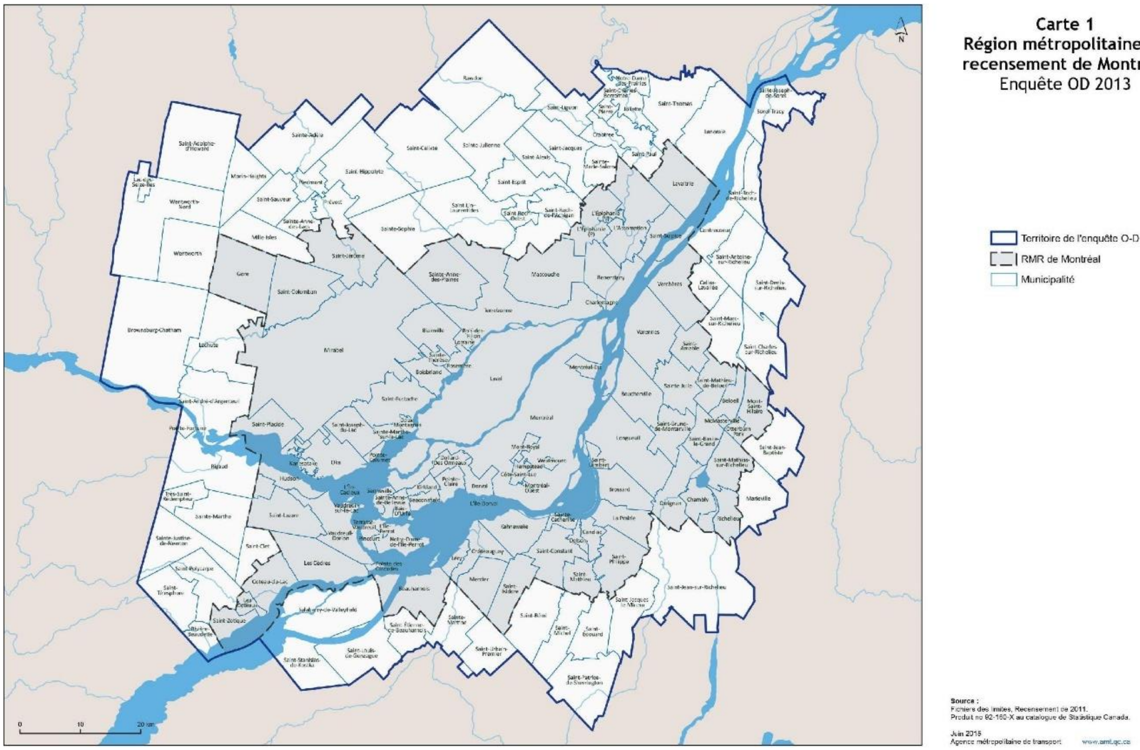
INTRODUCTION

In order for Canada to achieve its commitments under the Paris Agreement and for Quebec to realize its 2030 greenhouse gas (GHG) emission reduction target, it is increasingly recognized that steep emissions reductions from transportation sector will be required. GHG emissions in the transport sector have been constantly rising in Canada since 1990 and now represent over 28% of Canada's total emissions (ECCC, 2019). With fewer emissions from the power sector, the transport sector's share of total emissions in Quebec has risen to over 40% (MELCC, 2018).

Widespread vehicle electrification is a widely cited mitigation strategy for realizing emission reductions of this magnitude (Creutzig et al., 2015). Furthermore, early research on the impacts of vehicle electrification on electric grid management indicated the potential for significant benefits (Parks et al., 2007). Vehicle-grid integration, including bidirectional vehicle-to-grid interactions that effectively allow plug-in electric vehicles (PEVs) to function as storage device, offer the potential for creating significant synergies between PEVs and renewable energy generation (Lund and Kempton, 2008; Niesten and Alkemade, 2016). In this context, it is important to understand the interactions between unmanaged vehicle charging and renewable energy generation.

As vehicle electrification accelerates, the magnitude and timing of PEV charging will have important implications for grid operations, including the integration of intermittent renewable energy sources, and the cost of GHG emissions reductions. This paper describes an assessment of the suitability of available travel survey data in Quebec for use with a plug-in electric vehicle charging demand model (PEV-CDM) developed at the University of Vermont (UVM) and an application of that model to the greater Montreal area (see Figure 1). The PEV-CDM was first developed and applied using data from the National Household Travel Survey (NHTS) for the northeast United States (Howerter, 2019; Howerter et al., 2020) and builds on an earlier charging model described in Dowds et al. (2013). This paper represents a first effort to apply the model in Canada, and could be extended to other Canadian provinces.

Figure 1: 2013 OD survey Greater Montreal area



Source: AMT (2013: 12-13)

Quebec offers an interesting place to explore the impact of PEVs on charging demand. Given that electricity production in Quebec comes mainly from hydroelectricity and that surplus electricity is expected in coming years (Hydro-Québec, 2017), transport electrification is a promising strategy for reducing emission in Quebec. In Quebec, the use of PEVs is also incentivized through subsidies for the purchase of PEVs and electric vehicle supply equipment or EVSE (TÉQ, 2019). A zero emission vehicle mandate has also been in place since 2016 that requires auto manufacturers to hit PEV sales credit targets (Government of Quebec, 2018) while the development of the charging infrastructure throughout the road network is finance by the government. As part of its *2030 Sustainable Mobility Policy and Action Plan 2018-2030*, Quebec has the goal to have one million PEV on the road by 2030 (MTQ, 2018). The *Sustainable Mobility Policy* also proposes a 20% reduction of solo car trips, a 40% reduction of petroleum consumption in the transport sector and a 37.5% reduction below 1990 levels of GHG emissions in the transport sector. These efforts are part of suite of climate policies in the transport sector that includes the Quebec-California carbon market as well as the vehicle emission standards and the development of a clean fuel standard led by the federal government (Axsen et al., 2017; Melton et al., 2017; Purdon et al., 2019; Scott, 2017).

For this project, a joint team from the University of Vermont (UVM) and Institut québécois du carbone (IQCarbone), in collaboration with partners at the Ministry of Transportation of Quebec (MTQ) and university partners assessed whether or not MTQ data could be used with the PEV-CDM. These institutions are all partners of the Joint Clean Climate Transport Research Partnership (JCCTRP), which seeks to cultivate research linkages between the policy and modeling communities in Quebec, Vermont, Ontario and California. This process revealed that the MTQ data was sufficient to run a slightly simplified version of the PEV-CDM. Efforts were also made to apply the model in Ontario but it proved infeasible to acquire the necessary transportation within the time allotted.

THE MODEL

Overview of the PEV-CDM

Many PEV charging studies have made simplifying assumptions about vehicle travel, e.g. that all vehicles travel the same average mileage, and charging behavior, e.g. that all charging occurs at in the evening or off-peak (Ahmadi et al., 2015; Calnan et al., 2013; Foley et al., 2013). Other studies have constructed charging demand models using travel survey data in the context of grid modeling but their demand modeling has been limited to plug-in hybrid electric vehicles (Dowds et al., 2013; Vithayasrichareon et al., 2015). Some modeling efforts have simulated PEV “charging profiles” under assumptions that all vehicles will charge upon arrival as long as a stop has charging infrastructure and a 10-minute dwell time constraint is met (Vithayasrichareon et al., 2015). In reality, PEV charging decisions vary among individuals and several studies indicate that a driver’s desire to charge increases as the state of charge (SOC) decreases.

The PEV-CDM addresses this gap in the literature by producing hourly vehicle charging demand that is consistent with real-world driving patterns. Vehicle-based analysis of light-duty vehicle travel is used to inform minute-by-minute charging with electricity demand aggregated by the hour. These results are first determined for daily vehicle travel and then estimated for weekly vehicle charging. Final output for a single electric vehicle is a hourly, week-long vector of charging demand in kWh. All electric vehicle week vectors are then summed to arrive at total additional electric vehicle electricity charging demand and replicate to create annual charging demand patterns.

The PEV-CDM is built on two key assumptions. First, that travel patterns are dependent on the spatial distribution of origins and destination which change relatively slowly and therefore that near-future driving patterns will be broadly similar to the driving patterns occurring today. Second, that drivers are unlikely to significantly alter their travel patterns in order to accommodate technological differences between internal combustion engine vehicles (ICEVs) and PEVs, meaning that the driving patterns of future PEV drivers can be approximated by current ICEV travel patterns when that travel is compatible with PEV electric range. Given these assumptions, travel survey data can be converted to time-specific charging demand. Scenario analysis conducted with the PEV-CDM can capture how charging station availability (also known as electric vehicle supply equipment or EVSE availability), vehicle characteristics, and individual charging preference influences the timing of vehicle charging.

The PEV-CDM has been applied to model the impact of PEV charging demand in the northeast US. The main dataset used is the National Household Travel Survey (NHTS) produced by the US Department of Transportation. It documents every trip taken by each household member for all responding households as well as what vehicle (if any) was used for each trip. The NHTS includes daily, non-commercial travel by all modes, detailed characteristics, and expansion weights.

The PEV-CDM uses household travel survey data as its main input and simulates hourly PEV charging demand in four main steps:

1. First, vehicle travel profiles are created that link a trip log (recording the timing, mileage, and purpose of all unique trips taken by the vehicle), a corresponding stop log (recording the timing and duration for all periods on the travel day when the vehicle was stopped and the purpose for the trip preceding that stop), and household and driver attributes (e.g. gender, age, household income). Three derived variables, the longest trip length on the travel day, the total traveled miles for the travel day, and the total number of trips taken on the travel day are also calculated for each profile.

2. Second, the model calculates a PEV Compatibility Score for each vehicle profile. The compatibility score determines the relative frequency with which particular vehicle profiles are sampled by the PEV-CDM. Scores are calculated based on vehicle characteristics and travel patterns as well as on household variables and sociodemographic characteristics of the primary driver. Because of differences between the demographic data available in the MTQ dataset and in the NHTS dataset (discussed in more detail below), the Compatibility Score used in the Montreal application is a simplified version of the Compatibility Score used in the original applications of the PEV-CDM. The multipliers that contribute to the Compatibility Scores for the Montreal application are shown in Table 1 below. After the compatibility scores are calculated for each vehicle in the dataset, they are multiplied by the survey expansion weights to give the final weights for sampling profiles for each PEV type.

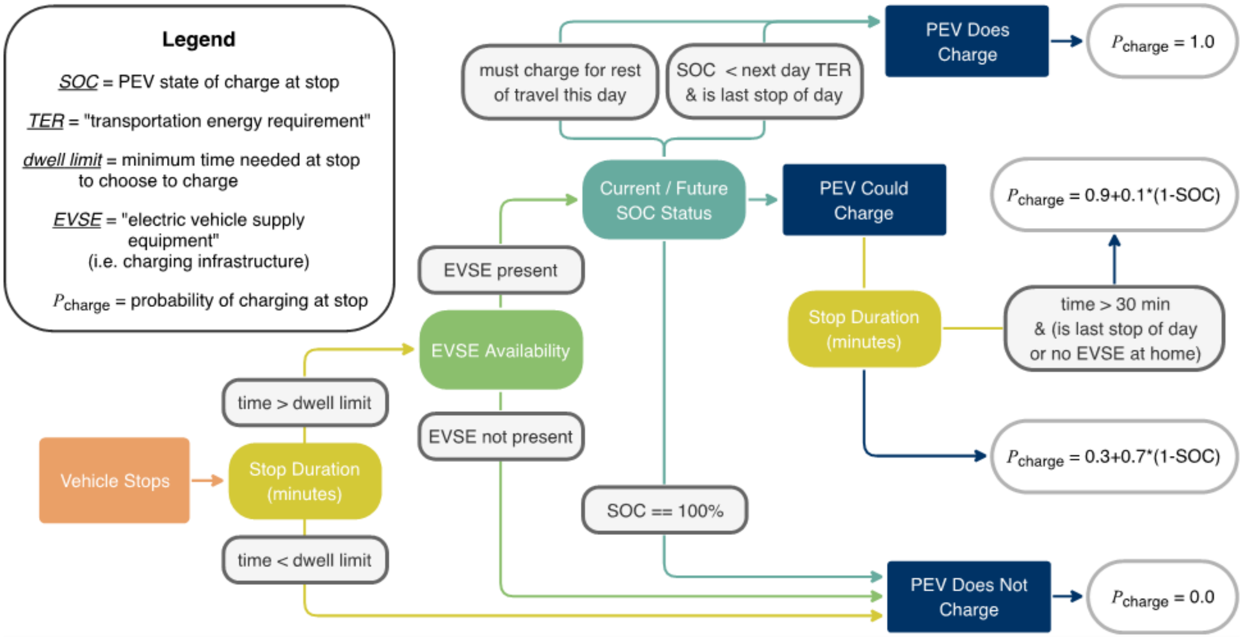
Table 1: Compatibility Score Multipliers

Variable	Multiplier	Notes
Household Income	Income/4 > PEV Price: 1 Income/4 < Price: 1-1000/diff	Current literature shows a weak relationship between income and PEV adoption.
Household Vehicle Count	2 or more vehicles: 1 1 vehicle: 0.8	Current literature shows higher PEV adoption for multi-vehicle households from Axsen et al., 2017
Driver Age	1-0.0042*(age-16)	Decreased likelihood of PEV ownership with age from Carley et al. 2013 (*16*)
Longest Trip Length	Trip length < PEV range: 1 Trip length > PEV range: 0	Profile is considered incompatible with a PEV type is the longest trip is greater than PEV range
Total Daily Trip Miles	Total Miles < PEV range: 1 Total miles > PEV range: 0.5	Profile computability is reduced if the total daily mileage exceeds PEV range reflecting range anxiety
Minimum Battery SOC if charging at every opportunity	SOC > 0.1: 1 SOC < 0.1: 0.7 SOC < 0: 0	Profile compatibility is reduced if SOC falls below 10% (range anxiety) and incompatible if the SOC is falls to 0.

3. A random draw of seven daily profiles (with probabilities of selection in proportion to their relative Compatibility Scores) are selected to create a full-week travel profile. In applications of the PEV-CDM using NHTS data, five weekday and two weekend profiles are used to create the weekly profile but only weekday travel is captured in the MTQ data.

4. The PEV-CDM charging behavior logic is applied to the weekly travel profile to determine the timing of charging given different EVSE availability scenarios. The charging logic is depicted in the figure below. Vehicles will never charge at stops without EVSE or when their battery is fully charged and will always charge at stops with EVSE if they lack sufficient energy to complete their next trip. In other cases, the charging decision is probabilistic. The charging process is repeated iteratively until the battery state of charge at the start and end of the week are identical to avoid discontinuities and then the weekly demand can be replicated to create a full year of charging demand.

Figure 2: Charging Demand Model Schematic



Comparison of U.S. and Quebec Datasets

The MTQ data used for this study is 2013 Montreal OD survey. Several difference in the MTQ to the NHTS data are discussed below.

1. The MTQ data is only collected for weekdays (Monday-Friday) during Fall 2013 and therefore does not capture weekend (Saturday-Sunday) or other seasons travel patterns. In order to create annual outputs from the PEV-CDM, it was necessary to use weekday data for weekend travel and to use the period of the survey for the whole year. Since trip

timing and trip destinations vary between weekdays and weekends (e.g., Krumm, 2012), this introduces an additional degree of error in the model inputs.

2. MTQ trip data is not associated with a vehicle identification and therefore driver identification is used as a proxy. Hence, it is not possible to capture if a vehicle is used by multiple drivers during the day. Furthermore, vehicle type information is not asked in the Montreal OD survey, so it is not possible to distinguish between car and truck trips. In the application of the PEV-CDM to the northeast United States, daily travel profiles for cars and trucks were never intermingled when creating weekly profiles. For the Montreal application of the PEV-CDM, all travel profiles were equally likely to be used for car and truck travel. To the degree that travel patterns (timing, distance, destinations) are correlated with vehicle type, this also introduces some degree of error to the model.

3. The distance of the trips that started or ended outside of the Greater Montreal could not be calculated in the MTQ data. Hence, those trips have been removed from PEV-CDM runs (about 1% of the overall trips). It should be noted that charging demand would be higher if these trips were included.

4. Finally, the demographic information included in the MTQ data is not exactly the same as in the NTHS data. MTQ age information is a five years interval, the household income group are larger in MTQ data than NTHS and there is no information on educational attainment. These issues required several simplifications to the calculation of vehicle Compatibility Scores.

PEV-CDM’s strengths and limitations

The strength of the PEV-CDM is that it utilizes empirical driver behavior to produce detailed for charging demand profiles that are consistent with the real-world travel behavior. Sensitivity and scenario analysis conducted with the PEV-CDM can be used to explore the impacts of EVSE availability and charging behavior preferences on hourly electricity demand. Since the timing of electricity demand determines what generating resources are available to meet charging demand and impacts the technical and economic challenges for operating the grid, the PEV-CDM is well suited to use with dispatch models and other energy sector modeling tools. In this application, the model is also unique in being able to link trip tour-based travel behavior data with time resolved electricity demand and regional dispatch capacity and, consequently, GHG emissions.

There are some limitations with the PEV-CDM. It does not predict the share of PEVs that will be on the road, only user-defined scenarios of PEV penetration. It also assumes that drivers will not alter their driving patterns. But there is evidence that the range of current PEVs disincentives their use for long-distance transport. Another limitation is that the PEV-CDM model does not include information in current EVSE in Quebec. This is important because Quebec has the largest network of ZEV charging stations in the country. It might be important to include a component to the PEV-CDM model that incorporates the existing charging station network in Quebec, including the geographic distribution of charging stations, on PEV electricity demand. A region with relatively more public EVSE would be presumably more likely to have charging stop outside of home. Finally, the current iteration of the PEV-CDM assumes that vehicle charging begins as soon as a vehicle arrives at a stop. The UVM research team is exploring PEV-CDM implementation where charging demand is represented so that charge timing can be optimized within a dispatch model subject to the constraints of the vehicles' actual travel behavior.

Several additional refinements to PEV-CDM have been identified by Howerter et al. (2020). These include sensitivity analysis surrounding the probability of charging at discretionary charging opportunities. The current probabilities reflect relatively conservative charging behavior that may result in drivers maintaining a higher SOC by charging more frequently than is consistent with current observations. In addition, as the PEV market is rapidly changing, the PEV performance characteristic modeled here could become dated and future modeling with different range and efficiency characteristics should be considered. The potential use of chagrin data survey could also help to improve model calibration.

MODELING RESULTS

Presentation of Quebec Results

Once IQCarbone completed a variety of data processing steps to format the MTQ data to be consistent with the input requirements of the PEV-CDM, UVM conducted three small-scale applications of the PEV-CMD modeling different EVSE scenarios for the greater Montreal region. These EVSE scenarios were:

1. **Home Charging Only:** In this scenario EVSE is available at all home locations but is unavailable at all other stop types.
2. **Home and Work Charging:** In this scenario EVSE available at both home and work locations but is unavailable at all other stop types.
3. **Universal Charging:** In this scenario EVSE available at all stop locations.

The PEV-CDM was run for 10,000 fully-electric PEVs for each scenario, which has been found to produce stable results in previous research that can be scaled up to represent actual PEV penetration at various levels as demanded by Quebec climate and transport policy. Reflecting the distributions of PEV cars and PEV trucks in the study region, two thirds of the vehicles were models as cars and one third as trucks. Cars were divided between low and high range vehicles. Vehicle range and performance characteristics are shown in the Table 2.

Table 2: Fully-electric PEV Characteristics

	Low Range PEV Car	High Range PEV Car	Low Range PEV Truck
Electric Range (mi)	110	310	290
Drive efficiency (kWh/100 mi)	30	30	35
Fraction of modeled PEVs	0.33	0.33	0.33

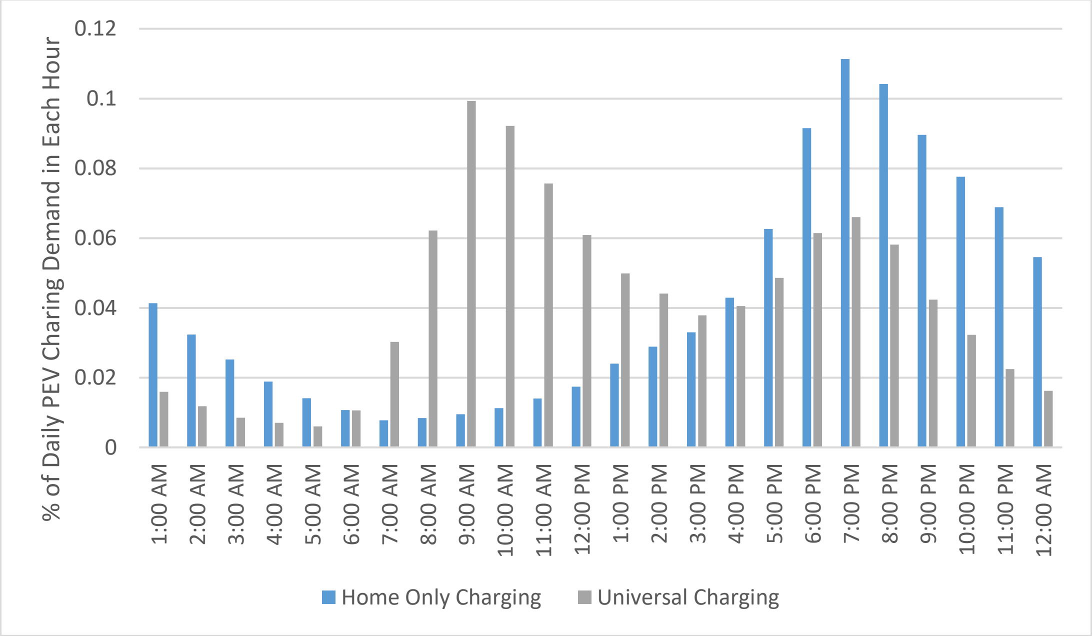
To simulate total annual charging demand, a week have been simulated by stringing together seven randomly selected days for the three scenarios. The week is then replicated 52 time to create a full year. Aggregate charging demand is fairly comparable across the model runs but highest in the universal EVSE scenario (Table 3). Universal EVSE availability leads to higher overall charging demand since a greater number of higher mileage vehicle profiles are PEV compatible with more EVSE.

Table 3: Aggregate Annual Charging Demand by EVSE Scenario for 10,000 fully-electrics PEVs for Greater Montreal area

EVSE Scenario	Annual Charging Demand (MWh)
Home Charging Only	23,445
Home and Work Charging	23,338
Universal Charging	24,568

Figure 3 below shows the proportion of total fully-electric PEV charging that occurs in each hour of the day for the "home charging only" and "universal charging" scenarios. As is evident in the figure, the availability of charging at non-home locations shifts a significant portion of charging demand from the evening and overnight hours to daytime hours which would promote greater compatibility with solar photovoltaics and, depending on the baseline demand, contribute to a more level load curve. For example, Hydro-Quebec has estimated that solar might contribute 1.3 TWh by 2029 (Hydro-Québec, 2019a: 6).

Figure 3: Proportion of total PEV charging



Interpretation of Results

A first finding is that transport data available in Quebec might be used in the PEV-CDM model. The PEV-CDM is designed to convert household travel survey data into time-of-day specific electricity demand for vehicle charging. This project demonstrated a high-level of compatibility between travel data collected in Quebec and the PEV-CDM. While there are several differences between the NTHS and MTQ data, these differences did not preclude using the MTQ data with the PEV-CDM.

Second, consistent with the northeast U.S. application, the Quebec application of the PEV-CDM model demonstrated that EVSE availability is an important determinant of the timing of vehicle charging. Given the charging logic represented in the charging demand model, our results indicate that when charging infrastructure was available at more stop locations, a larger portion of charging demand was shifted into the morning hours relative to home-only charging scenarios. This is important for balancing demand more evenly throughout the day rather than concentrating charging in the evening hours.

Third, although Quebec is an important exporter of electricity over the year, it has some electricity demand peak that reduce substantially net export of electricity. These peaks of electricity demand happen between 6h00-9h00 and between 16h00-20h00 during cold winter days (Hydro-Québec, 2019). All EVSE scenarios result in increasing these peak demands. Considering that these decreases of net export are costly and contribute to electricity production from non-renewable energy, electricity rate modulated on time of the day demand could influence charging decision and result in lower cost as well as lower emission outcomes.

A final finding is that expected PEV charging demand appears quite feasible under a range of low-carbon transport scenarios in Quebec if we extend greater Montreal result to the province (greater Montreal represent more than half of the province population). In Table 4 we specifically model fully-electric PEV penetration under the Quebec ZEV mandate for 2020 and 2025. These calculations were based on the fact that 30,850 fully-electric PEVs circulated in Quebec in 2019 (AVEQ, 2019). Future PEVs that would be added to the Quebec passenger vehicle fleet is based on a forecast of new car sales for 2020, estimated that 435,000 new vehicles (Scotiabank, 2019: 4). The ZEV mandate requires at least 9.5% of total ZEV credits to be earned by intermediate and large automakers by 2020 and 22% by 2025. The ZEV credits work so a PEV with a ~400 km range qualifies for 3 ZEV credits. While different combinations of fully-electric PEVs and partially-electric ZEVs are permitted under the Quebec ZEV mandate, we simplify the calculations by using fully-electric PEVs.

Based on these calculations, approximately 44,000 fully-electric PEVs are on the road in 2020 and 167,000 fully-electric PEVs by 2025. Using a simple multiplier based on the 10,000 ZEVs of the original modeling run, we estimate total ZEV annual charging demand at between 103,158-108,099 MWh in 2020 and 391,532-410,286 MWh in 2025 (Table 4). We note that are results are comparable to other estimates of PEV electricity demand. Hydro-Quebec has estimated that 635,000 PEV would be on the road in 2029, which would lead to an increase of 2.3 TWh in electricity demand (Hydro-Québec, 2019a: 6-7). If we take our 2025 estimate of electricity demand for fully-electric PEVs and multiply to reach the number of PEVs estimated by Hydro-Quebec for 2029, we arrive at 1.56 TWh. We note that our estimate is close to Hydro-Quebec estimation of solar's contribution of 1.3 TWh by 2029 (Hydro-Québec, 2019a: 6).

Table 4: Fully-electric PEV annual charging demand under various Quebec policy scenarios

EVSE Scenario	Units	Original Model	2020 ZEV mandate	2025 ZEV Mandate
ZEV Fleet	Units	10,000	44,000	167,000
Home Charging Only	MWh	23,445	103,158	391,532
Home and Work Charging	MWh	23,338	102,687	389,745
Universal Charging	MWh	24,568	108,099	410,286

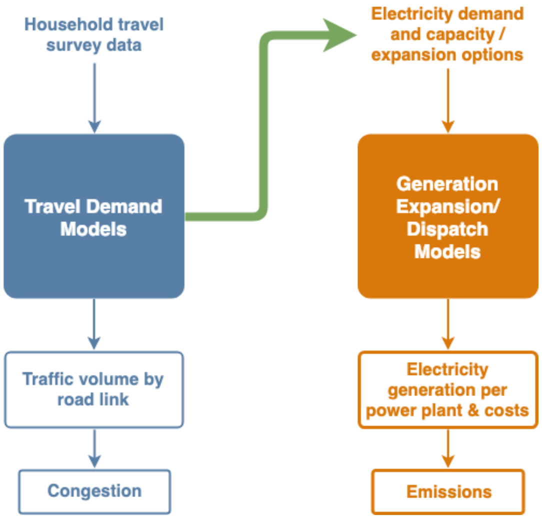
THE MODEL'S PLACE IN THE ECOSYTEM

Synergy with other models

The PEV-CDM is part of a model integrating transport and energy systems components developed by researchers at the University of Vermont (Aultman-Hall et al., 2012; Dowds et al., 2013; Farmer et al., 2010; Hilshey et al., 2012; Jackson and Aultman-Hall, 2010; Nam et al., 2015). One of the main uses of the PEV-CDM charging demand to date has been to produce input for an electric power dispatch modeling. The complete model integrates daily travel data-based charging profiles with a linear optimization, generation expansion/dispatch model. The model allows considerable detail for charging timing, which determines what generating resources are available to meet. See Figure 4.

Dispatch modeling enables the assessment of how vehicle electrification impacts the power generation in terms of costs, emissions, and energy renewable utilization. In the northeast U.S. generating capacity is divide among gas, nuclear, hydro and a growing set of renewable. The integrated model is particularly innovative, given that energy system and transport models are often conceptually distinct modeling efforts with, traditionally, little overlap between models and modeling communities. The integrated energy-transport system model developed by researchers at UVermont is one of the first of its kind. While the NHTS is the primary dataset for the PEV-CDM, the generation expansion/dispatch model relies on dataset known as eGrids, which is maintained by the EPA. It includes all power generating facilities in each state along with the capacity, efficiency, and emissions attributes of those power plants.

FIGURE 4 : OVERVIEW OF UVERMONT INTEGRATED ENERGY-TRANSPORT SYSTEM MODEL



How can the PEV-CDM model help at policy elaboration?

The PEV-CDM model lends itself to various policy applications. Charging demand profile created by the PEV-CDM can be used for a wide range of energy modeling applications to address a variety of questions related to vehicle electrification. At the macroscale, the UVM research team has used charging profiles from the PEV-CDM and its predecessor model to explore renewable energy utilization for vehicle charging as well as the cost of decarbonization

(Howerter et al., 2020; Howerter, 2019; Dowds et al., 2013) and to explore the impact of vehicle charging on transformer aging at the microscale (Hilshey et al., 2012).

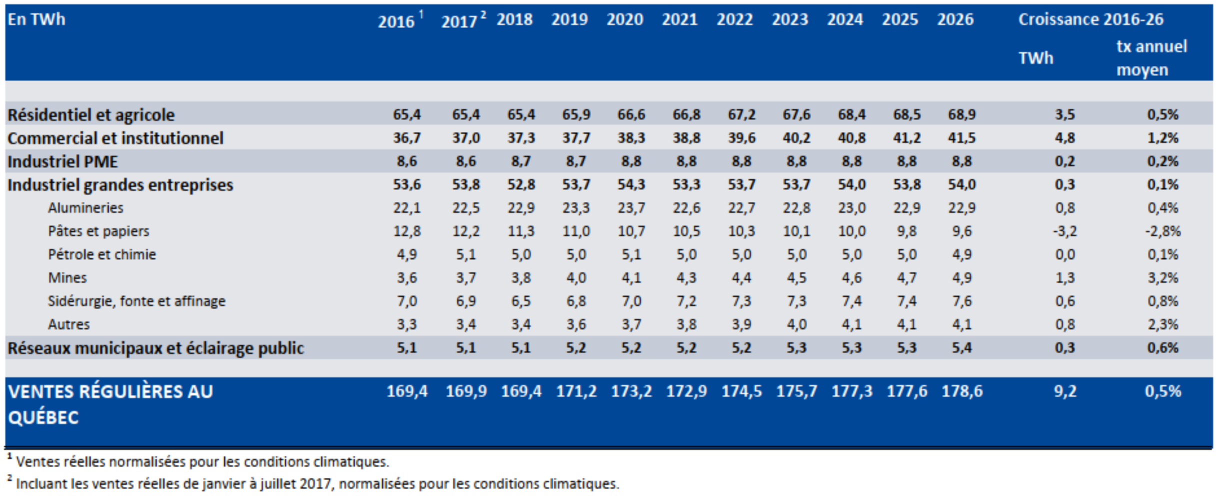
One pertinent example comes from application of the full, integrated energy-transport system model in New England and New York (Howerter et al., 2020). Results provide evidence of the importance of workplace charging: in the scenario with universally available charging infrastructure, 39% of all non-home charging demand occurred at workplaces and work stops had the highest percentage of non-home charging events. The "home-work" scenarios also had the lowest overall levels of additional CO2 emissions and the lowest maximum hourly emissions per PEV throughout the entire year. All EVSE scenarios result in increased peak demand and increased generation by non-renewable generating sources. This indicates that pricing or other mechanisms that influence charging decisions could result in lower cost, lower emissions outcomes. It also suggests that the availability of EVSE and related charging infrastructure could have an impact on grid management. Investment decisions pertaining to EVSE should consider how its availability will affect the time at which electricity is consumed during the day and hence the overall costs of electricity.

Given Quebec's hydroelectric potential, application of the full integrated energy-transport system model is arguably of less interest given low carbon content of hydropower relative to other fuels (Gagnon and Chamberland, 1993; Tremblay et al., 2004; Weissenberger et al., 2010). Currently, there is over 45,400 MW of installed hydro capacity in Quebec which generates approximately 96% of the electricity in the province (Whitmore and Pineau, 2018: 18). Wind power is the second largest source of electricity in the province with 3,882 MW of installed capacity that generates 4% of electricity. In this context charging demand and dispatch modeling would likely be more meaningful when conducted a regional level (e.g. Quebec and Ontario or Quebec and the northeast U.S.) where a more diverse set of generators could be called upon to serve charging demand.

A more interesting policy question for Quebec may be how PEV penetration might affect the energy balance in Quebec, particularly electricity produced by Hydro-Quebec. Total domestic electricity sales in Quebec were forecast at 173 TWh in 2020 and 178 TWh in 2025 (Figure 5). An additional 35-38 TWh might be expected to be exported on an annual basis between 2020 and 2025. Of 206 TWh of electricity sold by Hydro-Québec in 2017, 34 TWh was exported to Québec's outside markets while exports reached a record for the year 2018 at 36 TWh (Hydro-Québec, 2018; 2019b). Recall that, based on calculations above, total annual charging demand for a fully-electric PEV in Quebec of 167,000 vehicles in 2025 was estimated at 0.39-0.41 TWh. This indicates that switching to fully-electric PEVs is unlikely in Quebec is expected to result in only a modest increase in electricity demand that is unlikely to constitute a major diversion of Hydro-Quebec’s international business.

Finally, the application of the PEV-CDM, developed for US transportation data, in the Canadian context is important for cultivating research ties, policy understanding and international cooperation between US and Canada. This is particularly important given continued integration of US and Canadian auto-markets (Macdonald, 2019; Yates and Holmes, 2019) as well as coordination of important climate and transport policy initiatives.

Figure 5: Forecasted electricity sales by sector in Quebec



En TWh	2016 [1]	2017 [2]	2018	2019	2020	2021	2022	2023	2024	2025	2026	Croissance 2016-26	
												TWh	tx annuel moyen
Résidentiel et agricole	**65,4**	**65,4**	**65,4**	**65,9**	**66,6**	**66,8**	**67,2**	**67,6**	**68,4**	**68,5**	**68,9**	**3,5**	**0,5%**
Commercial et institutionnel	**36,7**	**37,0**	**37,3**	**37,7**	**38,3**	**38,8**	**39,6**	**40,2**	**40,8**	**41,2**	**41,5**	**4,8**	**1,2%**
Industriel PME	**8,6**	**8,6**	**8,7**	**8,7**	**8,8**	**8,8**	**8,8**	**8,8**	**8,8**	**8,8**	**8,8**	**0,2**	**0,2%**
Industriel grandes entreprises	**53,6**	**53,8**	**52,8**	**53,7**	**54,3**	**53,3**	**53,7**	**53,7**	**54,0**	**53,8**	**54,0**	**0,3**	**0,1%**
Alumineries	22,1	22,5	22,9	23,3	23,7	22,6	22,7	22,8	23,0	22,9	22,9	0,8	0,4%
Pâtes et papiers	12,8	12,2	11,3	11,0	10,7	10,5	10,3	10,1	10,0	9,8	9,6	-3,2	-2,8%
Pétrole et chimie	4,9	5,1	5,0	5,0	5,1	5,0	5,0	5,0	5,0	5,0	4,9	0,0	0,1%
Mines	3,6	3,7	3,8	4,0	4,1	4,3	4,4	4,5	4,6	4,7	4,9	1,3	3,2%
Sidérurgie, fonte et affinage	7,0	6,9	6,5	6,8	7,0	7,2	7,3	7,3	7,4	7,4	7,6	0,6	0,8%
Autres	3,3	3,4	3,4	3,6	3,7	3,8	3,9	4,0	4,1	4,1	4,1	0,8	2,3%
Réseaux municipaux et éclairage public	**5,1**	**5,1**	**5,1**	**5,2**	**5,2**	**5,2**	**5,2**	**5,3**	**5,3**	**5,3**	**5,4**	**0,3**	**0,6%**
VENTES RÉGULIÈRES AU QUÉBEC	**169,4**	**169,9**	**169,4**	**171,2**	**173,2**	**172,9**	**174,5**	**175,7**	**177,3**	**177,6**	**178,6**	**9,2**	**0,5%**

[1] Ventes réelles normalisées pour les conditions climatiques.

[2] Incluant les ventes réelles de janvier à juillet 2017, normalisées pour les conditions climatiques.

Source: Hydro-Québec (2017: 6)

NEXT STEPS

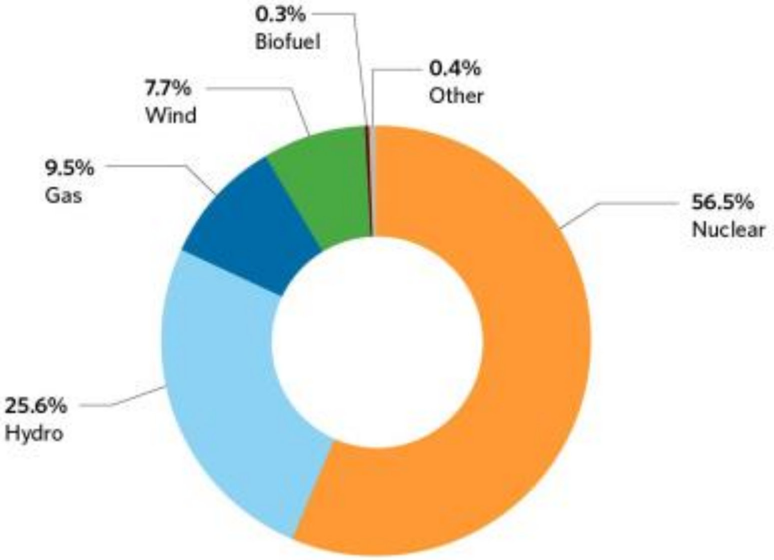
The logical next step would be to expand the application of the PEV-CDM in other Canadian provinces and incorporate the electricity generation and dispatch modeling component in order to apply the full integrated transport-energy system model there. As has been suggested earlier, given the orientation of the JCCTRP, Ontario is the most appropriate province to consider next.

Full application of the UVM energy-transport model in Ontario appears quite feasible. While appropriate Ontario travel data was identified with JCCTRP partners and preliminary evaluation suggested that it would also be compatible with the PEV-CDM, confidentiality restrictions prevented that acquisition of Ontario data within the timeframe of this project.

In Ontario, passenger transportation emissions (cars, trucks, bus, rail, domestic aviation) accounted for roughly 66% of transportation-related emissions in 2014, growing 15% since 1990, due primarily to increased vehicle miles traveled (VMT) and an increase in fleet composition of larger vehicles like SUVs, minivans and pick-up trucks (Government of Ontario, 2017). Freight emissions are also significant, making up roughly 30% of transport-related emissions in 2014 (Government of Ontario, 2017).

However, the power generation sector is much more diversified in Ontario, which makes the application of the generation expansion/dispatch model of considerable interest. In comparison to Quebec, nuclear currently dominates Ontario’s power sector followed by hydroelectricity and gas (Figure 6). The phase out of coal-fired electricity in 2014, which a decade earlier had provided 25 per cent of the province’s electricity supplies, has significantly decarbonized the electricity system. The province’s now relatively low-carbon electricity system, which consistently produces surpluses overnight, has made the increased use of electric vehicles attractive.

Figure 6: Projected production by fuel type to meet Ontario's energy demand, 2019-2021



Source: IESO (2019)

CONCLUSION

In this paper we have applied the PEV-CDM developed by researchers at the University of Vermont for application in the Canadian province of Quebec. Modeling outputs have been consistent with other efforts to estimate the electricity demand of levels of fully electric PEVs in Quebec consistent with the province's climate and transport policies. Our estimate of PEV electricity demand comparable to ZEV policy in Quebec is approximately 0.10-0.11 TWh in 2020, 0.39-0.41 TWh in 2025 and 1.56 TWh by 2029. This is well below current rates of electricity exports of Hydro-Quebec, which stood at 36 TWh in 2018, and comparable to estimated future solar capacity in Quebec. Results also indicate that the EVSE and related charging infrastructure will likely have a significant impact on when PEVs are charged during the day. This offers the opportunity to design charging infrastructure to balance with electricity demand and grid management.

Next steps for this modeling effort in Quebec would include assessing the impact of PEV charging demand as estimated by the PEV-CDM on electricity generating costs, wind utilization, and GHG emissions for Greater Montreal. In addition, the modeling could be expanded in geographic from Greater Montreal to Quebec as a whole and potentially Ontario as well. Refinement and validation of the charging logic with surveys of current PEV owners or other data sources would also be valuable.

Also significant, our findings indicate that the PEV-CDM model might be more widely applied across Canada to estimate PEV electricity demand. Application in Canadian provinces in addition to Quebec would be arguably more interesting, given the ability to link the PEV model outputs to an energy system component to estimate GHG emissions. PEV-CDM was developed to use NHTS data which is available for all 50 U.S. States and Washington D.C. Hence, this study could likely be extended to other jurisdictions. Household travel surveys similar to the NHTS are conducted in many jurisdictions including Quebec and Ontario.

The PEV-CDM can function as a standalone tool and provide insight into issues such as the total energy demand required for PEV charging, the impact of EVSE availability on the timing of charging demand and overall indication of the alignment between charging demand and intermittent renewable energy sources such as wind and solar. Its greatest research values however, comes when linked to other energy sector models. To date, the demand profiles produced by the PEV-CDM have been used as inputs to transformer aging and economic dispatch models. Future improvements to the PEV-CDM that could incorporate price signals from energy sector models into charging decisions would further enhance the utility of the model. However, this integrated transport-energy model has been developed and deployed successfully already by UVermont researchers in the northeastern US. Given that the authors of the current paper have already identified necessary travel data in Ontario and that its electricity is sourced from a broader array of sources than in Quebec, it makes an excellent candidate for extending the integrated transport-energy model into another Canadian province.

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APPENDIX: Model Outputs - Demand by Hour

Demand						Demand Share		
	Home Only	Home & Work	Universal			Home Only	Home & Work	Universal
1:00 AM	2.588456556	2.842461968	1.112457724		1:00 AM	0.041364336	0.047247205	0.015914
2:00 AM	2.021559796	2.272276716	0.826054584		2:00 AM	0.032305151	0.037769626	0.011817
3:00 AM	1.575752826	1.748405266	0.591125567		3:00 AM	0.025181017	0.029061871	0.008456
4:00 AM	1.18212068	1.300484781	0.493925395		4:00 AM	0.018890654	0.021616568	0.007066
5:00 AM	0.883381879	0.984281213	0.419630411		5:00 AM	0.014116716	0.016360654	0.006003
6:00 AM	0.670429727	0.746990848	0.738735278		6:00 AM	0.010713674	0.01241643	0.010568
7:00 AM	0.486617579	0.561922408	2.111680847		7:00 AM	0.007776299	0.009340235	0.030208
8:00 AM	0.526971259	0.545623039	4.344696205		8:00 AM	0.008421164	0.009069308	0.062152
9:00 AM	0.592334601	0.67817386	6.945684654		9:00 AM	0.00946569	0.011272559	0.09936
10:00 AM	0.701839653	0.752165702	6.444753534		10:00 AM	0.011215615	0.012502446	0.092194
11:00 AM	0.873955245	0.898288229	5.291266534		11:00 AM	0.013966075	0.014931284	0.075693
12:00 PM	1.089047667	1.164870979	4.255754027		12:00 PM	0.017403318	0.019362404	0.06088
1:00 PM	1.501450704	1.642945423	3.485295481		1:00 PM	0.023993646	0.027308925	0.049858
2:00 PM	1.808922972	1.791746394	3.079974917		2:00 PM	0.028907148	0.029782284	0.04406
3:00 PM	2.06572457	2.177279064	2.646013845		3:00 PM	0.033010917	0.036190581	0.037852
4:00 PM	2.687386054	2.88175553	2.830497617		4:00 PM	0.04294526	0.04790034	0.040491
5:00 PM	3.919856845	3.835098241	3.394801924		5:00 PM	0.062640524	0.063746736	0.048564
6:00 PM	5.726709635	5.222803876	4.295769737		6:00 PM	0.09151459	0.086813083	0.061452
7:00 PM	6.965374515	6.054550076	4.617183486		7:00 PM	0.111308838	0.10063831	0.06605
8:00 PM	6.521538438	5.722696761	4.063107528		8:00 PM	0.1042162	0.095122268	0.058124
9:00 PM	5.607564909	4.954838392	2.961230721		9:00 PM	0.089610621	0.082358979	0.042361
10:00 PM	4.857289585	4.424010671	2.252590551		10:00 PM	0.077620989	0.073535598	0.032224
11:00 PM	4.307212244	3.800860642	1.571612714		11:00 PM	0.068830583	0.063177641	0.022482
12:00 AM	3.415514182	3.156953721	1.130107298		12:00 AM	0.054580973	0.052474665	0.016167
Total	62.57701212	60.1614838	69.90395058		Total	1	1	1

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