THE SCHOOL OF PUBLIC POLICY

UNIVERSITY OF CALGARY

MASTER OF PUBLIC POLICY CAPSTONE PROJECT

Understanding charging patterns of electric vehicles (EVs) in Calgary and its implications for future electricity demand and response.

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1. Introduction

The federal government climate plan outlines a 30% reduction in greenhouse gas (GHG) emissions from 2018 levels by 2030. The plan requires the transportation sector, the second highest polluting sector after oil and gas, to reduce GHG emissions by 35 megatons. The projected reduction, which translates to a 41% decrease in GHG emissions per passenger vehicle over the coming decade, will necessitate a significant shift from combustion engine passenger cars to zero-emission vehicles. To achieve this reduction, the government of Canada has mandated a 100% zero-emission vehicle sales target for all passenger vehicles by 2035.

The electrification of the transportation sector is viewed as the most plausible solution for GHG emissions reduction. However, the transition from combustion engine vehicles to electric ones is challenging. Canadians own more than 35 million vehicles, of which more than 23 million are passenger vehicles. Shifting to EVs means millions of vehicles that previously relied on gas will need to be frequently charged. This will require a significant investment in infrastructure to ensure the electrical system can sustain the growing number of EVs. Further, shifting to EVs does not necessarily guarantee a reduction in GHG emissions, as in the case of provinces that generate electricity predominantly from emitting sources, such as Alberta.

This study aims to understand the impact of large-scale EV adoption on Calgary's electricity system and provide policy insights for the provincial government and utility companies to plan and prepare for a future of extensive electricity-charged vehicle usage. It analyzed charging data samples from local EV owners, including charging duration, times of day, and energy requirements. It then examined the impact on the current electricity generation capacity to predict the future demand utility companies will face.

The rest of the paper proceeds as follows: section 2 provides background information on Canada's GHG emissions, legislation, and Alberta's electricity system. Section 3 examines the path to net-zero GHG emissions, the consequences on the transportation sector, the current and future trends in EVs in Alberta, and the predicted effects of large-scale EV adoption. Section 4 outlines this study's methodology, data, and analysis. Sections 5 and 6 provide detailed results and discussion. Finally, section 7 provides policy recommendations for utility companies and municipalities based on this study's results.

2. Background and Motivation - Canada

2.1 Climate Change Panel:

The United Nations Intergovernmental Panel on Climate Change (IPCC) published its Sixth Assessment Report in 2021 (IPCC 2021). The report consolidates the work of hundreds of experts and peer-reviewed studies summarizing the current knowledge of the extent of human impact on climate change. It reiterates the unequivocal evidence that human activity, specifically burning fossil fuels, has increased the temperature of the atmosphere, oceans, and land by 0.8C to 1.3C.

Climate change affects every region across the globe. North America and Canada are predicted to experience periods of extremely hot weather, drought, heavy precipitation, and frequent floods. Limiting the impact of climate change to a specific level will require future reduction of

GHG emissions and ultimately reaching net zero CO_2 emissions. The IPCC report calls for every nation to do their best to reduce GHG emissions to a level that will limit global warming to below 1.5C above pre-industrial levels.

2.2 Canada's GHG emissions:

Canada's National Greenhouse Gas Inventory is prepared and submitted annually to the UNFCCC as required by the 2015 Paris Agreement. In the most recent, from 2020, Canada reported 672 Mt CO_2 equivalent. Although seemingly only a slight decrease from 2019 GHG emission of 738 Mt CO_2 equivalent (GHG emission is often measured in CO2 equivalent to account for the effective warming of different gasses), it is still a significant increase since 1990 (Fig. 1) (Canada Environmental and Natural Resources 2022).

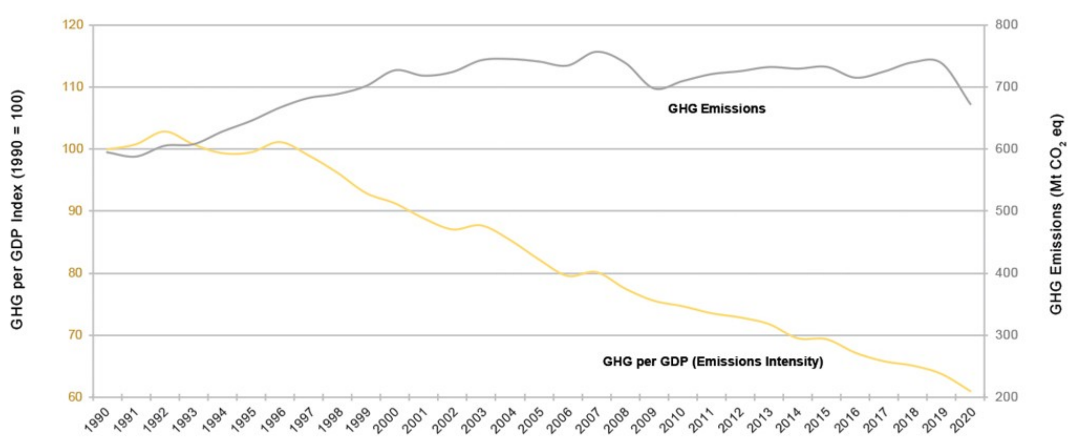

Figure 1: Canada GHG emissions 1990-2020. Source: Government of Canada. Environment and Natural Resources

2.3 Canada’s GHG emission – the transportation sector

The breakdown of Canada's emissions by sector indicates that oil and gas is the largest emitting sector, responsible for 27% of total emissions, followed closely by transportation (24%), commercial and residential buildings (13%), and electricity (8.5%) (Canada. Environmental and Natural Resources. 2022).

Canada's transportation sector overall GHG emissions increased by 15% from 2009 to 2018. In 2018 road transportation emitted 156 $MTCO_2$, 84% of the transportation sector emissions and 21% of Canadian GHG emissions—an increase of 19% from 2005. Passenger vehicles GHG emissions increased from 84 $MTCO_2$ in 2005 to 91 $MTCO_2$ in 2018 a 9.3% (Fig. 2).

Despite progressively stricter GHG emissions standards, GHG emissions from road transportation increased in the past year. This trend is attributed to the increase in overall passenger and freight activity and a shift toward larger passenger vehicles (SUVs and light trucks) and heavy-duty trucks (Canada. Transport Canada. 2022).

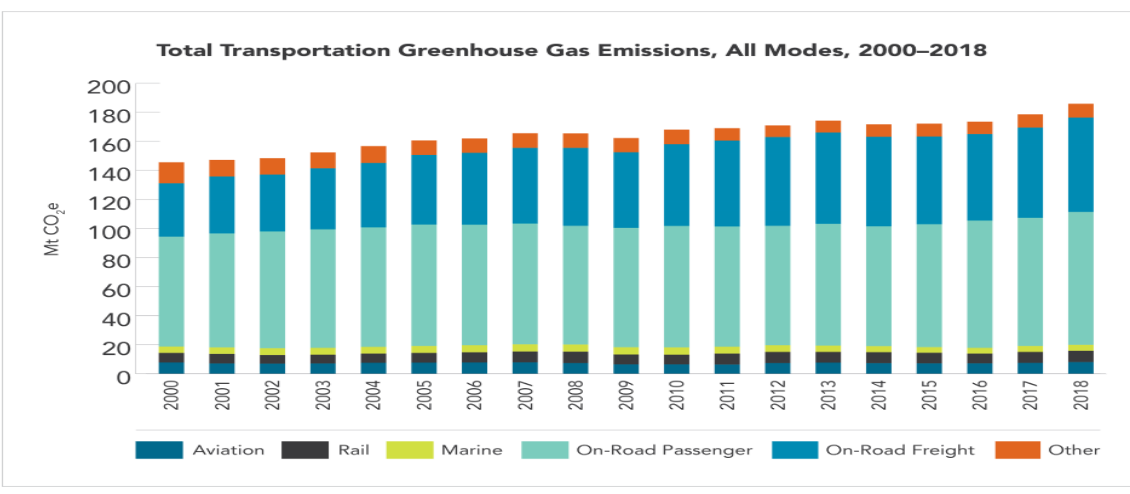

Figure 2:GHG emissions from transportation. Source: Canada. Transport Canada 2022.

2.4 General requirements for an increase in electrical capacity in Alberta based on future energy requirements

The Alberta Energy System Operator (AESO) 2021 Long Term Outlook is a detailed report forecasting future electricity supply and demand in Alberta in the next 20 years. The report examines key factors impacting electricity generation capacity, load, and demand. In a clean-tech scenario, where Alberta is moving toward decarbonization with an aggressive EV adoption rate, AESO predicts a significant rise in electricity demand combined with higher and extended peak demands. In 2040, if EVs will amount to 30% of all vehicles in Alberta, the average demand from EVs alone will reach 1,185 MW, and peak demand will reach 3,900 MW (AESO. 2021).

Although this represents an acute increase in demand, the AESO report suggests that the increase in load will be offset by lower demand from the oil and gas industry and an increase in rooftop solar panels.

The report indicates that EV peak load will be particularly high in the winter during the evenings, which corresponds with Alberta's maximum general energy consumption pattern, and will reach 18,000 MW, a significant increase from the current peak of 12,000 MW. The projected peak demand assumes EV drivers will charge their vehicles during high-demand hours, which emphasizes the need for managing EV charging to be spread over low electricity consumption times. This suggestion will be explored later in this study.

3. Electric Vehicles

3.1 EVs and the path to net-zero emissions

Electric vehicles provide an alternative to fuel-based cars by shifting the energy required to operate the vehicle from fossil fuel to electricity. Since electricity can be produced using renewable sources without increasing GHG emissions, EVs offer a green solution to the traditional mode of transportation.

A Healthy Environment and a Healthy Economy, the federal government's plan, projects that GHG emissions from transportation will fall by 35 MT below the 2018 level by 2030 (Canada. Minister of Environment and Climate Change 2020). Achieving this goal will require a 41% reduction in average GHG emissions per passenger vehicle. A report from the C.D. Howe Institute (Balyk, Livingston, Sara Hastings-Simon, and Bishop 2021) concluded that meeting this target will require a 2.5% fuel efficiency annual increase and an increase of EVs to 30% of the total vehicle stock. This corresponds to a 75% EV annual rise in EVs until 2030 and will fit with the federal government's mandatory EV sales target of 100% passenger vehicles in 2035. In Alberta, where total vehicle stock exceeds 3 million, this will correspond to over 1 million EVs by 2030.

3.2 Current and future trends of EVs in Canada and Alberta

The International Energy Agency (IEA) recently published a *Global EV Outlook 2022*. The report provides insight into current and future global EV markets, sales, and supply chain challenges (IEA 2022). The report outlines the rapid worldwide increase in EV sales, where nearly 10% of global car sales in 2021 were EVs, four-time the market share in 2019. To achieve net-zero GHG emissions by 2050, the IEA predicts that the worldwide EV stock will reach 350 million vehicles.

Statistics Canada provides information about the number of new vehicle registration in Canada (Table 1). Registration across all EV categories (battery electric, hybrid, and plug-in hybrid) showed a significant increase while total new vehicle registration declined overall from 2017 to 2021 (Statistics Canada 2022). The latest information from Statistic Canada regarding the total number of vehicle registration is dated back to 2019. In 2019, over 25 million road vehicles were registered in Canada with over 23 million vehicles weighing less than 4,500 kilograms, including passenger vehicles (Statistics Canada 2022a).

Table 1: Registration of new vehicles in Canada by fuel type. Source: Statistics Canada. Table 20-10-0021-01 New motor vehicle registrations

Geography	**Canada**					
Vehicle type	**Total, vehicle type 1**					
Statistics	**Number of vehicles**					
Fuel type	**2017**	**2018**	**2019**	**2020**	**2021**	**Overall % Change**
	Units					
All fuel types	2,039,236	1,975,860	1,930,445	1,545,561	1,646,609	-24%
Gasoline	1,929,627	1,834,883	1,776,571	1,384,928	1,415,361	-36%
Diesel	65,787	70,600	59,089	64,769	65,881	0%
Battery electric	9,079	22,570	35,523	39,036	58,726	85%
Hybrid electric	24,121	25,837	38,390	41,453	79,330	70%
Plug-in hybrid electric	10,617	21,713	20,642	15,317	27,306	61%
Other fuel types 2	5	257	230	58	5	0%

1. Total vehicle type excludes buses, trailers, recreational vehicles, motorcycles, snowmobiles, golf carts, etcetera.

2. Other fuel types include liquid propane, natural gas, hydrogen, etcetera.

3.3 Current and future EVs in Alberta

The Alberta Ministry of Transportation details overall vehicle registrations in the province by fuel type (Table 2). Recent data suggests that although EVs comprised a small percentage of the total registered vehicles in Alberta, the overall increase in registered EVs and hybrid vehicles was the largest over the past four years. The number of EVs in Alberta increased by 89% from 2017 to 2021, hybrid vehicles increased by 39%, and the overall number of vehicles registered in the province increased by only 3% (Alberta Government 2022)

Table 2: Registration of vehicles in Alberta by fuel type. Source: Alberta government.

Geography	**Alberta**					
Vehicle type	**Total, vehicle type 1**					
Statistics	**Number of vehicles**					
Fuel type	**2017**	**2018**	**2019**	**2020**	**2021**	**Overall % Change**
	Units					
All fuel types	3,529,229	3,557,005	3,638,913	3,603,945	3,629,314	3%
Gasoline	2,772,706	2,796,539	2,870,921	2,847,966	2,875,843	4%
Diesel	392,506	391,800	396,096	387,544	387,765	-1%
Battery electric	377	635	1,297	2,280	3,527	89%
Hybrid electric	16,678	18,364	20,702	23,606	27,459	39%
Other fuel types 2	4563	4304	4039	3945	3703	-23%

1. The Alberta Government does not specify if certain vehicle types are excluded from this report.
2. Other fuel types include liquid propane, natural gas, hydrogen, etcetera.

The distribution of EVs across the province shows a significant concentration of EVs in both Edmonton and Calgary, where the number of EVs is much higher than in rural Alberta or in small municipalities within the province (Fig. 3). Assuming this trend will continue in the future, more charging infrastructure will be required in those cities than anywhere else in the province.

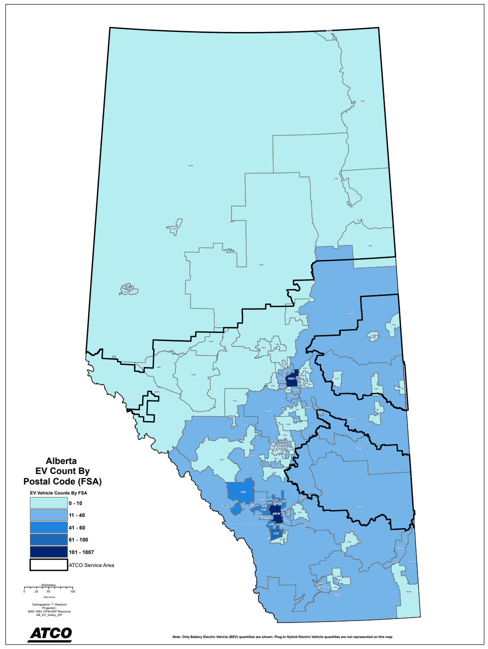

Figure 3: Alberta EV count by postal code. Source Atco. Provided by William York.

3.4 EVs charging overview

EVs are usually classified based on their degree of hybridization and fuel system (Table 3). The main categories include Hybrid Electric vehicles (HEV), Plug-in hybrid electric vehicles (PHEV), and battery electric vehicles (BEV). PHEV is an upgrade of HEV and includes a battery charger that allows charging from the electric grid while parking. The electricity stored in PHEVs usually provides for only a short driving range. In contrast, BEVs are driven only by an electric motor without liquid fuel. The electric energy required for the engine is provided by a rechargeable battery located in the vehicle and charged from the electrical grid while parking.

Table 3: Vehicle type comparison by fuel type and engines.

Type	**Internal Combustion Engine (ICE)**	**Hybrid Electric Vehicle (HEV)**	**Plug-in Hybrid Electric Vehicle (PHEV)**	**Battery Electric Vehicle (BEV)**
Power	Liquid Gas	Liquid gas and electric motor	Liquid gas and electric motor	Electric motor

Engine	ICE	ICE and electric motor	ICE and electric motor	Electric motor
Battery Capacity		1-5 kWh	20-40 kWh	70-90 kWh

3.5 Charging systems

Due to regional differences in the low-voltage distribution grid, charging standards differ at regional and national levels. Canada has two main EV chargers: alternative current (AC) chargers and direct current (DC) chargers. AC chargers provide alternating-current electricity and are divided into Level 1 and Level 2 chargers. DC chargers, also known as fast chargers, provide direct current electricity and are fast chargers that are usually installed in public charging stations.

Level 1 chargers are the standard chargers included with the purchase of EVs. They are the slowest charging option, providing 3 to 8 km of range per hour of charging (1.2-1.8 kW AC) and require a standard 120 V wall outlet. Level 1 chargers are often used at home for overnight charging. Level 2 chargers provide 16-90 km of range per hour of charging (depending on the vehicle and the available power). These chargers require a 208 – 240 V wall outlet (3.2 – 22 kW AC) and can be installed at home through third-party companies for an additional cost. Level 3 charges provide the fastest charging time and are typically installed in public charging stations. These chargers can supply up to 480 V and provide 50 -70 km of range per 20 minutes of charging.

3.6 The effect of the increase in EVs on the electrical system

The predicted increase of EVs requires careful consideration of the impact EVs penetration will have on the electricity system. First, a significant increase in EV adoption will increase electricity demand. Utility companies must evaluate their systems to ensure the electricity supply meets future needs. Second, in regions where part of the electricity is supplied with non-renewable sources, such as Alberta, further consideration is required to ensure that the replacement of combustion engine vehicles with EVs will ultimately result in an overall reduction of GHG emissions to justify the transition. Third, an increase in electrification can potentially increase electricity costs for consumers. Careful planning and policies should be considered to minimize the burden of the transition on consumer electrification.

3.7 EVs and the future cost of energy

Boston Consulting Group studied the cost of electricity due to the increased penetration of EVs on a generic utility with an initial system capacity of 12 GW and a baseline electricity sale of 40 million MWh (Sahoo, Karan, and Thomas 2019). The model assumes three different levels of EV penetration (10%, 15%, and 20% of total vehicles) and three different charging patterns: optimized, moderately optimized, and nonoptimized. Although no significant investment in capacity is assumed, in a 15% scenario with moderate optimization, the model stipulates a necessary $2.8 billion investment until 2030 in transmission and distribution to accommodate the demand for EVs.

The model suggests optimizing charging timing and location will significantly affect transmission and distribution costs. Optimizing charging patterns will reduce EV costs from

$5,800 to $1,700 per electric vehicle, strongly encouraging utility companies to shape customers charging behaviour and promote charging during off-peak hours.

3.8 EVs and the integration of renewable energy sources and GHG emissions

Keller et al. looked at the potential impact on British Columbia's electrical grid if the province's entire transportation fleet was converted to EVs by 2050 (Keller et al. 2019). The results showed that with 93% renewable energy penetration, electricity capacity would have to increase by up to 60% from current levels. Even with the large increase in electricity usage, GHG emissions will still be 30% lower than in a scenario with lower renewable penetration. This study also evaluated the impact of utility-controlled charging on energy cost and demand requirements. The results show that controlled charging, whereby utility companies can shift charging times to off-peak hours or periods with high renewable sources, may further decrease the electricity capacity needs by up to 7%, and system costs would fall by up to 3%. However, other studies suggest that although utility control charging reduces total demand, it can increase GHG emissions by shifting charging to hours of low cost when high-emitting electricity sources such as coal and natural gas predominantly supply the electricity load (Li et al. 2016).

3.9 Future Electricity Supply and Demand

Multiple studies in recent years attempted to evaluate the impact the electrification of the transportation sector will have on the electricity system. Madzharov et al. simulated different levels of EV penetration on a generic electrical system (Madzharov, Delarue, and D'haeseleer 2014). The results showed that generic electrical systems could only support 10 % of EV penetration with random charging patterns. These results assume that charging demand will peak during noon and evening, suggesting that regions must significantly increase their electricity supply capacity in anticipation of more extensive EV adoption.

Schill and Gerbaulet 2015 analyzed the impact of 10% EV penetration on the German power system. The results showed that although EVs account for a small portion of power consumption, hourly charged loads vary over time. Average charging times throughout the day peak in the afternoon, especially where no control mechanisms are in place. The results suggest that a large electric capacity extension is needed to accommodate the expansion of EVs, and the magnitude of the capacity increase will diminish with the implementation of controlled charging behaviour.

3.10 The social cost of EV charging

EVs' charging patterns will significantly impact energy demands during peak charging times (Kelly, MacDonald, and Keoleian 2012). In regions where electricity is not entirely generated by renewable sources, as in Alberta, switching from fossil fuel vehicles to electric vehicles does not guarantee GHG emission reductions. Therefore, the overall impact of an increase in EVs should consider not only the rise in electricity demand but also the social cost of GHG emissions due to an increase in electricity (Morrissey, Weldon, and O'Mahony 2016). Fang et al. calculated the social cost of EV charging using data for the Sacramento area in the United States (Fang, Asche, and Novan 2018). The report concludes that optimal charging times are dependent on the price of CO_2 emissions. Although the specifics vary for different regions, the paper clearly illustrates that incorporating emission consideration is essential when considering optimal EV charging time.

3.11 Review of EV charging behaviour

Previous studies of EV charging patterns identified four prominent charging locations: overnight charging at home, day charging at workplaces, public charging stations, and fast charging on travel corridors during longer trips (Hardman et al. 2018 and Lee et al. 2020). Charging preferences depend on individual driving patterns and vehicle range.

Data analysis of EV charging patterns in California reveals that home charging accounts for 50% to 80% of charging events (Franke and Krems 2013 and Schäuble et al. 2017). The dominance of home charging is influenced by owner access to home charging stations, workplace charging availability, and employers providing free charging stations. Fifteen to 20% of charging events occur at workplaces and 5% in public locations. A 2016 study in California found that price incentives of reduced electricity rates at night also encouraged EV owners to charge at home during the night (Hardman et al. 2018).

Lee et al. found that home charging was the predominant charging station even when other charging options were available. Furthermore, negligible variations between weekdays and weekend charging patterns support the conclusion that charging stations at workplaces will not change the frequency and usage of home charging stations (Lee et al. 2020).

3.12 Vehicle grid integrations and utility-controlled charging

One of the solutions proposed to mitigate the increase in total electricity demand was the implementation of utility-controlled charging (UCC), where utility companies can control EV charging capacity and time. UCC can allow utility companies to shift charging to low demand times, reducing total electricity load during peak hours. Implementing UCC requires communication between the grid and the vehicle, allowing the utility companies to switch charging on and off and allowing EV drivers to specify their charging needs.

The overall effect of UCC on future electricity demand, electricity cost, EV penetration, and GHG emissions depends predominantly on energy sources composition, the price of renewables, the cost of EVs, and charging station availability. Wolinetz et al. modelled the impact of UCC on achieving electricity cost reduction and GHG emissions reduction in British Columbia and Alberta when vehicle grid interaction is combined with far-reaching GHG reduction policies (Wolinetz et al. 2018). The results show that UCC provides only a small reduction in electricity price for both regions and has a minor contribution to increasing renewable integration regardless of GHG emissions policies.

4. Method

4.1 Data – EV Charging Stations

In 2019 a Calgary utility company launched a pilot program called "Charge Up." The program aimed to provide insight into EV owners charging behaviour, including charging start times, charging end times, and charging duration. To incentivize EV drivers or businesses to participate in the project, the utility company offered to pay up to 75% of the cost of the charger (for a maximum of $1,500 for a home station or $100,000 for a public charging station). Drivers and businesses agreed to order a charger from either Charge Point or FLO, install and operate it, and share the charging data with the utility company. Data was collected through Charge Point and FLO online portals. No data regarding driving behaviour was collected.

The initial phase of the project included data from 22 public stations (FLO charging stations), 28 home stations (6 FLO charging stations and 22 Charge Point stations), and three stations located in multi-unit apartment complexes (Charge Point Stations).

The data set for home stations included charging data from November 15, 2019, to April 21, 2022. The data for public stations included charges from January 1, 2020, to April 9, 2022. All charging stations, both public and private, were level 2 charging stations. The data sets for homes and public stations were analyzed separately. Multi-unit charging stations were analyzed as public stations. Table 4 summarizes the information collected for the FLO and Charge Point charging stations.

Table 4: Details of data collected in the study for both charging systems.

	Charge Point Stations	**FLO Stations**
Location	Home/Multi-units	Public charging/Homes
First Date	November 15, 2019	January 1, 2020
Last Date	April 21, 2022	April 9, 2022
Number of Charging Stations	22 home stations 3 multi-unit	6 home stations 22 public stations
Data Included	Location ID	Station Name
	Org Name	Connection ID
	Port Type	Connection Start Time
	Start Date	Connection End Time
	Start Time Zone	Connection Duration
	End Date	End Reason
	End Time Zone	Total kWh (kWh)
	Total Duration	
	Charging Time	
	Energy (kWh)	
	City	
	Country	
	Ended By	

Both home and public station data sets were analyzed for charging starting time distribution to understand charging behaviour. The data was further analyzed to estimate total EV charger energy consumption (kWh). Charge Point data included the time EVs connected to the charges and the entire charging duration, which was often shorter than the duration the EVs were hooked up to the charger. In contrast, FLO data only included connection start and end times.

As the current Charging Point data set did not provide state of charge information, it was impossible to conclude when charging occurred. Therefore, the analysis describing the total energy consumption of EVs per hour of the day includes the energy calculated from EVs with the corresponding starting time. For example, if an EV starting time was 3 pm and the vehicle was charged for two hours, while another EV starting time was at 4 pm and was charged for one hour, the total energy calculated at 4 pm only included the second EV charge. Albeit its limitations, the data does provide a minimum approximation of load during a specific time of day.

4.2 Data – Calgary's hourly load

The AESO provides hourly electricity load data for all regions of Alberta. EV charging time and energy consumption were analyzed relative to the overall electricity load in Calgary. The data specified hourly load in MW from May 2020 to Feb 2022. These values contain electricity load from all meters, including residential and commercial facilities. The values may contain 'behind the fence' loads and do not include transmission line losses. The data were analyzed to estimate the total load per hour for each month of the year.

AESO also provided historical hourly data on wind and solar generation from 2016 to 2020. The data was aggregated to understand the province's temporal patterns of wind and solar generation.

4.3 Data – Solar

EV energy consumption was compared to electricity production from a typical home solar power installation in Calgary. Solar data for the Calgary region was calculated using the PVWatts web application calculator. This calculator was developed by the US National Renewable Energy Laboratory (NREL). The NREL's PVWatts web application estimated the electricity production of a grid-connected photovoltaic system based on multiple inputs, including location, roof tilt, system size and outside temperature. In this study, the PV system used is assumed to be a 4 kW DC system made of Crystalline Silicon cell material with a glass module cover. A DC-to-AC ratio of 1.2, with a roof tilt of 20 degrees facing south and a system loss of 14%.

5. Results

5.1 Home Charging starting time

Charging starting time at private home stations was predominantly between 3 pm to 9 pm. Over 13% of all charges started between 5 pm and 6 pm, and over 48% of all charges started between the afternoon hours of 3 pm and 8 pm (Fig. 4).

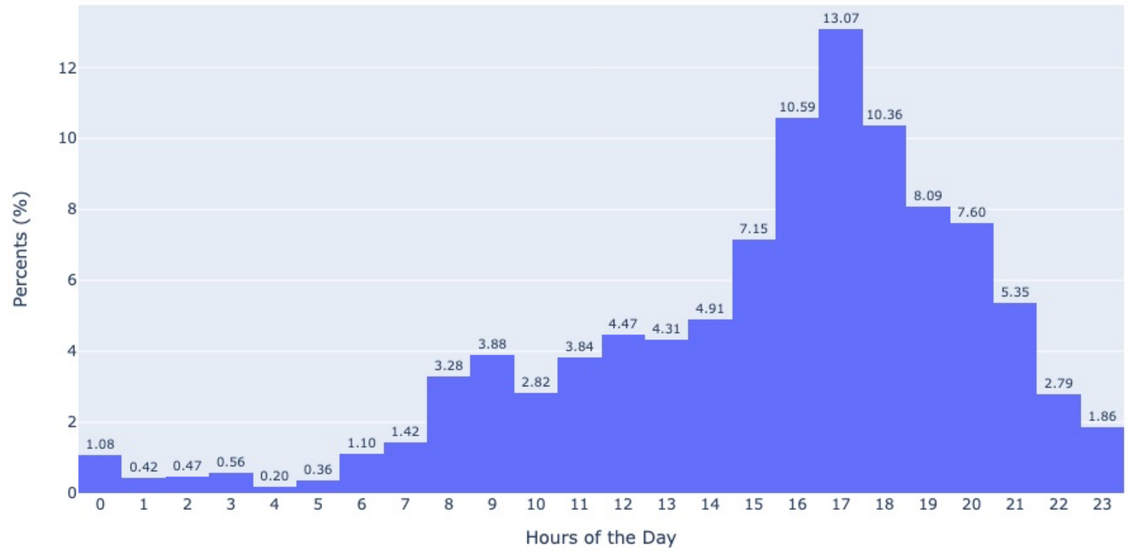

Figure 4: Percent of charging starting time per hour of the day for home stations.

Variations within each home charging station were significant. Although most home stations' median starting time was between 3 pm and 8 pm, most of the home stations still showed a wide range of charging starting times. Figure 5 provides descriptive statistics of home charging stations showing median, 1st and 3rd quartiles and outliers. The figure shows that at some homes, for example, Home1, 50% of charges started around the same time, while in others (e.g., Home7), starting time varied much more.

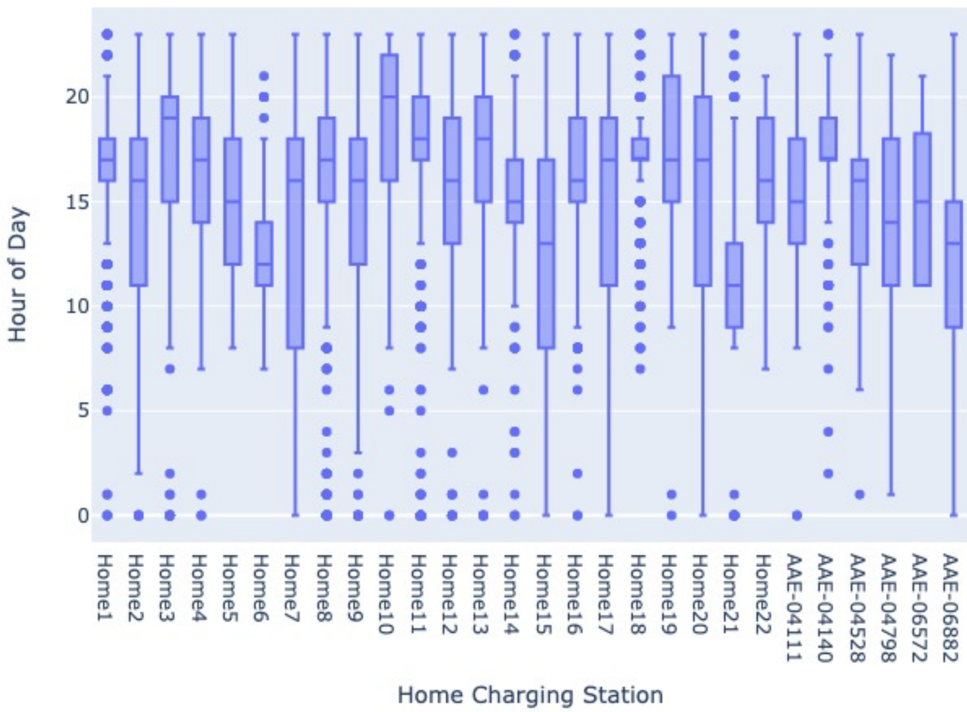

Figure 5: Boxplot of home charging starting time. Each box shows the median charging time (the line inside the box) and the lower and upper quartiles (median of the lower half of the data set and median of the upper half of it). The dots below and above the box are outliers, while the lines (whiskers) show the smallest and largest data points within 1.5 of the box size.

The results from home stations show that 48% of charges started between 4 pm and 8 pm over the span of the data collection. AESO defined electricity peak hours in Alberta as between 4 pm and 7 pm, suggesting that the demand from EV charging will add to the existing demand during peak time and agree with other similar studies. (Lee et al. 2020).

5.2 Public Charging starting time

Public charging stations had fewer data points than home stations. The total number of charging occurrences in public stations was 310 compared to 10,708 charging instances in home stations.

Therefore, results from public stations may not represent a future trend. Charging instances varied from 1 charge per station to 66 charges per station. The average number of charges was 12, with a standard deviation of 14.

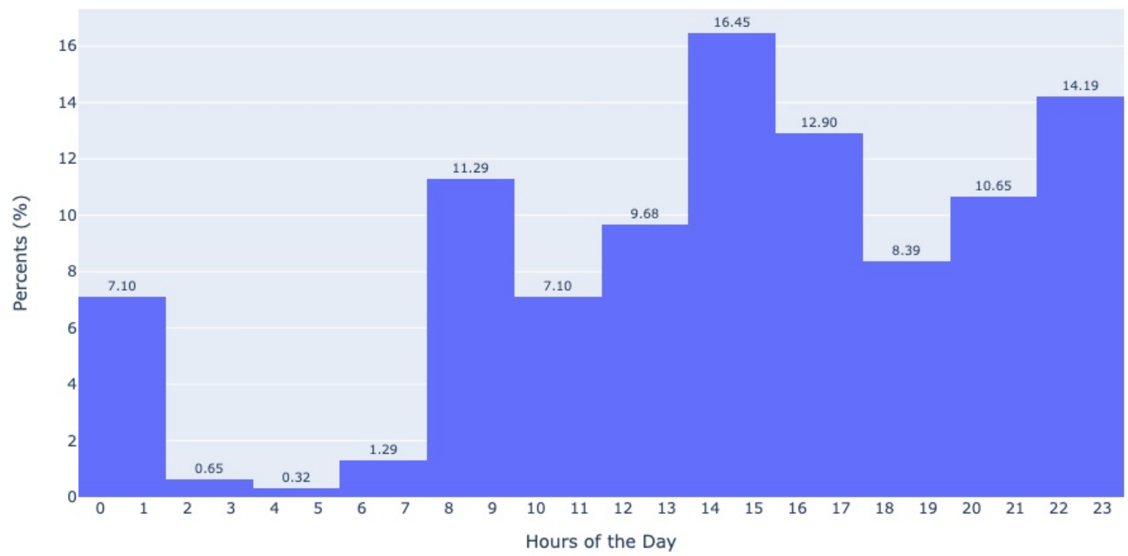

Figure 6: Percent of charging starting time per hour of the day for public stations.

Peak charging time occurs at 10 pm, with over 9.4% of charges starting times. Charging starting time was also high at 2 pm, with 9% of starting times, and at 4 pm, with over 8%. The mean charging energy was 18.74 kWh, and the median was 6.53 kWh. The mean charging duration was 258 minutes, and the median was 94.39 minutes (Fig. 6). Considering the limited data from public stations, the rest of the study will concentrate on the home charging stations.

5.3 Reasons for ending charge sessions

Both Charge Point and FLO datasets provide reasons for charging session termination. 95.5% of all sessions ended due to the cable being plugged out of the vehicle in the Charge Point stations, while only 40.6% of the FLO sessions ended for the same reason. 56.9% of the FLO sessions were terminated due to charging ended by the vehicle. In contrast, only 2.2% of the Charge Point sessions ended due to the end of the scheduled charging time (Fig. 7). Charge Point chargers provide the option to schedule a charge through the charger app. Since 22 of the 28 home charging stations were Charge Point stations, the results illustrate that most EV owners did not activate a charging schedule mechanism.

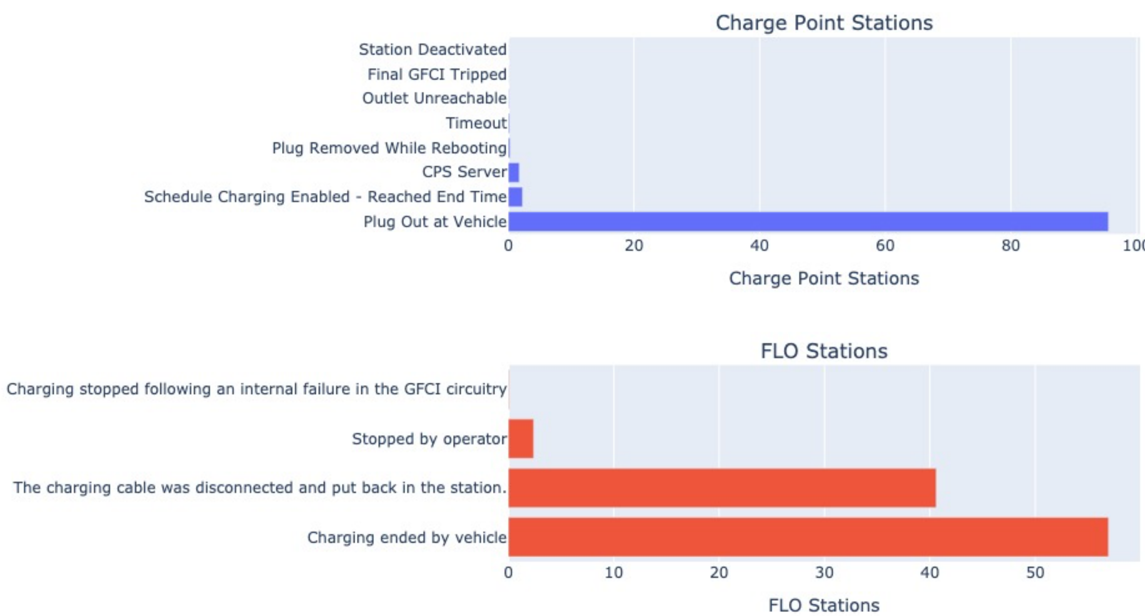

Figure 7: Reasons for charging session ending in percentage.

5.4 Energy Consumption

The average energy demand per charge for the home stations was 11.9 kWh. Twenty-five percent of charges consumed less than 4.1 kWh, and the median was 8.8 kWh. Since the actual charging time was unavailable, calculating average energy consumption per hour was not feasible. Instead, the results show the average energy consumption of charges starting at a specific hour.

Maximum energy consumption based on charging starting time peaked between 3 pm and 8 pm over different months of the year. Maximum energy consumption of 2154 kWh occurred in January between 6 pm and 7 pm, while the subsequent highest energy consumption occurred between 6 pm and 7 pm in March and February. Figure 8 shows the total charging demand per month of the year distributed over the hours of the day. The figure shows that median energy demand decreased during summertime and increased over the winter.

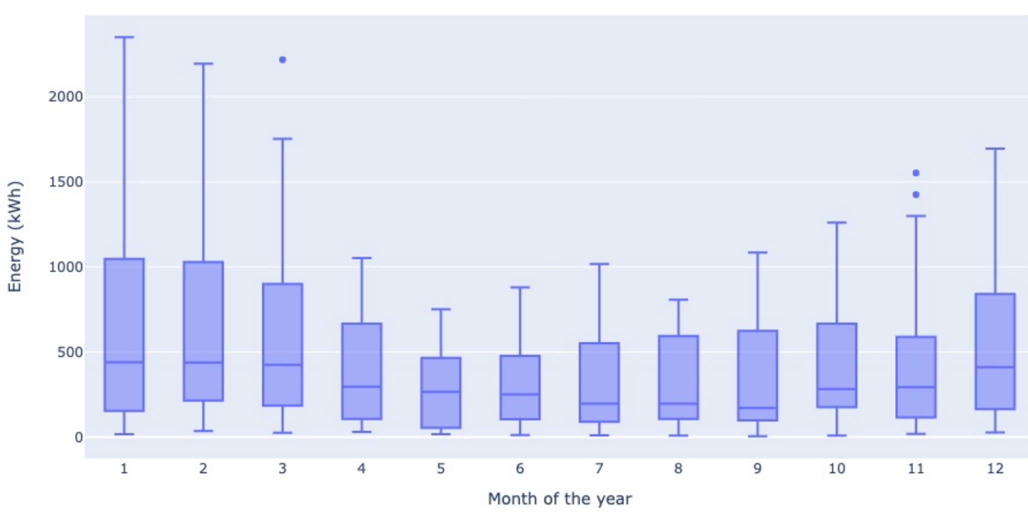

Figure 8: Total charging demand per month of the year distributed over the hours of the day. The box represents 50% of charges, and the line in the box shows the median energy demand. The solid lines above and below the boxes (whiskers) show the smallest and largest data points within 1.5 times the box size. The dots show outliners outside this range.

Aggregating data by homes, the mean energy consumption per charge was 12.76 kWh per home, and the median was 9.82 kWh. Significant variations were observed among home charging stations, as illustrated in Figure 11, where three homes (Home 10, Home 20, and Home 22) consumed significantly more energy than the rest of the home stations (Fig. 9)

Assuming most EV batteries are between 50 – 75 kWh, show that most events either did not fully charge the batteries or, most likely (since the charges were connected overnight), the EV's batteries were not completely flat at the beginning of the charge.

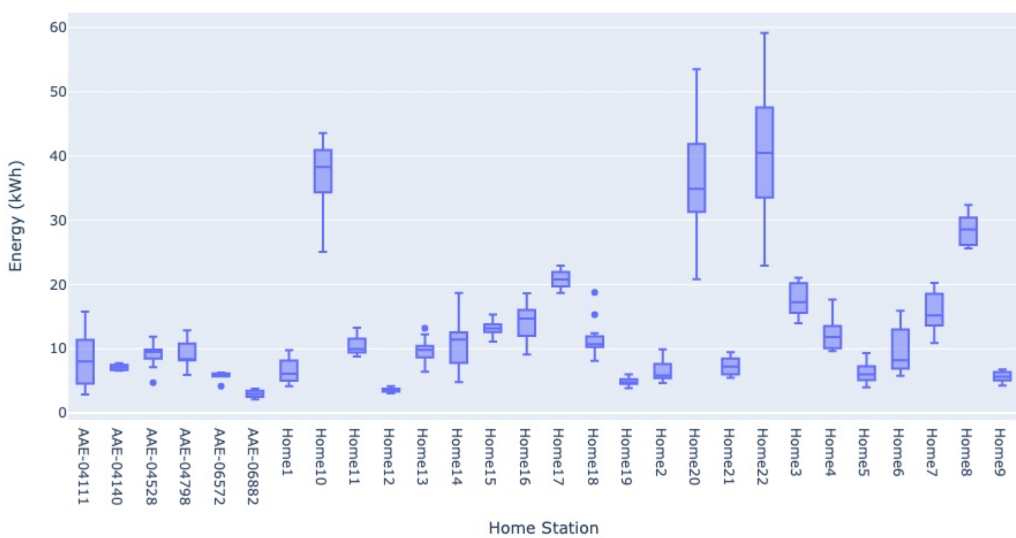

Figure 9: Mean home charging demand distributed over hours of the day.

5.5 Charging Durations

Charge Point stations provided information on actual charging duration. The mean charging time was 136.3 minutes, while the mean connection duration was 955.17 minutes (over 15 hours). The median was 107.2 minutes of charging and 756 minutes of charging connection. This suggests that the actual charging time was less than 20% of the connection time.

5.6 Calgary Hourly Load

Calgary's average hourly load peaks between 4 pm and 5 pm, with an average of 1323 MW. The average hourly load between 5 pm and 6 pm is very similar, with an average load of 1318 MW. Average loads stay above 1200 MW from 10 am until 8 pm, with an additional increase between 3 pm. Monthly average variations range from 1165.58 MW at 5 pm in May to 1487.15 MW in December and from 1413.93 MW at 4 pm in June to 1210.49 MW at 4 pm in May (Fig 10).

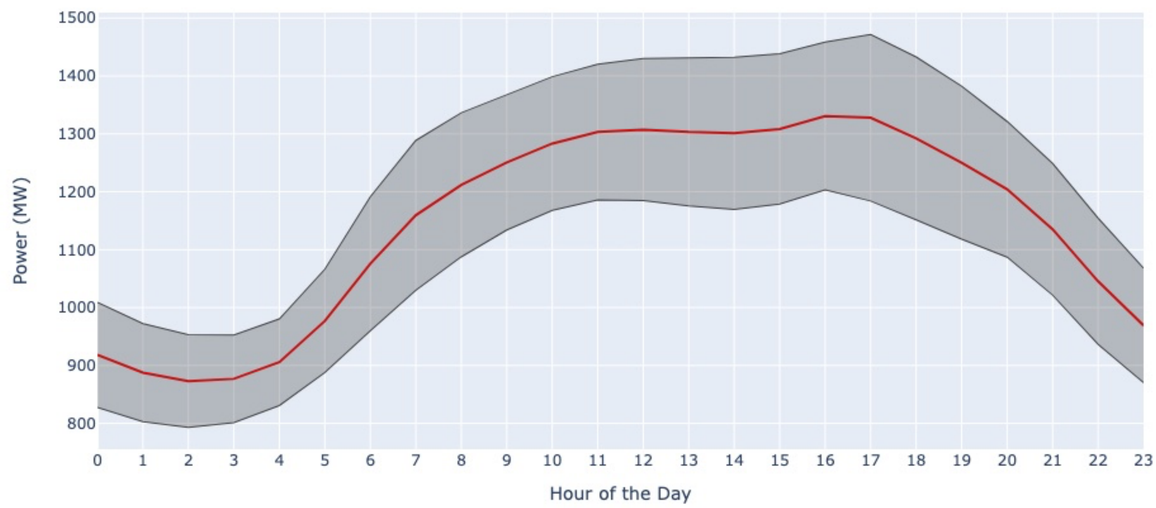

Figure 10: Hourly electricity demand in Calgary over the year. The red line displays the mean demand and the gray areas show the standard deviation. Source: AESO.

5.7 Electricity supply renewable sources

Home solar panels installed by EV owners can potentially offset some of the power needed to charge their EVs. This section describes the magnitude and temporal variation of a generic solar system installed in Calgary.

On average, a solar panel system of 4 kW installed in Calgary will produce 5184.71 kWh of DC output over a year. Maximum output will occur between 1 pm and 2 pm in July when the system can provide 76.87 kWh of electricity. Significant variations exist between the summer and winter months. The total output in December is 183.11 kWh, while in July, the total energy output increases to 639.58 kWh (Fig. 11).

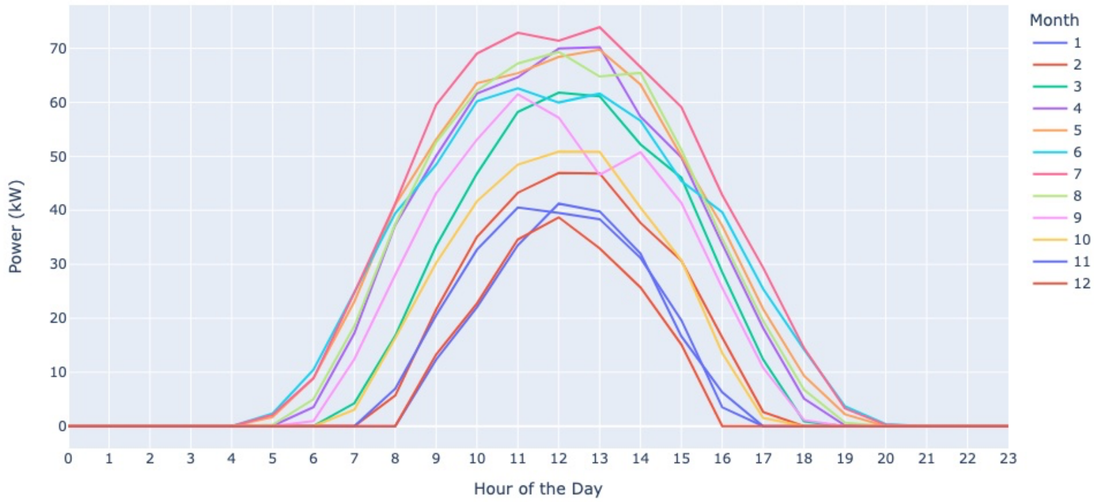

Figure 11: Predicted energy produced by a generic 4kW solar installation in Calgary. Source: US National Renewable Energy Laboratory

AESO published solar and wind power generation data in Alberta from 2016 until 2020. Comparing the data per month of the year and time of the day provide information on the compatibility of solar and wind in Alberta and their potential to offset electricity demanded by EV charging (Fig. 12 and 13). In the winter months, when solar generation is low, wind generation is at its peak. This pattern shifts in the summer months when solar generation is at its highest in Alberta and wind generation is relatively low. Wind generation is much more consistent overall compared to solar generations.

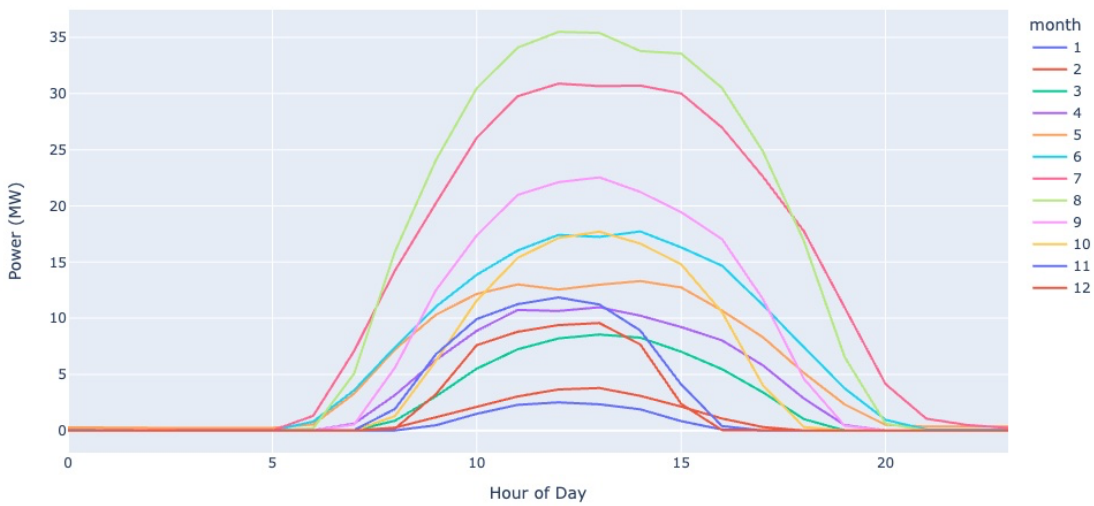

Figure 12: Average solar power generated in Alberta by month from 2016-2020. Source: AESO.

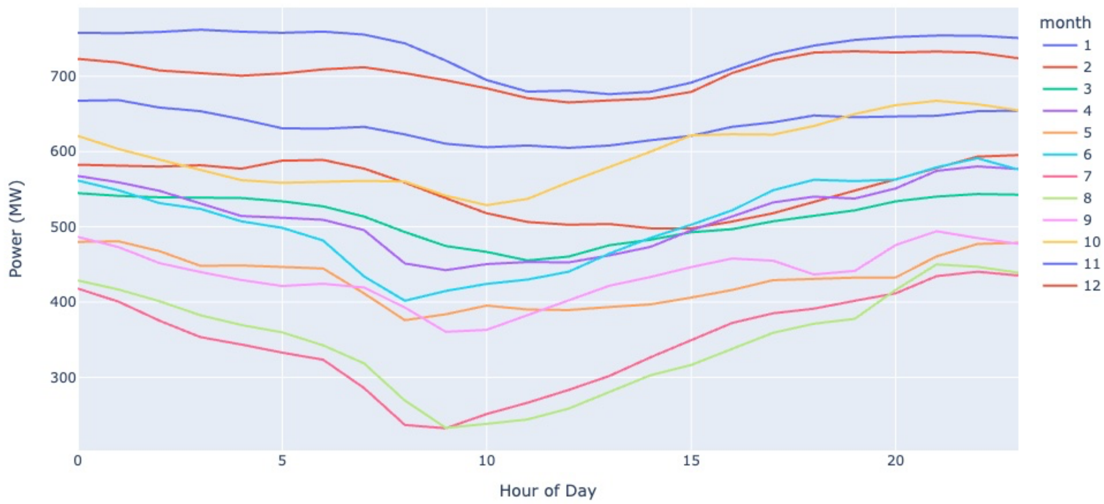

Figure 13: Average wind power generated in Alberta by month from 2016-2020. Source: AESO.

6. Discussion

6.1 EV charging behaviour

Part of this study's aim is to anticipate the impact of mass EV adoption on the electricity system in Calgary. Electricity demand seems to be predictable and successfully expected by utility companies. The following section attempts to generalize the above results and predict the impact of a significant increase in EVs in Calgary.

Most EV drivers start charging in the late afternoon and continue charging overnight. 5 pm was the most common charging starting time at home stations, coinciding with electricity peak demand. Additionally, most EV owners did not use the scheduled charging option and manually disconnected the charging cable to end the charging session.

The average energy consumption during charges was 11.91 kWh, and the mean charging duration at home stations was just over 2 hours (136 minutes). Considering that all charge stations used level 2 charges, with power output between 3 kW and 19 kW, the results are within the expected range of charging an EV battery. Typical EV batteries range from 37 kWh for the BMW i3 to over 140 kWh for the new Ford F-150 Lightning trucks. Residential Level 2 charges can produce between 3.84 kW and 12 kW power when connected to 16 Amps or 50 Amps breakers. To fully charge an EV with a 75 kWh battery with a Level 2 charge will take between six hours with a 50 Amps connection and 19 hours with a similar charger powered by 16 Amps. This suggests that most of the charges were used to either top partially charged batteries or were terminated before the battery was fully charged.

Charging consumption and duration suggest that charging times can easily be shifted away from peak demand while still achieving the same level of charging in the morning when drivers are ready to use their EVs. Furthermore, EV manufacturers are constantly increasing the vehicle's battery range and size to reduce driver's range anxiety. As EV battery sizes increase to accommodate an extended driving range, the time it takes to charge an EV battery fully will also increase.

Although Level 3 chargers with power output as high as 350 kW are entering the market, home chargers powered by a single phase 240V will not deliver significantly faster charging times in the future due to voltage and current limitations. If EV battery size increases and drivers require fully charged batteries, charging duration will also increase, and utility charging control will be less effective in shifting charging time to low peak hours. But, if driving patterns will not significantly change, EV owners will require less charging time with larger battery sizes. Hence, there will be more opportunities to shift charging away from peak demand. However, this is volume-dependent. With the projected increase in EVs, even if each vehicle requires less charging due to battery size, the overall electricity demand will increase, and more EV owners will require charging during peak times.

6.2 Prediction of future energy requirements based on current data

The results from this study strongly suggest that, without any charging control mechanism, electricity demand from EV charging will most likely increase during peak hours. ENAMX anticipates over 200,000 EVs in Calgary by 2030. While this is a significant increase from current EV numbers, it is still a small percentage of the total vehicles in the province. Assuming 48% of charges will start around 5 pm suggests that around 96,000 EVs will plug in at peak hour each day with an average demand of 11 kWh. This corresponds to an increase of over 1,000 MW in Calgary alone. Considering Alberta's current electricity capacity of 16,700 MW, this will imply a six percent increase in demand during peak hours.

A possible scenario to achieve the necessary reduction in GHG emissions explored by a report from the C.D. Howe Institute suggested that Alberta will need to increase its EV count to about 1 million vehicles. Calgary's population is over 30% of Alberta's (Alberta 2022a). EV concentration is currently much higher in urban areas (Fig. 3). It can be assumed that of the 1 million EVs predicted by this report, over 300,000 will be in Calgary, implying an even more significant increase in demand predicted by the utility company. This scenario will pose a considerable challenge and potentially overload different grid components, reduce grid reliability, and ultimately increase electricity costs.

The energy produced from a 4 kW roof installation in Calgary will generate over 5,000 kWh of energy per year. Our data shows that an average home EV charger will use 11 kWh per charge per day, adding up to 4,015 kWh per year. Solar peak power and EV peak demand happen during different hours of the day and at different times of the year. While peak solar power occurs during the summer in the middle of the day, EV charging occurs mainly during the early afternoons and nights and peaks during the winter. Therefore, even in the hypothetical scenario where a solar installation of 4 kW is added for every EV added to the grid, the misalignment in generation and consumption between solar and EV charging will do little to mitigate the increase in demand from EV adoption.

Charging times can also impact GHG emissions in Alberta. Since charging peak time coincides with a time of the day when solar production is rapidly diminishing, it can result in an increased demand for emitting electricity sources and an increase in GHG emissions. However, as illustrated in Figure 13, wind generation in Alberta usually peaks during the afternoon in the wintertime. Increasing Alberta wind capacity can potentially support EV charging demand while reducing the potential increase in GHG emissions.

7. Policy Recommendations

The results from this study show that with no policy intervention, the electrification of the transportation sector will strain the current electricity system. The predicted increase in charging requirements, specifically during peak hours, will overload the grid resulting in a price increase for consumers. It also can potentially increase overall GHG emissions, an outcome that will negate the underline intention of the transition. Public policies will play an essential role during this transition to ensure that Albertans and Calgarians continue receiving a reliable and affordable electricity supply while reducing GHG emissions toward a net-zero emission future. The following section outline policy recommendations that can support this outcome.

7.1 Policy recommendation 1 – Utility-control charging

Utility control-charging (UCC) is often suggested as one of the necessary policies to ensure the continuation of affordable electricity rates and the reduction of GHG emissions during the transition to EVs. While the overall effectiveness of UCC is debatable, even the most cautious studies that predict minor positive outcomes (Wolinetz et al. 2018) agree that the implementation of UCC will reduce future electricity prices. They also suggest that UCC can help integrate renewable sources into the grid faster in regions with no significant renewable generators (Bailey and Axsen 2015 and Babrowski et al. 2014).

Implementing UCC will allow utility companies to ensure a smoother load profile that will prevent additional investment in new generation capacity and help maintain the electrical system's reliability and affordability. Utility companies can use UCC to initiate charging during evenings and nights of high wind-generated capacity and support EV charging with renewable, low emitting energy sources. The UCC projects show that an average load from EV charging during demand response events can be reduced by over 40% and that charging control programs were insignificant in shifting load during weekdays from peak hours to periods where renewable generation is widely available (Wolinetz et al. 2018).

The Smart Electric Power Alliance (SEPA), a non-profit organization focusing on carbon-free energy systems with over 700 utility companies' members, published a guide to EV-managed charging. The report identifies 38 UCC pilot projects managed by utility companies across the U.S., showing that EV owners were likely to participate in managed control programs even when no incentives were offered. In Alberta, where electricity prices are not differentiated by time of use, and there is no price incentive for EV owners to charge at off-peak hours, this may suggest that drivers will participate regardless of financial savings (SEPA. 2019).

Most companies participating in SEPA's pilot programs expressed difficulties with networking-managed charging systems. Companies reported reliability issues with real-time data, which complicated charging behaviour forecasts. Currently, there are no requirements placed on EV manufacturers or charging companies to include networking devices that will provide vehicle-to-grid information and support UCC. Alberta's government and utility and transmission companies can do better by creating a policy restricting EV charging stations' sales only to those with communication devices supporting UCC. This will increase the driver's willingness to participate even without financial incentives.

Although UCC can help shift charging time from peak demand to low demand hours, the mass adoption of EVs predicted in the coming decade will eventually increase the demand, even with a larger battery size. Utilizing UCC successfully will only prolong the electricity demand spike. As more EVs enter the system, the high demand interval will ultimately stretch into low peak time and, eventually, limit the effectiveness of utility control charging. UCC implementation is an essential step but not a sufficient solution on its own to mitigate EV adoption challenges.

7.2 Policy recommendation 2 – Inform consumers and EV drivers about energy sources

Solar and wind in Alberta have opposite production patterns. To divert load to renewable energy, Alberta utility companies should incentivize EV owners to charge their vehicles during times of high renewable generation. Effective energy consumption will entail educating drivers to change charging patterns between winter and summer, i.e., daytime charging in the summer when solar power generation is peaking and nighttime charging in the winter when wind generation is high. This will positively reduce the pressure from the electricity grid, utilize renewable energy and help reduce the overall GHG emissions from the transportation sector.

Using renewable energy to curb emissions and effectively encourage consumers to change their charging habits requires a clear and simple presentation of data. Real-time information on grid energy sources is not readily available to consumers. While AESO publishes a Current Supply and Demand report updated every minute outlining the current power capability and generation (AESO 2022), it is not easily accessible and hard to comprehend. The Alberta Government and utility companies should combine forces to develop an app that displays up-to-date supply and demand information outlining the current energy sources mix and predictions for the coming hours. EV drivers and electricity consumers should easily comprehend the data and make educated decisions on when to charge their vehicles or use high-demand electricity appliances. Implementing an app that communicates information can encourage EV drivers to schedule charging time-based on the energy mix and encourage consumers to reduce electricity demand during high-demand periods. If wildly used, this app will help supports future Time of Use rates and other methods of incentivizing electricity consumers to shift their usage from peak time to low demand time or from periods of high GHG emissions to periods of high renewable generation.

7.3 Policy recommendation 3 - Increase wind capacity.

The results of this study suggest that, since most charging occurs at home during the evening, wind, as opposed to solar, can better offset EV charging consumption loads. The Canada Energy Future report requires Alberta to increase wind capacity generation to 60% of total energy generation by 2030 and over 70% by 2050 to reach net-zero GHG emissions. The government of Alberta needs to ensure that these goals are achieved in the coming decades.

The Canadian Renewable Energy Association (CanREA) published a report titled *CanREA's 2050 Vision: Powering Canada's Journey to Net-Zero.* The report outlined Canada's challenges and tasks to achieve net zero by 2050. Task 3 in the report calls for expanding solar and wind energy generation capacity significantly. The report distinguishes Alberta's fair, efficient and openly competitive market in encouraging new investment in wind and solar. Still, it suggests that private investment can be accelerated by removing market and regulatory barriers to developing new wind and solar projects. Policy changes can be instigated to allow it (Canadian Renewable Energy Association. 2021).

7.4 Policy recommendation 4 - Reduce driving

It is imperative to remember that the motivation behind the transition from combustion engine vehicles to electric vehicles is primarily the reduction of GHG emissions. Apart from ensuring that the transition will not increase emissions, nor increase costs for the public, there are other ways to reduce emissions from transportation. One of the most obvious solutions is to reduce the amount of car usage and driving. Calgarians emit more emissions per capita due to passenger transport than any other city in Canada (Kenworthy 2008). McQueen et al. estimated that replacing 15% of daily car trips in Portland, OR with e-bikes will reduce GHG emissions by 12%, even after considering the emission generated by e-bike charging (McQueen, MacArthur, and Cherry 2020).

Alberta provincial government and Calgary's and Edmonton's municipal governments should encourage residents to replace their short-trip car usage with low emitting transportation options such as bike and e-bike using a variety of policies. This can include prioritizing bike infrastructure over cars, tax incentives to encourage e-bike purchases, eliminating free parking, and media campaigns to reduce passenger car usage and GHG emissions.

8. Conclusions

Transportation electrification is happening rapidly in Canada and the rest of the world as part of a global effort to reduce GHG emissions and mitigate climate change. The upcoming increase in EVs will challenge many aspects of the current electricity system and can potentially increase electricity rates, overload the grid, create outages, and increase overall GHG emissions.

This study examined the charging behaviour of a sample of EV drivers in Calgary to gain insight into the effect this transition will have on the electricity system. It examined charging behaviour in both homes and public settings to understand temporal charging distribution and the energy requirements for charging. The data was compared to the Calgary region's average load and renewable generation.

The results indicate that most EV drivers charge during the afternoon and night when peak demand on the electric grid is high and charging times are not aligned with solar generation. If these charging patterns persist, even a modest increase in EV numbers in Calgary will result in higher electricity prices, grid overload, and potentially increased GHG emissions.

In response to this challenge, the government and utility companies will need to adopt policies to accommodate the upcoming mass adoption of EVs. These recommendations include shifting charging loads from peak demand to low demand using utility charging control, informing EV drivers and energy consumers about the energy sources mix, ensuring market and regulatory barriers are removed to encourage future investment in wind projects, and encouraging the public to reduce vehicle usage and shift to low-emitting transportation options.

Climate mitigation is a complex process that will require varied solutions. The transportation sector is responsible for 25% of GHG emissions in Canada. EVs will undoubtedly change this sector, and further studies examining charging patterns will help ensure this transformation benefits Alberta, Canada, and the rest of the world.

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