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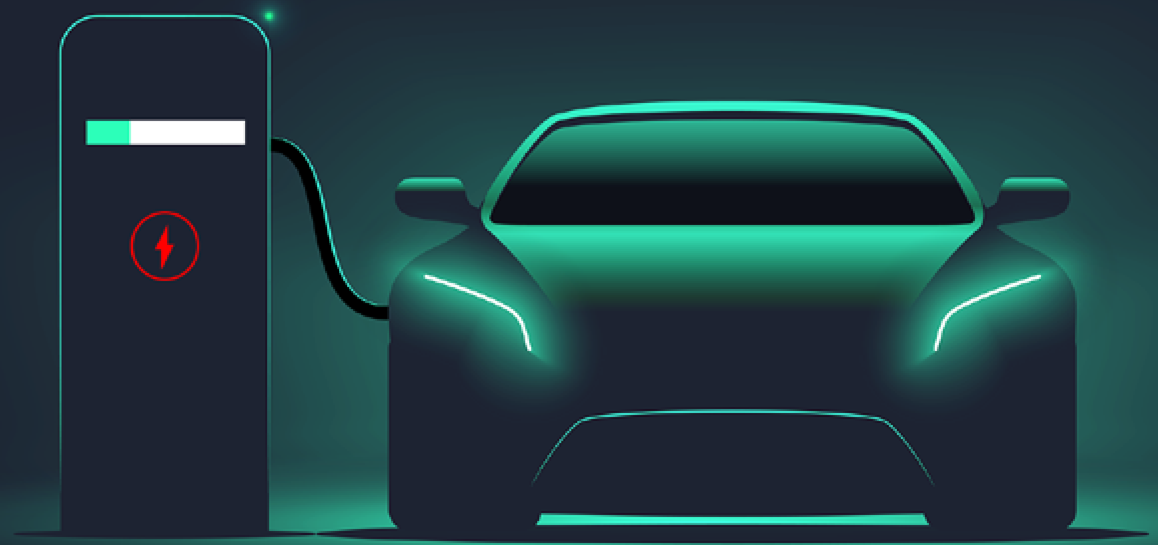
2024

FAILURE TO CHARGE

A Critical Look at Canada's EV Policy



Electric Vehicles and the Demand for Electricity

G. Cornelis van Kooten

ELECTRIC VEHICLES AND THE DEMAND FOR ELECTRICITY

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Executive Summary

As a component of climate mitigation policies, many governments have implemented measures to electrify the transportation sector. This has been done by setting target dates for when the sales of vehicles with internal combustion engines (ICEs) will end and providing subsidies for the purchase of passenger electric vehicles (EVs), production facilities, and charging stations. In Canada, current federal policy mandates all new passenger vehicles to be net-zero emissions by 2035, ultimately aiming for a fully electric new fleet.

Despite ongoing federal initiatives, EVs constitute a rising but relatively small share of the vehicle market, growing from less than 1% of sales in 2017 to 9.1% in the last quarter of 2022. Notably, British Columbia and Quebec boast higher proportions—18% and 14% of vehicles sold in the last quarter of 2022 were electric, respectively.

This study delves into the potential implications of the increasing adoption of EVs on both Canada's and various provinces' electricity grids. Our analysis provides estimates of the additional generating capacity required to meet the escalating demand from EVs. We do not look into the necessity for additional transmission lines for renewable power sources or upgrades to local delivery lines.

In the analysis, we employ a Monte Carlo simulation using data on battery efficiency, battery capacity and range for 299 EV models, and average annual driving distances by jurisdiction, to estimate the expected electricity demand (and variance of demand) for an individual EV within that jurisdiction. We then provide forecasts of

the future purchases of passenger EVs to obtain estimates of the potential future demand for electricity by this sector of the economy.

> "EVs could pose a significant burden on Canadian electricity grids, with system demand increasing by as little as 7.5% to as much as 15.3%, although the burden varies across the provinces."

Our results indicate that EVs could pose a significant burden on Canadian electricity grids, with system demand (also known as load) increasing by as little as 7.5% to as much as 15.3%, although the burden varies across the provinces from as little as 4.6% (Quebec) to as much as 26.2% (Ontario). Overall, Canada could see an increase in annual load ranging from 46.8 terawatt hours (TWh) to 95.1 TWh, with BC's load potentially increasing by 4.4-9.3 TWh, Ontario's by 19.0-38.2 TWh. and Quebec's by 10-21.7 TWh.

What does this imply for new generating capacities? We project that as many as 13 new gas plants of 500-MW capacity might be required in Canada: one in British Columbia, five in Ontario, and three in Quebec. Alternatively, it would be necessary to develop 10 new hydroelectric facilities equal in size to BC's Site-C (about 1,000 MW capacity): one in BC, four in Ontario, and two in Quebec.

If EV demand for power is to come from non-hydro renewable sources, wind is the most likely option. Assuming a capacity of 3.5 MW per turbine and average wind capacity factor of 25%, it would be necessary to build nearly 5,000 large turbines in Canada, with 560 in BC, 1860 in Ontario and 1200 in Quebec. Given the unreliability of wind energy, it would also be necessary to build peak-gas plants, hydropower and/or utility-scale battery storage capacity as backup. Importantly, because backup capacity cannot pay for itself as it does not deliver enough power during the year, it would need to be subsidized, thereby adding to system costs.

Unless society begins almost immediately to develop the required generating infrastructure, it will not be possible to meet the expected demand that EVs might pose for electricity grids in Canada. That is, if governments continue to push for an all-electric vehicle fleet by continuing to subsidize EV purchases directly, and through policies that raise gasoline prices and requiring all vehicles sold beyond 2030 or 2035 to be electric, it would be necessary to start construction of power plants to meet the anticipated increase in demand.

INTRODUCTION

Promotion of electric vehicles has become a major policy tool in many countries' efforts to reduce and perhaps even eliminate fossil fuel use, at least when it comes to vehicular transportation. The idea is that, by replacing internal combustion engines (ICEs) as the main source of locomotion, electric vehicles (EVs) would take advantage of electricity generated solely from renewable sources of energy, primarily and sometimes exclusively from wind and solar sources. There are many problems in moving toward a transportation system that relies solely on battery electric vehicles, even if only passenger cars, sport utility vehicles (SUVs), and light-duty trucks operate on batteries recharged from the electricity grid. Short-term problems relate to the availability of charging sites. In the longer term, inadequate electric-generating capacity, both renewable and thermal, and transmission infrastructure can hamper the transition away from ICEs.

In Canada, the federal government is planning to massively increase the use of EVs in the coming years. Current federal policy is that all new passenger vehicles must have net-zero emissions by 2035, eventually requiring 100% of the fleet to be electric. This study examines the impact of adopting electric vehicles—battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—on electricity demand. We investigate how much more electricity various Canadian power grids would need to generate to accommodate EVs. For example, we provide illustrations of what it means to generate this new electricity supply: How many power plants (say, equal in capacity to BC's Site C Project) would be required to generate this new electricity, or how much nuclear capacity would be needed in Ontario (viz., Ontario's Bruce Power plant) to meet EV demand? We also examine where the electricity needed to meet the demand from EVs is likely to come from.

We begin our investigation by looking at data on vehicle sales and registrations in Canada to get some notion of the penetration of electric vehicles in the vehicle fleet. We define the electric vehicles as those generally consisting of BEVs and PHEVs, distinguishing them from ICEs and hybrid vehicles that re-charge their batteries via a fossil-fuel driven ICE.

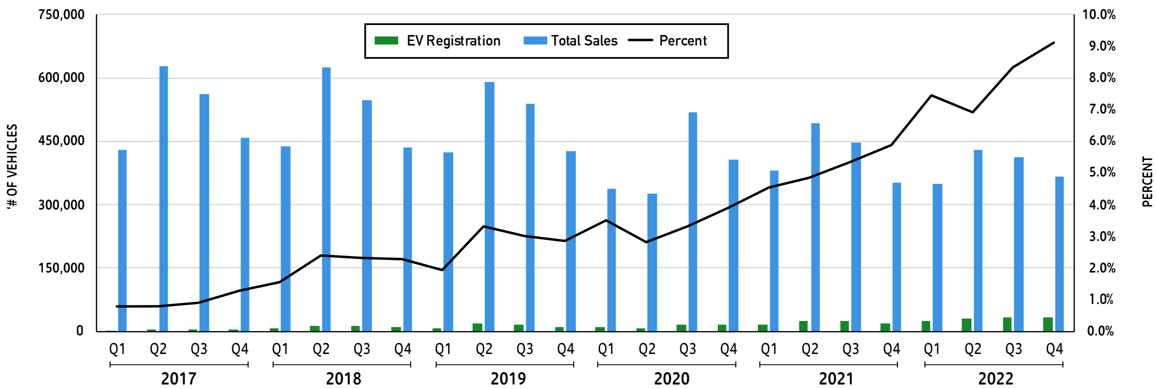
Data on sales of electric vehicles in Canada

Data on the registration of all fuel and vehicle types in Canada, including EVs, are available from Statistics Canada from the 1st quarter of 2017 through the 4th quarter of 2022 (Statistics Canada, 2023a). Data on the sale of electric vehicles are available for many cities and regions throughout Canada for the period 2017-2022 (data are lacking for Alberta, Nova Scotia, and Newfoundland and Labrador) (Statistics Canada, 2023b). Data on the sale of passenger vehicles, trucks and total vehicles, as well as their origin (e.g., domestic versus foreign manufacture) have been collected monthly since January 1946 through to the first few months of 2023; however, no distinction is made by the type of fuel the vehicles require (Statistics Canada, 2024a).

To determine the impact of policies favouring EVs over other vehicles, in figure 1 we plot quarterly EV registrations and total vehicle sales, and the proportion of the former to the latter. EV registrations constitute a small but rising proportion of all vehicles sales, rising from less than 1% of sales in 2017 to 9.1% in the last quarter of 2022.

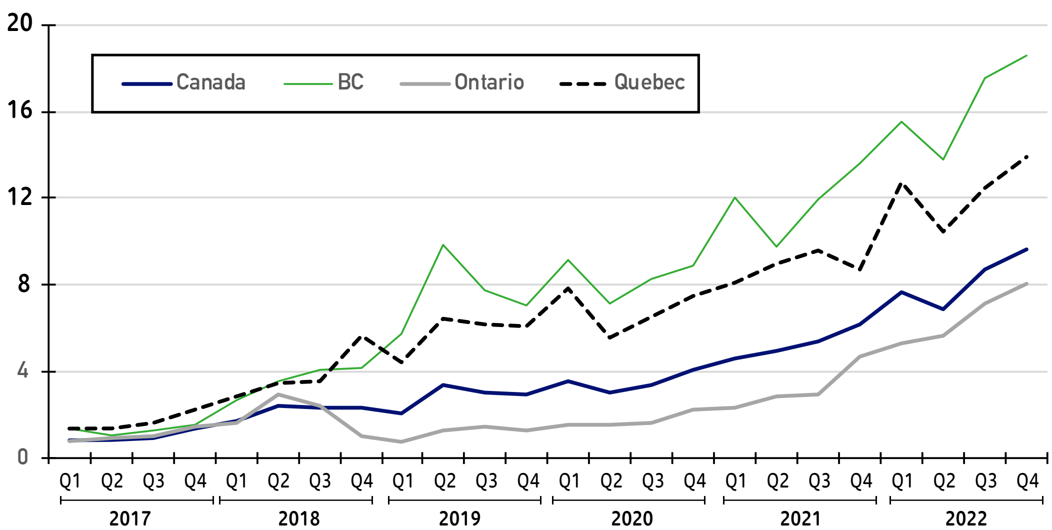
In figures 2 and 3, we provide information concerning the rate at which electric vehicles have been adopted. The number of battery EVs or PHEVs registered as a proportion of total vehicle sales over the period from Q1 2017 to Q4 2022 are provided for British Columbia, Ontario, Quebec, and Canada as a whole in figure 2. The data on EV registration and total vehicle sales for the last quarter of 2022 are shown in figure 3. Notice that British Columbia leads the rest of Canada in purchases of vehicles that draw power from the electricity grid; it is followed by Quebec, and then Ontario. More than 18% of vehicles sold in BC were EVs, compared with about 14% in Quebec, 10% in Canada (excluding the above provinces), and 8% in Ontario. The most obvious

Figure 1: Electric and total vehicle sales in Canada, by quarter, Q1 2017 through Q4 2022



Source: Statistics Canada, (2023a); (2024a); graph compiled by the author.

Figure 2: Percentage of new vehicle registration that is battery electric vehicles or plug-in hybrids, by selected provinces and Canada, 2017-2022.

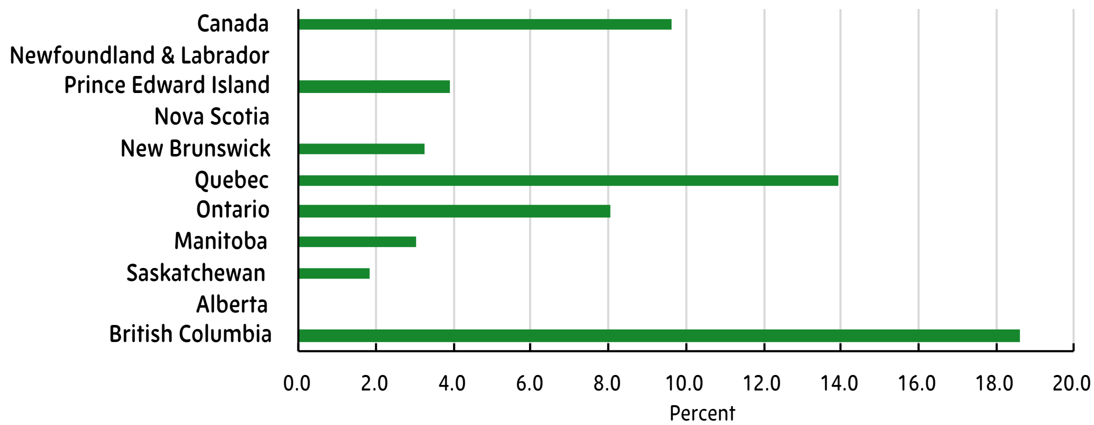


Source: Statistics Canada, (2023a); (2024a); graph compiled by the author.

explanations for the greater penetration of EVs in BC are its lower prices of electricity, its generally higher gasoline prices, and its milder temperatures, compared with other jurisdictions in Canada, although these factors might not be statistically significant determinants of purchases.

For more detailed information on the distribution of vehicle registrations by fuel type for the four jurisdictions, see figure 4. The data in the figure

Figure 3: Proportion of total vehicle sales accounted for by EVS, 2021-2022



Note: No data on electric vehicles are available for Alberta, Nova Scotia, and Newfoundland and Labrador.
Source: Statistics Canada, (2023a); (2024a); graph compiled by the author.

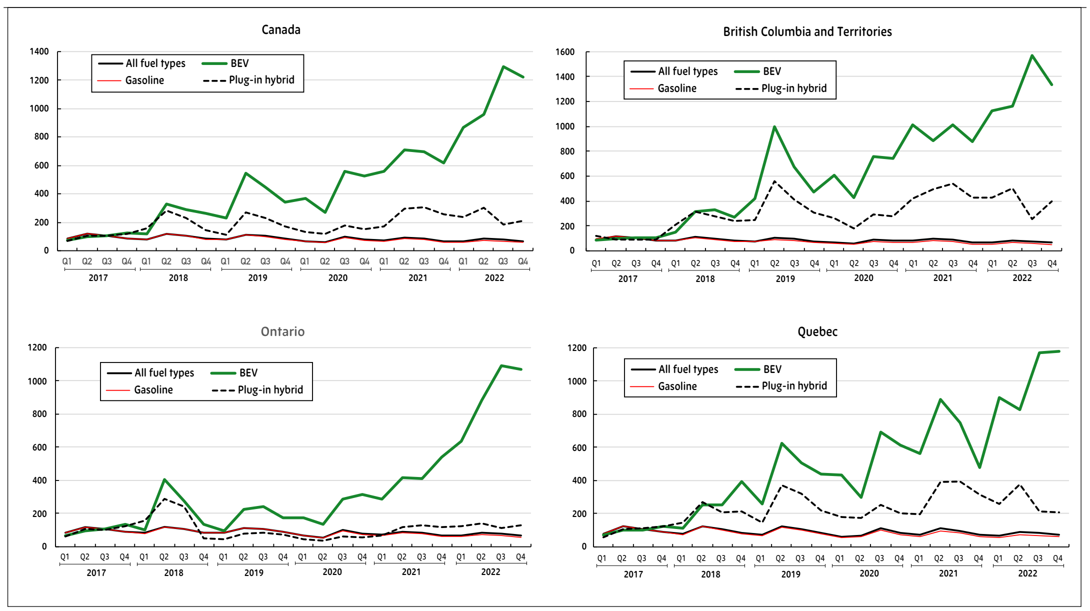
compare quarterly registrations of gasoline ICEs, BEVs, PHEVs and total fuel types with the baseline, 2017 registrations (2017=100). While total registration of vehicles and registrations of gasoline ICEs fell somewhat between 2017 and 2022 (gasoline-powered ICEs fell to a greater extent), EV registration rose significantly in all jurisdictions. While PHEV registration doubled overall (that in BC quadrupled), registration of BEVs rose by almost 12-fold (nearly 14-fold in BC). However, compared with ICE vehicles, EVs are quite a small proportion of all vehicles on the road at any given time (see figure 1).

Government policies to electrify transportation consist of legislation that focus on zero-emission targets, requirements to terminate the sale of ICEs after a specified date (2035, say), along with retail subsidies. The policies essentially force automobile manufacturers to build and sell more EVs, even if their costs are subsidized by higher prices for SUVs and small trucks. (In some countries, e.g., the US, these policies are reinforced by draconian tailpipe emission regulations that cannot be met by current ICEs.) The policies are effective in slowly electrifying the country's fleet of passenger cars, multi-purpose vehicles (mainly SUVs), vans and small trucks. The trend can be seen in figure 5, which shows cumulative sales of EVs and cumulative total vehicle sales from 2017 through 2022. The graph is similar to figure 1, except for the fact that, while quarterly registrations of EVs to total vehicle sales increased from less than 1% to 9% between 2017 and 2022, the increase in EVs as a proportion of total vehicles on the road increased from under

1% to only 3.5%—only one out of 28 vehicles on the road is an electric vehicle (not including those registered prior to 2017, which are primarily ICE vehicles).

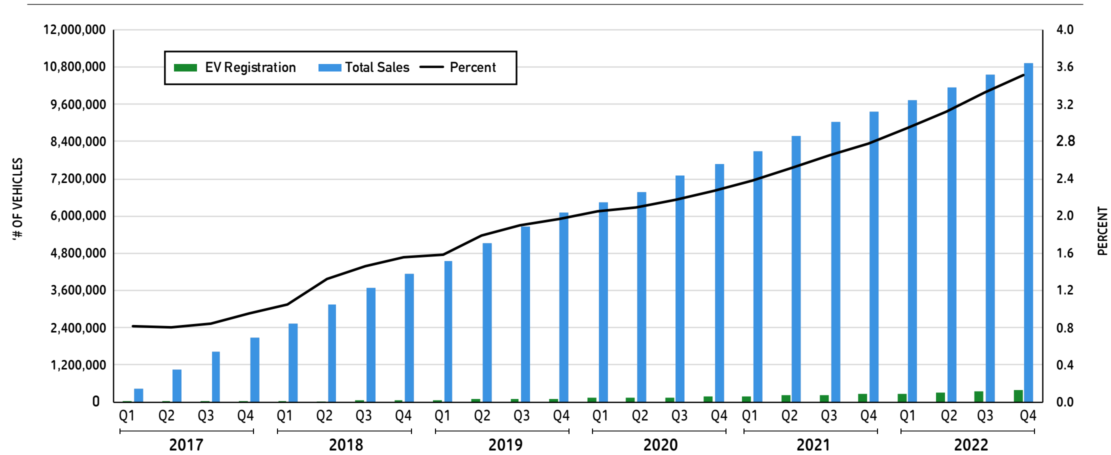
In conclusion, the uptake of electric vehicles over the past six years has been slow, although steadily increasing. Whether this will continue depends on government policies and the public's desire and ability to adopt this new technology. There are several specific concerns about

Figure 4: Growth in new vehicle registration, selected provinces and Canada, 2017-2022 (2017=100)



Source: Statistics Canada, (2023a); (2024a); graphs compiled by the author.

Figure 5: Cumulative sale of electric vehicles and all vehicles in Canada, 2017-2022



Source: Statistics Canada, (2023a); (2024a); graph compiled by the author.

EVs: because they weigh some 30% more than their equivalent ICEs, their tires wear out faster, which is accompanied by more particulate matter entering the atmosphere; EVs appear not to hold their value to the same extent as ICEs (Haynes, 2023); EVs take some 2.5 to 11.0 hours to recharge at the better charging outlets, and much longer at other outlets;[1] EVs (and backup batteries) can burst into chemical-fuelled fires that burn hotter and are more difficult to extinguish than ICE fires and could potentially damage concrete structures (Driessen, 2023; Tesla Fire 2023); and there are environmental issues related to the mining of the metals required to produce EV batteries and dispose of them (International Energy Agency, 2021; World Nuclear Association, 2021; Kara, 2022). Further, unlike ICEs, where the West has a technological advantage, China has an advantage in producing EVs and is fast replacing legacy manufacturers, such as Ford, GM, Toyota and Volkswagen, as the main producers of EVs, resulting in the hollowing out of factories and jobs in North America and Europe (Xie, 2023).

EV emissions realities start with physics. To match the energy stored in one kg. of oil requires 15 kg. of lithium battery, which entails digging up some 15,000 kg. of rock and dirt to access much needed minerals, such as lithium (15 kg. of lithium per battery), graphite, copper, nickel, aluminum, zinc, neodymium, and manganese. The global mining and minerals sector uses some 40% of all industrial energy, which is dominated by oil, coal, and natural gas. Further, it is unlikely that the increased global demand for electricity can and will be met from renewable wind and solar sources. (van Kooten, et al., 2020; Duan, et al., 2023; Mills, 2023). Given the emissions associated with the mining of inputs used in batteries and power generation equipment, and the extent to which power generation is not renewable, the climate change benefits of replacing the fleet of ICEs with EVs may be much lower than anticipated (Leyland, 2023; Finley, 2023; Ridley, 2023).

Resolution of some of these issues could well put a damper on the future development of electric vehicles. In this study, however, the focus is on Canada and the implications that EVs will have for power generation, particularly as it affects the need for additional generating capacity.

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1 Tesla charging information, with the maximum rate depending on the Tesla model being considered, available at <https://evcharging.enelx.com/ca/en/resources/blog/577-how-long-does-it-take-to-charge-a-tesla#:~:text=> [accessed 18 October 2022].

ELECTRICITY GRID AND ELECTRIC VEHICLES: SELECTED JURISDICTIONS

As the number of electric vehicles increases, the demand for electricity to recharge their batteries will increase accordingly. To date, there is little evidence to indicate that the power required by BEVs and PHEVs is a problem for the electricity grid—the current provincial grids appear to have sufficient capacity to handle the recharging requirements of EVs. This observation is corroborated by federal data, which indicate that, prior to 2021, the electricity use required amounts to about 0.4% of the second most important energy use, that for passenger transportation (Natural Resource Canada, 1991).

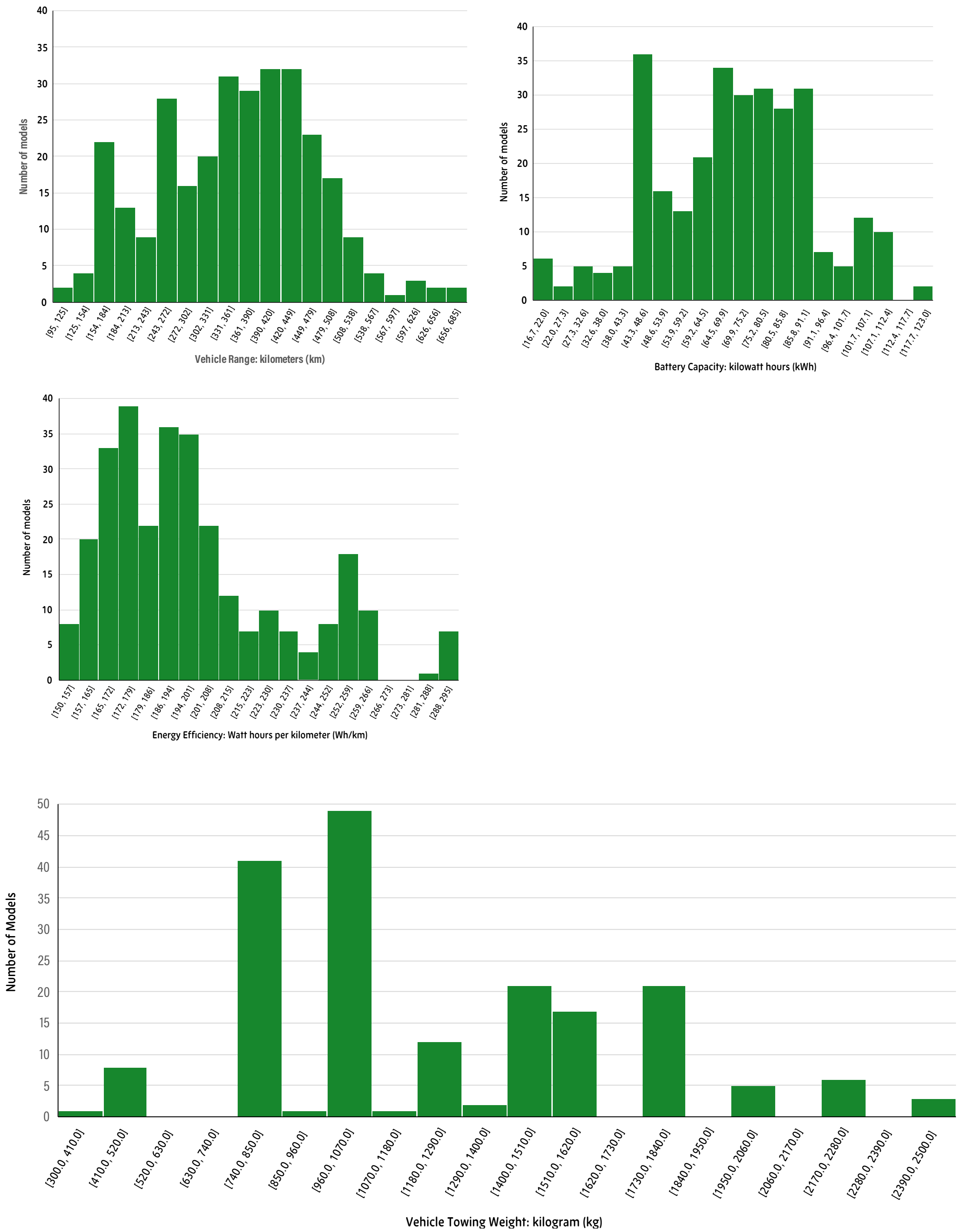
As of July 2023 there were some 344 different models of electric vehicles that consumers could potentially purchase, although the database we employ in the following discussion consists of 299 EV models (for a list of the models see Electric Vehicle Database, n.d.).[2] Data are available regarding the battery capacity, the associated energy efficiency and range, and towing weight. The data are summarized in table 1. The distributions of models with each of these characteristics are shown in figure 6.

Much of the information in table 1 and figure 6 is provided by the electric vehicle manufacturers, often based on tests performed under perfect conditions or from theoretical models.[3] In practice, batteries may not perform to the same levels indicated by the manufacturer; batteries should not, for example, be recharged in temperatures below

2 Our data are based on information accessed on March 16, 2023 <evdatabase.org>; since then, 45 new models have been added, although the majority are not available for purchase until later in 2023 or in 2024.

3 The authors of the Electric Vehicle Database point out that: "The EV Database aims to gather as much real-world data as possible. A lot of information in the car industry is often not applicable in practice, as these are often based on theoretical data gathered in laboratories. To avoid misunderstandings, the EV Database shows the official data in addition to the real-world data" (n.d.). We could not find evidence indicating that the theoretical and real-world data were separated. The website also provides a disclaimer concerning the use of the data.

Figure 6: Distribution of four characteristics of electric vehicle models:
Battery capacity, battery efficiency, vehicle range, and vehicle towing weight for selected models of electric vehicles (n=299, except n=188 for vehicle weight)



Source: Electric Vehicle Database, accessed March 16, 2023 freezing, as battery performance falls quickly when temperatures are below −30°C and declines somewhat as the batteries age. There is not enough information available to assess how performance is affected over time and under various weather conditions.

We analyze the potential demand that EVs pose on electricity grids in Canada in this section and provide background information and data on electricity supply and electric vehicles in Canada and its provinces are presented in table 2.

Table 1: Summary statistics of available electric vehicle models: battery capacity and energy, and vehicle range and weight

Statistic	Capacity (kWh)	Energy (Wh/km)	Range (km)	Weight (kg)
Mean	70.2	199.3	357.5	1,226.5
Maximum	123.0	295.0	685.0	2,500.0
Minimum	16.7	150.0	95.0	300.0
Median	71.0	192.0	365.0	1,000.0
Observations	299	299	299	188

Source: Electric Vehicle Database (n.d.).

Table 2: Electricity availability and electric vehicle requirements, 2022

Jurisdiction	Electricity supply (MWh)[a]	Average distance driven (km/year)[b]	Vehicles		Average energy per EV(kWh)[c]	Total energy use by EVs in jurisdiction (MWh)[d]	% of electricity use in jurisdiction
			Total	Electric (zero-emissions)			
Canada	578,273,577	15,200	21,351,392	510,135	3,030	1,545,468	0.27%
Newfoundland & Labrador	8,514,552	18,100	NA	NA	3,608	NA	NA
PEI	1,564,861	15,300	88,490	961	3,049	2,931	0.19%
Nova Scotia	10,417,930	16,600	NA	NA	3,309	NA	NA
New Brunswick	13,388,427	16,600	480,257	3,533	3,309	11,689	0.09%
Quebec	210,693,634	14,300	5,197,139	200,406	2,850	571,187	0.27%
Ontario	135,308,943	16,000	8,138,249	149,376	3,189	476,357	0.35%
Manitoba	25,411,885	14,800	613,566	4,550	2,950	13,422	0.05%
Saskatchewan	24,975,059	15,800	631,662	2,975	3,149	9,369	0.04%
Alberta	79,531,379	15,200	NA	NA	3,030	NA	NA
British Columbia	67,053,704	13,100	2,435,505	120,351	2,611	314,233	0.47%

a Source: Statistics Canada (2023c)
b Source: Natural Resources Canada (2010);], Statistics Canada (2022a)
c Source: Statistics Canada (2024a). NA=not available.
d Source: Author's calculations. NA=not available

To determine the strain that electric vehicles might impose on electricity grids in Canada and the impact of policies requiring the transition to EVs, we examine the installed capacity and generation by various energy sources in Canada and three major provinces—British Columbia, Ontario, and Quebec. The latest capacity data are available for the three provinces for 2022, but 2020 is the latest year data are available for capacity data in Canada. We also breakdown electricity generation by source in 2022 for the three provinces, as well as 2020 generation by source for Canada. For these categories, renewables include solar, wind, biomass, biofuels, and municipal solid waste sources. Hydro refers to run-of-river hydro, "storage hydro" (hydraulics with a large reservoir), wave, and tidal sources. Natural gas and oil refer to natural gas, biogas, oil, and diesel sources. Coal refers to coke and coal, while nuclear refers to nuclear power.

Each jurisdiction has incentivized the purchase of EVs in various ways. These include a minimum national carbon tax that progressively increases (and is mainly reflected in gasoline and diesel prices), EV-production mandates, government financing for charging stations, and subsidies for EV purchases. As the technology for EVs improves, consumers are more likely to purchase them. These factors all played a role in the increase in new electric vehicle registrations over the past several years (see figure 4).

Information concerning the vehicle fleet in Canada and the three provinces is provided in the previous section. We could not find any data for years before 2010, so we have taken the cumulative number of new vehicle registrations by province to get an idea of the fuel types that make up the fleet of vehicles in each jurisdiction. Realistically, there are probably more gasoline vehicles than our estimates indicate, because of the popularity of ICEs prior to 2010 (Statistics Canada, 2022). Due to the lack of data, in this section we only provide information on growth of EVs in comparison to growth in electricity demand since 2010 (Canada Energy Regulator, 2021; 2023-a). The focus is on electricity production and the potential to meet future load increases. Then, in section 4, we explore the extent to which generating capacity will need to be increased to accommodate electric vehicles in the future. We do not address the capacity of the electricity transmission and delivery systems to handle the increased demand that EVs will impose.

Canada

With its vast water supply, Canada has plentiful hydroelectric generation capacity, with 54% of total installed capacity attributed to hydraulic sources (table 3). This does not, however, imply that some 54% of the actual power generated in Canada comes from hydro. It depends on the relationship between capacity and generation—on the capacity factors (CF) of the various generating sources.[4] Hydropower is essentially generated in two ways. First, run-of-river power is nondispatchable—it must be used as it is generated or else it will need to be "discarded" (not generated or dispatched). The capacity to generate run-of-river electricity at any point in time depends on the rate of flow of the river. In contrast, storage hydroelectric capacity is determined by the capacity of the generating units and the height of the water in the reservoir behind the dam, which will fluctuate from one season and year to another. However, the available power in that case is dispatchable—controllable by the system operator.

Canada also has significant energy production capabilities coming from gas, wind, and nuclear sources. In 2020, about 74.2% of Canada's installed capacity came from hydro, nuclear, wind, and solar, all of which are considered green energy sources (Canada Energy Regulator, 2021). Most of Canada's energy, 61.9% of the total, came from hydro in 2020; 12.5% came from oil and gas, primarily for provinces and territories whose geography does not allow for hydraulics, and for remote communities. Although only Ontario and New Brunswick have nuclear energy capacity, this accounted for 13.3% of Canada's electricity production in 2020. Overall, some 82.5% of the country's electricity production came from green sources in 2020 (Canada Energy Regulator, 2021).[5]

In Canada as a whole EVs continue to be a very small proportion of total vehicles on the roads. Although new EV registrations have increased dramatically in the past couple of years, particularly BEVs, they remain a small fraction of the nation's EV fleet. New vehicle registrations since 2011 are likely

4 The capacity factor is determined by the actual output of a generating source over a given period divided by its rated capacity multiplied by the number of hours in the period (8,760 hours in a year, say).

5 In Canada, hydro produced 380.8 TWh of electricity in 2021, accounting for 59.4% of total electricity generation; in 2021, hydro accounted for 11.9% of total power generation in the EU and only 5.8% in the US (British Petroleum 2023).

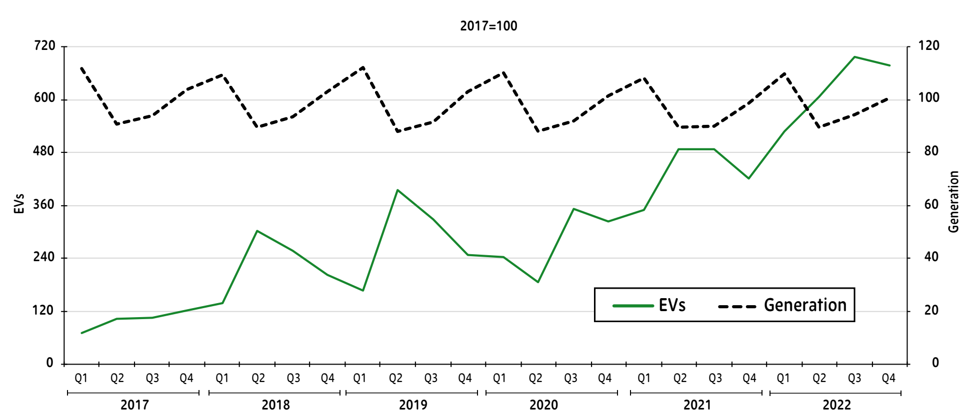
Table 3: Electricity capacity and generation, by power source, Canada, 2020 (percent)

	Capacity	Generation
Coal	6.03%	4.99%
Natural Gas	15.25%	11.93%
Oil	2.45%	0.56%
Hydro	54.97%	61.87%
Nuclear	9.01%	13.37%
Wind, Solar, Biomass	8.92%	5.67%
Solar	1.85%	0.36%
Biomass	1.53%	1.24%
TOTAL	100.0%	100.0%
Level	**148.9 GW**	**624 TWh**

Source: Canada Energy Regulator (2021).

still on the road (see column 3, table 2), which gives us an idea of the breakdown of vehicles on the road today. Between 2011 and the end of 2022, BEVs constituted only 1.3% of new vehicle registrations, while PHEVs accounted for 0.6%, and total zero or low-emitting EVs were responsible for less than 2% of the vehicles on the road. Electricity generation and EV registrations per quarter since 2017 (2017=100) are shown in figure 7) (Statistics Canada 2024b; 2023a). Electricity generation has stayed relatively constant, fluctuating with the seasons, but EV registrations within Canada have increased seven-fold since the beginning of 2017.

Figure 7: Growth in quarterly EV registrations and electricity generation or load, Canada, Q1 2017 – Q4 2022, 2017-2022 (2017=100)



Source: Statistics Canada, 2023a; 2024b

British Columbia

British Columbia relies predominantly on hydroelectricity, and its hydropower capacity represents over 87% of its total installed capacity. Overall, 91.6% of its total installed capacity is from hydro, wind, and solar sources owned by BC Hydro or individual power producers (IPPs) throughout the province (BC Hydro 2024a; 2024b). BC's IPPs produce about one-third of its power. The most recent data indicate that IPPs contribute about 18,875 GWh per year (BC Hydro, 2024b), while BC Hydro contributes 48,190 GWh annually, for a total of about 67,065 GWh in 2022 (see table 4).

Table 4: Electricity capacity and generation, by power source, British Columbia, 2022 (percent)

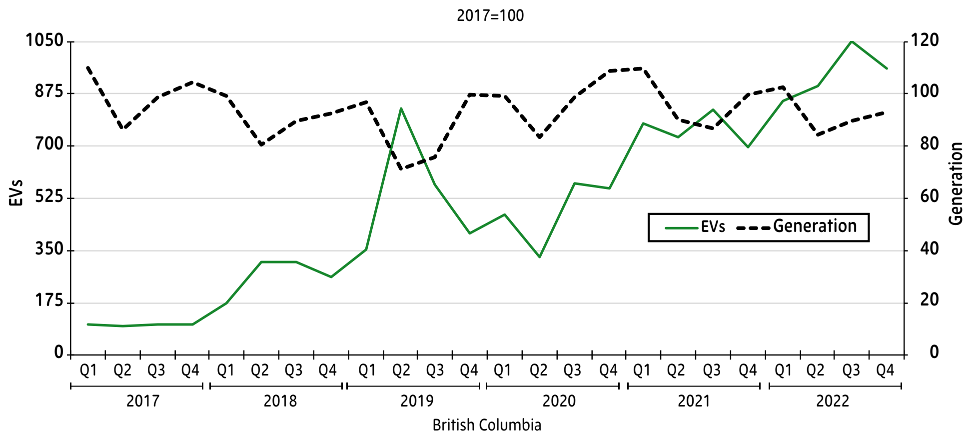
	Capacity	Generation
Coal	0.0%	0.0%
Oil and Natural Gas	3.4%	1.6%
Hydro	87.3%	90.3%
Nuclear	0.0%	0.0%
Wind, Solar, Biomass	9.4%	8.1%
TOTAL	100.1%	100.0%
Level	**17.6 GW**	**67.1 TWh**

Source: BC Hydro (2021).
Note: Capacity does not add to 100% due to rounding.

British Columbia and the territories have made significant progress transitioning to electric vehicles. However, based on new registrations per vehicle type, ICE gasoline vehicle registrations far exceed other fuel types, although BEVs have been growing in popularity, with almost 25,000 new registrations in 2022. British Columbia has significantly more electric vehicles on the road than Canada overall, with 3.2% and 1% of its cumulative new registrations attributable to BEVs and PHEVs, respectively.

Energy production fluctuates relatively little (depending on the season), whereas EV registrations increased almost 10-fold between 2017 and the end of 2022 (2017=100) (figure 8) (Statistics Canada, 2024b, 2023a). The growth in EV registrations relative to ICE vehicles was higher than in other provinces; well over 100,000 EVs have been registered since 2017. The rapid adoption of EVs in British Columbia could bode ill for future electricity developments as these have generally taken a long time to get approved, particularly in the case of hydroelectric projects.

Figure 8: Growth in quarterly EV registrations and electricity generation, British Columbia, Q1 2017 – Q4 2022, 2017 = 100.



Source: Statistics Canada (2024b; 2023a).

Ontario

Unlike British Columbia and Quebec (for Quebec see below), Ontario has a greater variety of electricity-generation assets, with nuclear energy contributing the largest share in Ontario's production capacity. Ontario has three nuclear power plants, including the Bruce generating station, which is one of the world's largest, with eight nuclear reactors. Of Ontario's total grid-connected capacity, 34% is attributable to nuclear, while only 27.5% is from oil and gas; total renewable-energy capacity accounts for 38.1% of the province's electricity-generating capacity (IESO, n.d.-a). However, because nuclear power plants continually operate at near capacity, this source accounted for 53.6% of Ontario's total electricity production in 2022. A combined total of 89.4% of the province's power generation in 2022 came from nuclear, hydro, wind, and solar sources (IESO, n.d.-b). Yet, only nuclear energy is sufficiently reliable enough to be used to provide base-load power (IESO, n.d.-c).

Ontario trails the rest of Canada in adopting electric vehicles, with gasoline powered vehicles representing almost all the new registrations in the province from 2011 to 2022. Unlike the other provinces, Ontario's primary

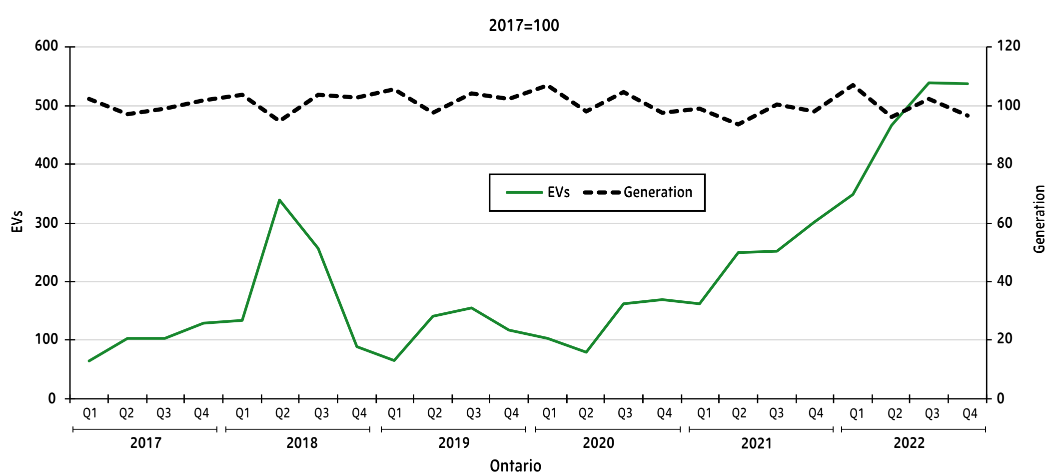
Table 5: Electricity capacity and generation by source, Ontario, 2022 (percent)

	Capacity	Generation
Coal	0.0%	0.0%
Oil and Natural Gas	27.5%	10.4%
Hydro	23.3%	25.9%
Nuclear	34.4%	53.7%
Wind, Solar, Biomass	14.8%	10.1%
TOTAL	100.0%	100.1%
Level	**38.1 GW**	**146.9 TWh**

Source: Independent Electricity System Operator (n.d.-c).
Note: Generation is over 100% due to rounding.

alternative to ICE vehicles in recent years is the hybrid vehicle, rather than the BEV. Since 2020, the number of newly registered cars has declined, but the numbers of new hybrid car registrations and new BEV registrations have both increased. Using cumulative new vehicle registrations since 2011, almost 1% are BEVs and about 0.4% are PHEVs, so less than 2% of vehicles on the road in Ontario are zero- or low-emission vehicles. The change in Ontario's EV registrations and energy production (2017=100) is shown in figure 9 (Statistics Canada, 2024b; 2023a). As indicated in the figure, electricity production is rather flat, but new EV registrations have increased about 5.5 times since 2017, which is lower than the national growth rate in EV registrations.

Figure 9: Growth in quarterly EV registrations and electricity generation, Ontario, Q1 2017 – Q4 2022, 2017 = 100



Source: Statistics Canada (2024b; 2023a).

Quebec

Quebec has developed hydroelectricity on a large scale and is the leading producer of renewable energy in Canada. Quebec's grid operates much like British Columbia's, with a primary provincial power supplier together with IPPs selling electricity to the grid. With the combination of Hydro Québec and the IPPs, the province has an installed generation capacity that is 87% hydro, and hydro and wind account for nearly 97% of Quebec's generating capacity (table 6). Quebec has the highest installed hydro capacity of any province in Canada, at approximately 47,733 MW.

Despite having 87% installed hydropower capacity, Quebec generates nearly 93% of its electricity from hydro. Thus, in 2022, the province produced almost 100% of its electricity from clean energy sources, with less than 0.1% coming from oil and gas (Hydro Quebéc n.d.-b). Quebec had the highest electricity generation in Canada in 2022, with production of 210.7 TWh (table 6).

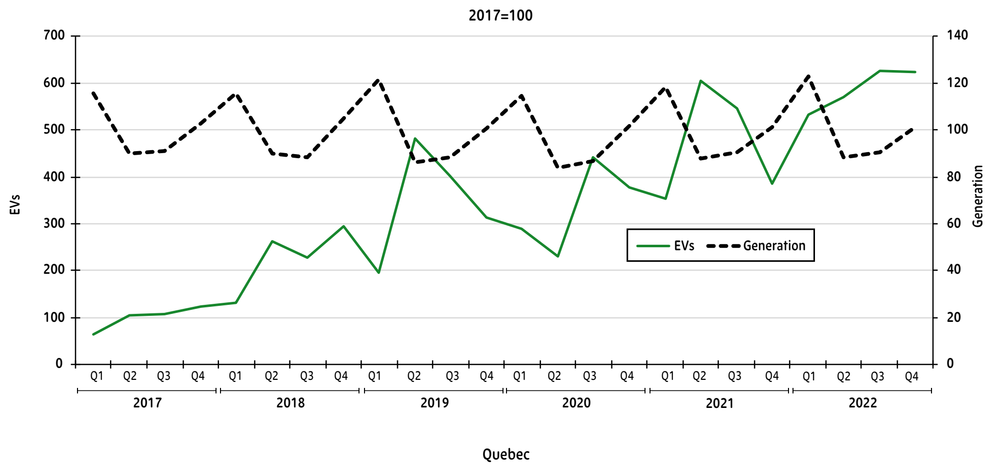
Table 6: Electricity capacity and generation, by power source, Quebec, 2022 (percent)

	Capacity	Generation
Coal	0.0%	0.0%
Oil and Natural Gas	3.4%	~ 0.0%
Hydro	87.3%	92.8%
Nuclear	0.0%	0.0%
Wind, Solar, Biomass	9.4%	7.2%
TOTAL	100.1%	100.0%
Level	**47.7 GW**	**210.7 TWh**

Source: Hydro Québec (2024; n.d.-a; n.d.-b).

Quebec has moved away from gasoline vehicles at an increasing rate, with a significant gap emerging between ICE and total registrations, although ICE still account for the great majority of its total new registrations. Cumulative new vehicle registrations in Quebec from 2011 to 2022 include a total of almost 2.1% BEVs and 1.3% PHEVs, which are both greater than the national mean. While electricity generation has stayed relatively constant over time, new EV registrations since 2022 have increased approximately six times above the 2017 average (figure 10).

Figure 10: Growth in quarterly EV registrations and electricity generation, Quebec, Q1 2017 – Q4 2022, 2017 = 100



Source: Statistics Canada (2024b; 2023a).

ELECTRIC VEHICLES AND ELECTRICITY GRIDS

In this section, we explore the potential strain that EV adoption puts on electrical systems across Canada, with particular emphasis on BC, Ontario, and Quebec. In addition to determining the electricity required by EVs, there is the problem of what the ultimate energy source might look like. We begin by considering possible sources of energy for generating the power required by EVs.

Evaluation of Potential Energy Sources for EVs

Power-generation sources are not all created equal, nor do they have the properties needed to facilitate the conversion of personal and commercial transportation to electric vehicles. Although investment in EVs is ongoing, harsh Canadian winters reduce the feasibility of EVs—batteries are less efficient and more difficult (and sometimes nearly impossible) to recharge if temperatures are well below freezing. This is a particular problem where outdoor parking prevails, which is the case at many workplaces and residential areas in some regions of Canada.

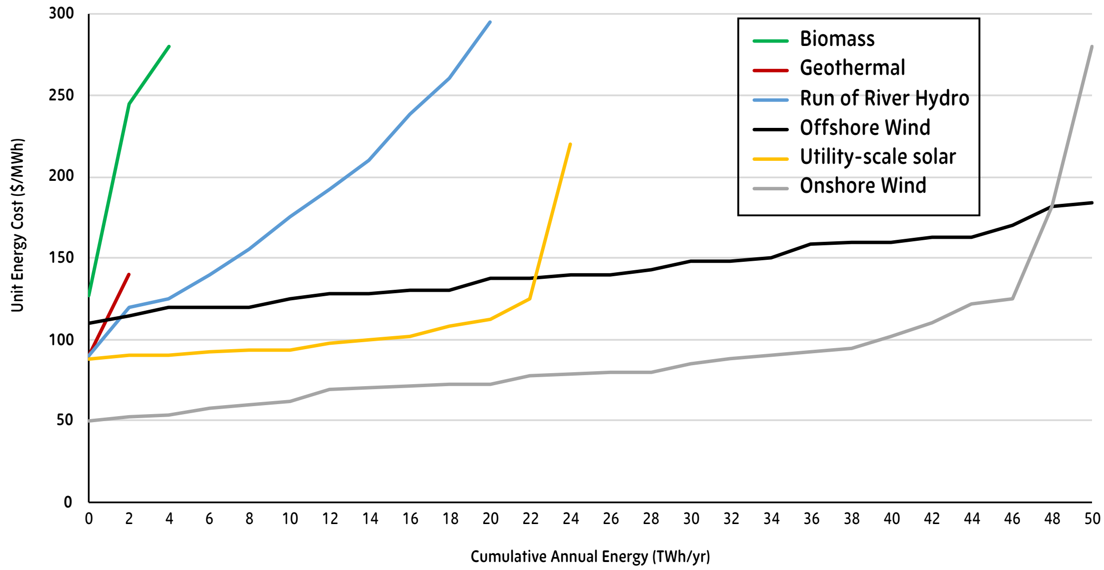
Further, most people will likely get into the habit of recharging their EVs in the evening when they arrive home from work and keeping them plugged in overnight, similar to how they recharge their phones. This provides the opportunity to charge their vehicles in heated or even unheated parking garages, or outdoors. Recharging batteries in the late afternoon or evening will lead to an increase in peak load. A shift to night-time recharging will increase both the baseload requirement—the electricity that is always demanded due to battery-powered transportation—which introduces an unpredictable component. Baseload capacity requires a generating source that is reliable and operates near capacity all year round except for planned outages. Baseload power can only be provided by a coal plant, combined-cycle natural gas turbine (CCGT), nuclear power plant, or hydro-with-reservoir facility. Wind cannot serve as a baseload power source because of its intermittency. The unpredictable nature of the night-time load resulting from EV recharging can be satisfied to some extent by baseload plants, but more likely by peak plants such as open-cycle natural gas turbines (OCGT) and diesel generators. Wind, run-of-river hydro and solar are also important potential energy sources (see figure 11), but they require OCGT facilities as backup. Even if wind capacity is increased, for example, it would be necessary to provide a reliable backup source of power if wind does not provide adequate power to meet the deficit in load. Solar power is also intermittent and would not be a viable option, since electricity will be needed in the evenings and overnight. For the shift to EVs to be most beneficial in reducing CO_2 emissions, it would be necessary to construct additional hydroelectric dams, invest in nuclear power plants, or build biomass facilities (see below).

Storage hydro is an option for some provinces, for example, British Columbia and Quebec, which have the available hydraulics (and reservoir), but there are some serious drawbacks. Storage hydro would require construction of an additional reservoir, which would impact the flow of current waterways. Though storage hydro is significantly more reliable than run-of-river hydro, the amount of water behind the dam still depends on unpredictable precipitation—a drought could significantly impact electricity generation. Construction of a hydroelectric facility of this size is likely not feasible in most jurisdictions due to environmental groups' opposition. Tidal power might be an option, because of its reliability, but tidal structures could harm marine life, while the energy generated would depend on the size of the tide shift, which is uncontrollable, albeit predictable.

Like other thermal electricity-generation sources, biomass burning to generate electricity can be made reliable and, if sufficient fuel is available, operated at high capacity. However, there is only so much biomass that can be used before it becomes costly to source. The marginal cost of biomass in British Columbia is indicated in figure 11;[6] the figure depicts how each additional unit of biomass energy becomes very expensive quite quickly, compared with other energy sources. Burning biomass works well at first,

6 Figure adapted from a graph found on BC Hydro's 2021 Resource Options Database, Figure J-2 (BC Hydro 2021).

Figure 11: Marginal cost of electricity sources, British Columbia, $/MWh



Source: BC Hydro (2021).

but when there is no more biomass in an area, it must be transported longer distances by trucks, which currently run on fossil fuels. If trucks and timber harvesting equipment were to be converted to EVs, there would be an additional load, requiring the hauling of even more biomass. If biomass were to be seen as a major fuel source, biomass crops would require large amounts of water, fertilizer and land devoted to timber production. This would crowd out farmland used to produce food crops, increase food prices, and lead to a more intensive agriculture, to the detriment of the environment (Marsh, 2022). Biomass fuels are a great option on a small scale, especially where biomass is available as a by-product of other primary activities. However, because the marginal cost of biomass power increases rapidly, making it not economically feasible for large-scale production of electricity, it cannot be relied on as a major energy source for electric vehicles. Further, biomass burning is not CO_2 neutral (van Kooten et al., 2021), which makes EVs less attractive as a means of meeting climate objectives.

Nuclear energy is likely the best green energy option for meeting new electricity needs, but it, too, has some drawbacks. Nuclear power plants can consistently operate near maximum capacity. In addition, since no CO_2 is emitted it is considered a green source of energy, although it is not renewable; uranium reserves are finite. Nuclear power is opposed because of its association with nuclear weapons, the problem of nuclear waste, and its potentially hazardous impact on life if there is a malfunction. Historically, nuclear disasters have been associated with major human and environmental catastrophes, andactual or perceived failures of power plants at Three-Mile Island (USA), Chernobyl (Soviet Union/Ukraine) and Fukushima (Japan) are still cited as environmental and human catastrophes (Process Industry Forum, n.d.). Because nuclear technology has constantly been improving and nuclear reactors are now safer than ever before, nuclear energy is one of the most feasible of all clean energy sources available to society today.

“Nuclear technology has constantly been improving and nuclear reactors are now safer than ever before, nuclear energy is one of the most feasible of all clean energy sources available to society today.

The final option to meet the additional electricity demand from EVs is to use natural gas or coal. Neither of these sources are considered green, and both are finite. It would not make sense to change the entire vehicle fleet from ICEs to EVs if power is produced from fossil fuels, since there would still be greenhouse gas emissions. In addition, it would likely lead to only a small decrease (or perhaps even an increase) in the overall carbon footprint, because EVs are less environmentally friendly to make (Broom, 2019; Marx, 2019; Mills, 2020).

IMPACT OF VARIOUS ELECTRICITY SOURCES ON POWER GENERATION FACILITIES

In this section, we provide crude estimates of the extra demand for electricity that might be expected and the potential need to construct new power generating facilities. We first provide estimates based on average data; we then use a Monte Carlo simulation to determine possible ranges of extra electricity demand.

For the initial analysis, we employ EV battery efficiency data from table 1 and average driving distances from table 2 (Electric Vehicle Database [n.d.]; Statistics Canada [2024-a, 2023-c, 22-a]; Natural Resources Canada [2010]; author's calculations). We multiply the mean distance driven in each jurisdiction by the cumulative total number of new vehicle registrations, over the period 2011 to 2022. We ignore vehicles older than 11 years old and assume no EV vehicles registered during this period are subsequently removed. This gives us an estimate of the total distance driven in each jurisdiction—the number of vehicle kilometres (km.). Finally, we multiply the total vehicle kilometres in each jurisdiction by estimates of the overall battery efficiency (watt hours per km, or Wh/km), thereby providing an estimate of the total additional energy (in gigawatt hours, or GWh=109 W) that the jurisdiction would need to produce to accommodate this many EVs. In doing so, we consider the maximum, minimum, mean, and median values of the battery efficiency, based on the efficiencies of the 299 models of EVs in reported table 1. The results are shown in table 7.

Table 7: Energy required to switch to electric vehicles, Canada and selected provinces[a]

	Canada	British Columbia[b]	Ontario	Quebec
Electricity generated in 2022 (GWh)	625,888	67,062	146,850	227,302
Annual distance (km)	15,200	13,100	16,000	14,300
Based on mean battery efficiency		GWh/year		
Mean demand	64,681	6,359	25,951	14,812
Current usage	1,254	267	362	499
Addition energy required	63,427	6,092	25,590	14,312
Mean Increase	10.1%	9.1%	17.4%	6.3%
Based on median battery efficiency		GWh/year		
Median demand	62,312	6,126	25,001	14,269
Current usage	1,208	257	348	481
Addition energy required	61,104	5,869	24,652	13,788
Median Increase	10.0%	8.8%	16.8%	6.1%
Based on low battery efficiency		GWh/year		
Maximum demand	95,740	9,412	38,413	21,924
Current usage	634	152	189	229
Addition energy required	95,106	9,260	38,224	21,696
Maximum Increase	15.3%	13.8%	26.2%	9.6%
Based on best battery efficiency		GWh/year		
Minimum demand	48,681	4,786	19,532	11,148
Current usage	1,856	395	535	739
Addition energy required	46,825	4,390	18,997	10,409
Minimum increase	7.5%	6.6%	12.9%	4.6%

a Because there are no data breaking down gasoline vs battery use in the average PHEV, we assume that BEVs and PHEVs operate in the same way.
b Includes the Territories.

Sources: Electric Vehicle Database (n.d.); Statistics Canada (2024-a, 2023-c, 22-a); Natural Resources Canada (2010); author's calculations).

The results indicate that EVs could pose a significant burden on Canadian electricity grids, with system loads increasing by as little as 7.5% to as much as 15.3%. Overall, Canada could see an increase in the annual load ranging from 46.8 terawatt hours (TWh) to 95.1 TWh, with BC's annual load potentially increasing by 4.4-9.3 TWh, Ontario's by 19.0-38.2 TWh., and Quebec's by 10-21.7 TWh.

In table 7 we do not account for marginal costs, under-reporting of numbers to insurance companies to obtain lower premiums, or growth in the overall vehicle fleet due to population growth. Economic theory suggests that as marginal costs decline consumers will consume more. Since energy from the grid is cheaper than gas, the marginal cost of driving a kilometre is less, so we could expect to see individuals driving more kilometres. It is also very plausible that individuals under-report their annual insurance estimates of the distances they drive, to get lower premiums, so the mean kilometers driven may be higher than stated.[7] With population growth, there would be a greater demand for vehicles, which would require more energy. Thus, we could expect the mean kilometres driven in each jurisdiction to increase, so the upper bound may be higher than is considered here, and the mean and median models are most likely lower estimates of the true generation increase needed.

Monte Carlo simulation

To get a better notion of the potential upper and lower bounds of future power needs for electric vehicles, we employ a Monte Carlo simulation to determine the battery efficiency (Wh/km), the distances driven in each jurisdiction (km), and the number of EVs likely on the road at some distant date. To do so, we employ triangle distributions. The triangle distribution requires a minimum value (the lowest value the variable might take), a maximum value, and a most likely value (or mode). This gives us a better understanding of what the additional load requirements will be with the added component of randomness and is more realistic for a real-life outcome.

For this simulation, we use a battery efficiency distribution that has a midpoint efficiency of 192 Wh/km, a minimum efficiency of 150 Wh/km, and a maximum efficiency of 295 Wh/km (see table 1). The distribution is assumed to be the same for each jurisdiction.

The numbers of vehicles registered by jurisdiction over the period 2011-2022 are shown in table 2. It is unlikely that these numbers represent the actual numbers of EVs on the road in the next decade. Therefore, we choose as our midpoints of the triangle distributions one-half of the vehicle totals (EVs plus

7 This may become less of a problem in the future, as some insurance agencies now require customers to provide evidence of annual distances driven from odometer readings.

ICEs) in table 2. The respective minimum and maximum values of the EVs on the road in the next decade are given by 0.25 and 0.90 of the total vehicles.

We do not have data on the distribution for kilometres driven in each jurisdiction, so we use the mean driven in each jurisdiction as the midpoint of the triangle distribution. For each jurisdiction, the minimum and maximum values of the triangle distribution are taken to be 90% and 120% of this value, respectively.

In each iteration, a random value is chosen from each of the three triangle distributions—battery efficiency, number of vehicles, and distance driven by an average vehicle—for each of the four jurisdictions discussed above. The results from 1,000 iterations are shown in table 8, for increased hourly and annual power requirements.

What are the implications for generating capacity in each jurisdiction? First, consider what would be required if all the added demand were to be met by CCGT or hydropower. Consider construction of a new hydropower facility, such as Site C in northern British Columbia. According to BC Hydro, "Site C will provide 1,100 megawatts of dependable capacity and will generate about 5,100 gigawatt hours of energy each year" (British Columbia, 2018). For Canada, the load coming from EVs in the next decade would require the construction of perhaps 10 hydro facilities like Site C, one built in BC, four in Ontario, and two in Quebec. Construction of even a single dam of that size is highly unlikely to happen within the next decade, based on how long it took to complete Site C. It is more likely that the added generating capacity would come from natural gas sources. In that case, it would be necessary to build 13 large gas plants of 500 MW capacity or greater in Canada, with one in BC, five in Ontario and three in Quebec.

If EV demand for power is to come from renewable sources, however, wind would be the most likely option. Assuming a capacity of 3.5 MW per turbine and average wind capacity factor of 25%, the requirements can be seen in the bottom two rows of table 8. For BC, 600 large wind turbines would need to be built within the next few years. However, given the unreliability of wind energy, it would also be necessary to build CCGT, hydropower and/or utility-scale battery storage capacity as backup. In general, backup requirements

Table 8: Estimated hourly and annual increase in load from electric vehicles, Canada and selected provinces

Item	Canada	British Columbia	Ontario	Quebec
Hourly increase (MW)				
Mean	4,345.25	488.91	1,629.33	1,048.78
Standard deviation	1,280.95	152.38	492.72	310.09
Annual increase (GWh)				
Mean	38,064.4	4,282.9	14,272.9	9,187.3
Standard deviation	11,221.2	1,334.8	4,316.2	2,716.4
Potential number of Site-C equivalents needed[a]				
Based on mean increase	7	1	3	2
Mean plus 1 standard deviation	10	1	4	2
Potential number of 500-MW Capacity gas plants needed[b]				
Based on mean increase	10	1	4	2
Mean plus 1 standard deviation	13	1	5	3
Wind Powered Capacity and Turbines (3.5 MW cap)				
Capacity (MW)	17,381	1,956	6,517	4,195
Number of turbines	4,966	559	1,862	1,199

a Number determined by dividing annual increase (GWh) by 5100 GWh projected annual output of Site C.
b Determined by dividing annual increase (GWh) by 3942 GWh, assuming 500-MW capacity plant operates 8760 hours at 90% capacity.
Source: Authors' calculations

amount to some 80% to 90% of installed wind capacity; however, because backup capacity cannot pay for itself as it does not deliver enough power during the year, it would need to be subsidized, thereby adding to system costs (van Kooten, Whithey and Duan, 2020: 196-204; Duan, van Kooten, and Liu 2020; van Kooten, 2016).[8]

Unless society begins almost immediately to develop the required generating infrastructure, it will not be possible to meet the expected demand that EVs might pose for electricity grids in Canada. That is, if governments continue to push for an all-electric vehicle fleet by continuing to subsidize EV purchases directly and through policies that raise gasoline prices, and requiring all vehicles sold beyond 2030 or 2035 to be electric, it will be necessary to start construction of power plants to meet the anticipated increase in demand.

8 The actual capacity and generation type required to backstop wind power will vary according to the makeup of the grid, location of wind turbines, interconnections, grid load profile, and many other factors.

DISCUSSION AND CONCLUSIONS

A study by Xia (2023) using city-level data for Canada found the factors in table 9 to have the greatest effect on the purchase of EVs.

Table 9. Main factors predicting consumers' purchases of EVs

Factor	Estimated coefficient
GDP per capita (income)	1.2406
Price of gasoline/diesel	0.2438
Rebate (subsidy)	0.2016
Winter temperature	0.0811
Charging station availability	0.0006

Note: Variables are in standardized form; only statistically significant explanatory variables shown.
Source: Xia (2023).

Income is the most important factor, followed by the price of gasoline and then the rebate. A municipality's average winter temperature is less important, with the availability of charging stations being the least important factor.

The gap between US and Canadian gasoline prices amounts to about CDN$0.50 per litre. While the carbon tax and some other costs of acquiring gasoline are important as factors that account for the difference between the Canadian and the American prices, a major factor is fuel taxes, some of which are meant to enhance and maintain transportation infrastructure and contribute to public transportation. Fuel taxes are meant to incentivize people to drive less and rely more on public transportation, thereby reducing congestion as well as CO_2 emissions. The driver of an electric vehicle does not pay fuel taxes. EVs are exempt from fuel taxes, they often benefit from low electricity rates (particularly in jurisdictions such as BC and Quebec that rely on hydroelectricity), and in some cases benefit from unrestricted access to high-occupancy lanes (HOVs). Overall, these incentives increase driving distances and reduce reliance on public transportation and other forms of transport, including walking and cycling. Thus, government policies related to EVs generally lead to greater congestion and deterioration of road infrastructure due to greater use by heavier vehicles, thus negating the emission-reducing benefits of EVs.

If the grid were to be fully green, each of the jurisdictions in this study would need to replace their current energy outputs with green energy. Some jurisdictions, such as British Columbia and Quebec, would be able to meet the extra electricity demand with renewable sources, because of their hydraulics. Even so, it might be challenging to construct new hydropower capacity, because of obstacles to their construction (as was the case with BC's Site C). In other parts of Canada, natural gas, and perhaps even coal, would be needed in order to meet additional demand. Of course, this would greatly reduce the emission-reduction benefits of adopting EVs.

Research suggests that, based on lifecycle analyses and the makeup of the average grid, the benefit from EVs is smaller than anticipated. Compared to an equivalent ICE vehicle, an EV reduces CO_2 emissions by perhaps as little as 15% after 200,000 km (Ridley, 2023). Savings of this magnitude could perhaps be realized through future improvements in ICE technology. When lifecycle emissions are counted, the emission-reduction benefits might be much smaller, depending on where the batteries and vehicles are built and how much fossil fuels are burned in mining cobalt, lithium, and other minerals. It also depends on lifetime emissions in rebuilding local electricity grids and producing the power needed to fuel EVs.

In conclusion, many obstacles have still to be overcome in switching to a completely electric vehicle fleet. Internationally, they include the costs of externalities related to pollution from mining and manufacturing processes. Locally, the major obstacle relates to the likelihood of constructing sufficient power generating capacity to meet the anticipated demand EVs would impose on electricity grids. The type of electricity that goes into the grid would also be a big consideration when switching over to EVs, as jurisdictions will need to increase their electricity production capabilities with green sources that meet the additional hourly load requirements and can be employed quickly to balance intermittent renewable energy sources. These would primarily have to be storage and the development of hydro and nuclear power—which are challenging to deploy in a timely way. The real-world situation is not as easy as merely replacing current ICE vehicles with EVs, and there are many obstacles to be overcome on the path of electrifying the personal vehicle fleets within Canada.

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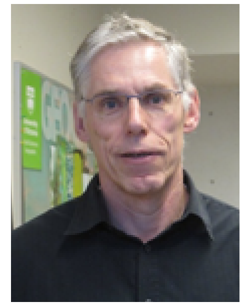

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Acknowledgments

The author is indebted to Coton Clarke for data collection and to two anonymous reviewers and Elmira Aliakbari for comments and suggestions on an earlier version of this study. Any remaining errors are the sole responsibilities of the author. As the researcher has worked independently, the views and conclusions expressed in this paper do not necessarily reflect those of the Board of Directors of the Fraser Institute, the staff, or supporters.

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Date of issue

March 2024

ISBN

978-0-88975-770-7

Citation

G. Cornelis van Kooten
Electric Vehicles and the Demand for Electricity
<http://www.fraserinstitute.org>

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