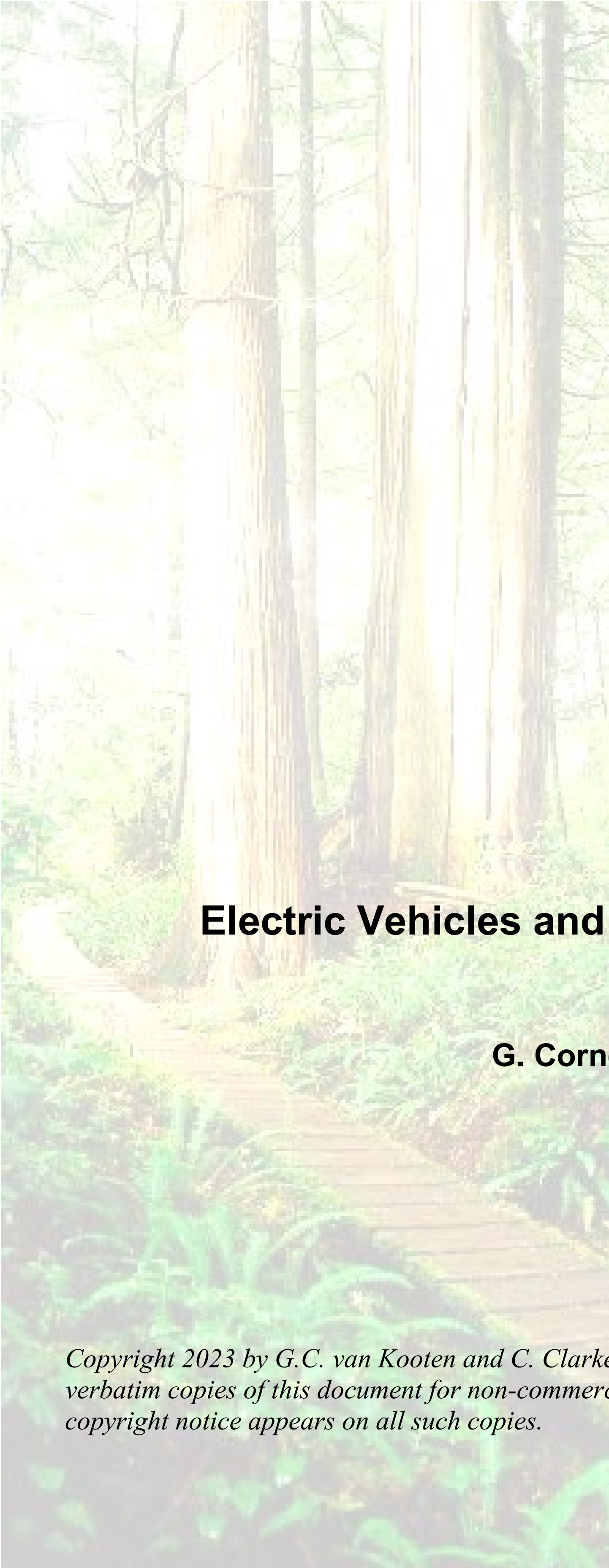

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Electric Vehicles and the Demand for Electricity

G. Cornelis van Kooten and Colton Clarke

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REPA Research Group
Department of Economics
University of Victoria PO Box 1700 STN CSC Victoria, BC V8W 2Y2 CANADA
repa@uvic.ca

http://web.uvic.ca/~repa/

ELECTRIC VEHICLES AND THE DEMAND FOR ELECTRICITY

by

G. Cornelis van Kooten and Colton Clarke
Department of Economics, University of Victoria

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INTRODUCTION

Promotion of electric vehicle 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, battery electric vehicles (BEVs) would take advantage of electricity generated solely from renewable sources of energy, primarily and sometimes exclusively wind and solar sources. There are many problems in moving toward a transportation system that relies solely on BEVs, even if only passenger cars, sport utility vehicles (SUVs) and light-duty trucks operate on batteries that are recharged from the electricity grid. Short-term problems relate to the availability of charging sites, while in the longer term inadequate electric generating capacity, both renewable and thermal, and transmission infrastructure can damper the transition away from ICEs.

In Canada, the federal government is planning to grow massively the use of electric vehicles (EVs) in the coming years. Current federal policy is that all new passenger vehicles will be net-zero emissions by 2035, eventually requiring 100% of the new fleet to be electric. This study examines the impact of adopting EVs—BEVs and plug-in hybrid electric vehicles (PHEVs)—on electricity demand. We investigate how much more electricity various Canadian power grids might 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) are 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? In this regard, 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 pertaining to the penetration of electric vehicles in the vehicle fleet. In doing so, we define the class of electric vehicles as those generally consisting of BEVs and plug-in hybrid vehicles, distinguishing these from ICE and hybrid vehicles that re-charge their batteries via a fossil-fuel driven ICE.

1. Data on Sales of Electric Vehicles in Canada

Data on registrations of all fuel and vehicle types in Canada, including electric vehicles, are available from Statistics Canada from the 1st quarter of 2017 through the 4th quarter of 2022 (Statistics Canada 2023a). Sales of electric vehicles are available for many cities and regions throughout Canada for the period 2017-2022, but any such data are lacking for the provinces of Alberta, Nova Scotia, and Newfoundland and Labrador.[1] In contrast, sales of passenger vehicles, trucks and total vehicles, as well as their origin (e.g., domestic versus foreign manufacture) are available monthly since January 1946 and through the first few months of 2023; however, no distinction is made by the type of fuel vehicles require (Statistics Canada 2023a).

To determine the impact of policies favoring 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. Clearly, EV registrations constitute a small but rising proportion of all vehicles sales, rising from

[1] Data for these provinces are simply unavailable. See Statistics Canada, New Zero-emission Vehicle Registrations, Quarterly. Table 20-10-0025-01. https://doi.org/10.25318/2010002501-eng.

less than one percent of sales in 2017 to 9.1% in the last quarter of 2022.

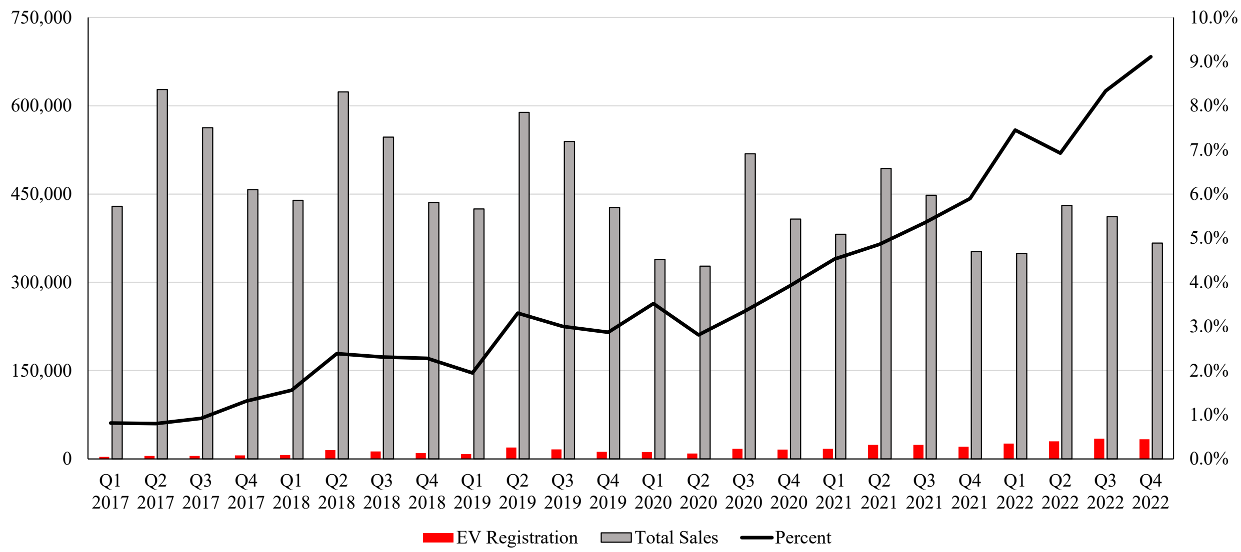

Figure 1: Electric and Total Vehicle Sales in Canada by Quarter, Q1 2017 through Q4 2022

In Figures 2 and 3, we provide greater information concerning the rate at which electric vehicles have been adopted. The numbers of battery electric vehicles or plug-in hybrids 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 registrations versus total vehicle sales for the last quarter of 2022 are then provided 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 appear to be EVs, compared to about 14% in Quebec, 10% in Canada (excluding the above provinces), and 8% in Ontario. The most obvious explanations for the greater penetration of EVs in BC are its lower prices of electricity, generally higher gasoline prices, and milder temperatures compared to other jurisdictions in Canada, although these factors might not be statistically significant determinants of purchases.

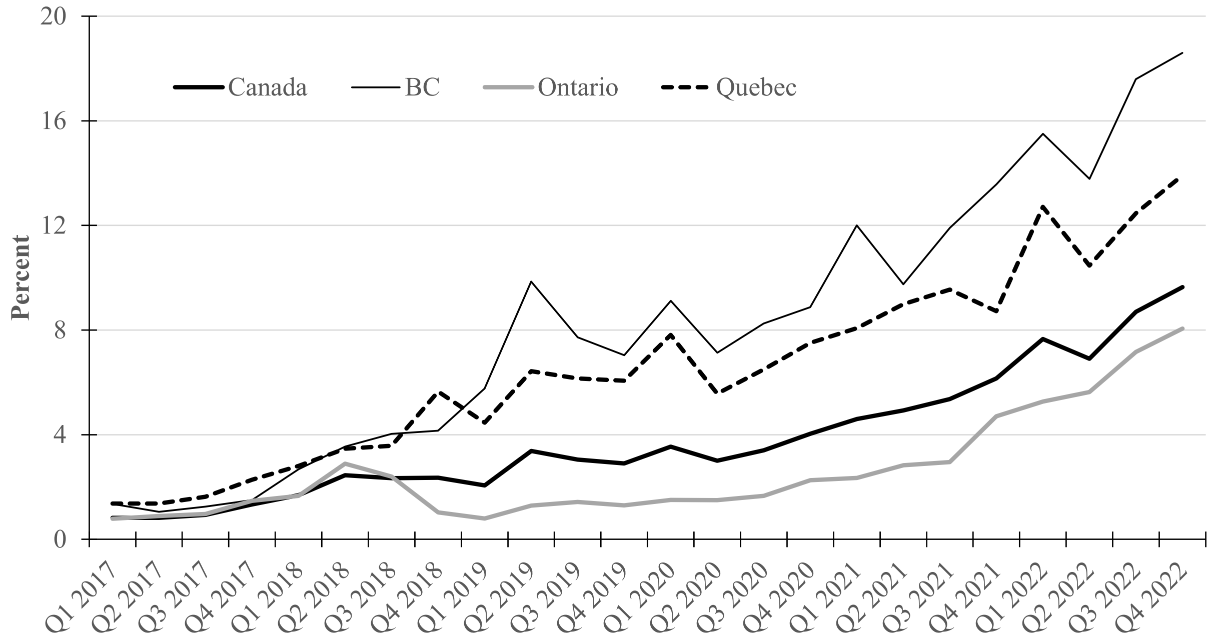

Figure 2: Percent of New Vehicle Registrations that are Battery Electric Vehicles or Plug-in Hybrids, by Major Provinces and Canada as a Whole

More detailed information concerning the distribution of vehicle registrations by fuel type for the four jurisdictions discussed in the preceding paragraph can be found in Figure 4. The data in the figure compare quarterly registrations of gasoline ICEs, BEVs, PHEVs and other fuel types to the annual baseline 2017 registrations (2017=100). While total registrations of vehicles and registrations of gasoline ICEs fell somewhat between 2017 and 2022 (with gasoline ICEs having fallen to a greater extent), EV registrations rose significantly in all jurisdictions. While PHEV registrations doubled overall (with those in BC quadrupling), those of BEVs rose by some twelve-fold (nearly 14-fold in BC). However, compared to ICE vehicles, EVs are quite a small proportion of all vehicles on the road at any given time (e.g., see Figure 1).

Government policies to electrify transportation consist of legislative mandates that focus on zero emission targets and entail requirements to prevent sales of ICEs after a certain date (2035, say), along with retail subsidies. The policies essentially force automobile manufacturers

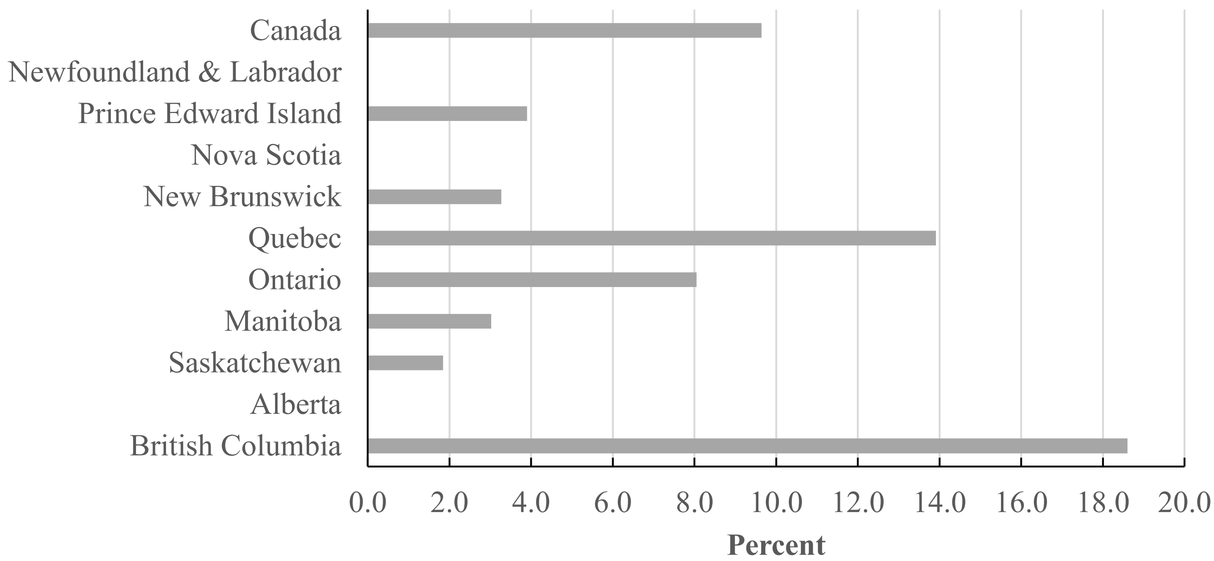

Figure 3: Proportion of Total Vehicle Sales Accounted for by EVs, 2021-2022
(No data on electric vehicles are available for Alberta, Nova Scotia, and Newfoundland & Labrador)

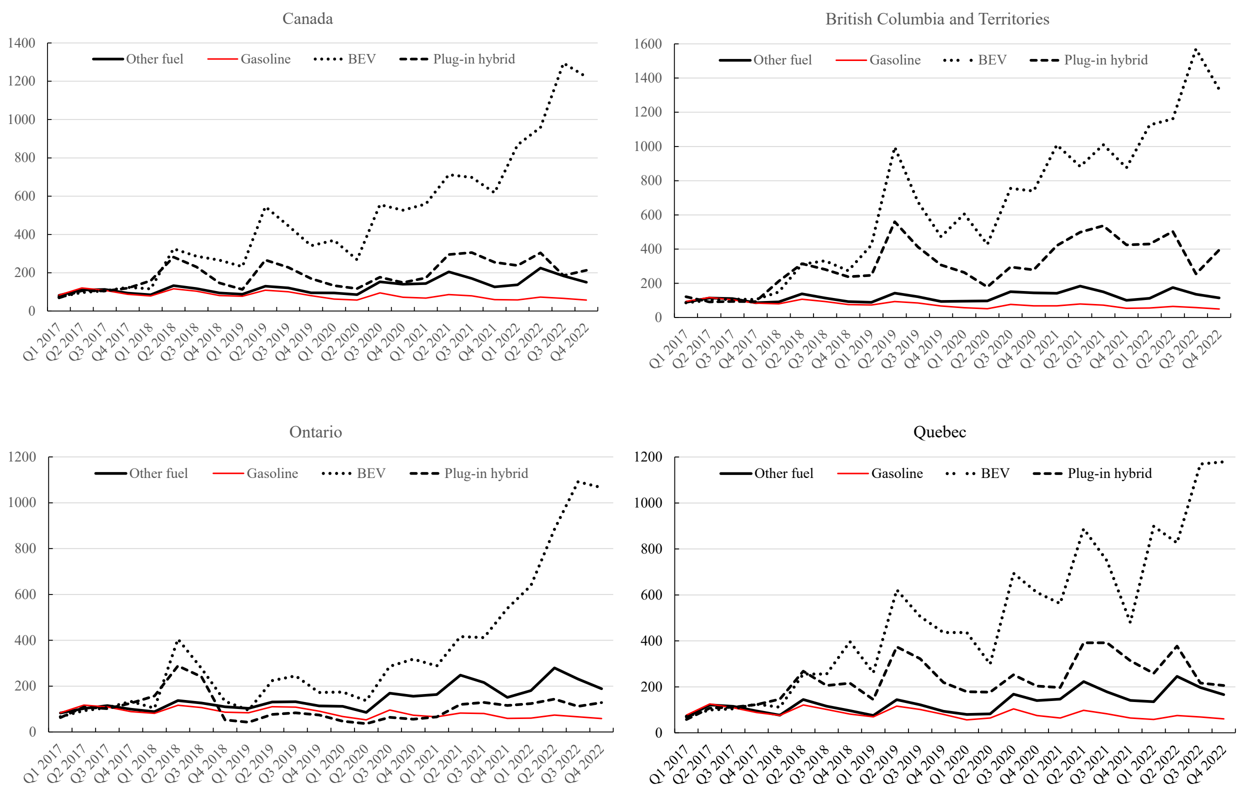

Figure 4: Growth in New Vehicle Registrations, Various Jurisdictions, 2017=100

to build and sell more EVs even if their costs are subsidized by higher prices for SUVs and small trucks. (In some countries, such as the U.S., these policies are reinforced by draconian tailpipe emission regulations that cannot be met by current ICEs.) These policies are clearly effective in slowly electrifying the country's fleet of passenger cars, multi-purpose vehicles (mainly SUVs), vans and small trucks. The trend in this regard is found in Figure 5, which shows cumulative sales of EVs versus cumulative total vehicle sales from 2017 through 2022. The graph is similar to Figure 1, except 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 every 28 vehicles on the road is an electric vehicle, without taking into consideration vehicles registered prior to 2017, which are primarily ICE vehicles.

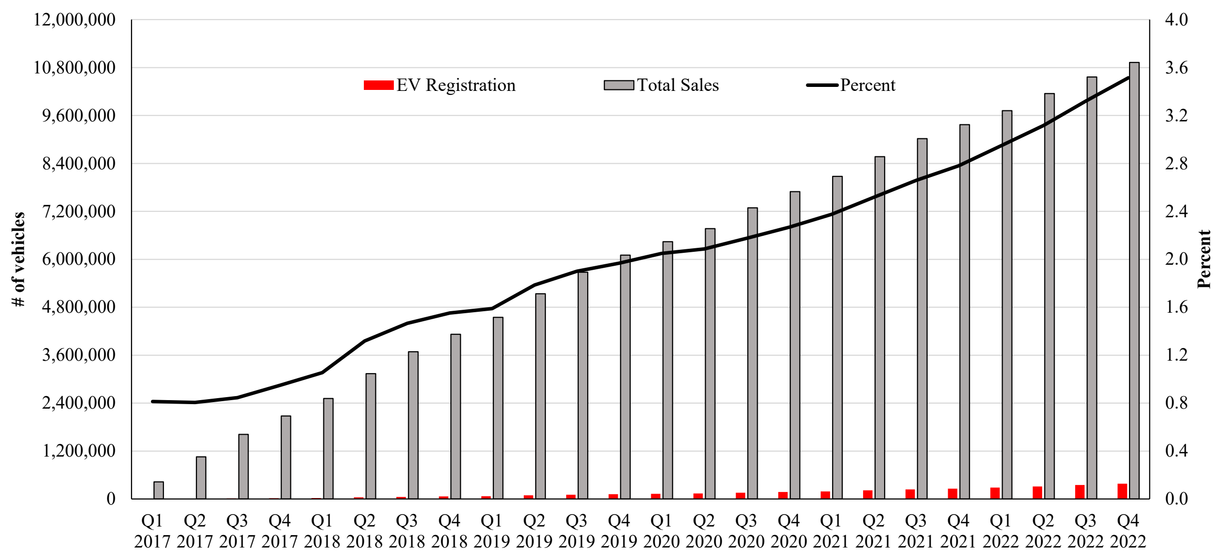

Figure 5: Cumulative Electric and Total Vehicle Sales in Canada, 2017 through 2022

In conclusion, the uptake of electric vehicles over the past six years has been slow, although steadily increasing. Whether this trend will continue depends on government policies and the public's desire and ability to adopt this new technology. There are also a number of concerns that could affect the publics' willingness to adopt EVs. These include:

1. The tires wear out faster because EVs weigh some 30% more than their equivalent ICE, which is accompanied by more particulate matter entering the atmosphere.[2]
2. EVs appear not to hold their value to the same extent as ICEs (Haynes 2023).
3. EVs can take 2.5 to 11.0 hours to recharge at the better charging outlets, and much longer at other outlets (Enel Way 2019).
4. EVs (and backup batteries) can burst into chemical-fueled fires that burn hotter and are more difficult to extinguish than ICE fires, and could potentially damage concrete structures (Driessen 2023).
5. There are environmental issues related to the mining of the metals required to produce car batteries and dispose of them (International Energy Agency 2021; World Nuclear Association 2021; Kara 2022).
6. Further, unlike ICEs where it has a technological disadvantage, China has an advantage in producing EVs and is fast replacing legacy manufacturers, such as Ford, GM, Toyota and Volkswagen, as the main source of vehicles, 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 in turn entails digging up some 15,000 kg of rock and dirt to access much needed minerals, such as lithium, graphite, copper, nickel, aluminum, zinc, neodymium, and manganese. The global mining and minerals sector uses some 40 percent 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

[2] At https://notalotofpeopleknowthat.wordpress.com/2022/07/08/tesla-owner-exposes-dark-secretabout-electric-cars/ [accessed 29 September 2022].

(van Kooten et al. 2020; Duan et al. 2023; Mills 2023). Therefore, it is questionable whether the increase in greenhouse gases resulting from the projected massive demand for EV batteries and electricity would make it worth the effort to replace the entire fleet of ICEs with EVs (Leyland 2023; Finlay 2023; Ridley 2023).

Resolution of some of these issues could well put a damper on the future development of electric vehicles. However, the focus of this study is on Canada and the implications that EVs will have for the generation of electricity, in particular the question pertaining to the need for additional generating capacity.

2. Electricity Grid and Electric Vehicle Profiles for 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 power demand 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. 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 EVs.[3] Data are available regarding the battery capacity, the associated energy efficiency and range, and vehicle weight. The data are summarized in Table 1. The distributions of models with each of these characteristics are provided in Figure 6.

Much of the information provided 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. In practice, batteries may not perform to the same levels indicated by the manufacturer;

[3] A list of electric vehicle models (including their brands) is found in the "Electric vehicle database" at https://ev-database.org/ [accessed 10 July 2023]. Our data are based on information accessed on March 16, 2023; since then, 45 new models have been added although the majority are not available for purchase until later in 2023 or in 2024.

batteries should not, for example, be recharged in temperatures below freezing, performance falls when temperatures are below –30ºC, and battery performance declines somewhat as batteries age. While these drawbacks are cited in various places, there is currently not enough information to indicate how performance is affected over time and under various weather conditions.

In the remainder of this section, we analyze the potential demand that EVs pose for the electricity grid and the extent to which generating capacity will need to be increased to accommodate electric vehicles in the future. We do not address a related issue, namely, the capacity of the electricity transmission and delivery system to handle the increased demand that EVs will impose.

To determine the strain that electric vehicles might impose on electricity grids in Canada, and the benefits from 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 for Canadian capacity data. We also present the breakdown of the generation by source in 2022 for the three aforementioned provinces, as well as the 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, wave, and tidal sources. Natural gas and oil refer to natural gas, biogas, oil, and diesel sources. Coal refers to coke and coal. Nuclear simply refers to nuclear power generation.

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), electric vehicle production mandates, government financing for charging stations, and subsidies for EV purchases. The consumer also prefers to pay for a substitutable good, so as the technology for EVs improves, consumers are more likely to purchase these products. These all play a role in the increase in new electric vehicle registrations throughout the years, as we see in the graphs under each jurisdiction in the following sections.

We present a breakdown of the vehicle fleet within Canada and the three provinces by looking at the new vehicle registrations in each. 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 due to the popularity of ICEs prior to 2010 (Statistics Canada 2022a). Due to the lack of data, we use these numbers for our model.

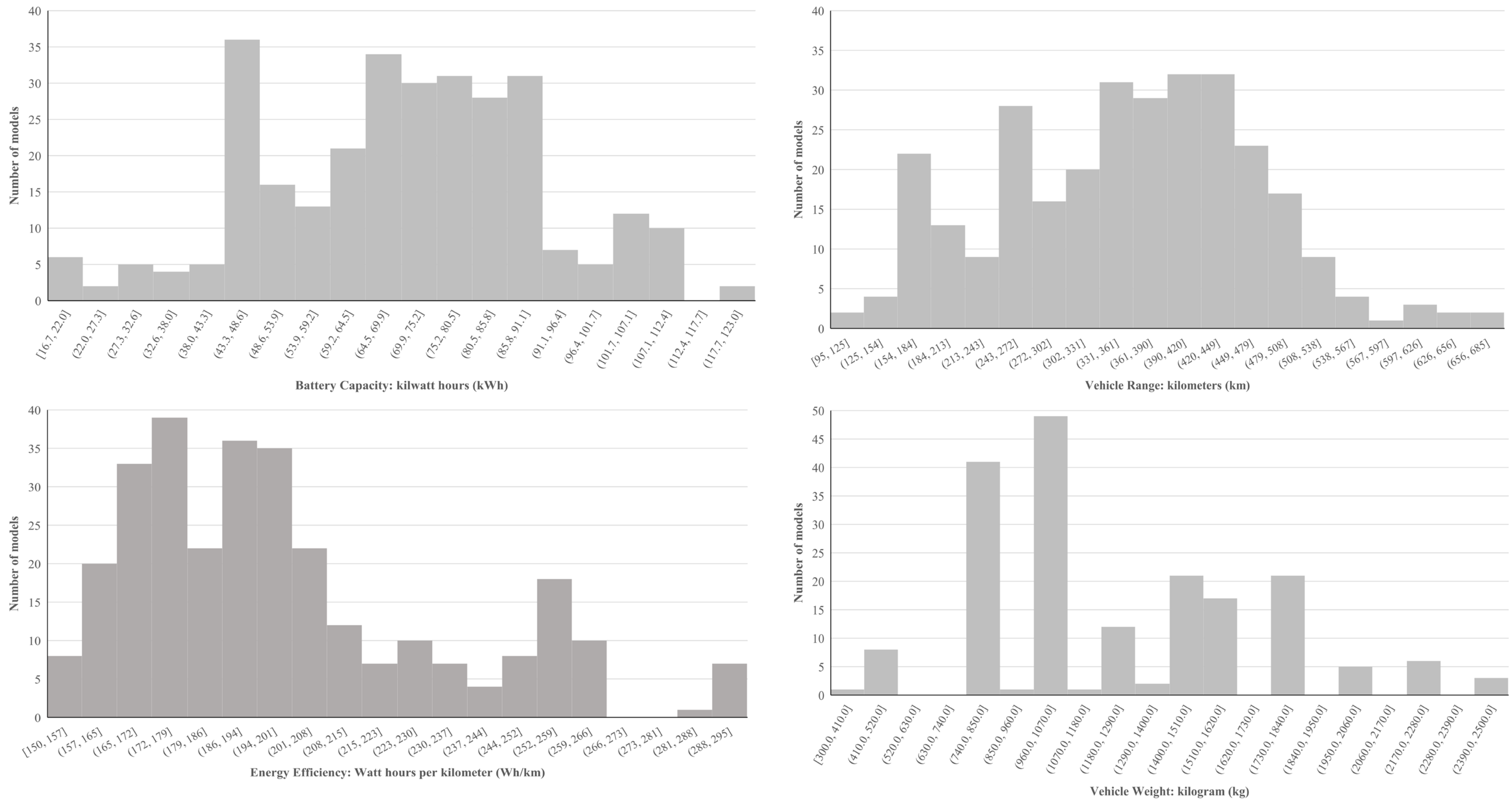

Figure 6: Distributions of Four Characteristics of Electric Vehicle Models: Battery Capacity, Battery Efficiency, Vehicle Range and Vehicle Weight across Different Models of Electric Vehicles (n=299, except n=188 for Vehicle Weight)

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 2023.

Table 2: Electricity Availability and Electric Vehicle Requirements, 2022

			Vehicles				
Jurisdiction	Electricity supply (MWh)[a]	Average distance driven (km/ year)[b]	Total	Electric (zero-emissions)	Average energy per EV (kWh)[d]	Total energy use by EVs in jurisdiction (MWh)[d]	% of electricity use in jurisdiction[s]
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
Prince Edward Isl.	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 2023b.
[b] Source: Natural Resources Canada 2010 and Statistics Canada 2022a.
[c] Source: Statistics Canada 2023c, NA=not available.
[d] Source: Author calculation. NA=not available

Canada

Electricity Grids

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. 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 (8760 hours in a year, say). For example, hydropower is essentially generated in two ways. First, run-of-river power is non-dispatchable—it must be used as it is generated or else it will need to be 'discarded' (simply 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, 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 power in this case is dispatchable—controllable by the system operator.

Canada also has significant energy production capabilities coming from gas, wind, and nuclear sources. In 2020, Canada had about 74.2% of its installed capacity coming from hydro, nuclear, wind, and solar sources, all of which are considered green energy sources (Statistics Canada 2022b). Most of Canada's energy, or 61.9% of total energy, came from hydro in 2020; 12.5% came from oil and gas, primarily from provinces and territories that lack the geography required for hydraulics and remote communities. Although only Ontario and New Brunswick have nuclear energy capacity, it 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 (Statistics Canada 2022b).

Table 3: Electricity Capacity and Generation by Source, Canada, 2020 (Percent)

	Capacity	Generation
Coal	5272%	4.99%
Natural Gas	16.33%	11.93%
Oil	2.43%	0.56%
Hydro	54.64%	61.87%
Nuclear	8.40%	13.37%
Wind, Solar, Biomass	9.09%	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 2022

Electric Vehicles

In Canada, electric vehicles have increased in recent years, but they remain a very small proportion of total vehicles on roadways as indicated in the following figures. Figures 7 and 8 demonstrate that, although new electric vehicle registrations have increased dramatically in the past couple of years, particularly BEVs, they remain a small fraction of the nation's electric vehicle fleet. Figure 9 provides the breakdown of cumulative new registrations between 2011 to 2022, demonstrating the small size of the electric vehicle fleet. New vehicle registrations since 2011 are likely still on the road (see 3rd numeric column in Table 2), so this 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%, with total zero or low emitting EVs responsible for less than 2% of the vehicles on the road. Electricity generation per quarter is plotted next to EV registrations per quarter since 2017, using the 2017 average as 100, in Figure 1 (Statistics Canada 2023a; 2023d). Electricity generation has stayed relatively constant, fluctuating with the seasons, but EV registrations within Canada have increased seven-fold since the beginning of

2017. The annual increase in new EV registrations and the cumulative number of EVs within Canada are provided in Figure 11.

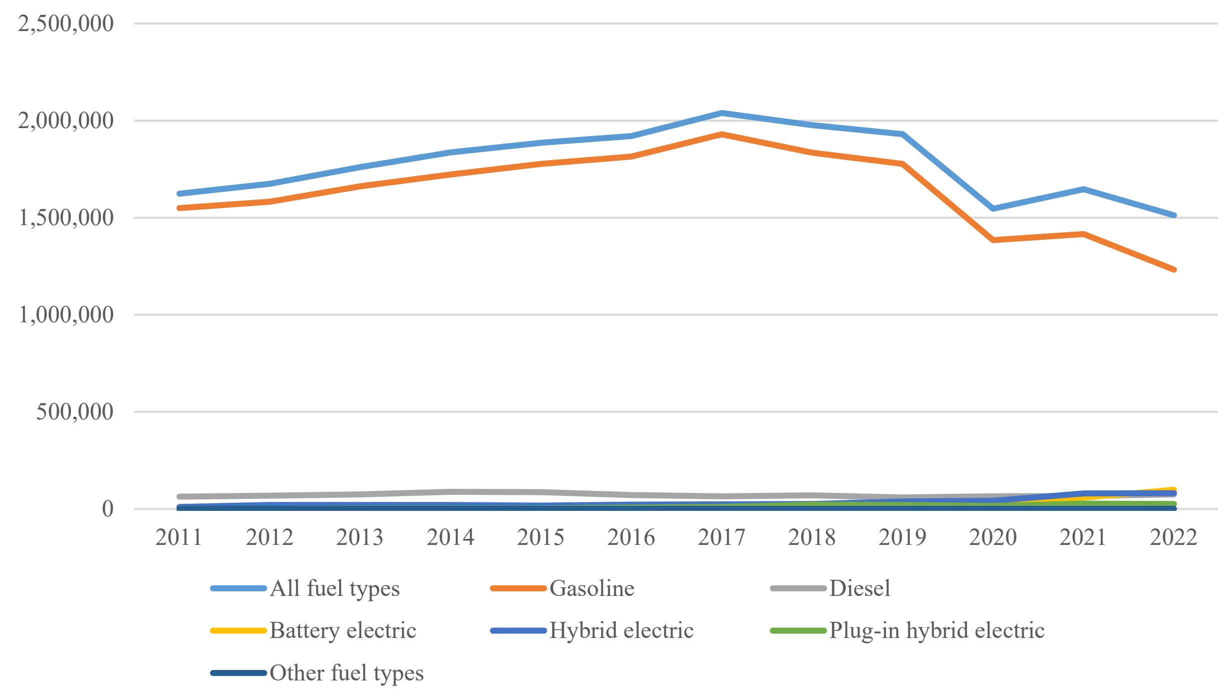

Figure 7: Annual New Registrations by Vehicle Type, Canada, 2011-2022. Source: Statistics Canada 2022a, 2023a.

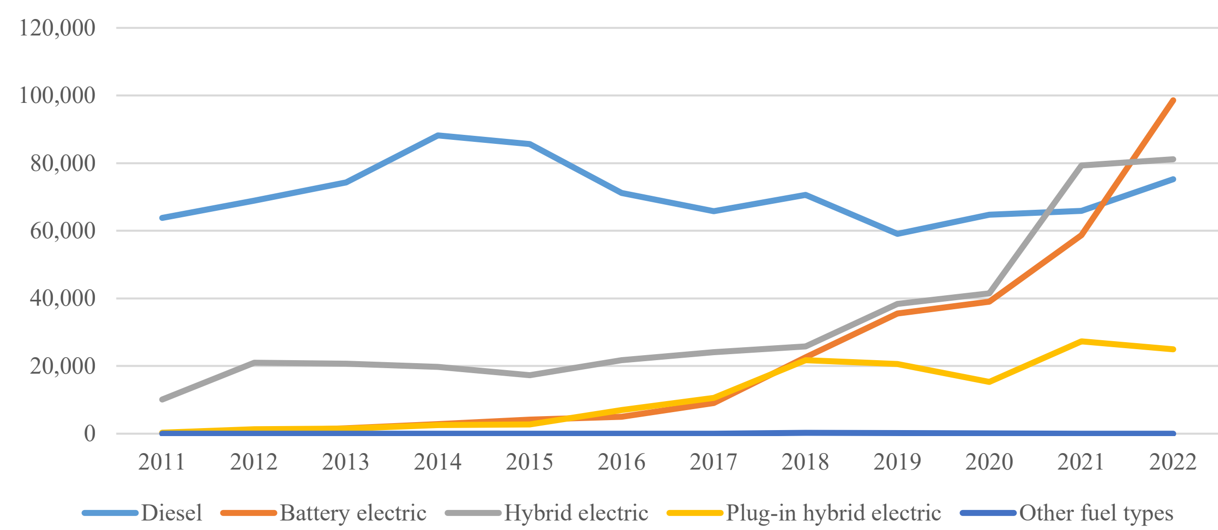

Figure 8: Annual New Registrations by Vehicle Type, Excluding Total and Gasoline, Canada, 2011-2022. Source: Statistics Canada 2022a, 2023a.

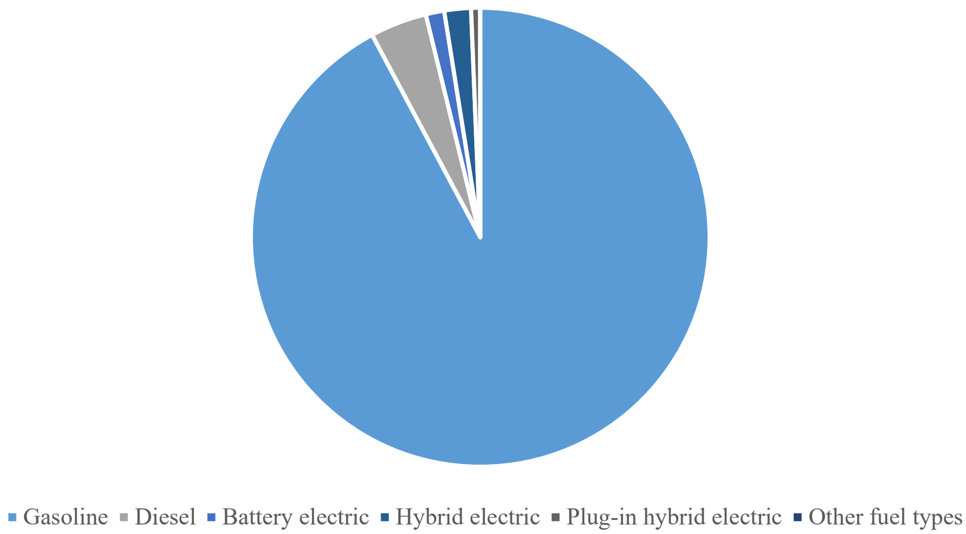

Figure 9: Annual Cumulative New Registrations by Vehicle Type, Canada, 2011-2022. Source: Statistics Canada 2022a, 2023a.

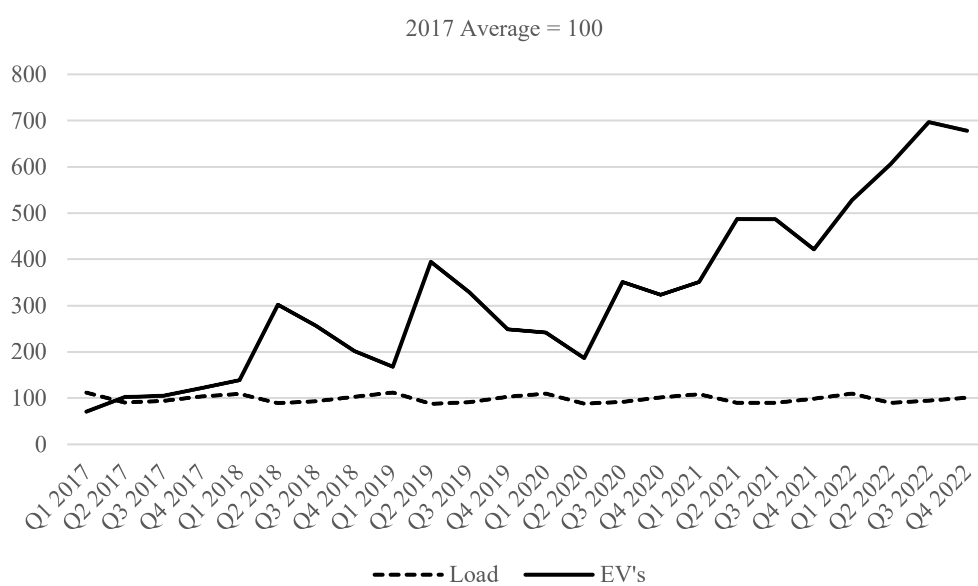

Figure 10: Growth in Quarterly EV Registrations versus Electricity Consumption or Load, Canada, Q1 2017 – Q4 2022, 2017 = 100. Source: Statistics Canada 2022a, 2023a.

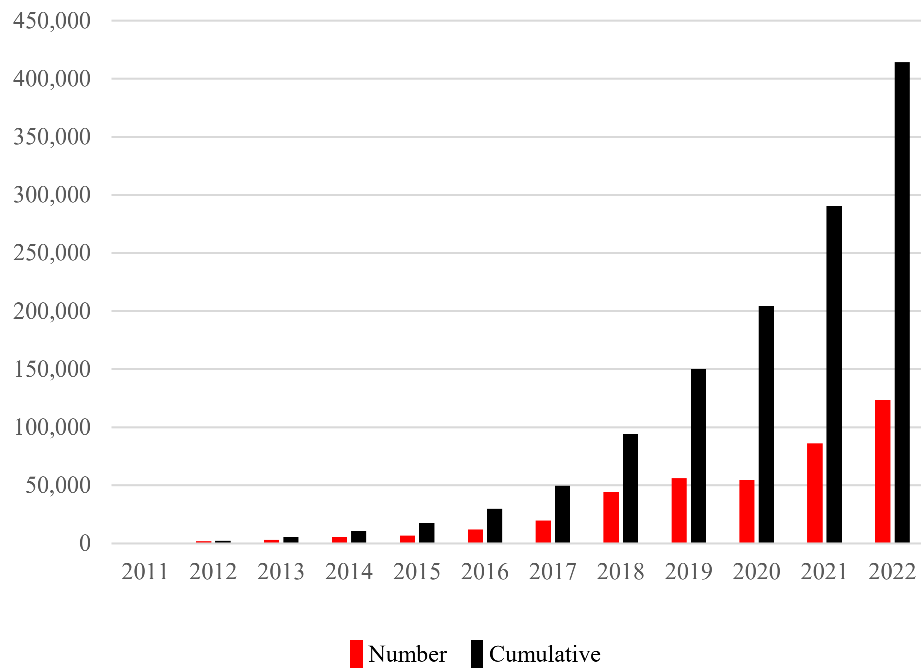

Figure 11: Annual EV Registrations, Canada, 2011-2022. Source: Statistics Canada 2022a, 2023a.

British Columbia

Electricity Grids

British Columbia relies predominantly on hydroelectricity, with hydropower capacity representing over 87% of total installed capacity. Overall, 91.6% of total installed capacity is from hydro, wind, and solar sources, owned by BC Hydro or individual power producers throughout the province (BC Hydro 2023). BC's Individual Power Producers (IPP) produce about one third of their power. The most recent data indicate that IPPs contribute about 18,875 GWh per year while BC Hydro contributes 48,190 GWh annually, for a total of about 67,065 GWh of production in 2022 (see Table 2) (BC Hydro 2023).

Table 4: Electricity Capacity and Generation by 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 2022
Capacity does not add to 100% due to rounding.

Electric Vehicles

British Columbia and the Territories have made significant progress transitioning to electric vehicles, as indicated in Figures 12 and 13. 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. As seen from Figure 14, the breakdown of British Columbia and the Territories' vehicle fleet indicates that this jurisdiction has significantly more electric vehicles on the road than Canada overall, with 3.2% and 1% of cumulative new registrations attributable to BEVs and PHEVs, respectively.

Setting average 2017 levels of each of energy production and new EV registrations at 100, we observe that energy production fluctuates relatively little (depending on the season), whereas EV registrations have increased almost tenfold between 2017 and the end of 2022 (Figure 15). The growth in EV registrations relative to fossil-fuel using vehicles is provided in Figure 16, again indicating how quickly EV adoption has taken place in British Columbia. This could bode ill for future electricity developments as these have generally taken a long time to go through the approval process, particularly in the case of hydropower projects.

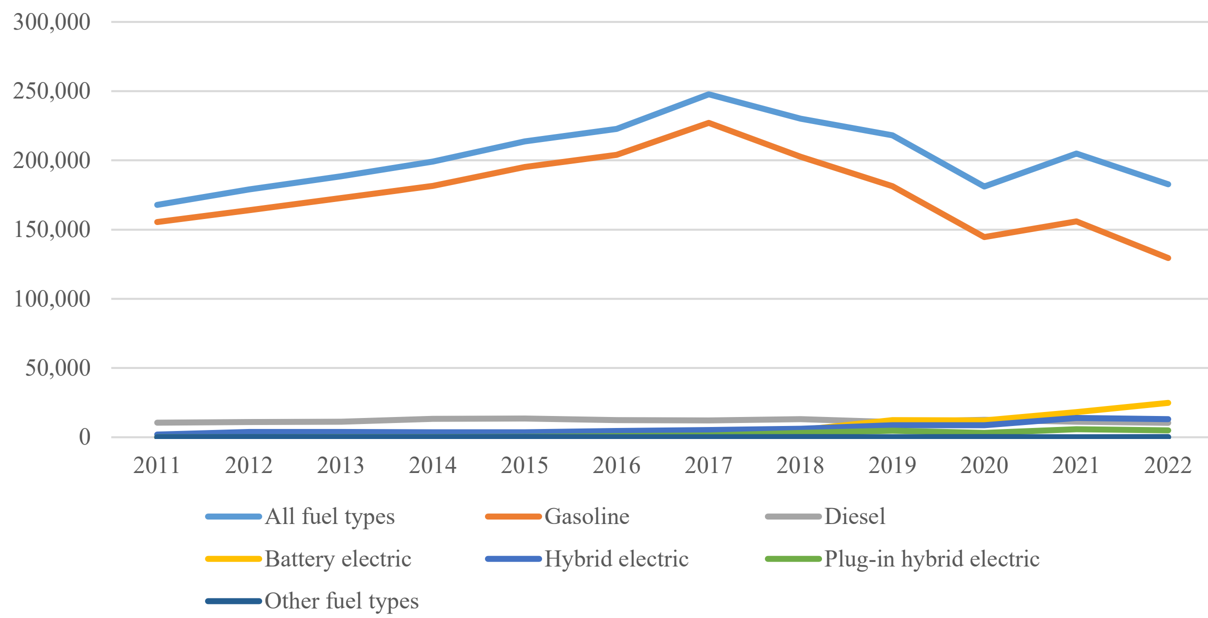

Figure 12: Annual New Registrations by Vehicle Type, British Columbia & Territories, 2011-2022. Source: Statistics Canada 2022a, 2023a.

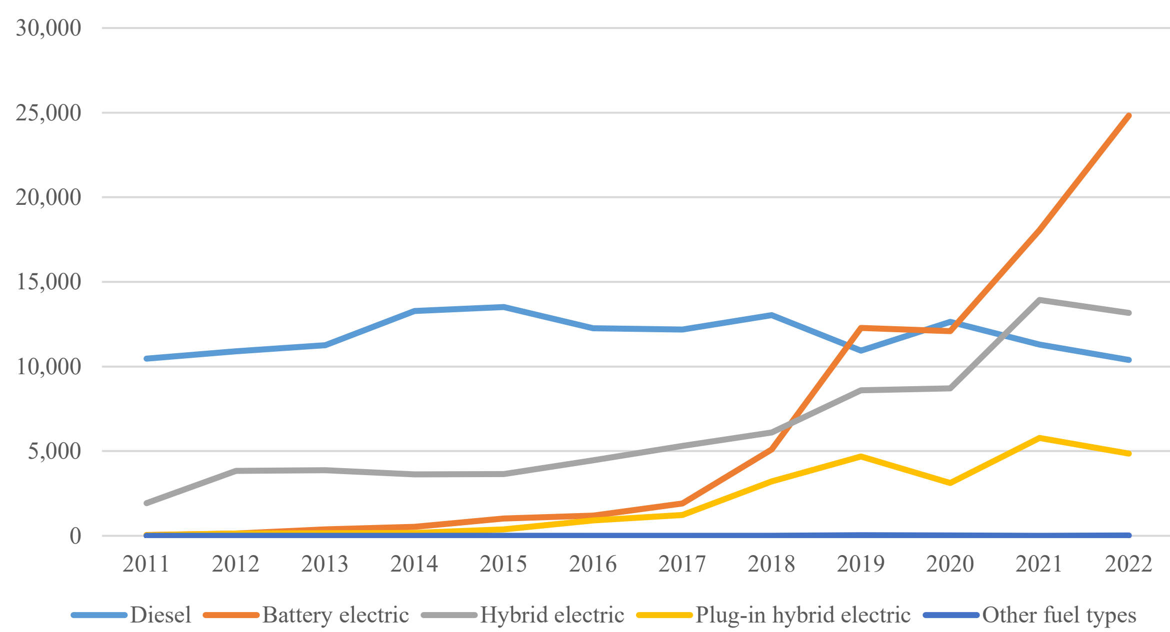

Figure 13: Annual New Registrations by Vehicle Type, Excluding Total and Gasoline, British Columbia & Territories, 2011-2022. Source: Statistics Canada 2022a, 2023a.

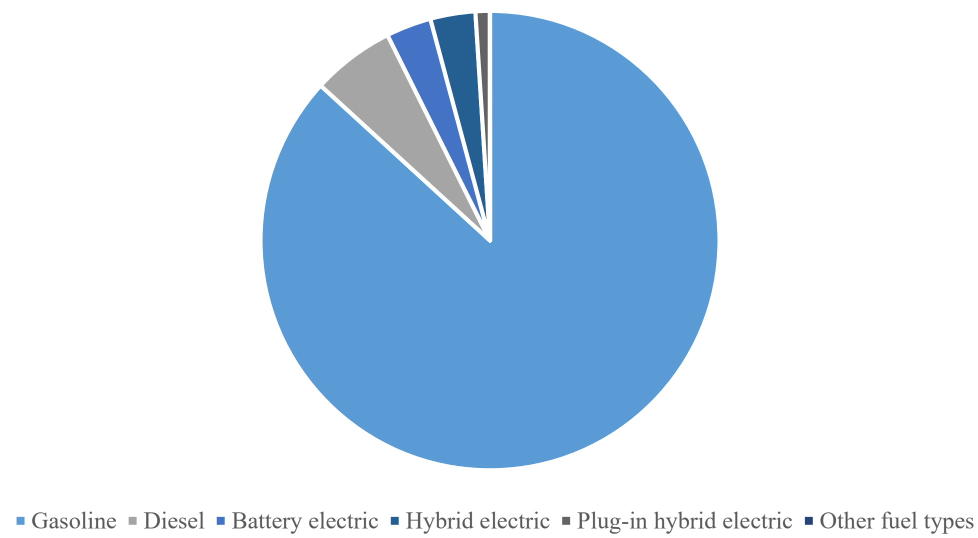

Figure 14: British Columbia & Territories Cumulative New Registrations by Vehicle Type over period 2011-2022. Source: Statistics Canada 2022a, 2023a.

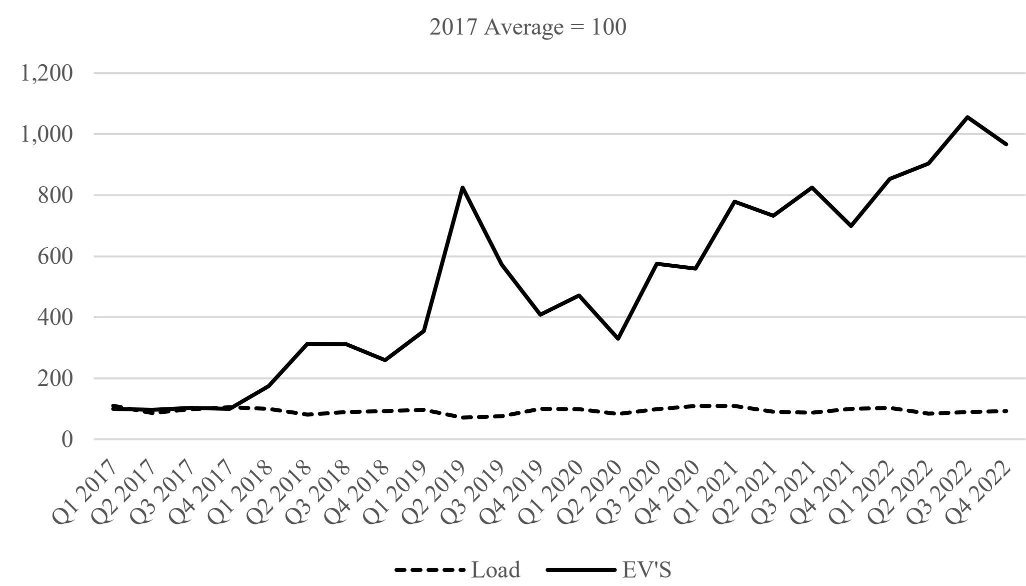

Figure 15: Growth in Quarterly EV Registrations versus Electricity Consumption, British Columbia, Q1 2017 – Q4 2022, 2017 = 100. Source: Statistics Canada 2023a, d.

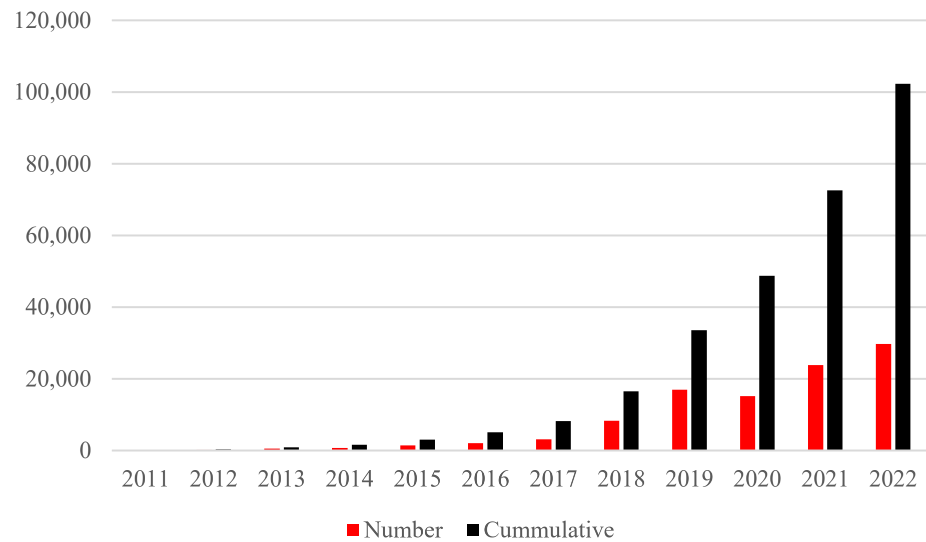

Figure 16: Annual EV Registrations, British Columbia, 2011-2022. Source: Statistics Canada 2022a, 2023a.

Ontario

Electricity Grids

Unlike British Columbia and Quebec (see below), Ontario has a greater variety of generation sources, with nuclear energy contributing the largest share in Ontario's production capacity. Ontario has three different nuclear power plants including the Bruce generating station, which is one of the world's largest with eight nuclear reactors—34.0% of Ontario's grid-connected capacity is attributable to nuclear, while only 27.5% from oil and gas; total renewable energy capacity accounts for 38.1% of the province's electricity generating capacity (IESO 2022). However, because nuclear power plants operate continually 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 2023a). Yet, only nuclear energy is sufficiently reliable enough to be used to provide base-load power (IESO 2023b).

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 (2023a,b). Generation is over 100% due to rounding.

Electric Vehicles

Ontario appears to trail the rest of Canada in adopting electric vehicles, with gasoline powered vehicles representing almost all the new registrations in the province between 2011 to 2022. Unlike the other provinces we examined, Ontario's primary 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 (see Figures 17 through 19). Using cumulative new vehicle registrations since 2011, we find that 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. Ontario's changes in EV registrations and energy production (using 2017=100) are provided in Figure 20. Energy production is rather flat but new EV registrations have increased about 5.5 times since 2017, a rate that is lower than the national rate of growth in EV registrations.

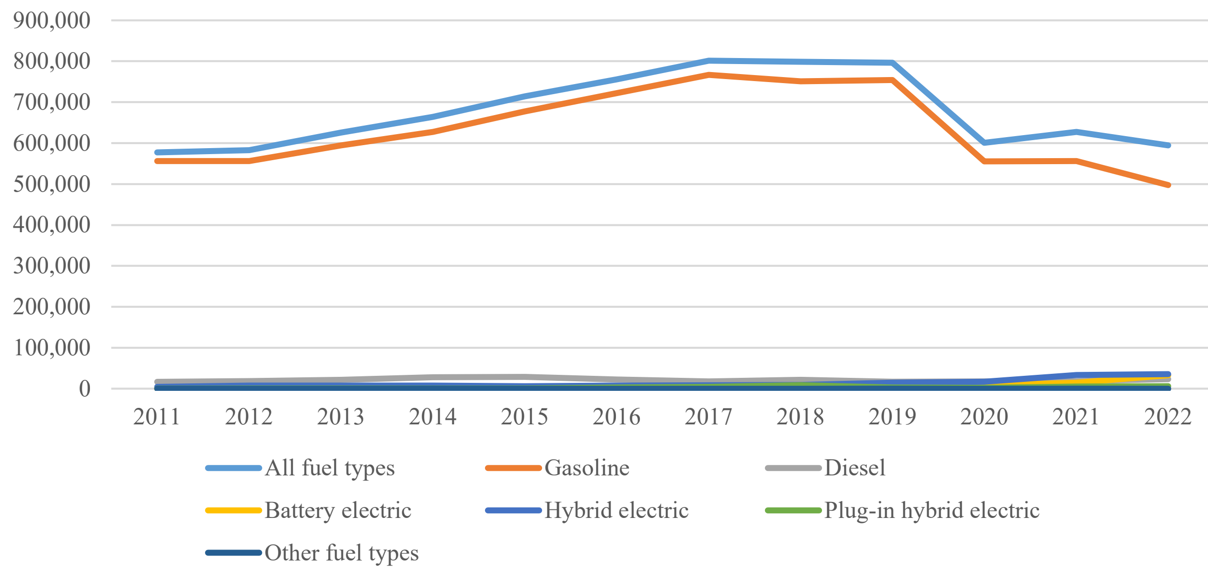

Figure 17: Annual New Registrations by Vehicle Type, Ontario, 2011-2022. Source: Statistics Canada 2022a, 2023a.

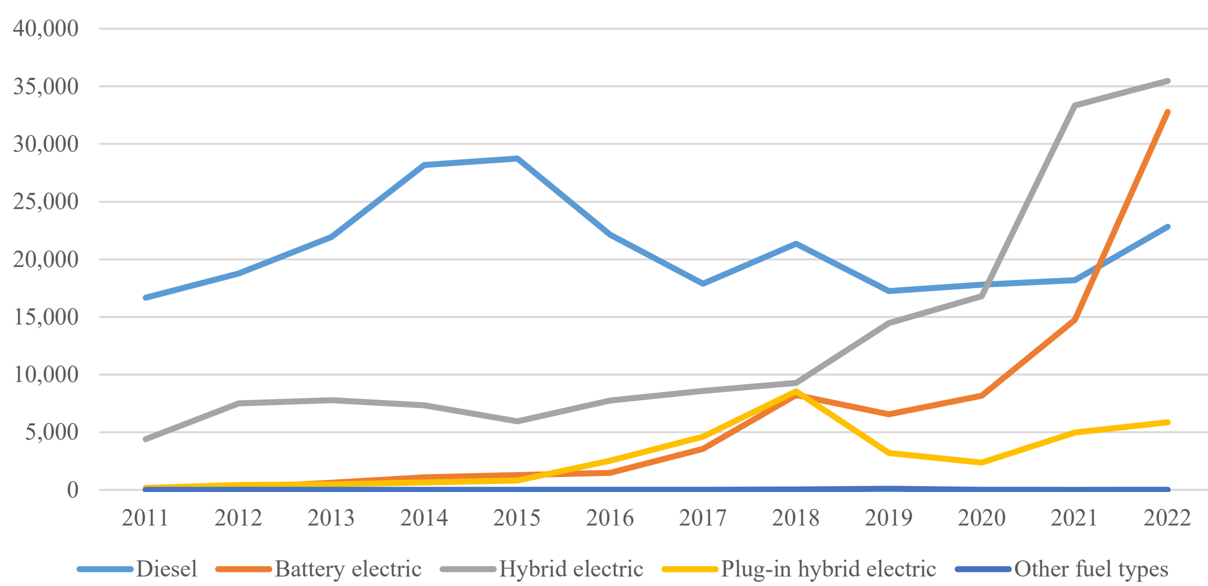

Figure 18: Annual New Registrations by Vehicle Type, Excluding Total and Gasoline, Ontario, 2011-2022. Source: Statistics Canada 2022a, 2023a.

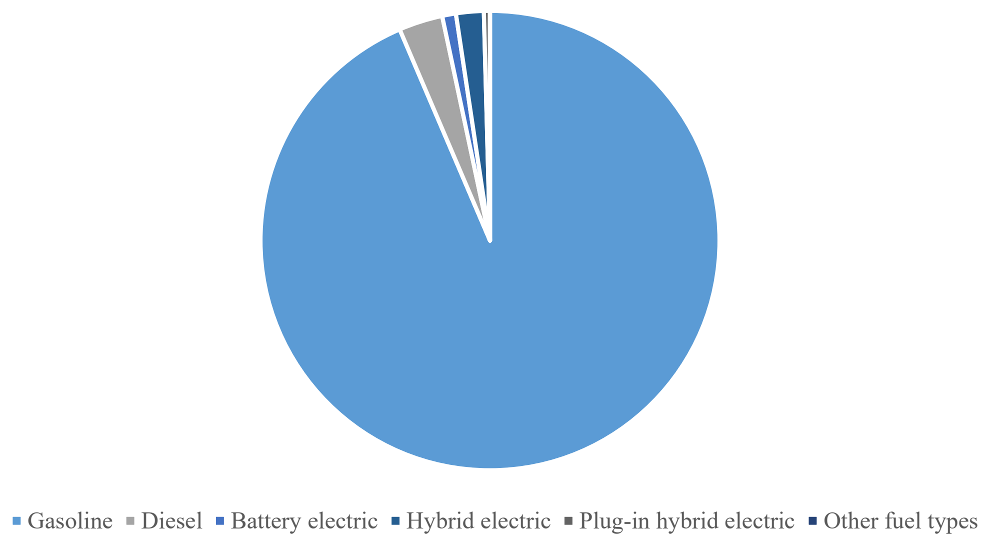

Figure 19: Annual Cumulative New Registrations by Vehicle Type, Ontario, 2011-2022. Source: Statistics Canada 2022a, 2023a.

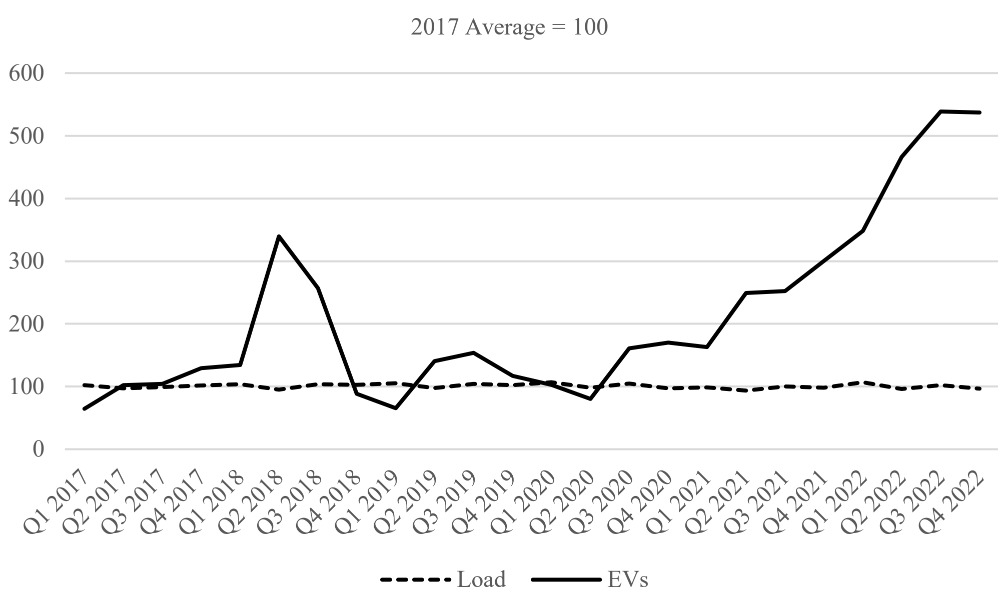

Figure 20: Growth in Quarterly EV Registrations versus Electricity Consumption, Ontario, Q1 2017 – Q4 2022, 2017 = 100. Source: Statistics Canada 2023a, 2023d.

Quebec

Electricity Grids

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

Despite having 89% installed hydropower capacity, Quebec generates nearly 93% of its electricity from hydro sources. 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 Québec 2022). Quebec had the highest electricity generation in Canada in 2022 with a production of 210.7 TWh (Table 2).

Table 6: Electricity Capacity and Generation by 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 (2022)

Electric Vehicles

Quebec has diverged away from gasoline vehicles at an increasing rate, with a significant gap emerging between ICE and total registrations, although gasoline vehicles still take up vast majority of the total new registrations within the province (Figure 21). Cumulative new vehicle registrations in Quebec (Figure 23) 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 electric vehicle registrations have increased approximately six times above its 2017 average (Figure 24).

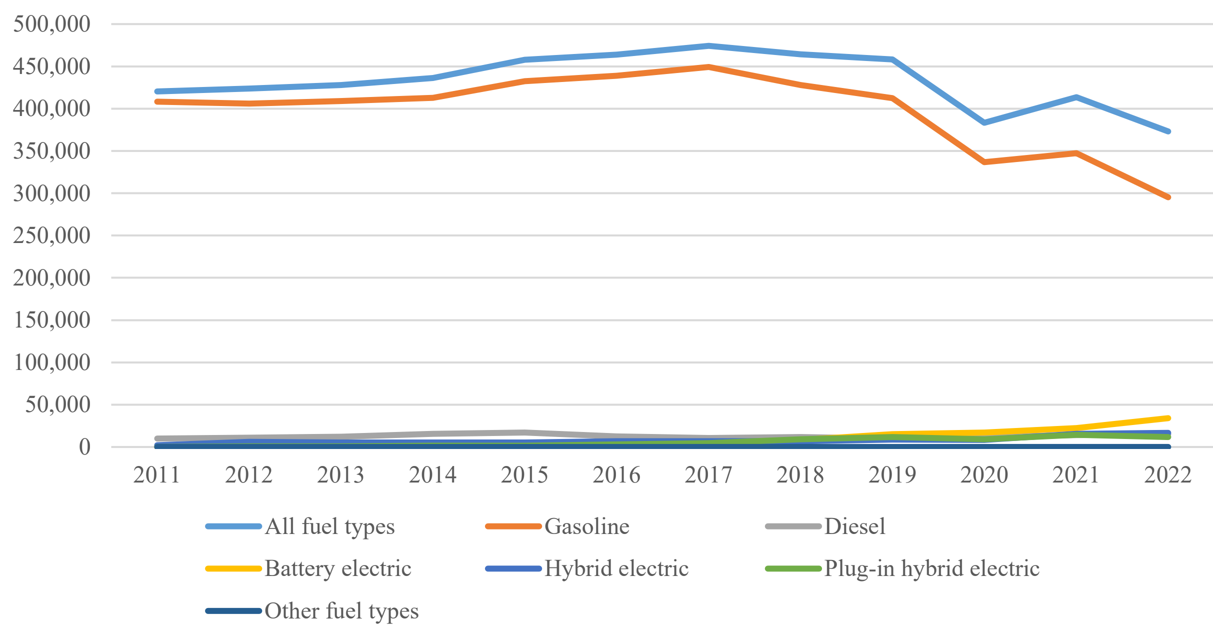

Figure 21: Annual New Registrations by Vehicle Type, Quebec, 2011-2022. Source: Statistics Canada 2022a, 2023a.

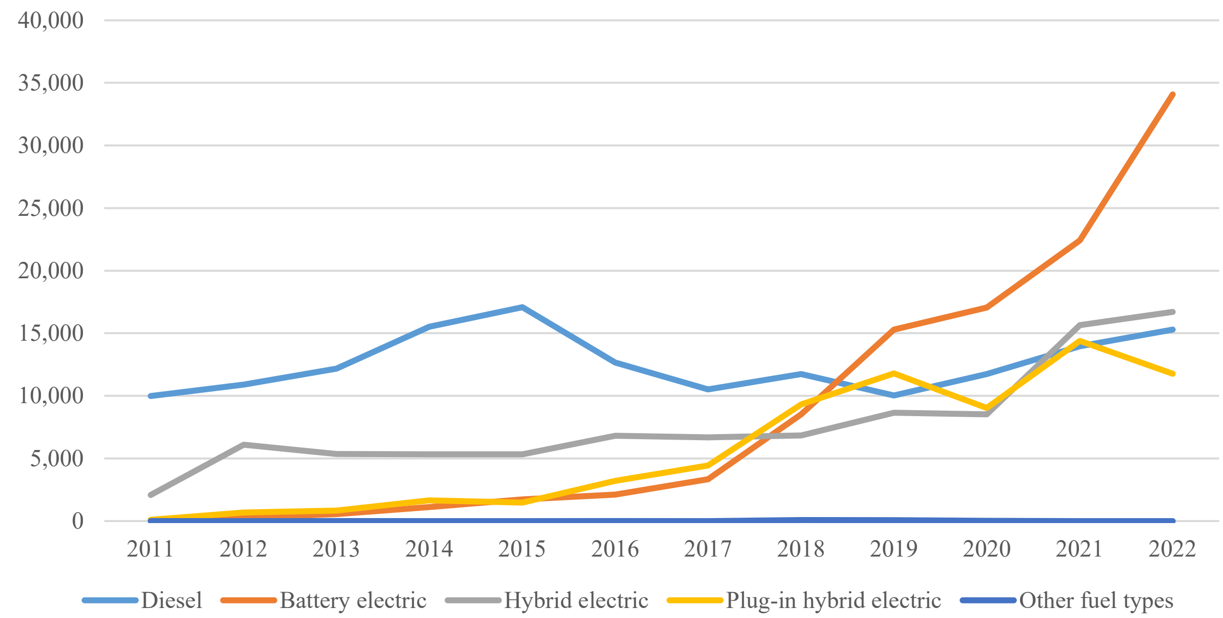

Figure 22: Annual New Registrations by Vehicle Type, Excluding Total and Gasoline, Quebec, 2011-2022. Source: Statistics Canada 2022a, 2023a.

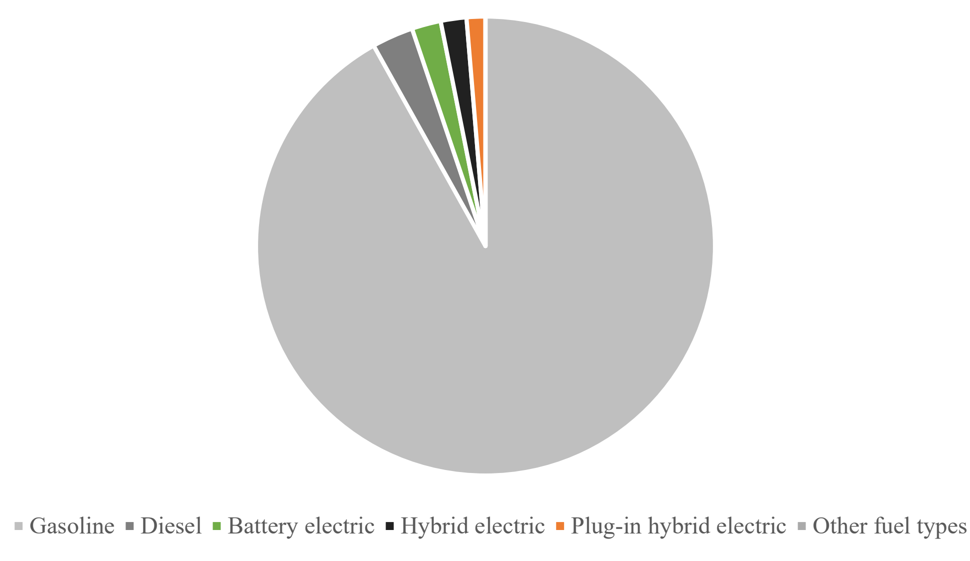

Figure 23: Cumulative New Registrations by Vehicle Type, Quebec, over period 2011-2022. Source: Statistics Canada 2022a, 2023a.

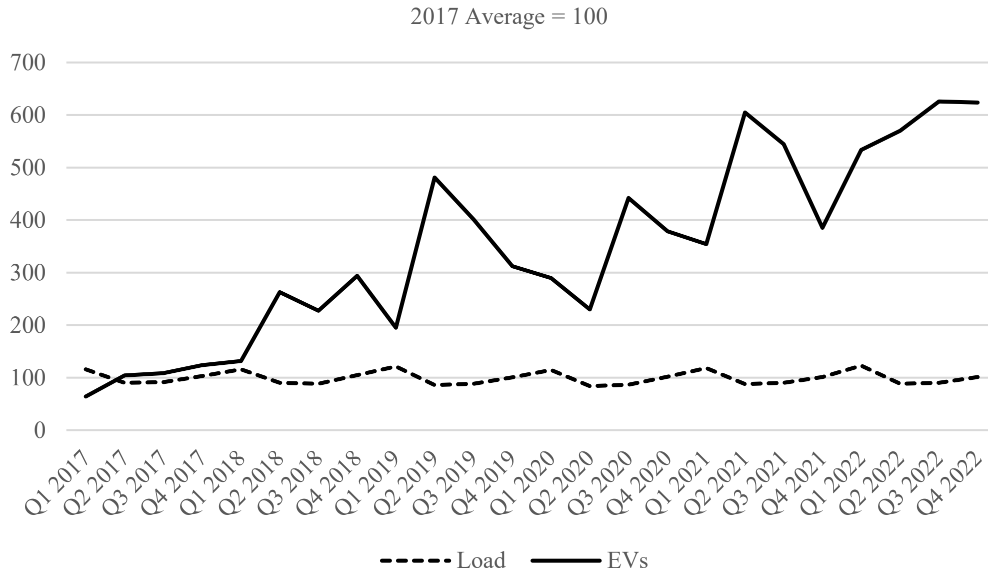

Figure 24: Growth in Quarterly EV Registrations versus Electricity Consumption, Quebec, Q1 2017 – Q4 2022, 2017 = 100. Source: Statistics Canada 2023a, 2023a.

3. 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.

Potential Energy Sources

Power generation sources are not all created equal, nor do they have the same properties needed to facilitate the conversion of personal and commercial transportation to electric vehicles. Although investment required for electric vehicles 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.

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 similarly 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, although this could potentially be shifted to nighttime hours. A shift to nighttime recharging will increase both the baseload requirement—the electricity that is always demanded due to battery-powered transportation—and 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, as wind cannot serve as a baseload power source due to its intermittency. The unpredictable component of the nighttime 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 and run-of-river hydro are also important, but they require OCGT facilities as backup; that is, even if wind capacity is increased, for example, it will be necessary to provide a reliable backup source of power in the event that the wind does not provide adequate power to meet the deficit in load. Solar power is also intermittent and will 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 will be necessary to construct additional hydroelectric dams, invest in nuclear power plants, or build biomass facilities (see below).

Storage hydro is an option for provinces such as British Columbia or Quebec that have the available hydraulics, but there are some serious drawbacks. Storage hydro would require construction of an additional reservoir, which will 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 conditions—a drought could significantly impact electricity generation. Construction of a hydroelectric facility of this size is likely infeasible in most jurisdictions due to environmental opposition. Tidal power might be a feasible option because of the reliability; however, tidal structures could harm marine life while the energy generated will depend on the size of the tide shift, which is uncontrollable albeit predictable.

Like other thermal 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 25; it depicts how each additional unit of biomass energy becomes very expensive quite quickly compared to other energy sources. Burning biomass works well at first, but when there is no more biomass in the area, it requires transporting biomass longer distances by trucks, which currently run on fossil fuels. If trucks were electrified along with timber harvesting equipment, 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 and fertilizer along with lands devoted to timber production; this would, in turn, crowd out farmland used to produce food crops, increase food prices and lead to a more intensive agriculture to the detriment of the environment (Energysage 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 economically infeasible for large-scale production of electricity, it could not be relied upon 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.

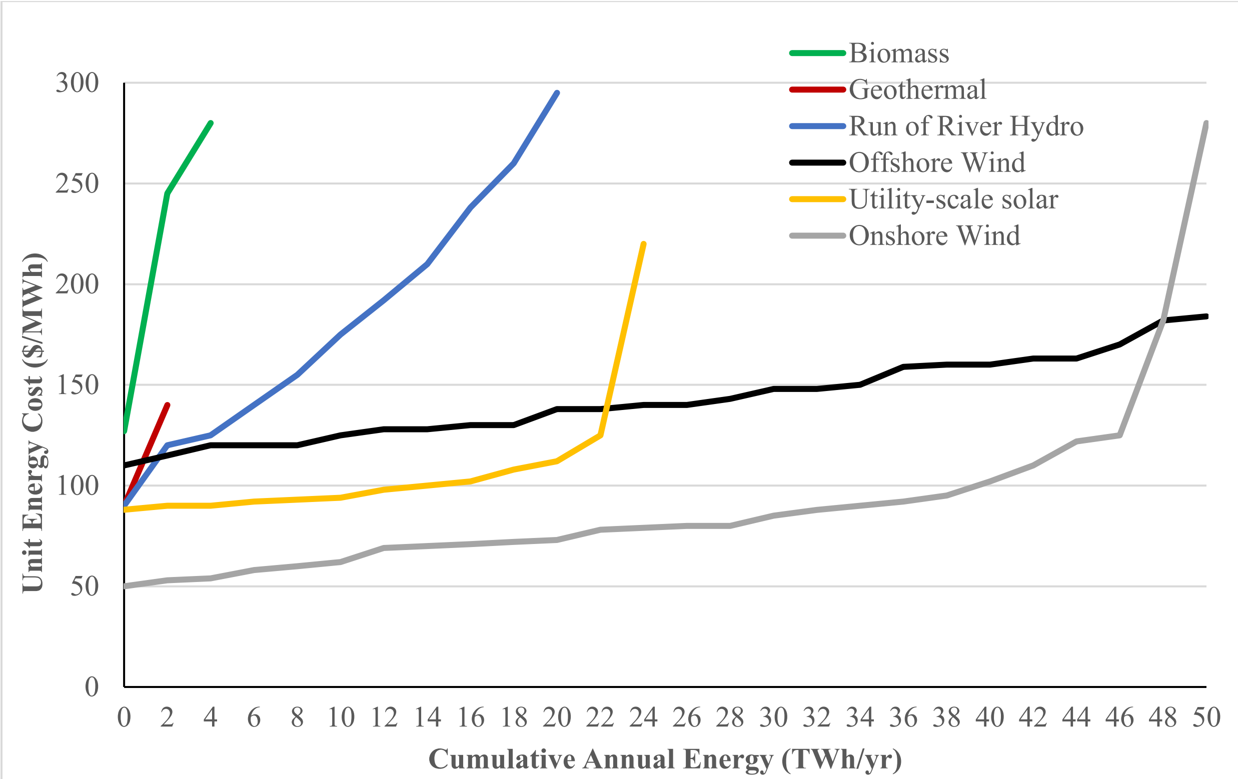

Figure 25: Marginal Cost of Different Electricity Sources in British Columbia, $/MWh. Source: BC Hydro 2021.

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 and, since no CO_2 is emitted, it is considered a green source of energy although it is not renewable as uranium reserves are finite. Nuclear power is opposed because of its association with nuclear weapons, the problem of nuclear waste, and its potentially hazardous impacts on life if there is a malfunction. Historically, nuclear disasters have been associated with major human and environmental catastrophe, with actual or perceived failures of power plants at Three-Mile Island (USA), Chernobyl (Soviet Union/ Ukraine) and Fukushima (Japan) still cited as environmental and human catastrophes (Process Industry Forum 2023). Because 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. However, it would not make any sense to change the vehicle fleet from ICEs to EVs to power the grid with fossil fuels, since there will be greenhouse gas emissions either way. This would cause an overall higher carbon footprint since EVs are less environmentally friendly to make.

Impact on Electricity Grids

Here 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 mean data and then provide 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. We multiply the mean distance driven in each jurisdiction by the cumulative total number of new vehicle registrations over the period 2011 through 2022. We ignore vehicles older than 11 years and assume no vehicles registered during this period were 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=10^9 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 reported efficiencies of 299 models of EVs as discussed with respect to Table 1. The results are provided in Table 7.

In Table 7, we do not account for marginal costs, under-reporting of numbers to insurance companies to obtain a lower premium, or growth in the overall vehicle fleet due to population growth. Economic theory suggests that, as marginal costs decline, consumers will decide to 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 estimations of the distances driven since there is an incentive to get a lower premium, so the mean kilometres driven may be higher than stated. With population growth, there would be a greater demand for vehicles, which would in turn 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, and the mean and median models are most likely lower estimates of the true generation increase needed.

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 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" (BCEMLCI 2018). Using data from Table 7, for Canada the load coming from EVs in the next decade would require the construction of perhaps 13 hydro facilities similar to Site C, with two of these to be built in BC, eight in Ontario and two in Quebec (Table 8). Construction of even a single dam of that size is highly unlikely 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 significant number of gas plants.

Table 7: Energy Requirements to Switch to Electric Vehicles[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
Mean				
Mean demand (GWh/yr)	64,681	6,359	25,951	14,812
Current usage using mean efficiency (GWh/yr)	1,254	267	362	499
Required energy using mean efficiency (GWh/yr)	63,427	6,092	25,590	14,312
Mean Increase	**10.13%**	**9.08%**	**17.43%**	**6.30%**
Median				
Median demand (GWh/yr)	62,312	6,126	25,001	14,269
Current usage using median efficiency (GWh/yr)	1,208	257	348	481
Required energy using median efficiency (GWh/yr)	61,104	5,869	24,652	13,788
Median Increase	**9.96%**	**8.75%**	**16.79%**	**6.07%**
Maximum				
Max demand (GWh/yr)	95,740	9,412	38,413	21,924
Current usage using max efficiency (GWh/yr)	634	152	189	229
Max required energy (GWh/yr)	95,106	9,260	38,224	21,696
Maximum Increase	**15.30%**	**13.81%**	**26.16%**	**9.55%**
Minimum				
Min demand (GWh/yr)	48,681	4,786	19,532	11,148
Current usage using min efficiency (GWh/yr)	1,856	395	535	739
Min required energy (GWh/yr)	46,825	4,390	18,997	10,409
Minimum increase	**7.48%**	**6.55%**	**12.94%**	**4.58%**

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

Table 8: Minimum and Maximum Numbers of Site-C Hydro Dams or Wind Turbines of 3.5MW Capacity Required to Meet Future Demand for Electricity from EVs, Various Canadian Jurisdictions

Scenario	Canada	BC	Ontario	Quebec
Site-C equivalent				
Minimum	9	1	4	2
Maximum	13	2	8	4
Wind turbines (3.5MW capacity)[a]				
Minimum	6,106	574	2,479	1,357
Maximum	8,441	1,226	5,010	2,857

[a] Assumes a capacity factor of 25%.

If EV demand for power is to come from renewable sources, however, wind is the most likely option. Assuming a capacity of 3.5 MW per turbine and average wind capacity factor of 25%, the requirements are provided in the bottom two rows of Table 8. For BC, between 570 and 1,200 large wind turbines will need to be built within the next few years. However, given the unreliability of wind energy, it will also be necessary to build CCGT, hydropower and/or utility-scale battery storage capacity as backup. In general, backup requirements 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 needs to be subsidized thereby adding to system costs (van Kooten 2016; van Kooten et al. 2020; Duan et al. 2020).

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.

4. Discussion and Conclusions

In addition to income level, four factors are important in determining whether a buyer will purchase an EV: the price of gasoline, access to charging stations, the cost of electricity, the subsidy or actual price difference between the EV and its ICE alternative, and, to a lesser degree, temperature. The price of gasoline is perhaps the most important determining factor followed by the existence of a subsidy. The gap between U.S. and Canadian gasoline prices amounts to about $C 0.50 per liter. While the carbon tax and some other costs of acquiring gasoline are important, a major factor accounting for the difference between the Canadian and the American prices is fuel taxes, some of which are meant to enhance and maintain transportation infrastructure and contributing 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, often benefit from low electricity rates (particularly in jurisdictions such as BC and Quebec that rely on hydroelectricity) and may 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, and some offsetting of 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 extra electricity demand from 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 will need to be relied upon to meet additional demand. Of course, this will 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.[4] Savings of this magnitude could perhaps be realized through future improvements in ICE technology. When lifecycle

[4] See https://www.dailymail.co.uk/debate/article-12276725/Why-Ill-buying-brand-new-petrol-car-just-2030-ban-says-MATT-RIDLEY.html?mc_cid=adbf88bcd3&mc_eid=3e8db95649 [accessed 24 July 2023].

emissions are counted, the emission-reductions benefits might be much smaller depending on where 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, there are many obstacles that remain 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 immediacy of constructing sufficient power generating capacity to meet the anticipated demand EVs will impose on electricity grids. The type of electricity that goes into the grid will also be a big consideration with switching over to EVs, as jurisdictions will need to increase their electricity production capabilities with green sources that still meet the additional hourly load requirements, and that can be employed quickly to balance intermittent renewable energy sources. These are primarily going to be storage and the development of hydro and nuclear power—sources of energy most likely to raise challenges to their timely deployment. The real-world situation is not as easy as merely replacing current ICE vehicles with EVs, and there will be many obstacles on the path of electrifying the personal vehicle fleets within Canada.

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Appendix

Table A1: Critical mineral inputs per MW of generating capacity

Mineral	Wind (kg/MW)	Solar (kg/MW)	Nuclear (kg/MW)	Major supplying countries
Aluminum	—	100	—	Smelter prod. China (56%) India (6%) Russia (6%) Canada (5%)
Boron	1	—	—	Turkey (39%) US (23%) Chile (14%) Kazakhstan (10%)
Cadmium	—	40	0.5	Ref. prod. China (33%) S. Korea (20%) Japan (8%)
Chromium	800	—	427	S. Africa (39%) Turkey (23%) Kazakhstan (9%)
Copper	2000	2000	60	Chile (28%) Peru (12%) China (8%) US (6%) Congo (6%)
Gallium	—	3	—	China (97%)
Indium	—	50	2	Ref. prod. China (39%) S.Korea (32%) Japan (10%) Canada (8%)
Lead	—	250	4	China (47%) Australia (10%) Peru (6%) US (6%)
Manganese	50	—	—	S. Africa (29%) US (17%) Gabon (13%) Ghana (7%)
Molybdenum	120	—	70	China (45%) Chile (19%) US (15%) Peru (10%)
Nickel	600	—	256	Indonesia (30%) Philippines (16%) Russia (10%) Australia (7%)
Niobium	—	—	2	Brazil (88%) Canada (10%)
Rare earths	188	—	0.5	China (63%) US (12%) Myanmar (10%) Australia (10%)
Selenium	—	40	—	Ref. prod. China (33%) Japan (28%) Germany (11%)
Silicon	—	15	—	China (64%) Russia (9%) Norway (5%) US (5%)
Silver	—	12	8	Mexico (23%) Peru (14%) China (13%) Russia (8%)
Tellurium	—	50	—	Ref. prod. China (62%) Japan (12%) Russia (9%) Sweden (9%)
Tin	—	450	5	China (27%) Indonesia (26%) Myanmar (17%) Peru (6%)
Titanium	—	—	1.5	China (28%) S. Africa (12%) Australia (11%) Canada (9%)
Tungsten	—	—	5	China (82%) Vietnam (6%) Mongolia (2%)
Vanadium	—	—	0.5	China (55%) Russia (25%) S. Africa (11%) Brazil (10%)
Zinc	5200	30	—	China (33%) Peru (12%) Australia (7%) India (6%) US (6%)
Zirconium/ Hafnium	—	—	32	Australia (39%) S. Africa (26%) US (7%)

Sources: World Nuclear Association 2021; World Bank 2017; IEA 2021; Hund et al. 2020; and USGS 2020, 2022. Refining shares are given where the minerals are co-produced. Co-products that are the main output then often drive supply. The inputs are for 'representative' technologies and relate to generating capacity. Since the capacity factors for solar and wind are 25–40% of those of nuclear plants, and the plants have lifespans about 40% of that of a nuclear plant, inputs per unit of energy generated over the life of the plant would be much more unfavorable for wind and solar. The table also ignores required energy, steel, cement, land and water inputs.