Electric Vehicles: Decarbonizing Road Transportation in BC

ASPC 498-T Final Project

Research Report

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Abstract

Transportation is the second-highest emitting sector in Canada, and 28% of BC's CO2e emissions are due to Road Transportation. Passenger emissions have increased since 1990, despite gains in fuel efficiency. The existing solutions of electric vehicles as a decarbonization approach are assessed, and gaps and levers of change were notes. In the technological realm, vehicle types and charging methods available in BC are examined, and the need for a closed-loop battery supply chain is emphasized. BCs Climate Action Policy has offered purchasing incentives and led to infrastructure development which has lead to the development of over 1,100 charging stations and 2,700 electric and hydrogen fuel cell vehicles being used in BC. To meet Climate Action goals of 30% PEV market share by 2030, strong supply focused policies will be needed in addition to the current demand focused policies. By 2050, we expect about 300,000 electric vehicles to be registered in the city of Vancouver. Although sales have grown steadily about 70% per year since 2011, today 60% of EV rebate qualified car dealerships have no EV cars available for purchase. Electric vehicles are well on their way to becoming the norm in BC, but an ideal solution may just be one in which the need for private transportation is decreased, not just the emissions.

Introduction

In order to reduce societal carbon emissions, a large role is placed on developing, and encouraging the use of, electric vehicles (EVs). We will examine the existing technology, policy, and market landscape of EVs in British Columbia, and assess the gaps to be filled if EVs are to truly become the future of sustainable transportation in BC. This includes: engineering challenges in regards to battery technology; policy challenges relating to economic accessibility and public perception of EVs; environmental justice and social adaptability; and the sustainability of such a shift in regards to production of electric vehicles and the energy requirements to power them.

Background

Transportation has the second-highest sectoral greenhouse gas emissions in Canada at 173 Mt CO_2e, or 24% of total emissions in 2015. Passenger and freight travel emissions make up 96% of sector emissions.[1] As of 2016, Road Transportation accounted for 17,291 out of 62,264 kt CO_2e emitted in BC, or 28% of emissions.[2]

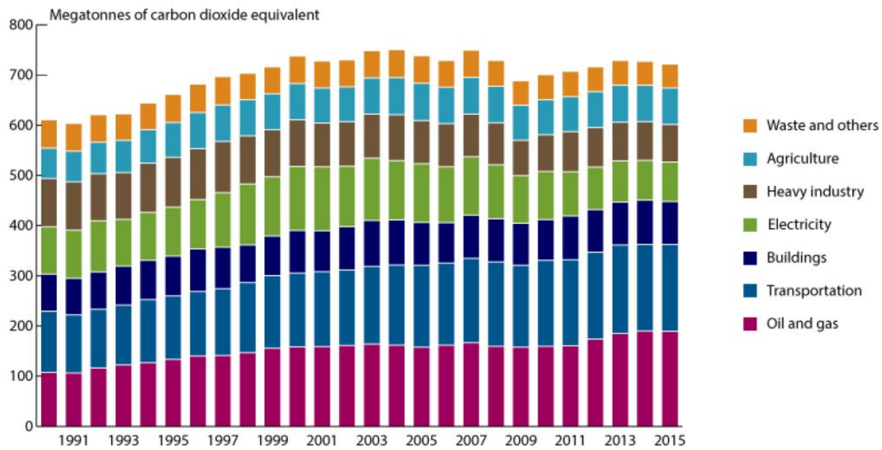

Fig. 1: Greenhouse gas emissions by Canadian economic sector, Canada, 1990 to 2015[1]

Although vehicles have become more fuel efficient, overall vehicle emissions grew by 42% from 1990 to 2015 due to higher number of vehicles on the road and increased use of higher emitting vehicle types: car emissions declined by 23%, but emissions from trucks, vans, and SUVs doubled, leading total passenger emissions to grow by 17%.

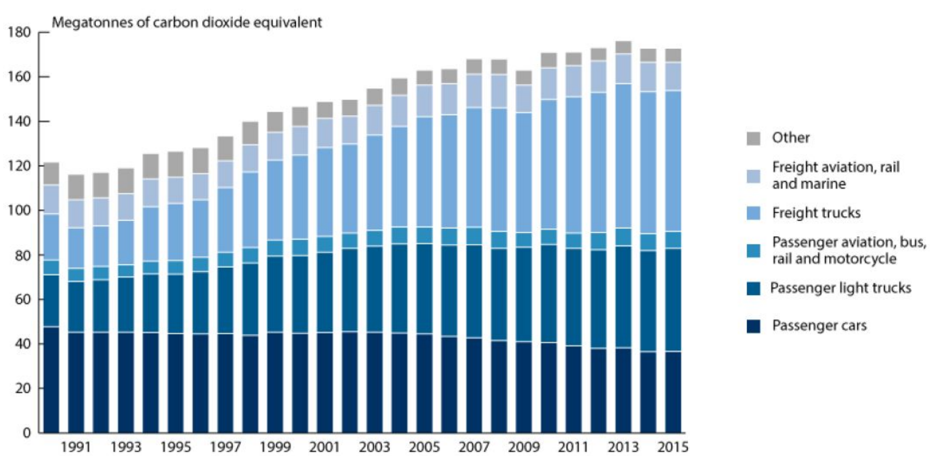

Fig. 2: Transportation sector greenhouse gas emissions, Canada, 1990 to 2015[1]

[1] (2018, June 6). Greenhouse gas emissions - Canada.ca. Retrieved March 30, 2019, from https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

[2] (n.d.). Provincial Greenhouse Gas Emissions Inventory ... - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Existing Solutions

Technology

The following section presents an overview of common EV types and charging options available in BC.[3] Technology not readily available in BC is also presented for background.

Vehicle Types

Battery Electric Vehicles (BEVS): A BEV uses a rechargeable battery and an electric motor. Some BEVs may use regenerative braking to regain ~5-15% power, but generally batteries must be connected to an external power source to recharge.

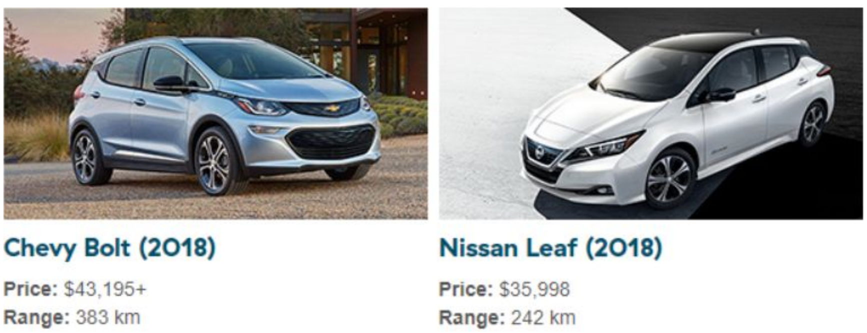

Fig. 3: BEVs available for purchase in BC[3]

Plug-in Hybrid Electric Vehicles (PHEVs): A PHEV is similar to a BEV, but uses a conventional Internal Combustion Engine when the rechargeable batteries can no longer power the electric motor. Unlike HEVs, PHEVs recharge using an external power source. PHEVs have a slightly higher initial cost than BEVs, but are able to go further between charges.[4]

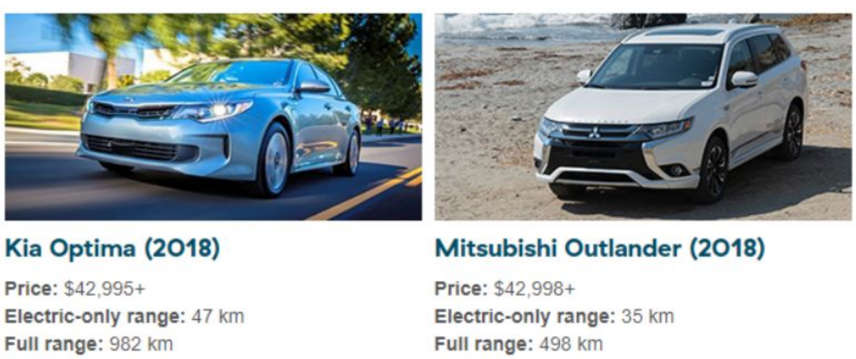

Fig. 4: PHEVs available for purchase in BC[3]

[3] (n.d.). Electric vehicles available in BC - BC Hydro. Retrieved March 30, 2019, from https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/options.html
[4] (n.d.). An overview of electric Vehicle concept and power management .... Retrieved April 2, 2019, from https://ieeexplore.ieee.org/document/7077026

Technology	Advantages	Disadvantages
Hybrid Electric Vehicle (HEV)	Reduced fuel consumption and emissions; Possibility to recover energy from regenerative braking	Higher initial cost; Component availability; Build complexity involving two power trains (Transmission Energy loss).
Plug-in Hybrid Electric Vehicle (PHEV)	Important grid connection potential; Reduced fuel consumption and emissions; Optimized performance; Possibility to recover energy from regenerative braking; 100% zero-emission capability.	Higher initial cost; Build complexity involving two power trains (Transmission Energy loss); Component availability; High cost of batteries and battery replacement; Added weight to be taken in consideration.
Battery Electric Vehicle (BEV)	Use of cleaner electric energy; Zero emissions Vehicle; battery recharging (Overnight or equipped Parking); Possibility to recover energy from regenerative braking; Lower operational costs; Quiet operation.	Short distance range; Battery technology still to be improved; Public recharging infrastructure to be improved.

Fig. 5: Advantages and disadvantages of main EV types[4]

Charging

Connection Methods

Conductive: A direct electrical connection between the battery and the power source, usually a plug-in insulated wire/cord set.

Inductive: A wireless charging connection which uses a magnetic field induced by a high AC current. Inductive charging technology is currently in limited use due to cost and complexity, and there are no publicly available wireless charging stations in BC.[5]

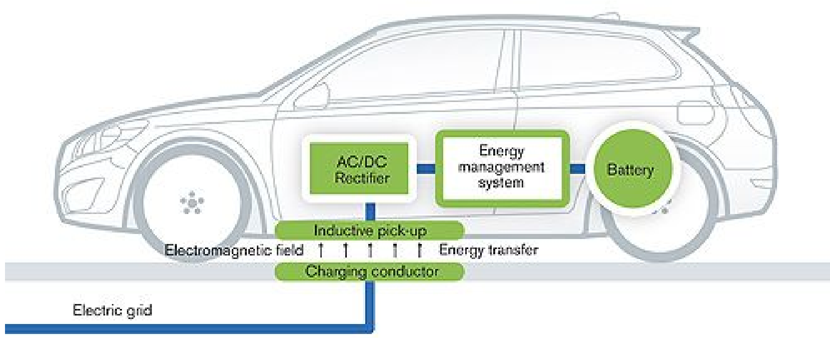

Fig. 6: Induction charging diagram[6]

Battery Swapping: Charging the battery by removing it from the vehicle and placing it in a specialized charging station. This technique is seldom used, and cannot be widely implemented without further standardization of battery size and geometry across manufacturers. Even then, the large size of EV batteries and the reliance on high powered charging stations make this method impractical for everyday use.[4]

[5] (n.d.). Public Charging - Plug In BC. Retrieved April 2, 2019, from https://pluginbc.ca/charging-stations/public-charging/

[6] (2011, May 25). Volvo working on wireless EV charging | GoAuto. Retrieved April 2, 2019, from https://www.goauto.com.au/news/volvo/volvo-working-on-wireless-ev-charging/2011-05-25/9536.html

Charging Levels

Level 1: Typically a standard three prong cord able to plug into common shared 120 VAC branch circuits intended for general use. Level 1 charging stations are not publicly available in BC, but are an option for charging at home.

Fig. 7: Level 1 charging cord

Level 2: Able to plug into 240 VAC, single phase branch circuit. The charging rate is significantly faster than Level 1 due to the increased voltage. Level 2 chargers may plug into EVSEs (Electric Vehicle Supply Equipment: charging stations plugged into 240V receptacles, similar to a residential clothes dryer plug) or use inductive charging.

Fig. 8: Level 2 charging station

DC Fast Charging: Uses an off-board charger to convert AC to DC power at 208, 400, or 600 VAC. This is the fastest charging method.[7]

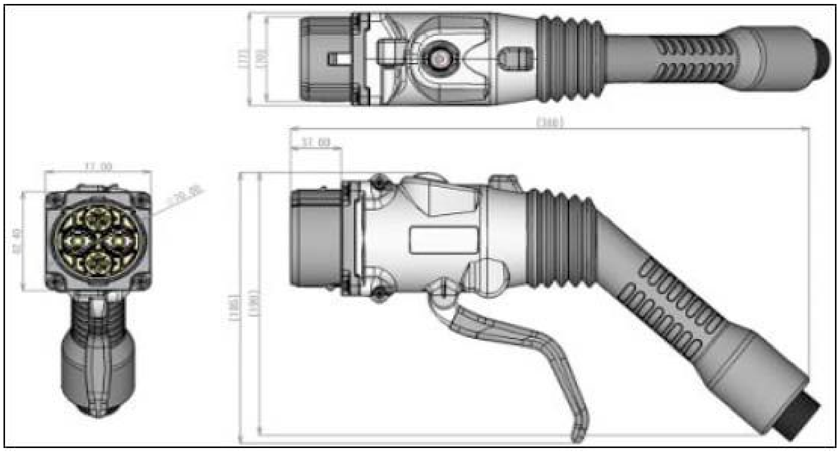

Fig. 9: DC Fast Charging converter plug

EVSE Configurations

An EVSE is the interface between the battery and the power supply, and mainly refers to different charging station circuit configurations. The EVSE configuration may affect charging time based on its grid connection, with higher available amperage leading to faster charging.

Circuit sharing methods may also impact charging time due to charging prioritization. The three common load-management methods are:

- Static: charges an EV if it is plugged in, regardless of battery level
- Rotational: charges each connected EV for a certain amount of time before rotating to the next, regardless of battery level
- Dynamic: uses feedback monitoring to determine which connection EV to charge based on highest need[8]

[7] (n.d.). canadian electric vehicle infrastructure deployment guidelines 2014. Retrieved April 2, 2019, from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/electric-vehicles/DC14-071%20Canadian%20EV%20Infrastructure%20Deployment%20Guidelines%202014_web.pdf

[8] (n.d.). Electric Vehicle Charging Infrastructure in Shared Parking Areas:. Retrieved April 2, 2019, from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/electric-vehicles/ev-charging-infrastructure-in-shared-parking-areas.pdf

Standards & Policies

Electric vehicle policy can be broken down into two categories: Demand side policy focuses on increasing the appeal and affordability of electric cars for consumers, typically through incentives to lower the price difference between electric and conventional vehicles, and infrastructure development, such as charging stations, to improve the practicalities of using an electric car; Supply side policy typically focuses on mandating what type of vehicles dealerships or auto manufacturers are able to sell.

CEV Program

The BC Climate Action Plan is the overarching policy regarding electric vehicle use in BC. The plan mandates that 100% of new cars to be zero-emission vehicles (ZEVs) by 2040; 30% ZEV by 2030 and 10% ZEV by 2025. These goals are to be achieved through the Clean Energy Program (CEV), "an incentive program for clean energy vehicles, supported by aggressive charging infrastructure installations, which has led to the purchase of 2,700 electric and hydrogen fuel cell vehicles and the development of over 1,100 charging stations in the province."[9]

The main areas under the CEV Program are:

1. CEVforBC™ vehicle point-of-sale incentives
    - $6,000 for the purchase or lease of a hydrogen fuel cell vehicle
    - $5,000 for the purchase or lease of a new battery electric vehicle
    - $2,500 – $5,000 for the purchase or lease of a plug-in hybrid electric vehicle
    - Vehicle incentives are available to B.C. residents, businesses, non-profit organizations and local government organizations.[10]
    - Funds Dispersed: $54,606,171
    - Funds Reserved: $2,831,000
    - Incentive Funds Available: $10,933,631[11]
2. Charging infrastructure investments
    - Phase 1:

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[9] (n.d.). CleanBC: our nature. our power. our future. - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

[10] (n.d.). CEVforBC™ Vehicle Incentive Program - Province ... - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/cev-for-bc

[11] (n.d.). CEV for BC. Retrieved March 30, 2019, from https://www.cevforbc.ca/

    - Installed 30 DCFC along major highways corridors (2012-2016).[12]
  - Phase 2
    - Charging Infrastructure Gap Analysis[13] (2015)
    - Continued Infrastructure development
3. Hydrogen fuelling infrastructure investments
4. Fleet adoption support & incentives
5. Research, training & economic development
6. Emotive public outreach & awareness

Specific municipalities, such as the City of Vancouver, also have their own policy regarding charging infrastructure. This includes the Vancouver Building Code requiring EV charging in all new construction. For new buildings current bylaw requires:

- 1 EV-ready stall in single-family homes with garages
- 10% of stalls be EV-ready in commercial buildings
- 100% of stalls be EV-ready in multi-unit residential buildings[14]

City of Vancouver Metered Parking Policy allows improved parking access to electric scooters:

- Registered and unregistered electric scooters to park for free in metered spaces marked for motorcycles or scooters
- Registered electric scooters receive a 75% discount on rates in regular parking metered spaces[15]

Additional supporting policies in BC include access to high occupancy vehicle (HOV) lanes, for eligible electric and hydrogen fuel cell vehicles, without considering the number of vehicle occupants.[16]

In 2018 BC's carbon tax was increased to $35 per tonne and is intended to increase by an additional $5 per tonne each year until reaching $50/tonne. This revenue is intended to support further decarbonization[17].

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[12] (n.d.). DC Fast Charger Program - Province of British ... - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/charging-infrastructure/dcfc-program

[13] (2015, August 31). BC DCFC Gap Analysis_FBC_Aug2015v2 - Plug In BC. Retrieved March 30, 2019, from https://pluginbc.ca/wp/wp-content/uploads/2015/10/BC-DCFC-Gap-Analysis-Report-FBC_Aug-2015.pdf

[14] (2018, March 14). Policy - Plug In BC. Retrieved April 1, 2019, from https://pluginbc.ca/policy/

[15] (2018, March 14). Policy - Plug In BC. Retrieved March 30, 2019, from https://pluginbc.ca/policy/

[16] (n.d.). CleanBC: our nature. our power. our future. - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

[17] (n.d.). CleanBC: our nature. our power. our future. - Government of BC. Retrieved March 30, 2019, from

Market

Electric vehicle sales in Vancouver are growing steadily, with about 70% growth year-over-year since 2011. There are 12,000 clean energy vehicles are registered in B.C., which the province says is the highest adoption rate in the country[18]. By 2050, B.C is expecting to have about 300,000 electric vehicles registered.[19]

Fig. 10: Year over year sales by month in Canada[20]

Costs

Although the initial purchase price of an electric car is higher than most similar-sized internal combustion engine equivalents, the yearly savings on fuel and maintenance can be a great incentive for consumers. According to the Canadian Automobile Association vehicle cost calculator using 20,000 kilometres of driving a year as the constant, if we compare the fuel cost of electric vehicles with internal combustion power ones, EVs result in cheaper fuel costs[21] (App.Table1).

Over a period of eight years, maintenance on an electrical car is about a third cheaper than maintenance on a car with an internal combustion engine. However, the current prices of

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https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

[18] CBC News. (2018). *Every new car sold in 2040 will be zero-emission, B.C. government says | CBC News*. Retrieved from: https://www.cbc.ca/news/canada/british-columbia/every-new-car-sold-in-2040-will-be-zero-emission-b-c-government-says-1.4913679.

[19] Vancouver, C. (2019). *Electric Vehicles*. [online] Vancouver.ca. Retrieved from: https://vancouver.ca/streets-transportation/electric-vehicles.aspx.

[20] Schmidt, E. (2018). *Electric Vehicle Sales In Canada, 2017*. [online] FleetCarma.Retrieved from: https://www.fleetcarma.com/electric-vehicle-sales-canada-2017/

[21] Bchydro.com. (2019). *Costs of electric vehicles*. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/costs.html

electric car batteries are about $350 US per kWh. Although this represents a huge decrease from a few years back, since between 2007 and 2014 battery pack prices have decreased an average of 14% per year, the target now is to produce batteries that can be sold for for $150 US per kilowatt-hour.[22]
According to CAA's Electric vehicle Cost Calculator, if we consider an 80% of charging to be done at home the compared costs of electric vehicles to an internal combustion power one per month are lower. [23]

Supply

According to Clean Energy Canada, from all 322 car dealerships in BC that qualify for am EV rebate 60% of them had no EV cars on their lots available to purchase, and the wait time to get an electric car would be three months to a year, impacting consumer preferences because of unmet demand[24](App.Fig.12).

BC Hydro has installed around 1,000 charging stations in the province. Plugshare and Chargehub are two mobile apps that can show EV charging stations near your location or destination.

Demand

According to Fleetcarma, a clean-tech information and technology company, at the end of quarter three in 2017, there were 950 sales of EVs and in 2018, the end of quarter three saw 2,389 sales of EVs in B.C.[25] The provincial government offers credits of up to $5,000 for the purchase or lease of a new plug-in hybrid or battery EV, and $6,000 for a new hydrogen fuel cell EV.[26].

On the other hand, if you scrap your older, gas-powered vehicle the SCRAP-IT program offers the following rebates on purchases: $6,000 for a new electric vehicle and $3,000 used electric vehicle [22]. However the electric vehicle must be purchased from one of the program participant's dealerships.

In terms of consumer preferences, Electric vehicles are quite and require less maintenance than conventional ones. Additionally, they are flexible at fuelling, since they can be charged at home,

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[22] Bchydro.com. (2019). *Costs of electric vehicles*. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/costs.html
[23]Bchydro.com. (2019). *Costs of electric vehicles*. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/costs.html
[24] Clean Energy Canada. (2018). *Most B.C. dealerships still don't have an electric car to sell you: report - Clean Energy Canada*. [online] Retrieved form: http://cleanenergycanada.org/most-b-c-dealerships-still-dont-have-an-electric-car-to-sell-you-report/
[25] Schmidt, E. (2018). *Electric Vehicle Sales In Canada, 2017*. [online] FleetCarma.Retrieved from: https://www.fleetcarma.com/electric-vehicle-sales-canada-2017/
[26] (n.d.). CEVforBC™ Vehicle Incentive Program - Province ... - Government of BC. Retrieved March 30, 2019, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/cev-for-bc

businesses, parking, etc. British Columbia has the highest penetration of EVs in Canada based on the ratio of conventional vehicles to EVs per province[27] (Fig.10).

Jurisdiction	Average distance traveled by light vehicles in 2009[a] (1000skm)	Ratio of number of CVs to EVs[b]
Quebec	14.7	214
Ontario	16.0	296
British Columbia	13.0	177
Newfoundland and Labrador	15.1	1424[c]
Prince Edward Island	15.1	
Nova Scotia	17.4	
New Brunswick	16.1	
Manitoba	15.0	
Saskatchewan	15.3	
Alberta	16.1	
Yukon	–	
Northwest Territories	–	
Nunavut	–	

Fig. 10: Vehicle information in different provinces of Canada[28]

Identifying Gaps and Levers of Change

Technology

EREVs

Extended Range Electric Vehicles (EREV) are essentially a high-powered BEV where the battery charge is maintained by a small engine-generator unit, allowing it to travel significantly further distances.[4] Although 95% of car trips in BC's urban areas are less than 30 km, well within regular EV range, rural drivers may need additional range for regular use;[29] As EREVs develop longer ranges and become more accessible for purchase in BC, it may lead to drivers in less urban areas to purchase an EV. This is an important step towards decarbonization, as these drivers are unable to use alternative sustainable transportation methods such as public transit or cycling.

[27] Verma, A., Raj, R., Kumar, A., Kumar, M., & Ghandehariun, S. (2015). Assessment of renewable energy technologies for charging electric vehicles in canada. *Energy, 86*, 548-559. doi:10.1016/j.energy.2015.04.010
[28] Verma, A., Raj, R., Kumar, A., Kumar, M., & Ghandehariun, S. (2015). Assessment of renewable energy technologies for charging electric vehicles in canada. *Energy, 86*, 548-559. doi:10.1016/j.energy.2015.04.010
[29] (n.d.). Public Charging - Plug In BC. Retrieved April 1, 2019, from https://pluginbc.ca/charging-stations/public-charging/

Wireless Charging

As previously mentioned, induction charging is not publicly available in BC. If the province were to implement and incentivize public wireless charging stations, the convenience of charging might lead to more consumers purchasing an EV.

Battery Supply and Disposal

In addition to the battery use issues mentioned above, there are concerns about both the supply and disposal of battery materials. Elements used in EV batteries are connected to political and environmental concerns: Over half of the world's cobalt comes from the Democratic Republic of Congo, where approximately 20% of it is mined by hand by children as young as 7 years old, and major EV manufacturers such as GM and Tesla have failed to disclose their approach to ensure their suppliers are not linked to these exploitative labour practices.[30] Lithium is connected to environmental concerns and land use conflicts in Tibet and Bolivia.[31] Nickel is usually mined in politically stable countries, but is toxic to extract from the ground.[32] There are also concerns that there is not enough of these materials on Earth to completely electrify transportation with current battery technology.[33]

On the disposal side, there is still need for development in end-of-life options. Industry and academia are working together to find ways to repurpose used batteries in grid-scale storage applications, remanufacture them for reuse in new vehicles, and recycle their components into new battery grade materials. There are considerable challenges such as no safe lithium-ion recycling facilities or processes, and a lack of a strong value-chain to support battery recycling. However, these solutions would also address many of the concerns from the supply side by reducing the need for new materials to be extracted, and would lower overall supply and processing costs.[34]

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[30] (2016, September 30). Electric cars: Running on child labour? | Amnesty International. Retrieved March 30, 2019, from https://www.amnesty.org/en/latest/news/2016/09/electric-cars-running-on-child-labour/

[31] (2018, April 17). Why the electric vehicle revolution will bring problems of its ... - Phys.org. Retrieved March 30, 2019, from https://phys.org/news/2018-04-electric-vehicle-revolution-problems.html

[32] (2017, August 24). Nickel mining: the hidden environmental cost of electric cars .... Retrieved March 30, 2019, from https://www.theguardian.com/sustainable-business/2017/aug/24/nickel-mining-hidden-environmental-cost-electric-cars-batteries

[33] (2018, April 17). Why the electric vehicle revolution will bring problems of its ... - Phys.org. Retrieved March 30, 2019, from https://phys.org/news/2018-04-electric-vehicle-revolution-problems.html

[34] (2018, August 27). Creating a Second Life for EV/PHEV Batteries - National ... - CNRC-NRC. Retrieved March 30, 2019, from https://www.nrc-cnrc.gc.ca/eng/publications/nrc_pubs/energy_storage/2016/summer_main_article2016.html

Standards & Policies

A 2017 Simon Fraser University case study of electric vehicle use in BC looked at how policy can affect the BC plug-in electric vehicle market. This study shows that for BC to meet the goals outlined in the Climate Action Plan both supply and demand side policies will need to be increased.

The study found that a no policy baseline simulation for annual PEV sales can lead to a 7% market share by 2030. A strong demand focused PEV policy could lead to 17 - 28% market share. To meet BC's Climate Action goal of 30% market share by 2030 an additional strong supply focused policy would be needed alongside current policies[35]

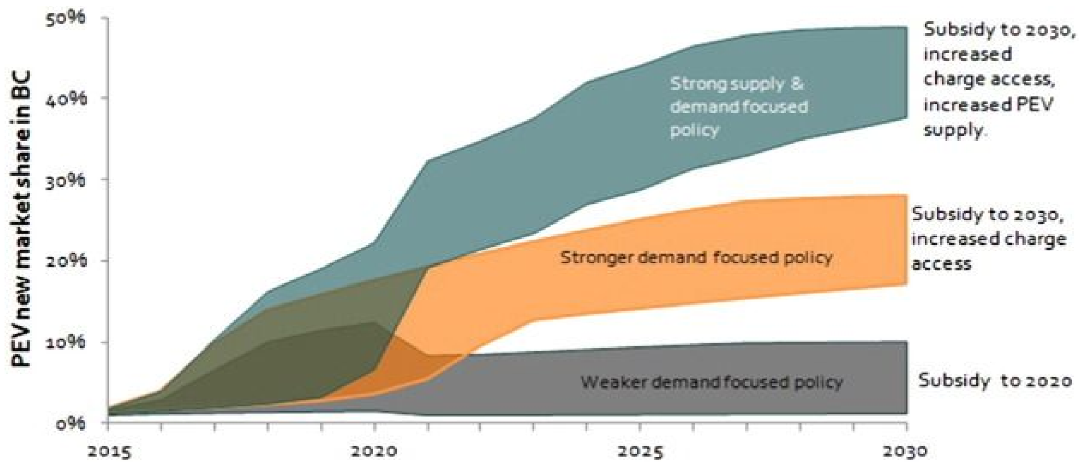

Fig. 11: PEV market share under varying policy scenarios[36]

A follow up study, also from Simon Fraser University, found that Canada's current policies can support 5-11% market share by 2030. Long-term incentives, $6,000 - 10,000 per PEV, may be needed to meet the 2030 Climate Action goal of 30% market share. This would incur significant government costs. To avoid these costs the researchers propose mandating ZEV sales targets for suppliers. This would encourage suppliers to use intra-firm cross-price subsidization, lowering the sale price of PEVs and increasing the price of non-PEVs to compensate. These sort of supplier quotas would incur very little government cost and would effectively create the required shift in vehicle use.

When discussing the shift towards electric vehicle use a common concern is that of the quantity of electricity required to power an electric transportation future. A study of public domain data, published by various government agencies found that British Columbia currently produces

[35] (n.d.). How policy can build the plug-in electric vehicle market: Insights from .... Retrieved March 30, 2019, from https://www.sciencedirect.com/science/article/pii/S0040162516307570
[36] (n.d.). How policy can build the plug-in electric vehicle ... - Science Direct. Retrieved April 2, 2019, from https://www.sciencedirect.com/science/article/pii/S0040162516307570

enough electricity for 47% of ICE vehicles to be replaced with PEVs. Ensuring the supply of this electricity would require reducing power which is currently exported to the USA. This would require the USA to develop increased power generation which, based on current electricity sources in the USA would not be a majority renewable. Though this shift to electric vehicles would reduce GHG emissions in Canada, the shift in USA energy production would result in a net global increase of 20 million tonnes in yearly GHG emissions and a net decrease of $600 million annually in provincial government revenue.[37] This is an important consideration which should be included in BC Climate Action policy.

Market

Supply

The BC government has proposed provincial sales targets for EVs to be 5% by 2020, 10% by 2025 and 30% by 2030[38]. Additionally, the City of Vancouver is committed to expand the electric vehicle infrastructure, and improved the public network of charging stations available. With the introduction of small fees to charging stations, turn-over and plug sharing will be increased. Additionally there will be data gathering to identify areas of low use in order to reduce their fees accordingly[39].

Three new rebates for families, multi-unit residences and workspaces, will be funded with $1.85 million from the Province of British Columbia as part of its Clean Energy Vehicle Program and administered by Plug In BC[40](App.Table 2). The EV charging station user fees, along with any parking fees, will be paid as a blended rate at the charging station, unless otherwise noted. Blended rate of parking and EV charging station range from $2 per hour to $8.50 per hour[41].

The adoption of the zero-emissions mandate would require automakers (not individual dealerships) to sell a minimum share of EVs in B.C. every year would ensure EVs to be available on dealership lots.

Demand

Global warming and energy security have generated renewed interest in hybrids, and demand is expected to grow continuously now that improved batteries such as nickel metal hydride (NiMH) have became available, and assuming current policy to evolve. According to Bloomberg, Electric cars will be cheaper to own than conventional cars by 2022 and projects that 35% of

[37] (2017, February 1). Some less-discussed externalities of contemporary electric vehicle .... Retrieved March 31, 2019, from https://www.sciencedirect.com/science/article/pii/S0360544216317832

[38] Smith, M., & desLibris - Documents. (2018). *Batteries not included* Clean Energy Canada.

[39] Vancouver, C. (2019). *Electric Vehicles*. [online] Vancouver.ca. Retrieved from: https://vancouver.ca/streets-transportation/electric-vehicles.aspx.

[40] Bchydro.com. (2019). Incentives for electric vehicles. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/rebates-and-incentives.html

[41] Bchydro.com. (2019). Incentives for electric vehicles. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/rebates-and-incentives.html

global new car sales will be EVs by 2040[42]. Additionally, a recent study from BC Hydro found that one in three British Columbians expect their next car to be an EV[43].

Environment

the GHG mitigation potential from CVs' replacement with EVs ranges from 4306.6 to 5059.4 kg CO2-eq/year/vehicle. However, if EVs are charged with electricity generated from renewable resources, there is additional GHG mitigation that ranges from 4332.4 to 8203.9 kg CO2-eq/year/vehicle[44].

Social Perception

Shoppers who engage in green behaviors are stereotyped by others as more feminine and see themselves as feminine as well. Marketers need to mimic successful approaches in other products to combat feminine stereotypes, this can be done to improve the adoption of electric cars by both female and male populations[45].

Electric vehicles could be part of an act of Conspicuous Conservation. For example, given its design the Toyota Prius is unmistakable, and it marks whoever is driving it as someone who cares about the environment. As a result, it introduces them to new friends, businesses, opportunities, etc. This effect has been predicted to have a worth of as much as $7,000[46].

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Conclusion

Decarbonizing road transportation in BC using Electric Vehicles is a solution with many interrelated variables and relationships e.g. improved technology leads to consumer demand, which leads to supply based policy and attracts industry investment, which again leads to improved technology. However, there are issues with this approach. For one, consumer incentives are meant to make purchasing an EV comparable to purchasing a new conventional vehicle, but realistically there are still people who will not be able to afford this option. Public transit, bike lanes, and hydrogen fuel cells must be investigated to form a more holistic solution.

Even if improvements in technology, policy, and cost make EVs significantly more accessible, there is still the risk of increasing overall emissions as more drivers get on the road (similar to the issue mentioned of passenger emissions increasing despite fuel efficiency increasing in conventional cars). Furthermore, although this report focuses on BC, overall accessibility of EVs would spread globally, meaning that regions who obtain energy from non-renewable sources would see a large increase in electricity consumption.

As future engineers and policy makers, it is our responsibility to ensure that our time, energy, and financial resources are invested in solutions that will have a significant and lasting positive impact. Ultimately, electrifying road transportation only has the potential to lower emissions, not completely decarbonize it. A more effective long-term solution may be to lower the need for private transportation and invest in low or zero emission public transportation strategies.

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Appendix

Fuel costs - EV	**Fuel Costs- Conventional Vehicle**
2016 Nissan Leaf S: $400	$1,872 for a gas-powered compact car
2016 Chevy Volt: $568	$1,872 for a gas-powered compact car
2016 BMW i3: $396	$1,872 for a gas-powered compact car
2016 Tesla S (P90D): $532	$2,076 for a gas-powered, full-size car

Table 1: Fuel Cost Comparison. Bchydro.com. (2019). *Costs of electric vehicles*. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/costs.html

Single- Families	**Multi-Unite Residences**	**Workspaces**
Covers 75% of costs, up to $750, for the purchase and installation of a Level 2 (208v/240v) charging station.	Covers 75% of costs, up to $4,000, for the purchase and installation of a Level 2 station (208v/240v).	Covers 50% of costs, up to $4,000, per Level 2 station (or $2,000 per Level 1 (120 v) station).

Table 2: Rebates. Bchydro.com. (2019). *Costs of electric vehicles*. [online] Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/owning-an-electric-vehicle/costs.html

Hydrogen fuel-cell vehicle, via the CEV of BC program	New battery electric vehicle	Plug-in hybrid electric vehicle
$6000	$5000	$2,500 - $5000

Table 3: Incentives to purchase of lease
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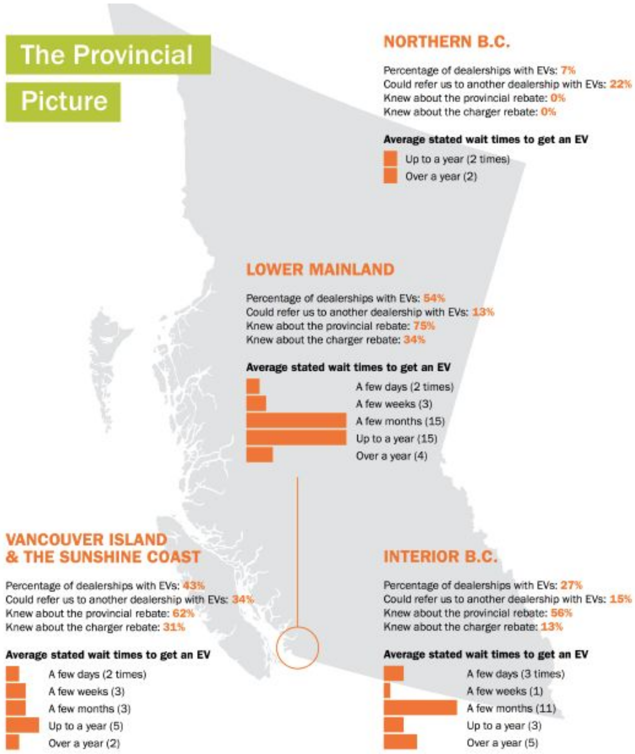


Figure 12. Information on BC dealerships, rebates and EVs availability
Smith, M., & desLibris - Documents. (2018). *Batteries not included* Clean Energy Canada.

LEVEL 1		
Standard outlet: 120 V	Charging time	
A Level 1 charge simply requires a standard 120-volt outlet. The power demand is comparable to a 1,500-watt air conditioner.	Plug-in hybrid: 6 to 8 hours Battery electric: 11 to 16 hours	

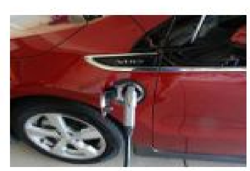
LEVEL 2		
Charging station: 240 V	Charging time	
A Level 2 charge can be done using a 240-volt charging station installed outside your home or in your garage. The power demand is comparable to a stove or clothes dryer.	Plug-in hybrid: 3 to 4 hours Battery electric: 6 to 8 hours	

Table 4: Charging Times for Level 1 vs Level 2.
Retrieved from: https://www.bchydro.com/powersmart/electric-vehicles/charging/charging-at-home.html