ELECTRIC VEHICLES AND THE CARBON TAX: THE COST-EFFECTIVENESS OF CANADIAN GHG MITIGATION POLICIES

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Abstract

In Canada, the transportation sector and fuel sectors account for half of all greenhouse gas (GHG) emissions despite having one of the world's cleanest electricity generation profiles. Governments are reacting to mitigate these GHG emissions by supporting strategies that discourage fossil fuel consumption through electric vehicle (EV) incentive programs and carbon pricing legislation. This study aims at quantifying the return on investment of provincial EV incentive programs by; (1) estimating the equivalent dollar value of EV based GHG reductions from different EV market penetration scenarios across Canada combined with the equivalent cash rebate for each scenario; (2) comparing the cost of GHG reductions with the existing carbon price; and (3) quantifying the gap between the two GHG mitigation strategies. The study utilizes predictions and lifecycle assessment tools for three Canadian provinces: British Columbia, and Quebec, and Ontario. The findings highlight that the GHG reductions from EV will not return on the public money invested. While the full breadth of GHG benefits were not examined, these findings nonetheless provide policy makers with indications of the effectiveness of EV incentive programs and the current price of carbon emissions in Canada.

1. Introduction

On April 22nd, 2016, a total of 175 countries signed the Paris agreement and pledged to mitigate climate change (United Nations, 2016). Canada, one of the signees, initiated a national plan in the Pan-Canadian Framework on Clean Growth and Climate Change in response (Pan-Canadian Framework on Clean Growth and Climate Change, 2016). The framework's central principal is pricing carbon pollution alongside complementary actions to expedite the reduction of greenhouse gas (GHG) emissions by 30% below the 2005 level of 738 Mt CO_2 eq by 2030 (Canadian Environmental Sustainability Indicators, 2017). The major emitters of GHG nationally are the fuel and transportation sectors; they accounted for almost half of the total GHG emissions in 2016. Furthermore, oil production and distribution accounted for 73% of the fuel sectors emissions, and passenger cars and light trucks accounted for 50% of the transportation sector related emissions (Canadian Environmental Sustainability Indicators, 2017). The Pan-Canadian Framework reacts to these major GHG contributing sectors by proposing the development of a carbon pricing regime and supply-focused incentives to hasten the adoption of zero-emission vehicles (ZEV).

Pricing carbon pollution is broadly recognized as an effective method to reduce GHG emissions and British Columbia, Alberta, Ontario (formerly), and Quebec already have their own carbon pricing regime in place. However, the Pan-Canadian Framework outlines the Federal Carbon Pricing Benchmark, which legislates that all provincial and territorial carbon pricing schemes must meet specific emissions criteria.

Pricing must be based on GHG emissions and apply to a broad set of sources. Pricing must be structured as either an explicit price-based system (i.e. carbon tax or carbon levy) or a cap-and-trade system whose emissions-reduction target is equal or greater than Canada's 30% reduction target. Jurisdictions which choose an explicit price-based system must begin at a minimum of $20 /t CO_2 eq in April 2019 and increase by $10 a year to reach $50/t CO_2 eq by 2022. For jurisdictions that don't meet these criteria, the federal government will introduce backstop legislation that will apply this price-based carbon pricing system on distributors, importers, or producers of fuels and an output-based pricing system on facilities that produce major emissions.

In conjunction with the national carbon price scheme, this inquiry examines the incentives offered at the provincial level for ZEV and the provincial ZEV market share. ZEVs are defined as Battery Electric Vehicles (BEV), Hydrogen Fuel-Cell Vehicles (FCEV), and Plug-in Hybrid Electric Vehicles (PHEV). These vehicles offer the potential for significant reductions in light-duty vehicle tailpipe emissions and are essential for long-term reduction of transportation GHG emissions (Pan-Canadian Framework on Clean Growth and Climate Change, 2016). Kennedy (2015) has identified that for electric vehicles to be environmentally competitive, the carbon intensity in electricity generation must be below the 600 g CO_2 eq/kWh threshold. Canada's electricity generation profile scores far below this threshold at 167 g CO_2 eq/kWh; meaning the utilization of fully electric vehicles such as BEVs will significantly reduce the Well-to-Wheel GHG emissions in Canada (Kennedy, Key threshold for electricity emissions, 2015). Additionally, Requia et al. (2017) further identified that ZEV are exceptionally effective in offsetting GHG emissions in the provinces of British Columbia, Manitoba, Ontario, Quebec, and Newfoundland and Labrador, those with significantly low carbon intensity of electricity generation (Requia et al., 2017).

As such, point-of-purchase incentive programs for ZEV are currently available in three of these provinces: British Columbia, Ontario (formerly), and Quebec. As a result of these programs, by the end of 2017 Canada had approximately 48,000 PHEVs and BEVs on the road; a 68% increase from the benchmark set the year prior. This portion of vehicles still only accounts for 1.4% of the passenger vehicle market share (Electric Vehicle Sales in Canada, 2018). Studies predict that consumer uptake will not meet a ZEV market share which reflects the national GHG emissions target of 2030 despite large investment in financial incentives (Noel Melton, 2017). Studies that react to this finding focus largely on quantifying the GHG emissions benefits of ZEV (Weeberb J. Requia, 2017) and the econometric analyses of consumer's willingness-to-pay for ZEV (Mark Ferguson, 2018; Alan Jenn, 2018).

Taken together, both carbon pricing and ZEV incentives aim to mitigate GHG emissions; carbon pricing economically dissuades participation in GHG emitting activities and ZEV incentives encourage adoption of a reduced emissions alternative to conventional passenger vehicles. However, there are several discrepancies on the GHG emissions offset, their carbon priced value, and EV incentives distributed that requires further investigation. This injury aims to quantify these discrepancies in order for policymakers to provide clear indications on the return on investment of the ZEV incentive program and EV incentive spending in Canada. It should be noted that hereafter the inquiry will refer to EV (which include BEV and PHEV) in place of ZEV as FCEV are currently not available in Canadian markets.

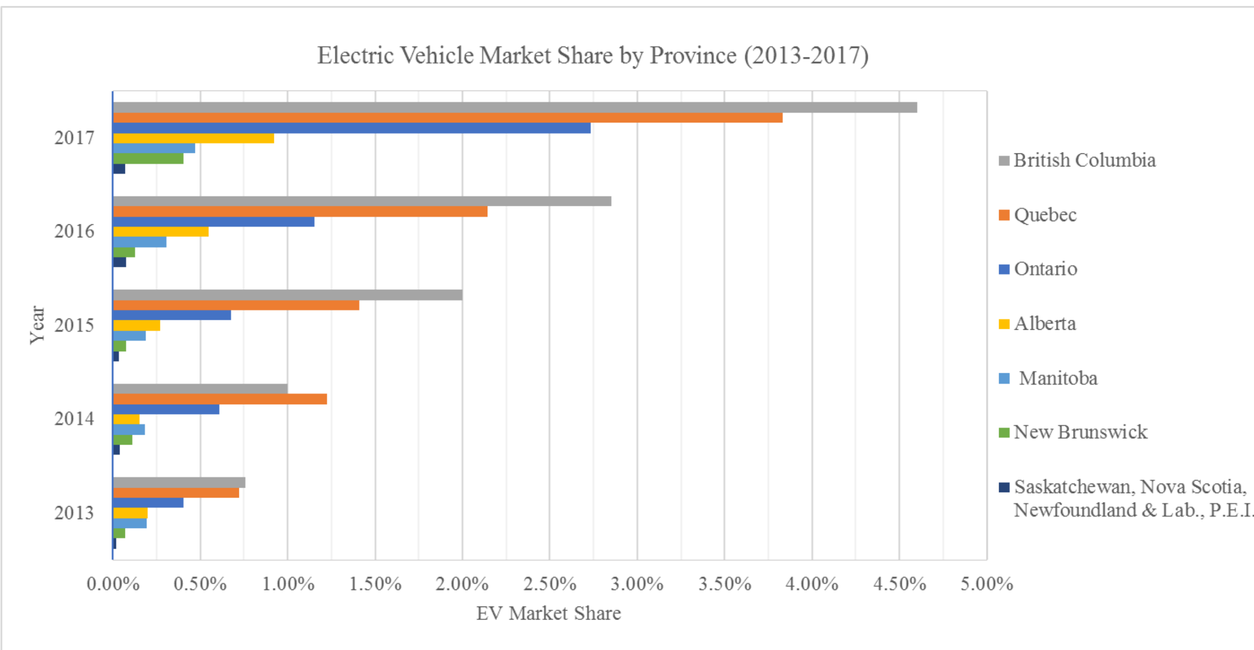
2. EVs Incentives: Policies and Their Impact on Market share

Federal and provincial incentives to promote the adoption of ZEVs in Canada have been steadily increasing over the last decade making the need to evaluate their efficiency at reducing GHG emissions more urgent. Coupled with the 2019 introduction of a federal carbon tax legislation, EV incentives can be quantifiably assessed on its ability to reduce GHG emissions per dollar invested.

While all provinces have EV policies such as vehicle emissions standards and some form of public charging infrastructure, only three provinces (Ontario, Quebec, and British Columbia) additionally offer ongoing EV financial incentives and carbon tax policies (Noel Melton, 2017). Ontario's Climate Change Strategy offered rebates between $8,000 - $14,000 for new EV purchases and up to $1,000 for the purchase of a charging station. The newly elected provincial government dismantled the EV rebate program as of June 2017. Quebec's Transportation Electrification Action Plan administers between $500 - $8,000 on a purchase or lease of a new EV, up to $4,000 on the purchase of a used EV that is at least three years old, and up to $600 for purchase and installation of a charging station. The Clean Energy Vehicles for British Columbia program distributes rebates between $2,5000 to $5,000 for a purchased or leased new EV and no rebate for charging equipment. As a consequence of EV supportive policy, sales in Ontario, Quebec, and British Columbia accounted for 95% of the 19 000 EVs sold nationwide in 2017 and these provinces displayed a significantly higher provincial EV market share compared to other provinces in Canada as illustrated in

Figure 1.

Figure 1: Yearly EV Market Share by Province (fleetcarma 2017)



As relevant to this inquiry's scope, three broad categories of research emerge within the study of EV related GHG emissions, EV adoption, and EV incentive policies. The first category predates the 1980s (Salihi, 1973), (Hamilton, 1980) and is rooted in measuring the environmental impact of EV under varied levels of resolution and transparency (Weeberb J. Requia, 2017), (Patrick Jachem, 2015), (Troy R. Hawkins B. S.-B., 2012). Current literature concurs that the GHG emissions produced during EV manufacturing is substantially offset throughout the vehicle's lifecycle given appropriate electricity generation profiles and grid capabilities. British Columbia, Ontario, and Quebec have the aforementioned characteristics to support the growth of EV market share (Piyaruwan Perera, 2017).

The two other categories of research are motivated by the findings of the first. The second research category assesses the effectiveness of EV incentive policy and EV market penetration from a policy perspective similar to the works presented in (Johannes Kester L. N., 2018) (Alan Jenn K. S., 2018) (John Axesn, 2016) (M.J. Eppstein, 2011). Studies in this category find that financial incentives are effective to a degree that varies based on jurisdiction, incentive distribution method, and program duration. Furthermore, EV adoption is sensitive to vehicle charging infrastructure (Z. Lin, 2011). The third research category applies behavioural macroeconomic theory to determine the efficiency of EV adoption (Mark Ferguson, 2018) (Jonn Axsen, 2015) (William Sierchula, 2014) (Hidrue, 2011). Other topics within EV related GHG emissions, adoption, and incentive policies such as infrastructure maintenance and energy consumption topics are beyond the scope of this inquiry.

Financial incentives are examined from an EV user and policy perspective. From a user perspective, financial incentives have shown to increase EV adoption but may also mask other influential factors. Ferguson et al (2018) analyzed the results from a 2015 Canadian national survey on EV consumer willingness-to-pay (WTP) and four classes of consumer emerged: ICEV-oriented, HEV-oriented, PHEV-oriented, and ICEV-oriented. Findings stated that classes were defined by household socio-demographics and ICEV-oriented and HEV-oriented classes consistently discounted financial incentives. Other studies (Jonn Axsen, 2015) (William Sierchula, 2014) (Hidrue, 2011) support the findings of Ferguson et al. (2018).

From a policy perspective, literature has also shown that financial incentives are effective at increasing EV market share. Hardman et al. (2017) reviewed current available research on the efficacy of financial incentive policies at promoting the adoption of EV. A commonality between the studies in agreement is the variance in EV uptake depending on the resolution studied and consumer purchasing habits; revealing a multitude of factors aside from financial incentives contribute to EV adoption such as program longevity, non-financial incentives, and method of financial reimbursement. The few studies in disagreement all provide a note of caution that their correlative results are not evidence of a causal relationship, particularly as it relates to an industry experiencing radical innovation.

Literature from the user and policy perspective concurs that financial incentives are effective at increasing EV market share however, studies have not extensively explored the cost-effectiveness of EV incentive programs against their GHG benefit. This inquiry aims to do so by quantifying the in-use lifecycle GHG emissions from the increased EV market share with provincial carbon prices.

3. Carbon pricing: Policies and impact on Market share

Literature has shown that carbon pricing can be a cost-effective instrument to mitigate GHG emissions (Andrea Baranzini, 2017) (Boyce, Carbon Pricing: Effectiveness and Equity, 2018). It encourages conservation and substitution for both households and industries by internalizing the external cost of carbon production. The prospects of rising carbon prices also promote innovation of GHG intensive activities in the long term (Boyce, Carbon Pricing: Effectiveness and Equity, 2018).

Mirroring economists' agreement on the case for carbon pricing but disagreement on policy mechanisms, the provinces of British Columbia, Quebec, Ontario (as of July 2017), and Alberta all have their own forms of carbon pricing. British Columbia was the first to introduce a carbon tax and revenue recycling scheme in 2008. Its carbon tax has been assessed to have had a modest impact on the level of Greenhouse Gas emissions and no net negative economic and employment impacts on the province (Yamazaki, 2017) (Elgie, 2012) (Nicholas Rivers, 2015). Additionally, the carbon tax has been found to be progressive such that below-median income households are affected less than above-median income households despite criticism from analysts stating that low-income earners would be most affected (Marisa Beck, 2015). Quebec and the state of California have a joint cap-and-trade system. Ontario previously participated in this system, but the province's newly elected government dismantled the province's cap-and-trade policy in July 2017. Cap-and-trade systems are regarded as being more politically favourable than a carbon tax but present the opportunity to allocate permits freely to industry (Harrison, A Tale of Two Taxes: The Fate of Environmental Tax Reform in Canada, 2012).Alberta has a carbon price on emissions from large industrial emitters since 2007 but has expanded the tax to broader sectors in 2017. The other 6 Canadian provinces remain without a carbon pricing regime until 2019 when Canada's federal government introduces a standard carbon pricing scheme.

Carbon pricing policy, as any other mitigation policy, can be politically unfavourable and mis-designed to be counterproductive. Two major concerns arise with the first being carbon leakage (when industry chooses to move production to other jurisdictions with more lax emissions constraints) (Hanna Wang-Helmreich, 2019) and the second being the decreasing competitiveness of domestic energy intensive trade exposed (EITE) firms (Christoph Bohringer, 2017). In line with these concerns, Liu et al (2017) analyzed the macroeconomic impacts of the carbon tax on Saskatchewan, a petroleum and coal intensive economy, and found that GHG emissions and provincial GDP will decrease due to consumption reduction, income decline, and import increase. Saskatchewan is a province with little opportunity for fuel switching and they suggested that carbon tax revenue should support clean coal and petroleum technologies to realize GHG emission reduction targets and minimize provincial GDP decline (Lirong Liu, 2017). Carbon pricing and policies that support innovative technology are largely complementary and are both necessary to minimize carbon leakage and reinvent carbon polluting industries to meet aggressive GHG mitigation targets (Andrea Baranzini, 2017) (Boyce, Carbon Pricing: Effectiveness and Equity, 2018).

Carbon pricing often falls below the social cost of carbon (SCC) which is calculated from integrated assessment models weighting the benefits of mitigation against its cost as prescribed by future emissions predictions (Boyce, Carbon Pricing: Effectiveness and Equity, 2018). Wang et. al (2019) conducted a meta-analysis of recent literature on SCC and concluded that there was a large gap among values that ranged from -13.36 to $2378.91/ CO2 eq tonne, averaged to $54.70/ CO2 tonne eq, and appeared to increase in more recent studies due to an increase in cautionary assumptions (Pei Wang, 2019). As the SCC is commonly denoted in monetary units of US dollar, the average SCC is evaluated at $72 CAD/ CO2 tonne eq.

In Canada's political climate, there is a disconnect between climate change research and policy. The proposed $20 / tonne CO2 eq price point is viewed contentiously despite SCC research deeming it too low to meet Paris Agreement targets (Andrea Baranzini, 2017). This suggests that over-supplementing the GHG reduction effort with more politically favourable mitigation policies is a necessity.

But to over-supplement at what cost. Carbon pricing and EV incentives have the same objectives; they aim to reduce the impacts of climate change through the reduction of GHG emissions. However, EV policy research consistently fails to consider local carbon pricing or SCC within their scopes. The role of carbon pricing legislation is to internalize the external cost of carbon pollution and if EV incentive policies neglect comparing the resulting GHG savings to the carbon price, there will be a discrepancy which demonstrates that the GHG savings are either over-valued, under-valued, or incorrectly valued.

Therefore, there is a dire need for research studies to tie together related mitigation policies. The utility of increasing EV adoption is predicated on research which demonstrates relative GHG reduction through EV lifecycle assessments. The value amount of EV incentive offerings is based on research which models the consumer's willingness-to-pay for EV. The policy mechanisms of financial investments are decided upon through the examination of case studies. However, a holistic financial evaluation of EV GHG reduction is crucial for policy makers when determining both the scale and feasibility of EV incentive programs offerings and as a factor when determining an appropriate price for carbon emissions. This evaluation is missing from current research and thus this inquiry aims to contribute to this gap and utilizes

4. Methodology

It should be noted that the scope of this inquiry is limited to Canadian provinces that: 1) have offered direct financial EV incentives, and 2) have a carbon price estimation. As a result, British Columbia, Ontario and Quebec are the focus provinces and only financial EV incentives (no EV charging rebates) are included in this study.

The first stage of the inquiry estimates the operational Well-to-Wheel GHG emission associated with the life of all new passenger vehicles sold from 2013 to 2018; years with active EV incentive programs for all provinces. The lifetime per vehicle is estimated to be 15 years thus, the 6 years of EV incentive offerings result in 20 years (2013-2033) of potential GHG emissions offset due to EV market share increase. Data used for this stage includes new passenger-vehicle sales, which is a proportion of ICEV and EV, vehicle kilometre travelled (VKT) per vehicle per year, and average ICEV and EV fuel and electricity consumption based on passenger-vehicle model types (compact, full-size, mid-size, mini-compact, station wagon, two-seater). These inputs derive an estimated lifetime GHG emissions generated from current EV and ICEV sold from 2013-2018.

The second stage identifies the estimated difference between annual GHG emissions for ICEV and the GHG emissions offset due to EV adoption by subtracting the lifetime GHG emissions assuming 100% ICEV market share using the method outlined in the first stage. The last stage of the inquiry compares the cost of GHG reduction based on EV incentives against the carbon price in each province. The estimation of each stage and the inputs and data sources are detailed in the Figure 1 and Table 1 below.

Figure 2: Methodology overview

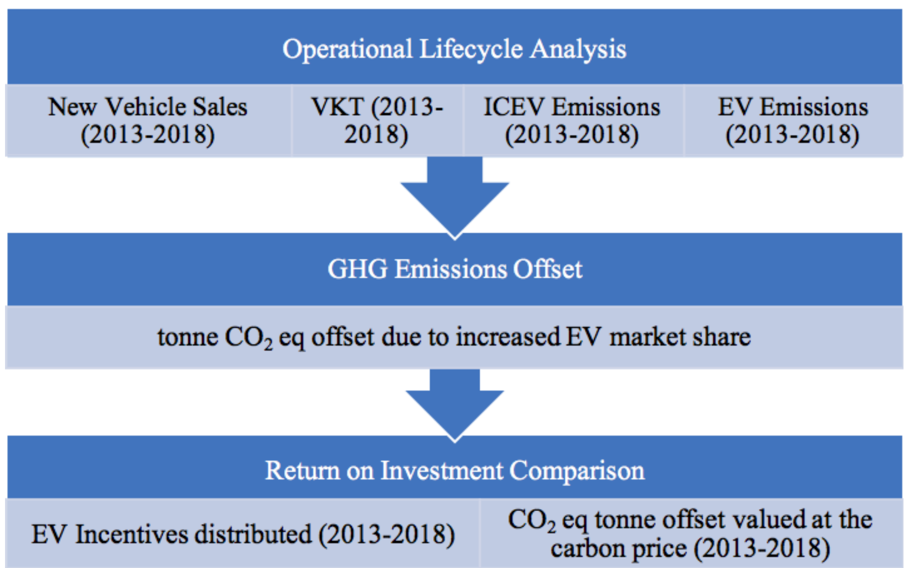


Table 1: Data sources

Input	Dataset
Annual new passenger vehicles sales (values exclude minivans, sport-utility vehicles, light and heavy trucks, vans and buses) for 2013-2018, per province.	New motor vehicle sales, by vehicle type, (Statistics Canada, 2019).
Annual BEV and PHEV sales for 2013-2018 per province.	EV Sales in Canada, Year-end Update, (Fleetcarma, 2018).
Provincial VKT for 2013-2018. Assumed to equal 2009 provincial rates.	VKT per province, annual, (2000-2009), (Canadian Vehicle Survey, 2009).
GHG intensity of electricity generation per province for 2013-2016. 2016-2018 values assumed to equal 2016 values.	Electricity Generation and GHG Emission Details for Canada, (Environment and Climate Change Canada Data, 2016).
2.29 kg of CO2 released per litre gasoline burned. Same value is assumed to apply per province from 2013-2018.	(Canada Natural Energy Board, 2018).
Average combined (highway and city driving) gasoline/electricity consumption of ICEV, BEV, and PHEV, per model year (2013-2018). Passenger vehicles averages (compact, full-size, mid-size, mini-compact, station wagon, subcompact, two-seater) were equally weighted and values were assumed to be the same in all provinces.	Fuel Consumption Ratings (2013-2018), per light-duty vehicle model type, (Natural Resources Canada, 2019).
Provincial EV Incentives British Columbia: BEV $5000 / PHEV $2500 (2013-2018); Quebec: BEV: $8000, $3000 / PHEV $500, $4000, $800 (2013-2018); Ontario: BEV $11000 - $14000 (2018) / PHEV: $5000-$14000 / BEV and PHEV $5000 - $85000 (2013-2018).	British Columbia: (2018 Eligible Vehicle Customer Handout, 2019) Quebec: (Transition énergétique Québec, 2018) Ontario: (Incentives and Eligible Vehicles under the Electric and Hydrogen Vehicle Incentive Program, 2018; Ontario Newsroom, 2010).
British Columbia Carbon Price: Carbon Tax of 30$/t CO2 eq (2013-2017) / 35$/t CO2 eq (2018). Quebec Carbon Price: the highest of the average or median quarterly auction bid price, averaged, for an annual carbon price (2013-2018). Ontario Carbon Price: the highest of the average or median quarterly auction bid price, averaged, for an annual carbon price (2017-2018). Carbon price between 2013-2016 assumed to equal the average 2017 value.	British Columbia: (British Columbia's Carbon Tax, 2019). Quebec: (The Carbon Market, 2019). Ontario: (Past auction information and results, 2018).

The operational lifecycle analysis component was completed under the following assumptions:

- Estimated lifespan of all vehicles is 15 years;
- Annual VKT is assumed to be constant per province based on historic VKT data and VKT is assumed equal for ICEV and EV within each province;
- GHG intensity of electricity generation varies across provinces yet remains constant over time for all provinces due to negligible change throughout the analysis period (2013-2018);
    - i.e. EV sold in 2013 in British Columbia assumes an electricity GHG intensity of 1.09 kt CO_2 eq/kWh for their 15-year lifetime and EV sold within the province in 2014 assume 1.07 kt CO_2 eq/kWh.
- Electricity generation intensity values have not been adjusted to include distribution losses;
    - marginal regional grid GHG intensity, vehicle size, driving pattern, loading, etc. are out of the scope of this study.
- EV incentives in British Columbia have been $5,000 per BEV and $2,500 per PHEV throughout 2013-2018. The range of incentives in Ontario and Quebec are dependent on battery capacity and propulsion type;
    - In Ontario for 2018 and 2017 models, incentives were averaged and assumed to be $13,353 and $13,444 for BEV and $9,000 and $8,731 for PHEV in 2017 and 2018 respectively. BEV and PHEV for remaining model years were estimated to be an upper average and a lower average of $5,000-$8,500 respectively.
    - For Quebec the same average incentive value was used for all model years. BEV offers ranged from $3000-$8000 and PHEV offers ranged from $500-$8000.
- EV incentives are assumed to be distributed to 100% of the EVs sold;
- Emissions offset through leased EV were not considered within the study's scope;

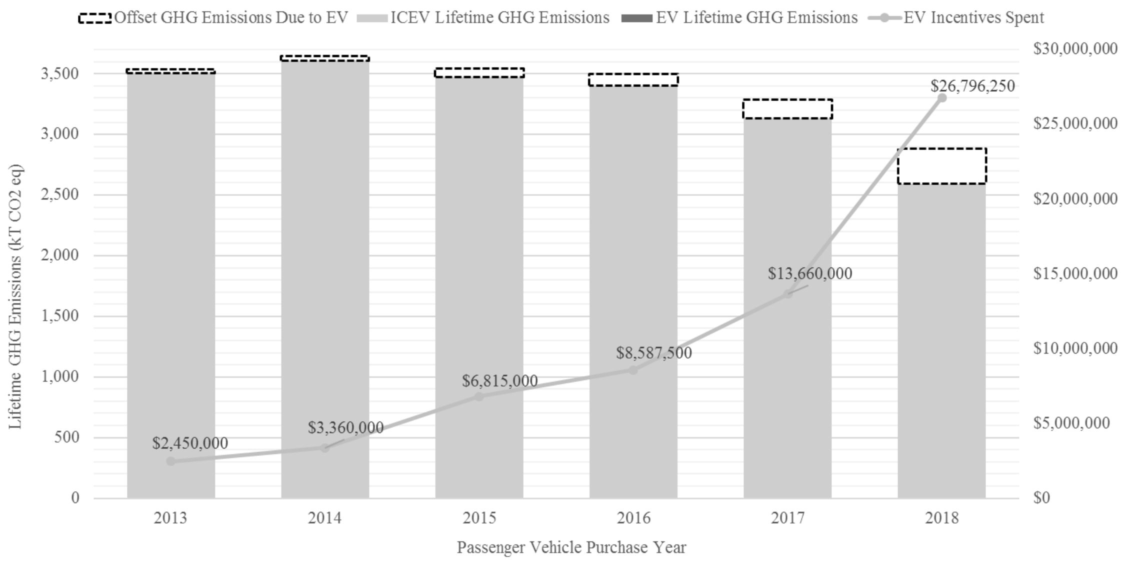
5. Results

Estimated GHG emissions from 2013 to 2018 as a result of EV incentive programs is shown in Figure 2 for British Columbia, Ontario, and Quebec respectively. However, as highlighted in the methodology, the GHG benefit of EVs is extended through the lifetime of the vehicle, which is assumed as 15 years in this study. As expected, the GHG benefit of EV could be clearly seen over the vehicle's lifetime due to low carbon intensity in the electricity generation profile.

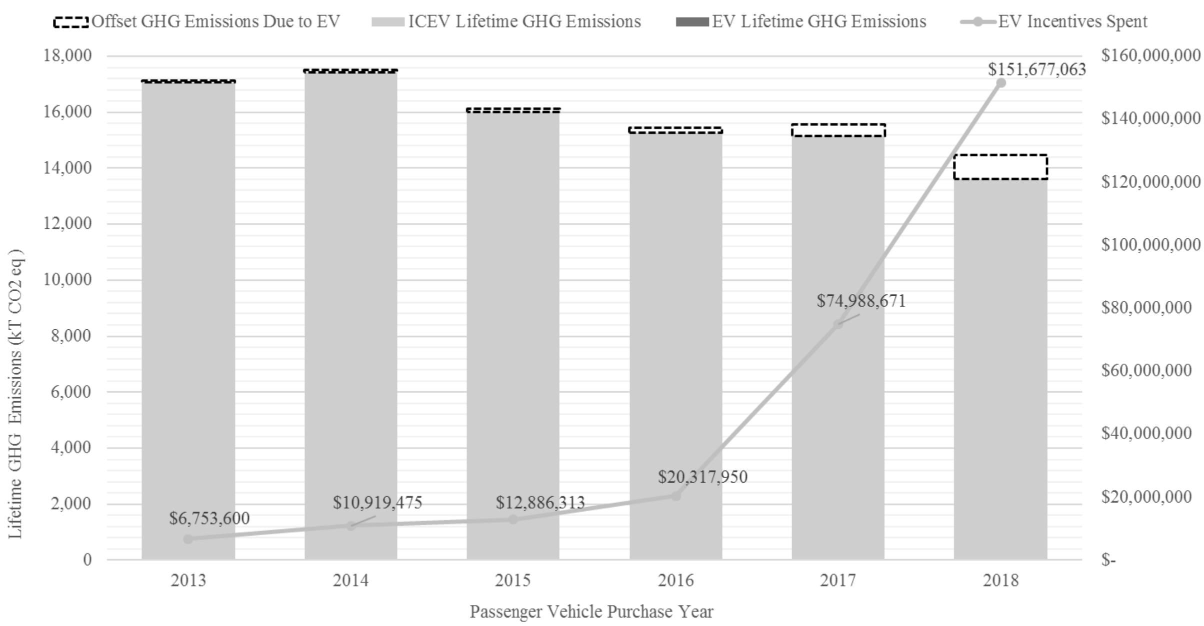
All three provinces have low electricity intensity (British Columbia: 9.2 – 11.1 kg CO_2 eq/ kWh -, Ontario: 36-66 kg CO_2 eq/kWh, Quebec: 1.1-2 kg CO_2 eq/kWh) resulting in EV emitting 0.1-4.0% (BEV: 0.1-3.5% / PHEV: 0.2-4.6%) of the GHG that comparative ICEV emit and thus resulting in lower GHG emissions from new passenger vehicles.

Figure 3: Estimated operational lifetime GHG emissions (kT CO_2 eq) and associated EV incentives from new passenger vehicles sold in (a) British Columbia, (b) Ontario, (c) Quebec.

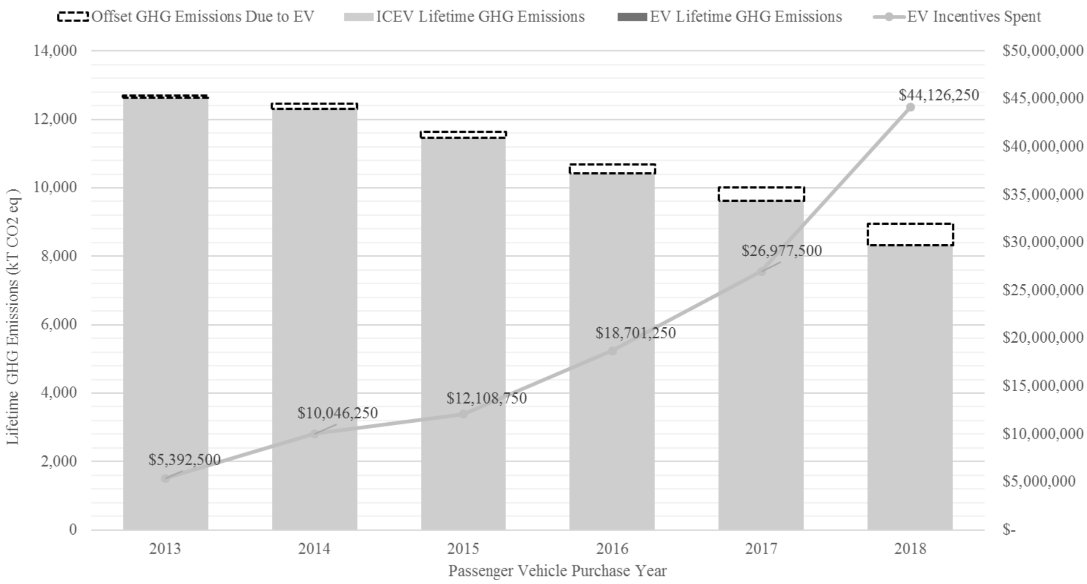
(a): British Columbia



(b): Ontario



(c): Quebec



However, the amount of EV incentive spending to achieve these GHG reductions varies significantly between provinces. Figure 3 presents the value of the estimated GHG emissions offset due to increased EV market share of the provinces and the value of the estimated EV incentives distributed.

In all three provinces, the EV incentives per unit reduction of GHG is significantly higher than the carbon price. Table 2 provides clear values of the accumulative GHG reduction resulting from the adoption of EV. The values include the lifetime of vehicles sold between 2013-2018, resulting in accumulative GHG reduction until 2033. All provinces overspent on their GHG savings in relation to their provincial carbon price evaluation. Ontario overspent by $241 million, Quebec by $85 million and British Columbia by $40 million.

Figure 4: EV Incentive distributed and the carbon priced value of corresponding GHG emissions offset, per province

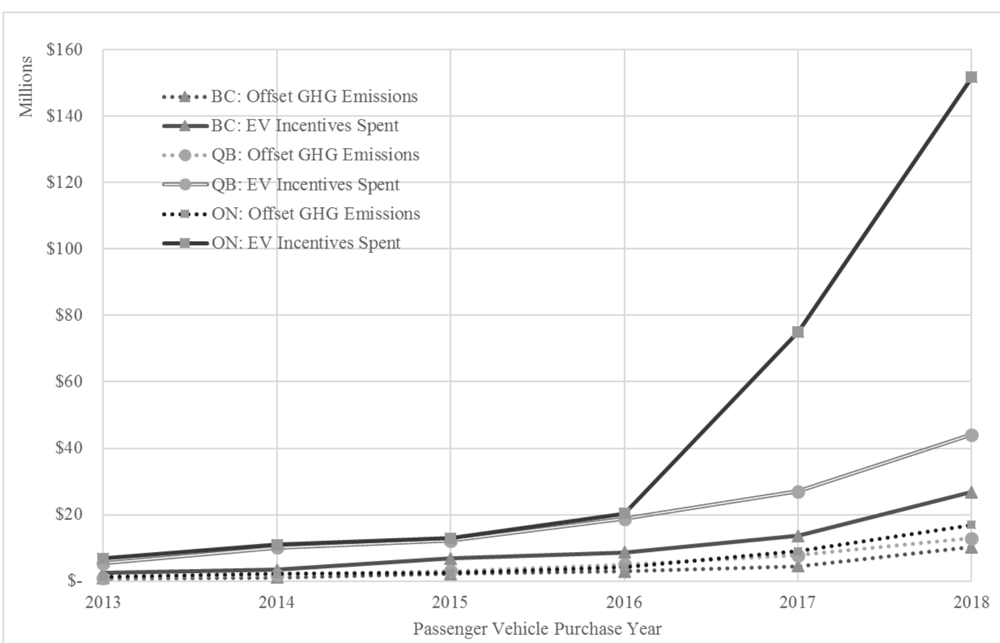


Table 2: Accumulated EV incentives and GHG emissions offset from EV in British Columbia, Ontario, Quebec

Vehicle Lifetime	***Accumulated GHG Emissions Offset Due to EV (kT $CO_{2\ eq}$)***	***Accumulated Value of GHG Emissions Offset (Millions CAD)***		***Accumulated EV Incentives Distributed (Millions CAD)***	
2013-2028	164.76	$	3,076,507.59	$	14,596,100.00
2014-2029	278.69	$	5,121,597.25	$	24,325,725.00
2015-2030	354.28	$	7,625,782.64	$	31,810,062.50
2016-2031	554.46	$	12,000,437.92	$	47,606,700.00
2017-2032	942.55	$	21,179,052.09	$	115,626,171.40
2018-2033	1768.27	$	39,965,900.13	$	222,599,563.00
Total	4063.01	$	88,969,277.62	$	456,564,321.90

6. Conclusion

EV incentives are associated with increased EV market uptake in Canada, however the amount of EV incentives distributed needs to be evaluated against the potential value of the GHG emissions offset to ensure that the return on public money invested is maximized. The only financial value of carbon emissions currently effective in these three Canadian provinces is the carbon tax. However, the quantity of incentives distributed in all three provinces through 2013-2018 significantly vary, and out values the carbon value of the estimated GHG emissions offset. The findings of the inquiry highlight the disconnect between these two GHG mitigating policies signaling a low evaluation of the current price of carbon and a disproportionally high rate of EV financial incentive distribution.

Carbon pricing has been shown to be a cost-effective instrument to mitigate GHG emissions since it encourages conservation and substitution for both households and industries by internalizing the external cost of carbon and funding complementary technology-specific policies (Baranzini et al., 2017; Boyce, 2018). However, the price of carbon in Canada consistently falls below the social cost of carbon (SCC), which is calculated from integrated assessment models weighting the benefits of mitigation against its cost as prescribed by future emissions predictions (Boyce, Carbon Pricing: Effectiveness and Equity, 2018). Wang et. al (2019) conducted a meta-analysis of recent literature on SCC and found the average SCC is \$54.70/ t CO_2 eq and appeared to increase in more recent studies due to cautionary assumptions (Wang et al., 2019). As the SCC is commonly in USD, the average SCC is evaluated at \$72 CAD/ t CO_2 eq, outvaluing the provinces \$12-\$35/t CO_2 eq carbon price through 2013-2018 and outvaluing the current federal plan of a minimum \$50/t CO_2 eq by 2021. Furthermore, even if the accumulated GHG emissions offset is valued at the SCC, the value of GHG incentives distributed still significantly outvalues this financial evaluation.

GHG mitigation funding is limited and determining an equitable amount for EV incentives is crucial. Understandably, increasing the price of carbon is politically unfavourable and policy can be mis-designed to be counterproductive. While financial incentives are highly effective in increasing EV adoption, there are other cost-effective measures that can increase EV adoption which can be further promoted (Kester et al., 2018; Jenn et al., 2018; Axesn et al., 2016; Eppstein et al., 2011). For example, EV mandates placed on vehicle retailers and manufactures, requiring them to meet certain EV sale targets and internally subsidize the MSRP of EV through ICEV profit streams, can be effective (Sykes et al., 2017). Other non-financial methods are also effective such as increased awareness of EV benefits (reduced operational cost, green plate benefits, HOV access, etc.) and continued spending on public charging infrastructure to combat consumer’s primary issue with EV, range anxiety, are very important to expedite EV adoption (Ferguson et al., 2018; Melton et al., 2017; Z. Lin, 2011).

While this study provides a high-resolution estimation of operational lifecycle emissions from ICEV and EV, it highlights the financial discrepancy between two policies that should be complimentary and the need to re-evaluate current EV incentive offerings. A blend of policies financial, non-financial, and regulative policy is politically necessary to support EV adoption, however more cost-effective strategies need to be further explored to increase the GHG emission offsetting effectiveness of public money.

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