Major Research Paper

Track Record of Zero-Emission Vehicle Mandates in Canada and the United States

Jonathan Gendron-Rossignol

Student Number: 5699434

Supervisor: Professor Nicholas Rivers

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Graduate School of Public and International Affairs

University of Ottawa

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Abstract

In 2018, the road transportation sector accounted for 22 and 28 percent of Canada and the United States' GHG emissions, respectively (Environment and Climate Change 2020, 21; U.S. Environmental Protection Agency 2020). To mitigate those emissions, several Canadian provinces and US state governments have deployed zero-emission vehicle (ZEV) mandate regulations which require vehicle manufacturers to sell an increasing percentage of ZEVs as part of their total sales. This study investigates whether ZEV mandates have been effective at promoting ZEV adoption and availability in subnational jurisdictions in Canada and the US. Three findings emerge but with important caveats. First, jurisdictions with ZEV regulations appear to have on average higher ZEV adoption and availability than their counterparts without such regulations. However, there is insufficient evidence to establish a clear link between regulations and ZEV adoption and availability. Second, there is a pattern of increased ZEV adoption following the adoption and implementation of a regulation. However, there are several inconsistencies in this pattern and there are many other factors that could influence ZEV adoption, including the introduction of popular new ZEV models, varying consumer preferences, declining ZEV prices and the potential impact of other environmental policies. Third, jurisdictions with more stringent ZEV regulations may experience greater ZEV adoption and availability in the long term. However, all the ZEV regulations in the US have similar stringency. Overall, British Columbia has the most stringent regulation. However, the added stringency of its compliance requirements only take effect starting in 2026. Therefore, it remains unclear whether this added stringency is responsible for greater ZEV adoption and availability in the province.

Jonathan Gendron-Rossignol
5699434

Track Record of Zero-Emission Vehicle Mandates in Canada and the United States

1. Introduction

In 2018, the road transportation sector accounted for 22 and 28 percent of Canada and the United States' GHG emissions, respectively (Environment and Climate Change 2020, 21; U.S. Environmental Protection Agency 2020). Of these emissions, 48 percent in Canada and 59 percent in the US were produced by light-duty internal combustion engine vehicles (ICEVs) (Environment and Climate Change 2020; U.S. Environmental Protection Agency 2020). Evidence suggests that transitioning to zero-emissions vehicles (ZEVs) is an effective approach to curb these emissions ("Energy Technology Perspectives 2020" 2020; Kamiya, Axsen, and Crawford 2019). ZEVs are generally understood to include battery-electric, plug-in hybrid electric and hydrogen fuel cell vehicles (Transport Canada 2020).

Canadian provincial and US state governments have deployed several policies to support greater adoption of ZEVs in their respective markets. A key example is a ZEV mandate regulation which requires vehicle manufacturers to sell an increasing proportion of ZEVs as part of their total sales. The first ZEV mandate was established in California in 1990 and similar policies have since been either adopted or announced in fifteen other US states as well as the Canadian provinces of Quebec and British Columbia. Several studies suggest that a federal ZEV mandate in Canada, combined with other policies, could be an effective approach for a transition to ZEVs to help meet GHG emissions reduction targets (Melton, Axsen, and Moawad 2020; Rivers and Wigle 2018; Axsen, Plötz, and Wolinetz 2020). ZEV mandates are found to be effective because they can help address supply-side barriers to ZEV adoption, namely in terms of model availability and dealership inventory (Melton, Axsen, and Moawad 2020, 3).

This study assesses whether ZEV regulations have been effective at increasing ZEV adoption and availability in sub-national jurisdictions in Canada and the US. The hypothesis is that there is a relationship between ZEV regulations and ZEV adoption and availability. This hypothesis has three components:

1. Jurisdictions with ZEV mandates have on average higher ZEV adoption and availability than their counterparts without such regulations in place;
2. There is a significant increase in ZEV adoption and availability following the adoption and implementation of a ZEV regulation;
3. Jurisdictions with more stringent ZEV regulations have greater ZEV adoption and availability.

The main finding of this study is that there appears to be a relationship between ZEV regulations and ZEV adoption and availability. However, there is insufficient evidence to attribute these changes to regulations. Moreover, some jurisdictions with pre-existing high rates of ZEV uptake and availability adopt regulations. Secondly, there appears to be a pattern of increased ZEV adoption following the announcement and implementation of a ZEV regulation. However, there are several inconsistencies with this pattern and there are potentially many other explanations for these increases. Third, jurisdictions with more stringent ZEV regulations may experience greater ZEV adoption and availability in the long term. However, ZEV regulations in the US have similar stringency and British Columbia's more stringent requirements are only effective starting in 2026.

This analysis has eight sections including this introduction. Section 2 is a review of the literature on ZEV regulations. Section 3 covers the methods used to compare ZEV regulations and assess their impact in subsequent sections. Section 4 provides a brief history of ZEV regulations and then compares said regulations in Canada and the US. Sections 5 provides an overview of ZEV purchase subsidies to keep track of their potential influence on ZEV adoption and availability. Sections 6 and 7, compare ZEV adoption and availability between jurisdictions in Canada and the US. Section 8 recaps on the findings and provides a discussion of the study's limitations.

2. Literature Review

The main approaches to reduce road transport GHG emissions are: switching to low-carbon fuels, increasing vehicle energy efficiency and reducing vehicle travel (Axsen, Plötz, and Wolinetz 2020). To implement those approaches, three kinds of policies are generally used: price mechanisms (e.g. carbon tax, ZEV purchase incentives), regulations that target certain emission pathways (e.g. vehicle emission standards, ZEV mandate), and policies that aim to reduce vehicle travel (e.g. promoting public transit, building bike lanes, supporting teleworking) (2020).

2.1. Assessments of ZEV Regulations

There are five criteria commonly used in the literature to assess policies aiming to reduce transport-related GHG emissions (Bhardwaj et al. 2020; Melton, Axsen, and Moawad 2020): 1) effectiveness, 2) cost-effectiveness, 3) political acceptability, 4) policy simplicity, and 5) transformational signal. As discussed below, ZEV mandate regulations have the potential to perform well on most of these criteria.

2.1.1. Effectiveness

Effectiveness is a policy's ability to contribute to mitigating GHG emissions (Bhardwaj et al. 2020, 316). ZEV mandates are widely believed to be among the most effective policies to increase ZEV adoption and, by doing so, mitigate transport GHG emissions (Melton, Axsen, and Moawad 2020; Axsen, Plötz, and Wolinetz 2020; Rivers and Wigle 2018; Bhardwaj et al. 2020). Based on modelling studies, a stringent ZEV mandate (e.g. 40% ZEV market share by 2040) is found to be among the most effective policies at reducing long-term GHG emissions in the transportation sector (Melton, Axsen, and Moawad 2020; Melton, Axsen, and Goldberg 2017).

The main benefit of a ZEV mandate is that it establishes a mandatory requirement for vehicle manufacturers to transition to ZEVs. While other policies can promote greater vehicle fuel efficiency or low-carbon fuels, they do not necessarily support a transition away from gasoline and diesel (Melton, Axsen, and Moawad 2020, 12). In many cases, making ICEVs more efficient remains a cheaper option for vehicle manufacturers in the short term and they may not have as much incentive to retool their production lines and invest in ZEV development in the absence of a mandate (Jenn et al. 2019, 572). On the other hand, a ZEV mandate offers no incentives for improving the GHG performance of the existing vehicle stock since it only focuses on new vehicles. Accordingly, a ZEV mandate is most effective when combined with other policies supporting ZEV adoption (e.g. purchase subsidies) as well as policies aiming to reduce the GHG emissions of ICEVs (e.g. low-carbon fuel standard and a vehicle emission standard) (Melton, Axsen, and Goldberg 2017; Melton, Axsen, and Moawad 2020; Rivers and Wigle 2018).

However, a recent study in the US has found that combining a ZEV mandate with a vehicle emission standard can potentially contribute to ZEV adoption while resulting in greater GHG emissions (Jenn, Azevedo, and Michalek 2019). This can occur when the credits obtained by vehicle manufacturers for the sale of ZEVs can also count towards the credit system of the vehicle emission standard (2019). The net effect is that more ZEVs are sold while enabling greater leniency on the fuel efficiency of ICEVs (2019). Therefore, it is important to account for policy interactions when designing a ZEV mandate as the combined effect can potentially result in greater GHG emissions (2019).

2.1.2. Cost-Effectiveness

Cost-effectiveness is measured as the cost per tonne of GHG abated (Bhardwaj et al. 2020, 316). On its own, a ZEV mandate regulation for light-passenger vehicles is estimated to be among the most expensive policies for the Canadian economy, topped only by purchase subsidies (Rivers and Wigle 2018, 11). Although a ZEV mandate should not require much government spending, it is likely to result in significant costs for affected vehicle manufacturers (Melton, Axsen, and Moawad 2020, 10). Canadian households and businesses will likely incur additional costs as ZEVs are sold at a higher price on average. Vehicle manufacturers are also likely to increase the price of ICEVs to absorb the added expenses of producing and selling greater numbers of ZEVs (Rivers and Wigle 2018, 1). However, these costs can potentially be mitigated if a ZEV mandate is combined with a strong low-carbon fuel standard due to their mutually reinforcing interactions (Rivers and Wigle 2018, 12–13). The low-carbon fuel standard increases the cost of fossil fuels and, combined with the ZEV mandate, leads to greater ZEV adoption which in turn lowers the costs of compliance to the fuel standard for manufacturers due to the lower proportion of ICEVs on the road (2018, 12–13). Alternatively, a stringent ZEV mandate of 40 percent adoption by 2040 accompanied by short-term purchase incentives is also an effective policy package but at a potentially higher cost for governments than a fuel standard (Melton, Axsen, and Moawad 2020, 11–12).

2.1.3. Political Acceptability

Political acceptability is whether citizens and other key stakeholders (e.g. other levels of government, vehicle manufacturers) support or oppose the policy (Bhardwaj et al. 2020, 316). In a study comparing the public support for various policies targeting passenger vehicles in Canada and California, ZEV mandate had the second lowest level of public support after a low-carbon fuel standard and a vehicle emission standard, and only above a carbon tax (Long, Axsen, and Kitt 2020, 110). Awareness was also the lowest among supply-side policies surveyed (2020, 111). However, public support for a ZEV mandate varies based on the stringency of the policy and the jurisdiction surveyed (2020, 111). Varying between provinces, 34 to 55 percent of Canadians were in favour of a strong mandate of 100 percent ZEV adoption by 2040, which is British Columbia's target, with slightly higher levels support for a less stringent policy of 30 percent adoption by 2030 (2020, 111). Support was generally higher in jurisdictions with a ZEV mandate in place, namely Quebec and British Columbia, and was the lowest in Alberta (2020, 107). Industry support for a ZEV is likely to be even less enthusiastic due to the significant costs of switching from producing ICEVs to ZEVs. Accordingly, political pushback is likely to be greater in states and provinces where the automobile industry represents a large part the economy and have more clout, such as Ontario in Canada and Michigan in the US (Melton, Axsen, and Moawad 2020, 13). Similarly, there is likely to be more opposition in provinces whose economies are still very reliant on fossil fuels, for example Alberta and Saskatchewan in Canada and Texas in the US. An analogous pattern has been the opposition from Alberta, Saskatchewan and Ontario when the Canadian federal government introduced the carbon tax in 2018 as part of the Pan-Canadian Framework on Clean Growth and Climate Change.

2.1.4. Policy Simplicity

Policy simplicity is defined as the "requirement for drafting new legislation, coordination within government, and monitoring and enforcement" (Melton, Axsen, and Moawad 2020, 5). A ZEV mandate is relatively complex to establish, monitor and enforce. This is due to the credit system used to calculate the progressively increasing sale requirements which vary according to the types of vehicle sold and the size of the vehicle manufacturer (Melton, Axsen, and Moawad 2020, 10; Moawad and Wolinetz 2019). Also, each vehicle manufacturer must submit yearly reports on their ZEV sales activities as well as any credits they bank or trade with other manufacturers. All of this must be monitored by governments who must also enforce penalties for non-compliance. The complexity of ZEV mandates can be an issue in securing buy-in from the various stakeholders, and maintaining transparency and trust which is important for public support (Long, Axsen, and Kitt 2020, 112).

2.1.5. Transformational Signal

The transformational signal of a policy is whether it provides added stimulus to stakeholders across the economy for a transition to a low-carbon economy. This includes simulating research and development, infrastructure innovation and pathway directionality (2020, 5; Bhardwaj et al. 2020, 316). A ZEV mandate is found to send the strongest transformational signal relative to other policies in terms of directionality, namely regarding investment towards ZEV development and commercialization (Melton, Axsen, and Moawad 2020, 10). By signalling a clear and long-term government commitment towards greater ZEV adoption, a mandate also helps overcome the previous cycles of “hype and disappointment” regarding alternative fuels previously created by government, industry and other stakeholders without proper policy backing (Melton, Axsen, and Sperling 2016). In fact, a technology-specific mandate that focuses on plug-in electric vehicles is said to bring earlier technological breakthroughs and improve the long-term cost-effectiveness of the policy compared to a technology-neutral mandate (Fox, Axsen, and Jaccard 2017, 145). However, there is risk in a technology-specific approach if it mistakenly “puts all its eggs” on a long-term technology that ends up being more expensive (2017, 145).

In sum, a stringent ZEV mandate is understood to be both effective and cost-effective when combined with the appropriate ZEV policies, politically supported to varying degree depending on the jurisdiction, complicated for governments to administer, and capable of sending a strong transformational signal. However, the main potential contribution of a ZEV mandate is arguably its ability to address supply-side barriers to ZEV adoption. This is what this study aims to investigate further.

2.2. Addressing Supply-Side Barriers

Policies can be understood as demand-focused by encouraging ZEV purchase (e.g. financial and non-financial incentives) or supply-focused by encouraging ZEV production and sale (e.g. ZEV regulation) (Melton, Axsen, and Goldberg 2017, 1). A ZEV mandate regulation is supply-focused because it targets vehicle manufacturers and has the potential to address supply barriers to ZEV adoption. Two of the most prevalent barriers are ZEV model variety and dealership inventory (Melton, Axsen, and Moawad 2020, 3).

Model variety is the availability of ZEV across different class of vehicles. Past modelling studies have found that limited variety of ZEV models can be a barrier to higher adoption rates (Greene, Park, and Liu 2014, 46–47; Wolinetz and Axsen 2017). Others have also found that US cities with greater model availability tended to have higher ZEV adoption than their counterparts with lower availability (Lutsey et al. 2015, 5). As of January 2021, there are only 22 non-luxury plug-in electric vehicles (below CAD 50,000) available in Canada (PlugNDrive Buyer's Guide 2021). In the US, there are 32 non-luxury plug-in electric vehicles (below USD 50,000) are currently available (Alliance for Automotive Innovation 2021; EV Adoption 2020). This is important since model variety, along with price and range, were found to correlate directly with greater ZEV adoption in a study covering 31 countries, including the US (Kim, Lee, and Lee 2017). Model variety is also particularly important in the Canadian and US markets where SUVs and light-duty pickup trucks represented close to 70 percent of new vehicle registrations in both markets in 2019 (Statistics Canada 2021; IHS Markit 2020). However, most ZEVs currently available are sedans. As of January 2021, only six SUVs and pick-up truck models of non-luxury plug-in electric vehicles (below CAD 50,000) are available in Canada (PlugNDrive Buyer's Guide 2021). In the US, fourteen SUVs and pick-up truck models of non-luxury plug-in electric vehicles (below USD 50,000) are available (EV Adoption 2020). Assuming Canadian and US consumer preferences remain consistent over the coming decades, ZEV manufacturers will have to substantially increase their model offering to go beyond the early adopters and reach mainstream customers.

Limited ZEV inventory at dealerships is also a critical barrier to wider adoption. Studies in Canada and the US have shown that most dealerships have little or no inventories of ZEVs (Le and Linhardt 2019; Dunsky Energy Consulting 2020; Matthews et al. 2017). Similarly, other studies have shown that dealerships were often dismissive or uninformative about electric vehicles, and would attempt to orient customers towards ICEVs instead (Zarazua de Rubens, Noel, and Sovacool 2018; Le and Linhardt 2019). Dealerships were found to promote ICEVs at the expense of ZEVs due to the additional costs of supporting ZEV sales, such as providing maintenance services (e.g. battery replacement) and installing charging infrastructure (Le and Linhardt 2019, 12). Dealership willingness to sell, their knowledge of electric vehicles as well as on-site availability, were found to be key factors in a customer's purchase decision in Ontario as well as several northern European countries (Matthews et al. 2017; Zarazua de Rubens, Noel, and Sovacool 2018).

A ZEV mandate regulation with stringent long-term requirements can be hypothesized to help overcome these supply barriers in two ways. First, a ZEV mandate creates sales requirements for vehicle manufacturers which should incentivize them to ensure dealerships have sufficient inventory to at least comply with the requirements. The mandate can also create a deterrent via non-compliance penalties for manufacturers that do no sell sufficient ZEVs and are not stocking sufficient dealership inventory. Second, a ZEV mandate is believed to send a strong transformational signal, namely in terms of investment towards ZEV research, development and commercialization (Melton, Axsen, and Moawad 2020, 10). In principle, this should encourage vehicle manufacturers and dealerships to lower adoption barriers, namely by increasing the ZEV model variety on offer, stocking up on those models, and effectively marketing them to consumers (Sykes and Axsen 2017, 457).

3. Methods

This study aims to assess the impact of ZEV regulations in Canada and the US. However, it does not account for the types of change that a retrospective impact analysis of an environmental policy would generally aim to measure: (1) changes in GHG emissions, (2) environmental outcomes, (3) co-benefits, and (4) costs (Cropper, Morgenstern, and Rivers 2018, 359). Instead, this study attempts to measure if ZEV regulations are succeeding at delivering on a more immediate set of outcomes, namely ZEV adoption and availability. To achieve this goal, this analysis compares the ZEV mandate regulations in Canada and the US, and then investigates their impact on ZEV adoption and availability. Purchase subsidies are also considered since they are found to have an important influence on ZEV adoption (Azarafshar and Vermeulen 2020).

3.1. ZEV Regulation Comparison

The ZEV regulations in Canadian provinces and US states are analysed to provide an understanding how these regulations work and how they compare to one another, namely in terms of stringency. This analysis begins with a brief history of ZEV regulations. This is needed to explain how US states with ZEV regulations have adopted California's regulations while, in Canada, Quebec and British Columbia have distinct regulations. Accordingly, the remainder of the comparison focuses on California, Quebec, and British Columbia's regulations. The comparison is divided in three segments each covering different parts of ZEV regulations, based on the analysis by Moawad and Wolinetz (2019): (1) the mechanisms that enable vehicle manufacturers to earn compliance credits; (2) vehicle manufacturer classes and the application of compliance requirements; and, (3) over compliance, monitoring and penalties for non-compliance.

3.2. ZEV Subsidies Comparison

This section provides a quick summary of the relevant ZEV purchase subsidies adopted by jurisdictions in Canada and the US. Purchase subsidies are found to have a strong effect on ZEV adoption in Canadian provinces (Azarafshar and Vermeulen 2020). Several jurisdictions have adopted subsidies during the period included in this study to assess the impact of ZEV regulations. Therefore, subsidies that may have influenced the ZEV adoption data are analyzed in this study. Also, the amounts and eligibility criteria of these subsidies have been modified over the years. These changes are not accounted for in this study since the goal is only to be mindful of the potential influence of subsidies on ZEV adoption. Some regional organizations and municipalities offer ZEV purchase subsidies. These are not included since the ZEV adoption data is specific to Canadian provinces and US states, and not to municipalities.

3.3. ZEV Adoption Comparison

To attempt to measure the impact of ZEV regulations, a comparison of ZEV adoption is made between jurisdictions that have regulations (ZEV jurisdictions) and those that do not (non-ZEV jurisdictions), both before and after the regulations are adopted. This comparison is based on the World Bank's difference-in-differences policy impact assessment method (Gertler et al. 2016, 129). The year before the regulation is adopted (Year 0) is understood as a baseline (2016, 132). The baseline allows for the measurement of any potential changes in ZEV uptake in the year following a regulation's adoption (Year 1). In short, if there are differences between Year 0 and Year 1 as well as differences between ZEV jurisdictions and non-ZEV jurisdictions during the same period and subsequent years, this may suggest that ZEV regulations are having an impact on ZEV uptake (2016, 132). Lastly, ZEV regulations are generally adopted several years before sales requirements become enforced on manufacturers. This assumes that the regulation sends a transformational signal to manufacturers to begin the production and sale of ZEVs in preparation for future requirements. Accordingly, this assessment looks at changes in ZEV adoption following the adoption of a ZEV regulation but also pays attention to such changes following the subsequent enforcement of the regulation's sales requirements.

There are two main conditions for the applicability of this impact assessment method. First, the samples being compared should follow a relatively similar trend prior to the introduction of the studied policy. This is referred to as the "equal trends" assumption (2016, 136). In this case, ZEV adoption rates need to be relatively similar between ZEV and non-ZEV jurisdictions for two years before the adoption of a regulation (2016, 137). It is not clear that this analysis meets the condition for "equal trends" since some jurisdictions have generally higher rates of ZEV adoption (e.g. California, Quebec and British Columbia). Furthermore, ZEV sales data is not available for two years prior to the introduction of a regulation for many US states. Even so, this analysis can still provide a sense of whether differences in trend were present prior to or if they followed the adoption of regulations in some of the states. The second condition for a difference-in-differences assessment is that the trends should be relatively constant across all jurisdictions (2016, 141). In other words, aside from the impact of the regulations, there should not be other factors that can account for significant changes in ZEV adoption in some jurisdictions during the studied period. This condition may also not be met since several jurisdictions in Canada and the US have been adopting varying types of environmental policies since the 1990s, many of which have likely influenced ZEV adoption. Also, the growth of ZEV manufacturers like Tesla and the declining prices in ZEV technology have likely also contributed to ZEV uptake. As mentioned, the introduction of purchase subsidies will be included in this assessment but this is far from an exhaustive analysis as there are many other factors that could have influence changes in ZEV adoption and availability. Nonetheless, this comparison will provide a descriptive analysis of ZEV adoption between ZEV and non-ZEV jurisdictions.

ZEV adoption is assessed in Canada and the US separately using metrics that are different but comparable. In Canada, ZEV adoption is measured as the percentage of total new light-duty vehicle registrations that are ZEVs from 2011 to 2020. This data is collected from a convenience sample of jurisdictions which make their new ZEV registrations publicly available through Statistics Canada (2021). This includes Prince-Edward Island, Quebec, Ontario, Manitoba, Saskatchewan, and British Columbia and the three territories. In the US, ZEV adoption is measured as the percentage of total new light-duty vehicle sales that are ZEVs from 2008 to 2020. This data is also based on a convenience sample of ZEV sale estimates made publicly available by a private transport research firm (Alliance for Automotive Innovation 2021). This sample includes California, Colorado, Michigan, Minnesota, Montana, New York, Oregon, Texas, Vermont, Virginia, Washington, and Wisconsin. For this analysis, ZEVs entail battery electric vehicles, hydrogen fuel cell vehicles, and plug-in hybrid electric vehicles.

3.4. ZEV Availability Comparison

Regulation impact on ZEV availability is assessed by analyzing and comparing model variety and dealership inventory data between jurisdictions with and without ZEV regulations, in Canada and the US. The data is sourced from publicly available studies and reports. Because jurisdiction-specific data is relatively limited, a difference-in-differences assessment is not possible for ZEV availability.

4. ZEV Regulations

This section analyzes the different ZEV regulations adopted by sub-national jurisdictions in Canada and the US to understand how they function and compare their stringency. The potential variations in stringency between regulations could help account for differences in impact on ZEV adoption and availability. This comparison begins with a quick overview of the history of ZEV regulations in the US and Canada to help explain their evolution and current iteration.

4.1. Brief History of ZEV Regulations

The first ZEV sales requirement was introduced in 1990 as part of Section 1960.1 of Title 13 of the California Code of Regulations, known as the Low Emission Vehicle I regulation. This regulation has since been updated by the California Air Resource Board (CARB) through several iterations found under Sections 1962, 1962.1 and 1962.2 of Title 13 of the California Code of Regulations. The evolution of California's ZEV regulation is summarized in Table 1.

The original 1990 regulation required manufacturers to have a specific percentages of passenger cars and light-duty trucks certified as ZEVs for 1998 to 2003 and subsequent model years (California Air Resources Board 1990; 2021). From the outset, the CARB acknowledged that several issues needed to be addressed prior to the effective implementation of the requirements, namely the state of commercial ZEV technology (2021). Accordingly, in 1996, the "ramp up" requirements from 1998 to 2002 were eliminated while keeping the ten percent ZEV requirement for 2003 and subsequent years (2021). In 1999, the CARB adopted a second iteration of the regulation under Section 1962 which reaffirmed the ten percent ZEV requirement for 2003 and following model years (1999). However, the implementation of the 2003 and 2004 requirements was hampered by a lawsuit from the automobile industry and an injunction from a federal district judge (2021). The lawsuit was resolved with the amendment of the regulation for the ZEV requirements to be delayed until 2005 (2003; 2021). In 2008, a third iteration of the regulation was adopted under Section 1962.1 which established ZEV requirements for 2009 to 2017 and subsequent model years (2008). In 2012, CARB adopted the current iteration of the regulation under Section 1962.2 setting requirements for 2018 to 2025 and beyond (2012). In sum, California pioneered the ZEV regulation but had to make significant adjustments over the years to align with the development and commercialization of ZEV technology and to ensure compliance from the auto industry. This is made evident by the non-enforcement of early ZEV requirements from 1998 to 2004, and the resetting of the requirements between the last two iterations of the regulation, from 14 percent in 2017 to 4.5 percent in 2018 (see Table 1).

California's ZEV regulation has been adopted in twelve other states in the US with some modifications, namely in terms of manufacturer's ability to bank, trade and use credits for compliance. These ZEV states are New York, Vermont, Massachusetts, Connecticut, Rhode Island, New Jersey, Oregon, Maine, Maryland, Colorado, Washington, and Virginia. In 2019, Minnesota and New Mexico announced their intention to adopt California's ZEV regulation (Minnesota Pollution Control Agency 2019; Office of the Governor, State of New Mexico 2019). In 2020, Nevada followed suit (Nevada Division of Environmental Protection 2020). In Canada, the provinces of British Columbia and Quebec have adopted ZEV regulations, in 2017 and 2020, respectively (Government of Quebec 2017a; Government of British Columbia 2020). Their regulations are based on California's model but have significant differences. The comparison below focuses on the latest ZEV regulations from California, Quebec, and British Columbia because the regulations in the US are very similar but are notably different in Canada.

Table 1: Timeline of ZEV Regulations in the United States

CARB Regulation			13 CCR S.1960.1 LEV I		13 CCR S.1962 Zero-Emission Vehicle Standards						13 CCR S.1962.1 Zero-Emission Vehicle Standards							13 CCR S. 1962.2 Zero-Emission Vehicle Standards							
ZEV Requirement			2%	5%	10%	10%	10%	10%	10%	10%	11%	11%	11%	12%	12%	12%	14%	4.5%	7%	9.5%	12%	14.5%	17%	19.5%	22%
State	1990	1992	1998-2000	2001-2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015-2017	2018	2019	2020	2021	2022	2023	2024	2025+
CA	1960.1		1962							1962.1				1962.2											
NY		1960.1										1962.1		1962.2											
VT							1962			1962.1						1962.2									
MA																									
CT						1962					1962.1				1962.2										
RI						1962								1962.1 1962.2											
NJ								1962		1962.1				1962.2											
OR								1962							1962.1 1962.2										
ME											1962.1			1962.2											
MD																									
WA																				1962.2					
CO																		1962.2							
VA																					1962.2				

Legend

196X.X	Adoption of California Regulation		S.1960.1 ZEV Requirement		S.1962.1 ZEV Requirement
	ZEV Requirement Not Implemented		S.1962 ZEV Requirement		S.1962.2 ZEV Requirement

Sources: (California Air Resources Board 1990; 1999; 2003; 2008; 2012; 2021; New York Department of Environmental Conservation 1992; 2009; 2012; New York Department of State 2011, 23; 2013, 22; Vermont Department of Environmental Conservation 2005; 2008; 2014; Massachusetts Department of Environmental Protection 2020, 414; Connecticut Department of Energy and Environmental Protection 2004; 2013; Rhode Island Department of Environmental Management 2004; 2012; New Jersey Department of Environmental Protection 2006; Oregon Department of Environmental Quality 2006; 2013; Maine Department of Environmental Protection 2012; Maryland Department of the Environment 2007; Colorado Department of Public Health and Environment 2018; Washington State Legislature 2020; General Assembly of Virginia 2021)

4.2. Credit-Generating Mechanisms

Each ZEV regulation sets a required number of credits that vehicle manufacturers must earn for a given model year to comply with the regulation. Most regulations offer several ways by which manufacturers can earn credits. However, selling ZEVs is the main way for manufacturers to do so. The credits earned per ZEV sold depends on the type of vehicle and the formula used to calculate the number of credits earned per sale. ZEVs with longer electric ranges and lower or no operating emissions, earn more credits per sale. The credit system gives flexibility to manufacturers to be able to meet the regulation's requirements by selling different types of ZEVs based on what is more cost-effective for them.

4.2.1. Vehicle Types

There are different types of ZEVs and each jurisdiction categorizes these vehicles in slightly different ways. As summarized in Table 2, California and Quebec have four nearly identical vehicle types encompassing six electric ranges. The "zero-emission vehicle" include battery electric vehicles and hydrogen fuel cell vehicles. The "battery vehicle with extended range" in California and "vehicle with ranger extender" in Quebec, include plug-in battery electric vehicles with an internal combustion engine that is used solely as a generator for the battery to extend the electric range. Because of the use of an internal combustion engine, range extender types have a higher threshold of electric range than the "zero-emission vehicle" type. The "transitional zero-emission vehicle" and the "low-emission vehicle" include most plug-in hybrid electric vehicles and hydrogen combustion engines. They comprise three electric ranges which are similar in California and Quebec. The distinction with the above-mentioned range extender vehicle type, is that these vehicle types include plug-in electric hybrid vehicles that use internal combustion engines to propel the vehicle once the battery has been depleted and not just as a range extender. The "neighborhood electric vehicle" and the "low-speed motor vehicle" are also similar with some differences in terms of speed. Both include low-speed electric vehicles like golf carts.

British Columbia has a total of nine vehicle types, grouped under three ZEV classes. Many of the vehicle types are similar to those in the California and Quebec regulations. British Columbia's "battery electric vehicle" and "fuel cell electric vehicle" are the equivalent of the "zero emission vehicle" of the other two jurisdictions. The "extended range electric vehicle" is the equivalent of the "battery electric vehicle with extended range". There are three main differences in the British Columbia regulation relative to California and Quebec. First, there are specific vehicle types for fuel cell vehicles. Second, British Columbia distinguishes between plug-in electric vehicles that use internal combustion engines as a range extender and those that use it as a secondary propelling motor, namely the "plug-in hybrid electric vehicle". However, these differences are superficial since the electric range thresholds for the corresponding vehicle types are the same across jurisdictions. The third difference is that British Columbia does not include "low-speed vehicle" type and therefore does not offer sale credits for them. However, it is not clear that this is a significant difference since the sales volume for this type of vehicle is small relative to other light-duty passenger vehicles. Overall, while the vehicle types are organized differently in British Columbia relative to California and Quebec, the criteria are almost the same and the differences likely do not represent much variation in stringency between jurisdictions.

4.2.2. Vehicle Credit Formula

As per Table 2, each regulation allocates ZEV credits to vehicle manufacturers based on formula that vary according to the vehicle type, electric range, compliance to GHG emission standards and other parameters. In general, the vehicle types that produce less emissions and have longer electric ranges, earn more credits. The weight distribution of the formulas is relatively similar across regulations. For example, the "zero-emission vehicle" and range extender vehicle types in Quebec and California and the "ZEV Class A" in British Columbia can all earn up to four credits per vehicle. The "transitional zero-emission vehicle", "low-emission vehicle" and "ZEV Class B" vehicle types can only earn up to 1.1 credit per vehicle with an additional 0.2 credits per vehicle that have an electric range of 16 kilometers or more that complies with the emission standards of the US Environmental Protection Agency (EPA) Urban Dynamometer Driving Schedule.

There are two key differences between the regulations' vehicle credit formula. First, Quebec and British Columbia's formula provide nearly 38 percent less credit per kilometer of electric range beyond the minimum thresholds than the corresponding formula in the California regulation (i.e. "R", the electric range is multiplied by 0.6214). This suggests greater stringency in the Canadian regulations since, all else being equal, manufacturers must sell a greater number of vehicles to comply with credit requirements. A second difference is that California offers an additional 0.75 credit per "transitional zero-emission vehicle" that is a hydrogen combustion engine vehicle with a minimum range of 250 miles (402 km) in accordance with the EPA emission standards. Manufacturers can also earn credits from hydrogen combustion vehicles in Quebec or British Columbia, however, there is no extra credit for additional range. Again, suggests that the requirements in Quebec and British Columbia are a little more stringent relative to similar regulations in the US.

Table 2: ZEV Regulation Vehicle Types and Credit Formula

California 13 CCR S. 1962.2	Quebec CQLR A-33.02, r. 1	British Columbia SBC 2019, c. 29
	Vehicle Types (R[1])	
Zero-emission vehicle (ZEV): (a) does not produce emissions during operation (b) R ≥ 50 mi (80 km)	**Zero-emission vehicle (ZEV)**: (a) does not produce emissions during operation (b) R ≥ 80.47 km	**ZEV Class A** **Battery electric vehicle (BEV):** (a) powered by a battery only charged externally (b) R ≥ 80.47 km **Extended range electric vehicle (EREV):** (a) powered by a battery charged externally (b) ICE used only to charge battery (c) R ≥ 121 km **Fuel Cell Electric Vehicle (FCEV):** (a) powered by a hydrogen fuel cell (b) R ≥ 80.47 km
Battery electric vehicle with extended range (BEVx): (a) powered by a battery charged externally (b) ICE used only to charge battery (c) R ≥ 75 mi (121 km)	**Vehicle with range extender (VRE):** (a) powered by a battery charged externally (b) ICE used only to charge battery (c) R ≥ 121 km	**ZEV Class B** **EREV – medium:** (a) powered by a battery charged externally (b) ICE used only to charge battery (c) 16 ≤ R < 121 km **Plug-in hybrid electric vehicle (PHEV):** (a) powered by battery charged externally (b) R ≥ 16 km (c) not a BEV or BEV-short
Transitional zero-emission vehicle (TZEV): (a) a plug-in electric hybrid vehicle or a hydrogen combustion vehicle (b) three types of R	**Low-emission vehicle (LEV):** (a) a plug-in electric hybrid vehicle or a hydrogen combustion vehicle (b) three types of R	
Neighborhood electric vehicle (NEV): (a) ZEV with speeds < 25 mi/h (40 km/h) (b) acceleration 0 to 20 mi/h (0 to 32km/h) in 6 seconds or less (c) R ≥ 25 miles (40 km)	**Low-speed vehicle (LSV):** (a) three or more-wheeled ZEV that reach max speeds of 32 to 40 km/hour in < 1.6 km of distance (b) R ≥ 40 km	**ZEV Class C** **BEV – short:** (a) powered by a battery only charged externally (b) R < 80.47 km **EREV – short:** (a) powered by a battery charged externally (b) ICE used only to charge the battery (c) R < 16 km **FCEV – short:** (a) powered solely by a hydrogen fuel cell (b) R < 80.47 km **PHEV – short:** (a) powered by a battery charged externally (b) R < 16 km (c) not a BEV or BEV-short
	Vehicle Credit Formula	
ZEV credits (max 4/vehicle) = (0.01 x R) + 0.5	**ZEV credits (max 4/vehicle)** = (0.01 x R x 0.6214) + 0.50	**ZEV Class A credits (max 4/vehicle)** = (R x 0.006214) + 0.50
BEVx credits (max 4/vehicle) = (0.01 x R) + 0.5	**VRE credits (max 4/vehicle)** = (0.01 x R x 0.6214) + 0.50	
TZEV credits (three R): • 0 < R < 10 mi = 0 • 10 ≤ R < 80 mi = (0.01 x R) + 0.3 • R ≥ 80 mi = 1.10 • Meet EPA emissions and R ≥ 10 mi = extra 0.2	**LEV credits (three R)**: • 0 < R < 16 km = 0 • 16 ≤ R < 129 km = (0.01 x R x 0.6214) + 0.3 • R ≥ 129 km = 1.10 • Meet EPA emissions and R ≥ 16km = extra 0.2	**ZEV Class B credits** = (R x 0.006214) + 0.30 • Meet EPA US06 emissions and R ≥ 16 km = extra 0.2 • Max 1.1 (without extra) or 1.3 (with extra) per new EREV medium or PHEV
NEV credits = 0.15	**LSV credits** = 0.15	**ZEV Class C credits** = Not eligible for credits

Sources: (California Air Resources Board 2019, 218–38; Government of Quebec 2017a; Government of British Columbia 2020)

[1] "R" is the electric range of a vehicle based on the EPA and the CARB method of estimating range.

4.2.3. Other Credit-Generating Activities

Aside from the sale of new ZEVs mentioned above, regulations also allow vehicle manufacturers to earn credits through other activities that contribute to the reduction of transport related GHG emissions. California's regulation allows vehicle manufacturers to earn up to half of their credit requirements through four alternative activities (California Air Resources Board 2019, 234). First, manufacturers can sell medium-duty "zero-emission vehicles" and "transitional zero-emission vehicles" using the same credit formula as their light-duty equivalents (2019, 230). Second, manufacturers can claim credits for up to 25 demonstration vehicles that are classified as "zero-emission vehicles, battery electric vehicles with extended range, transitional zero-emission vehicles or neighbourhood electric vehicles" (2019, 231). Demonstration vehicles are used to test early technologies in terms of safety, infrastructure and fuel specifications (2019, 231). Third, manufacturers can earn up to one tenth of their ZEV credits from transportation systems which involve projects for "zero-emissions vehicles" or "transitional zero-emission vehicles" within model years 2001 to 2008 that are used to demonstrate new intelligent technologies such as reservation management or linkage public transit (2019, 231, 180). Fourth, manufacturers can earn credits for over compliance to the federal GHG emission program requirements by at least two grammes of carbon dioxide per mile from model years 2018 to 2021 (2019, 233). The maximum percentage of credits that manufacturers can earn per model year using this method are as follows: 50 percent in 2018 and 2019; 40 percent in 2020; and, 30 percent in 2021 (2019, 233).

In comparison, Canadian regulations allow fewer alternative activities to generate credits, and these credits can account for a smaller proportion of a manufacturer's compliance requirements. Under the British Columbia regulation, vehicle manufacturers can earn credits through initiative agreements for the sale of "ZEV Class A" or "ZEV Class B" previously used outside of British Columbia or the sale of medium or heavy-duty ZEVs (Government of British Columbia 2020, 9–10). Only five percent of the total ZEV credit requirements can be met through these agreements starting in 2020 and subsequent model years (2020, 10). Under the Quebec regulation, vehicle manufacturers can earn a reduced number of credits through the sale of reconditioned ICEVs with less than 40,000 km mileage into one of the four types of ZEVs (Government of Quebec 2017a, 7, 9). Starting in 2020, vehicle manufacturers can earn up to 30 percent of their credits permitted for a given vehicle type with the sale of reconditioned ZEVs (Government of Quebec 2017a, 7). Once again, Quebec and British Columbia's regulations appear more stringent than California's. California offers four different ways for manufacturers to meet up to half of their credit requirements while Quebec and British Columbia only allow limited alternatives to fulfill up to 30 and 5 percent of their ZEV requirements, respectively.

4.3. Application to Vehicle Manufacturers

The main way for vehicle manufacturers to comply with regulations is by earning credits through the sell of ZEVs as a required percentage of vehicle sales in a given model year. However, the credit requirements vary based on the size of the vehicle manufacturer, the type of vehicles sold, and the vehicle sales formula used to calculate the requirements. Over time, larger vehicle manufacturers are required to earn an increasing proportion of their credits from ZEV types with no operating emissions (e.g. battery electric vehicles and hydrogen fuel cell vehicles) as opposed to ZEV types with potential operating emissions (e.g. plug-in hybrid electric vehicles with low electric range).

4.3.1. Manufacturer Classes

While manufacturer classes may seem similar across jurisdictions, there are key differences between them, as summarized in Table 3. In all three jurisdictions, vehicle manufacturers are categorized based on their average sales volume. This volume is calculated by averaging a manufacturer's sales in a given jurisdiction for the three model years immediately preceding the compliance year (Government of British Columbia 2020, 6; Government of Quebec 2017a, 3; California Air Resources Board 2019, 2–4). California and Quebec have the same sales volume thresholds for manufacturer classes, despite the fact the Quebec has a significantly smaller light-duty vehicle sales market. In 2019, Quebec had over 458,000 new light-duty passenger vehicles on the road while California had over 1.8 million (Statistics Canada 2021; California Energy Commission 2021). Therefore, all else being equal, Quebec's regulation probably places more vehicle manufacturers in the small or intermediate classes than California or British Columbia. This indicates lesser stringency since Quebec's regulation does not have compliance requirements for small volume manufacturers and has more flexible compliance requirements for intermediate volume manufacturers than the other two regulations (Government of Quebec 2017a; California Air Resources Board 2019, 220; Government of British Columbia 2020, 6). Conversely, British Columbia has lower sales volume thresholds for manufacturers classes than both California and Quebec which is logical since it also has a smaller light-duty vehicle market. Lastly, California's regulation counts medium-duty vehicles towards a manufacturer's average sales while Quebec and British Columbia only count light-duty vehicles. This suggests that California's regulation classifies more manufacturers as having intermediate or large sales volume which qualifies them for ZEV requirements.

Another key distinction between regulations is how vehicle manufacturers are reclassified in cases of significant change in average sales. In California, a small volume manufacturer is re-classified as a larger manufacturer, if its three-year average sale exceeds the volume of its current manufacturer class for three consecutive model years (California Air Resources Board 2019, 220). An intermediate volume manufacturer is re-classified as a large volume manufacturer, if its three-year average sale exceeds the volume bracket of its current manufacturer class for five consecutive model years (2019, 221). An intermediate volume manufacturer does not get re-classified as a large manufacturer if its global average revenue was US$40 billion or less during one of the three-year averages (2019, 221). A large volume manufacturer or intermediate volume manufacturer are re-classified as a smaller manufacturer if their three-year average sales fall below the threshold for their manufacturer class for three consecutive model years (2019, 221–22). In Quebec, a manufacturer is reclassified as a larger or smaller manufacturer if its three-year average sale is above or below the volume bracket of its current class for three consecutive model years (Government of Quebec 2017a, 4). The British Columbia regulation does not directly address the issue of manufacturer reclassification. The interpretation of this study is that a manufacturer is automatically reclassified as a larger or smaller manufacturer if its three-year average sales is above or below its current volume bracket for a single mode year. Compared with the other two regulations, California is more lenient towards vehicle manufacturers since it requires five consecutive years sales average (instead of three) and a global average revenue of US$ 40 billion for an intermediate volume manufacturer to be reclassified upwards. Quebec and British Columbia are similarly stringent on manufacturers regardless of size. However, if the interpretation above is correct, British Columbia's regulation is more reactive to average sale changes since it requires a single average for reclassification while Quebec requires three consecutive averages.

Table 3: ZEV Regulation Manufacturer Types

California 13 CCR S. 1962.2	Quebec CQLR A-33.02, r. 1	British Columbia SBC 2019, c. 29
Manufacturer Classes		
Large volume manufacturer (LVM): average California sales ≥ 20,001 vehicles/year	**Large volume manufacturer (LVM):** average Quebec sales ≥ 20,001 vehicles/year	**Large volume supplier (LVS):** average sales volume ≥ 5,000 vehicles/year
Intermediate volume manufacturers (IVM): average California sales between 4,501 and 20,000 vehicles/year	**Intermediate volume manufacturers (IVM):** average Quebec sales between 4,501 and 20,000 vehicles/year	**Medium volume supplier (MVS):** average sales volume between 1,000 and 4,999 vehicles/year
Small volume manufacturers (SVM): average California sales ≤ 4,500 vehicles/year	**Small volume manufacturers (SVM):** average Quebec sales ≤ 4,500 vehicles/year	**Small volume supplier (SVS):** average sales volume of < 1,000 vehicles/year
Average Sales to Determine Manufacturer Class		
Average of the vehicles sold during the three model years (MY) immediately preceding the compliance year (CY). This includes light and medium-duty vehicles.	Average of the vehicles sold during the three model years (MY) immediately preceding the compliance year (CY). This includes motor vehicles that can carry nine	Average of the vehicles sold during the three model years (MY) immediately preceding the compliance year (CY). This includes

	persons and with a gross weight < 4,500 kg.	motor vehicles with a gross weight ≤ 3,856 kg.
Example: CY2019 average sales = (MY2018 sales + MY2017 + MY2016) / 3	Example: CY2019 average sales = (MY2018 sales + MY2017 + MY2016) / 3	Example: CY2019 average sales = (MY2018 sales + MY2017 + MY2016) / 3

Sources: (California Air Resources Board 2019, 218–38; Government of Quebec 2017a; Government of British Columbia 2020)

4.3.2. Compliance Requirements

Small manufacturers do not have compliance requirements in any of the three regulations (Government of Quebec 2017a; California Air Resources Board 2019, 220; Government of British Columbia 2020, 6). However, all manufacturers in British Columbia are subject to non-binding provincial targets of ZEVs accounting for 10 percent of new light-duty vehicle sales in 2025, 30 percent in 2030, and 100 percent in 2040 (Legislative Assembly of British Columbia 2019, 5–6). Also, the province prohibits all manufacturers from selling non-ZEVs starting in 2040 (2019, 6).

As shown in Figures 1 to 5, all jurisdictions have the same total compliance requirements for large and intermediate manufacturers from 2020 to 2025, but they differ significantly in previous and subsequent model years. Quebec and British Columbia have lower requirements than California in the pre-2020 model years. This is likely because Quebec and British Columbia adopted their regulations much closer to their first compliance years giving less time for manufacturers to adjust. California has adopted the latest iteration of its regulation in 2012 and had previous iterations going back to 1990. This gave more time for manufacturers to ramp up ZEV production and earn credits. More importantly, British Columbia's compliance requirements are significantly more stringent in the long-term than in California and Quebec. British Columbia's regulation establishes increasingly stringent requirements up to 2040 which are then maintained for subsequent years. In 2040, British Columbia's regulation requires manufacturers to earn a minimum of 259 percent of total vehicle sales in compliance credits. Credit compliance beyond 100 percent of total vehicle sales is required to meet British Columbia's target of 100 percent ZEV market share by 2040 since each ZEV sale can earn multiple credits. In contrast, California and Quebec require that manufacturers earn a minimum of 22 percent of their total vehicle sales as credits in 2025 and in subsequent years.

Another key difference between jurisdictions is the minimum ZEV quotas for large and intermediate manufacturers. Starting in 2018 in California and 2020 in Quebec, large manufacturers are required to earn most of their credits from the sale of “zero-emission vehicles” or “battery electric vehicles with extended range/vehicles with range extender”, and “zero-emission vehicles” need to account for at least half of those credits. Similarly, large manufacturers in those jurisdictions are only allowed to meet a small percentage of their compliance requirements from the sale of low-speed vehicles. California allows for partial ZEVs[2] sold under previous iterations of its regulation to count towards some compliance requirements (see “All Credits” in Figures 1 and 3). Quebec also allows manufacturers to use some credits previously earned from the sale of ZEVs going back to 2014. On other hand, British Columbia does not provide credits for ZEV sales prior to 2019 and large manufacturers are required to meet an increasing percentage of their compliance requirements with credits earned from the sale of “ZEVs Class A”. The regulation allows large manufacturers slightly more flexibility to choose between the different types of vehicles under “ZEV Class A”, but the total percentage requirement for corresponding vehicle types is the same as the other two regulations up to 2025. For intermediate manufacturers, California and Quebec allow more flexibility in how they earn their credits relative to large manufacturers. However, starting in 2020, California requires that intermediate manufacturers earn an increasing proportion of their credits from the sale of “zero-emission vehicles”, “battery electric vehicles with extended range” and “transitional zero-emission vehicles”. This is slightly more stringent than Quebec which allows intermediate manufacturers to earn all their credits from the sale of any eligible type of ZEVs. Here again, British Columbia is the most stringent since it requires that intermediate manufacturers obtain most of their credits for the sale of vehicles types under either “ZEV Class A” or “ZEV Class B”.

[2] Quebec provides credits for the sale of reconditioned ZEVs and British Columbia does so for ZEVs previously used outside of the province. However, unlike California’s partial ZEVs, these are not represented in the Figures 2, 4 and 5 since they are technically the same ZEV types as the ones that are represented.

Figure 1: California LVM Compliance Requirements

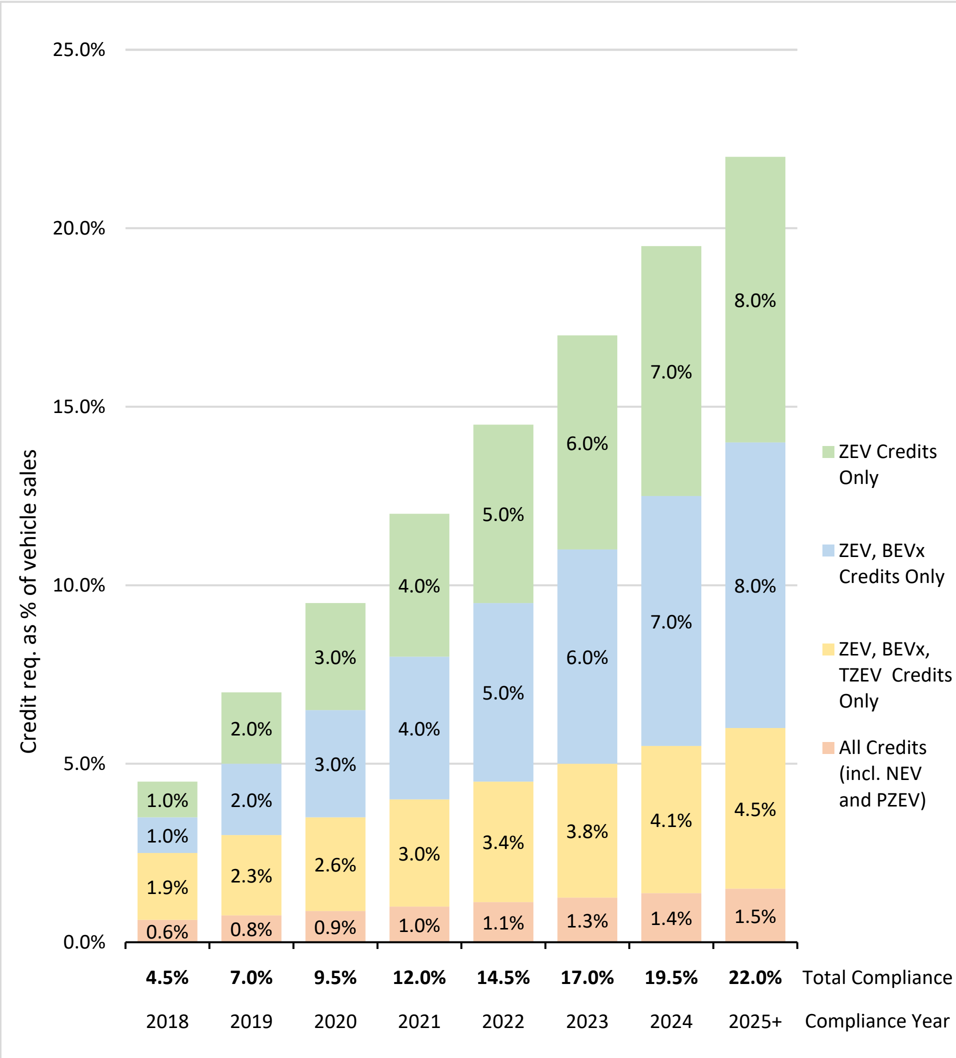
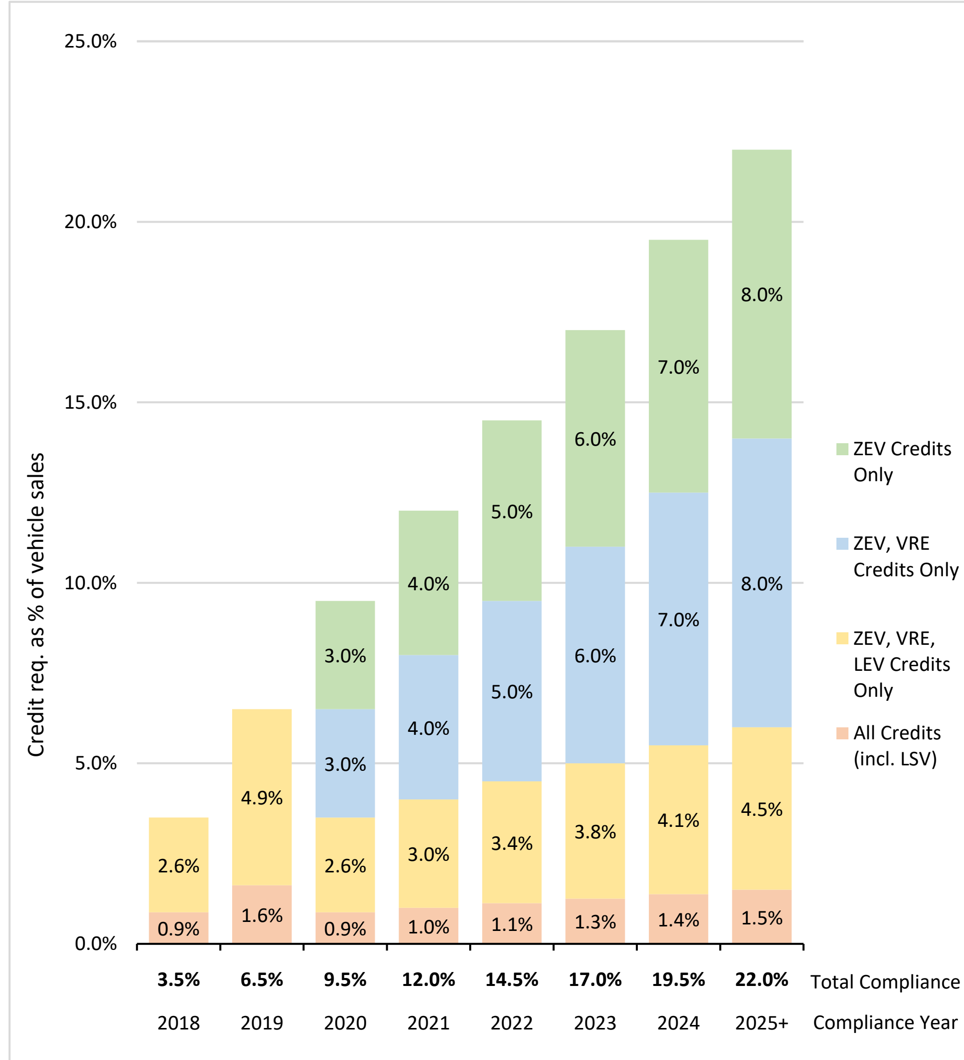


Figure 2: Quebec LVM Compliance Requirements



Sources: (Moawad and Wolinetz 2019; California Air Resources Board 2019, 218–38; Government of Quebec 2017a)

Figure 3: California IVM Compliance Requirements

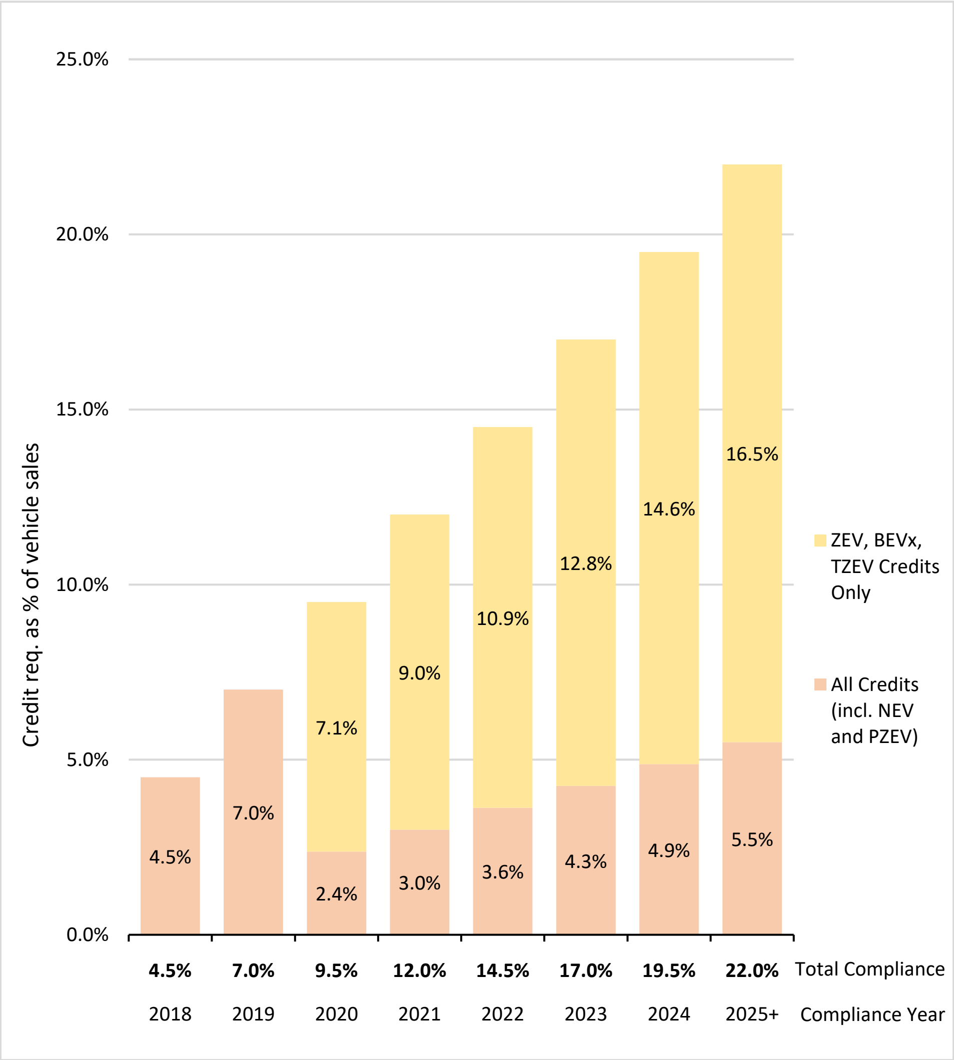
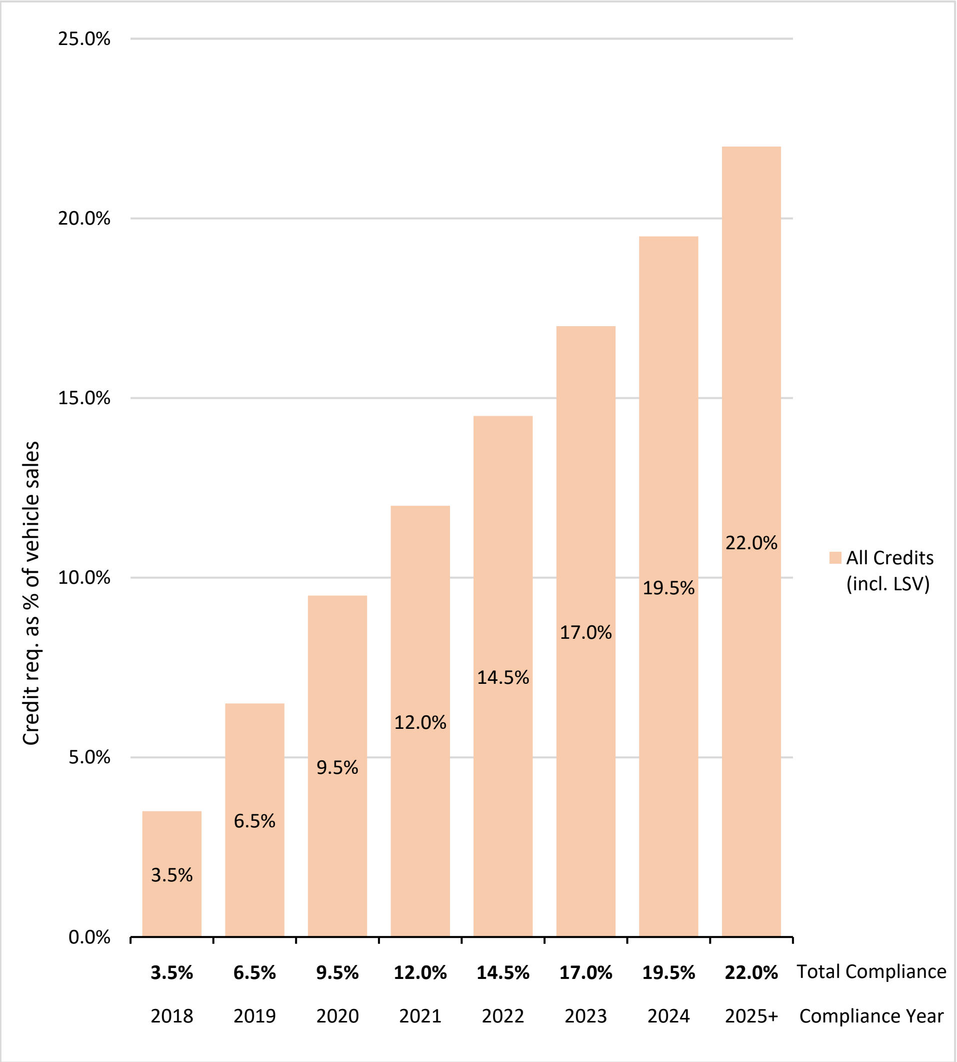
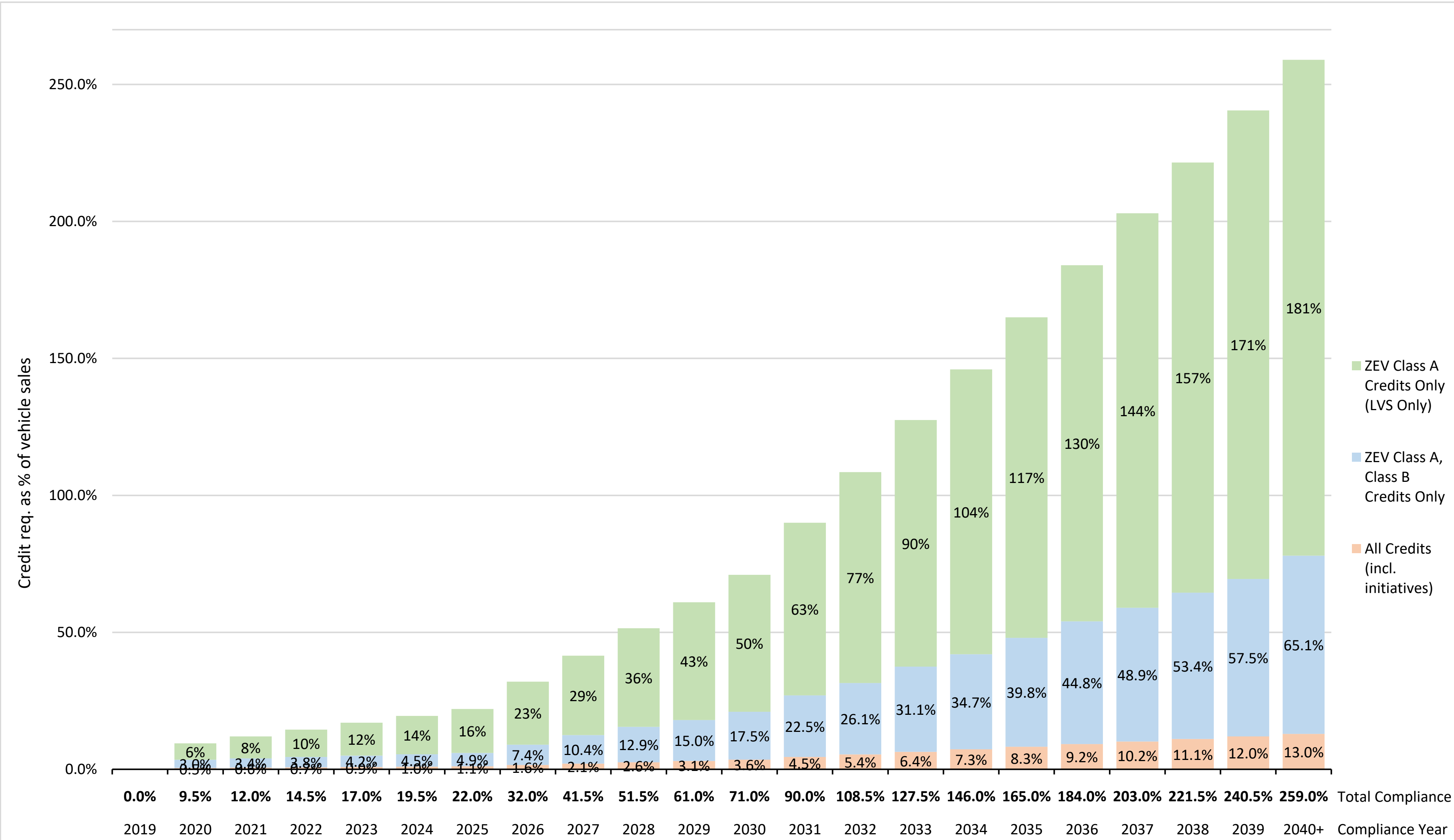


Figure 4: Quebec IVM Compliance Requirements



Sources: (Moawad and Wolinetz 2019; California Air Resources Board 2019, 218–38; Government of Quebec 2017a)

Figure 5: British Columbia LVS and MVS Combined Compliance Requirements



Sources: (Legislative Assembly of British Columbia 2019; Government of British Columbia 2020)

4.3.3. Compliance Credit Formula

All three regulations use the same formula to calculate the number of credits that vehicle manufacturers must earn to meet the above compliance requirements. The number of credits for a given model year is calculated by multiplying the required compliance percentage with a manufacturer's vehicle sales. However, the vehicle sales in question are calculated differently across jurisdictions.

As pert Table 4, California and Quebec calculate a vehicle manufacturer's vehicle sales by averaging the vehicles sold during the second, third and fourth model years preceding the compliance year. California's regulation also allows vehicle manufacturers' to use the compliance year vehicle sales to determine their compliance credits for up two model years between the 2018 and 2025 (California Air Resources Board 2019, 219). To be eligible, vehicle manufacturers must show that their sales have decreased by at least 30 percent from the previous year due to circumstances beyond their control (2019, 219). Quebec's regulation applies the same rule as California allowing manufacturers to use the compliance year vehicle sales to determine compliance credits for a maximum of two model years within a period of eight consecutive years (Government of Quebec 2017a, 8). In British Columbia, compliance credits are determined using the number of vehicles sold during the compliance year (Government of British Columbia 2020, 7; Legislative Assembly of British Columbia 2019, 7). While this ensures that compliance credits are more aligned with the vehicle sales of a vehicle manufacturer on a year-to-year basis, it also means that the required number of credits is potentially more volatile if a vehicle manufacturers sales rise or declines on a given year.

Table 4: ZEV Regulation Compliance Credit Calculation

California 13 CCR S. 1962.2	Quebec CQLR A-33.02, r. 1	British Columbia SBC 2019, c. 29
Compliance Credit Formula		
Number of credits required = compliance requirement percentage x vehicle sales (see below)		
Vehicle Sales Formula		
Average of new vehicles sold during the second, third and fourth model years (MY) preceding the compliance year (CY). This includes passenger cars (can carry ≤ 12 person), light-duty trucks (weight ≤ 3,856 kg) and excludes “NEVs”. Example: CY2019 = (MY2017 + MY2016 + MY2015) / 3	Average of new vehicles sold during the second, third and fourth model years (MY) preceding the compliance year (CY). This includes motor vehicles that can carry up to nine persons and with a gross weight < 4,500 kg. Example: CY2019 = (MY2017 + MY2016 + MY2015) / 3	Sale of new vehicles during compliance year (CY). This includes motor vehicles with a gross weight ≤ 3,856 kg. Example: CY2019 = MY2019

Sources: (California Air Resources Board 2019, 218–38; Government of Quebec 2017a; Government of British Columbia 2020)

4.4. Over Compliance, Monitoring and Penalties

Each regulation sets rules regarding credits earned from exceeding the compliance requirements, the monitoring of manufacturer compliance and penalties for non-compliance. Vehicle manufacturers that go beyond the compliance requirements can bank, trade, and use the earned credits. This incentivizes and rewards manufacturers to produce and sell large number of ZEVs early on. Manufacturers are required to report on their ZEV sales every year and those that do not meet the above compliance requirements are faced with fines and other penalties. This is also to incentivize manufacturers to sell more ZEVs and deter them from neglecting their requirements.

4.4.1. Over Compliance and Credit Trade

Regulations vary on the ability of manufacturers to earn, bank and trade credits, namely those earned for over compliance to ZEV requirements. In all jurisdictions, small manufacturers can earn, bank and sell credits to other manufacturers despite not having binding requirements (Legislative Assembly of British Columbia 2019, 9; National Assembly of Quebec 2016, 2–3; California Air Resources Board 2019, 220). In California, up to model year 2025, large and intermediate manufacturers can use credits earned from the sale of ZEVs under previous iterations of the regulation, and the sales of “neighborhood electric vehicles”, to satisfy up to 25 percent of their compliance requirement that can be met with “transitional zero-emission vehicles” sales on a given model year (California Air Resources Board 2019, 232). Manufacturers in California and other states that have adopted its regulations can also trade ZEV credits with each other according to a set of conditions (2019, 225–27). Under the Quebec regulation, a manufacturer that has accumulated credits for the sale of new or reconditioned ZEVs in model years 2014 to 2017 can use these credits to meet up to 35 percent the compliance requirements for the corresponding type of ZEVs for the 2018 to 2021 model years, and 25 percent of requirements for subsequent model years (National Assembly of Quebec 2016, 3–4; Government of Quebec 2017a, 14; 2017b, 3). Starting in 2018, a manufacturer in Quebec that earns credits beyond its compliance requirements can accumulate them and use those credits to comply with up to 25 percent of the requirements of a subsequent model year (Government of Quebec 2017b, 2). Also, a vehicle manufacturer can trade or sell its credits with other vehicle manufacturers as long as the transaction is documented (National Assembly of Quebec 2016, 3). The British Columbia regulation states that only ZEV sales made in 2019 and subsequent years are eligible for credits and that suppliers can transfer or sell credits to each other so long as they inform the provincial government (Legislative Assembly of British Columbia 2019, 9; Government of British Columbia 2020, 9). In sum, California provides the most flexibility for manufacturers to earn, bank and use credits from selling ZEVs under previous versions of its regulations as well as he ability to trade credits in other states with the same ZEV regulation. The downside is that this regulation may result in lower stringency as manufacturers can more easily maximize the sale of ZEVs in some states to comply with requirements in other states, without having to increase the sale of ZEVs in the latter states. Quebec comes in second in terms of stringency since it allows for less banking of previously earned ZEV credits and trading opportunities are limited to the province. Lastly, British Columbia is once again the most stringent since its does not allow for the earning, banking or trading of ZEV credits prior to 2019.

4.4.2. Monitoring and Enforcement

All three jurisdictions monitor and enforce manufacturer compliance slightly differently. In California, a vehicle manufacturer who does not meet its required compliance credits in a given model year must make up the deficit by the next model year (California Air Resources Board 2019, 234). However, an intermediate manufacturer can request an extension for up to three consecutive model years if it meets two conditions: (1) it has delivered “zero-emission vehicles” or “transitional zero-emission vehicles” for sale in California within that model year, and (2) it demonstrates how it will make up the credit deficit within the requested time period (2019, 234). In Quebec, vehicle manufacturers do not have such grace periods. They have to submit their compliance reports by September 1st following the compliance year (National Assembly of Quebec 2016, 4). The government can investigate a vehicle manufacturer if it suspects a manufacturer is violating the regulation (2016, 5). Manufacturers must keep compliance records for at least eight years as the government may request them and reassess compliance (Government of Quebec 2017a, 13). The British Columbia regulation provides a manufacturer twenty days following the end of the compliance year to submit a compliance report (Government of British Columbia 2020, 10). The province can reassess the latest five model year reports and can request information, an audit or initiate an inspection from a vehicle manufacturer at any time (Legislative Assembly of British Columbia 2019, 12–14). Accordingly, manufacturers must keep records of the previous six model year reports (2019, 13). To recap, California is more lenient with intermediate manufacturers providing a chance to make up deficits. Quebec and British Columbia have similar reporting requirements and enforcement.

4.4.3. Penal Provisions

All three regulations are similar in terms of penalties for non-compliance. Manufacturers who fail to meet their compliance requirements are subject to a penalty of $ 5,000 per ZEV credits, in their respective currencies (California Air Resources Board 2016, 234; State of California 2016, sec. 43211(b); National Assembly of Quebec 2016, 3; Government of Quebec 2017a, 11; Government of British Columbia 2020, 10; Legislative Assembly of British Columbia 2019, 15). In British Columbia, if a manufacturer is not able to meet its requirements on time, it can also purchase credits from the province for the price of $5,500 per credit, presumably to avoid having to pay a penalty and having a deficit carry over in the following compliance year (Government of British Columbia 2020, 10). In Quebec and British Columbia, manufacturers that commit offences (e.g. submitting false or misleading reports) can face severe fines. Depending on the offence, this includes fines up to $ 1,500,000 dollars in Quebec, and up to $1,000,000 or imprisonment for up to 6 months in British Columbia (Government of Quebec 2017a, 14; Legislative Assembly of British Columbia 2019, 16–17). In British Columbia, manufacturers that do not abide with the prohibition of non-ZEV sales starting in 2040 can also face a penalty of up to $500,000 or imprisonment for up to 6 months, or both (Legislative Assembly of British Columbia 2019, 17).

4.5. Stringency Comparison

A more rigorous analysis would be required to properly determine which regulation is more stringent for each of the components. For the purposes of this study, a general assessment of stringency is provided based on the above considerations. In terms of credit-generating mechanisms, all three regulations are similar but Quebec and British Columbia appear to be more stringent since they provide less credits per ZEV sold, and British Columbia does not provide any credits for low-speed ZEVs. Furthermore, California offers more flexibility for manufacturers to comply outside of selling ZEVs for up to 50 percent of their requirements. Regarding compliance requirements, British Columbia's regulation is significantly more stringent since it sets increasing requirements up to 2040 with the goal of 100 percent ZEV adoption, while California and Quebec have almost identical requirements that plateau in 2025. For over compliance, all three jurisdictions allow vehicle manufacturers to bank and trade credits among themselves, but California extends this to twelve other US States making it more flexible. For monitoring and enforcement, all regulations have similar reporting requirements and the same penalty per missing ZEV credit. However, California provides a grace period for non-compliant intermediate manufacturers while the other two regulations do not.

Overall, British Columbia's ZEV regulation is significantly more stringent than its counterparts, mostly due to the long-term compliance requirements. California and Quebec's regulations have more in common but it is not clear which one is more stringent. It is unlikely that British Columbia's greater stringency will account for significantly higher ZEV adoption and availability relative to other jurisdictions. This is because the ZEV adoption and availability data only extends to 2020; the same year the British Columbia ZEV regulation was adopted. More importantly, the added stringency in compliance requirements only takes effect after 2025. However, there it is possible that some manufacturers have started ramping up their ZEVs sales to earn early compliance credits which could be reflected in the ZEV adoption and availability data discussed in the following sections.

5. ZEV Subsidies

This section provides a quick summary of the relevant ZEV purchase subsidies in Canada and the US at the federal and provincial/state levels. The focus is on the subsidy programs within jurisdictions that are also analyzed in the subsequent section on ZEV adoption. The tables below include the target audiences that are eligible for each subsidy program, namely residents (RES), businesses (BUS), lower levels of government (GOV) and non-profit organizations (NPO).

5.1. Canada

As per Table 5, British Columbia was the first province to adopt a ZEV rebate program in 2011, followed by Quebec 2012, and then Ontario in 2016. In 2018, Ontario cancelled its program following a change of government (Bickis 2018). In 2019, the Canadian Federal Government implemented a nation-wide ZEV rebate program which can be combined with the provincial subsidies. In 2021, Nova Scotia has also announced a ZEV rebate (Luck 2021). However, the later is outside the scope of this study since ZEV adoption data only extends to 2020. When it was active, Ontario's program offered by far the largest rebate per vehicle which likely had a greater impact on ZEV adoption and availability. Quebec now offers the largest subsidy followed by British Columbia and both of their programs have been in place for several years. These subsidies could have had a sustained influence on ZEV adoption and availability during the period following their implementation.

Table 5: ZEV Subsidy Programs in Select Canadian Jurisdictions

Jurisdiction	Active	Programs	Subsidies	Audiences
British Columbia	2011-	CleanBC Go Electric Program	Up to $ 3,000 rebate per battery electric, hydrogen fuel cell, plug-in hybrid electric vehicle	RES, BUS, GOV, NPO
Quebec	2012-	Roulez vert Program	Up to $ 8,000 rebate per battery electric, plug-in hybrid electric or hydrogen fuel cell vehicle	RES, BUS, GOV, NPO
Ontario	2016-2018	(Terminated)	Up to $ 14,000 rebate per electric vehicle	RES
Federal	2019-	Zero-Emission Vehicles Program	Up to $ 5,000 rebate per battery-electric, hydrogen fuel cell of plug-in hybrid vehicle *Can be combined the provincial subsidies	RES, BUS, GOV, NPO

Sources: (Ministry of Energy, Mines and Low Carbon Innovation n.d.; Government of Quebec 2021; Government of Ontario 2016; Bickis 2018; Transport Canada 2020)

5.2. United States

As shown in Table 6, the subsidy programs in the US vary considerably between jurisdictions. The Federal Government was among the first to introduce subsidies in the form of tax credits in 2008 and 2010. The state of Washington then adopted a similar ZEVs sale and use tax exemption starting in 2009. In 2010, California introduced ZEV purchase rebates for residents, businesses, public fleets, and non-profit organizations. The same year, Vermont adopted its own rebate program, followed by Colorado in 2012, Texas and Virginia in 2014, New York in 2017, and Oregon in 2019. Aside from the Federal Government, California and Colorado offer the largest subsidies for residents and businesses. Also, California and Vermont introduced subsidy programs specifically designed to help lower income households. This could potentially have helped promote greater ZEV adoption among the wider population, since middle- and high-income household are already better positioned to purchase ZEVs which tend to be more expensive to purchase than corresponding ICEVs. Like in Canada, all the jurisdictions considered in this study that have adopted a ZEV regulation, have also implemented a purchase subsidy.

Table 6: ZEV Subsidy Programs in Select US Jurisdictions

Jurisdiction	Active	Programs	Subsidies	Audiences
Federal	2008-	Fuel Cell Motor Vehicle Tax Credit	Up to $ 8,000 tax credit per fuel cell vehicle *Can be combined with state rebates	RES, BUS
	2010-	Federal Tax Credits for New All-Electric and Plug-in Hybrid Vehicles	Up to $ 7,500 tax credit per battery electric or plug-in hybrid electric vehicle *Can be combined with state rebates	RES, BUS
Washington	2009-	Clean alternative fuel vehicles and high gas mileage vehicles	Sales and use tax exemption (up to $ 25,000) per hydrogen fuel cell, battery-electric or plug-in hybrid electric vehicle	RES, BUS, GOV, NPO
California	2010-	Clean Vehicle Rebate Project	Up to $ 7,000 rebate per fuel cell electric, battery electric or plug-in hybrid electric vehicle	RES, BUS, GOV, NPO
	2018-	Clean Vehicle Assistance Program	Up to $ 5,000 grant per plug-in hybrid electric vehicle *Can be combined with the Clean Vehicle Rebate Project	Low- and moderate-income RES
Vermont	2010-	Plug-in Electric Vehicles Incentive Program	Up to $ 4,000 rebate per battery electric or plug-in hybrid electric vehicle	Low- and moderate-income RES
Colorado	2012-	Charge Ahead Colorado	Up to $ 8,260 for the cost differential between comparable gasoline and electric vehicle	GOV, NPO
	2017-	Innovative Motor Vehicle Tax Credit	Up to $ 7,000 tax credit per battery electric or plug-in hybrid electric vehicle	RES, BUS
Texas	2014-	Light-Duty Motor Vehicle Purchase or Lease Incentive Program	Up to $ 2,500 rebate per hydrogen fuel cell, battery electric or plug-in hybrid vehicle	RES, BUS
Virginia	2014-	Vehicle Fuel Conversion Incentive Program	Up to $ 10,000 for the incremental cost of a new electric vehicle	GOV
New York	2017-	Drive Clean Rebate for Electric Cars	Up to $ 2,000 rebate per battery electric or plug-in hybrid electric vehicle	RES, BUS, GOV
Oregon	2019-	Oregon Clean Vehicle Rebate Program	Up to $ 2,500 rebate per plug-in hybrid electric vehicle or battery electric vehicle	RES, BUS, GOV, NPO

Sources: (U.S. Internal Revenue Service 2008; U.S. Department of Energy 2021; Washington State Department of Revenue 2019; California Clean Vehicle Rebate Project 2021b; 2021a; Clean Vehicle Assistance Program 2021; Drive Electric Vermont 2021; Colorado Regional Air Quality Council 2021; Colorado Department of Revenue 2019; Texas Commission on Environmental Quality 2021; Virginia Clean Cities 2018; New York State Energy Research and Development Authority 2020; Oregon Department of Environmental Quality 2021)

6. ZEV Adoption

This section investigates if there are noticeable changes in ZEV uptake following the adoption of a ZEV regulation as well as the enforcement of their corresponding sale requirements. ZEV purchase subsidies are also included to keep in mind their potential impact.

6.1. Canada

Figure 6 provides the percentage of new light-duty vehicle registrations that were ZEVs from 2011 to 2020 in British Columbia and the Territories, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, and Prince Edward Island. The yearly percentage of ZEV registrations in each jurisdiction can be compared with Table 7 which provides a timeline of subsidies and regulations that may have impacted ZEV adoption.

The potential effect of purchase subsidies should be considered before assessing the impact of ZEV regulations. Starting in 2012, Quebec and British Columbia, followed by Ontario, all had noticeably greater rate of ZEV adoption than other Canadian provinces. As shown in Table 7, this is potentially due to the adoption of subsidies in 2011 in British Columbia and 2012 in Quebec. However, subsidies appear to have a more notable impact on ZEV adoption in Ontario. The sudden uptake of ZEVs in that province in 2016 corresponds with the adoption of its rebate program. A dramatic fall in ZEV registrations in 2019 also seems to align with the termination of the rebate program during the of summer 2018 (Bickis 2018). This perceived difference in impact of subsidies between provinces could be explained by the fact that Ontario's ZEV rebate program offered a $14,000 rebate per vehicle which was significantly larger than those offered in other provinces. For comparison, Quebec's rebate program is currently the most generous, but it only offers up to $8,000 per vehicle, or up to $13,000 when combined with the federal discount. Also, only British Columbia and Prince-Edward Island show a marked increase in ZEV adoption in 2019 when the federal government launches its rebate program. This suggests, there is a lag of at least one year between the introduction of rebate programs and notable changes in ZEV adoption.

The potential impact of ZEV regulations is less evident for several reasons. First, Quebec and British Columbia had higher ZEV adoption than other Canadian provinces before the adoption of regulations. This was likely due to ongoing purchase subsidies. In fact, British Columbia already had the second highest percentage of new ZEV registrations. Second, while ZEV adoption grew rapidly in both provinces following the adoption of their respective regulations, there are other likely explanations for the increase in registrations. Both provinces passed an act for the adoption of a ZEV regulation one year before it was adopted. Quebec passed the act in 2016 which saw an increase in ZEV registrations. Quebec then adopted the regulation 2017 which also had greater ZEV adoption followed by a noticeable increase in 2018 which coincided with start of ZEV requirements. Similarly, in 2018 the BC government announced its commitment to adopt a ZEV regulation and establish an enforceable target of 100 percent ZEV adoption by 2040 (Government of British Columbia 2018). The same year, ZEV adoption increased dramatically and increased further in 2019 with the passage of an act for the adoption of the regulation. At first glance this may seem as if ZEV regulations are having an impact on registrations. However, several other factors could have contributed to greater ZEV adoption. Following its release in mid-2017, the Tesla Model 3 contributed to a dramatic increase in overall ZEV sales in 2018 in both Canada and the US, as will be discussed further below (Lambert 2018; U.S. Department of Energy 2020a). Since this corresponds with the sharp increases in ZEV registrations that also occurred in 2018 in the US, it is likely that greater ZEV adoption had more to do with increased demand for Teslas and other ZEVs as opposed to vehicle manufacturers suddenly increasing production and sale of ZEVs.

Overall, provinces that have ZEV regulations have on average experienced higher levels of ZEV adoption than their counterparts. However, Figure 6 and Table 7 do not provide sufficient evidence to determine if there is a relationship between regulatory action and ZEV adoption. Even if there is such a relationship, it is even less clear to what extent increases in ZEV adoption are attributable to regulations as opposed to other factors. These factors include other ZEV-supportive policies such as subsidies and carbon pricing, the introduction of the very popular Tesla Model 3, declining prices of ZEVs, and the growing demand for ZEVs from environmentally concerned consumers. Moreover, provinces with pre-existing high ZEV uptake may also be more inclined to adopt ZEV regulations, as shown in British Columbia. One possible explanation for this occurrence is that it is less politically risky for a province to adopt an enforceable regulation if there is already considerable public support towards ZEVs manifested by strong ZEV adoption.

Figure 6: ZEV Adoption in Select Canadian Provinces, 2011-2020

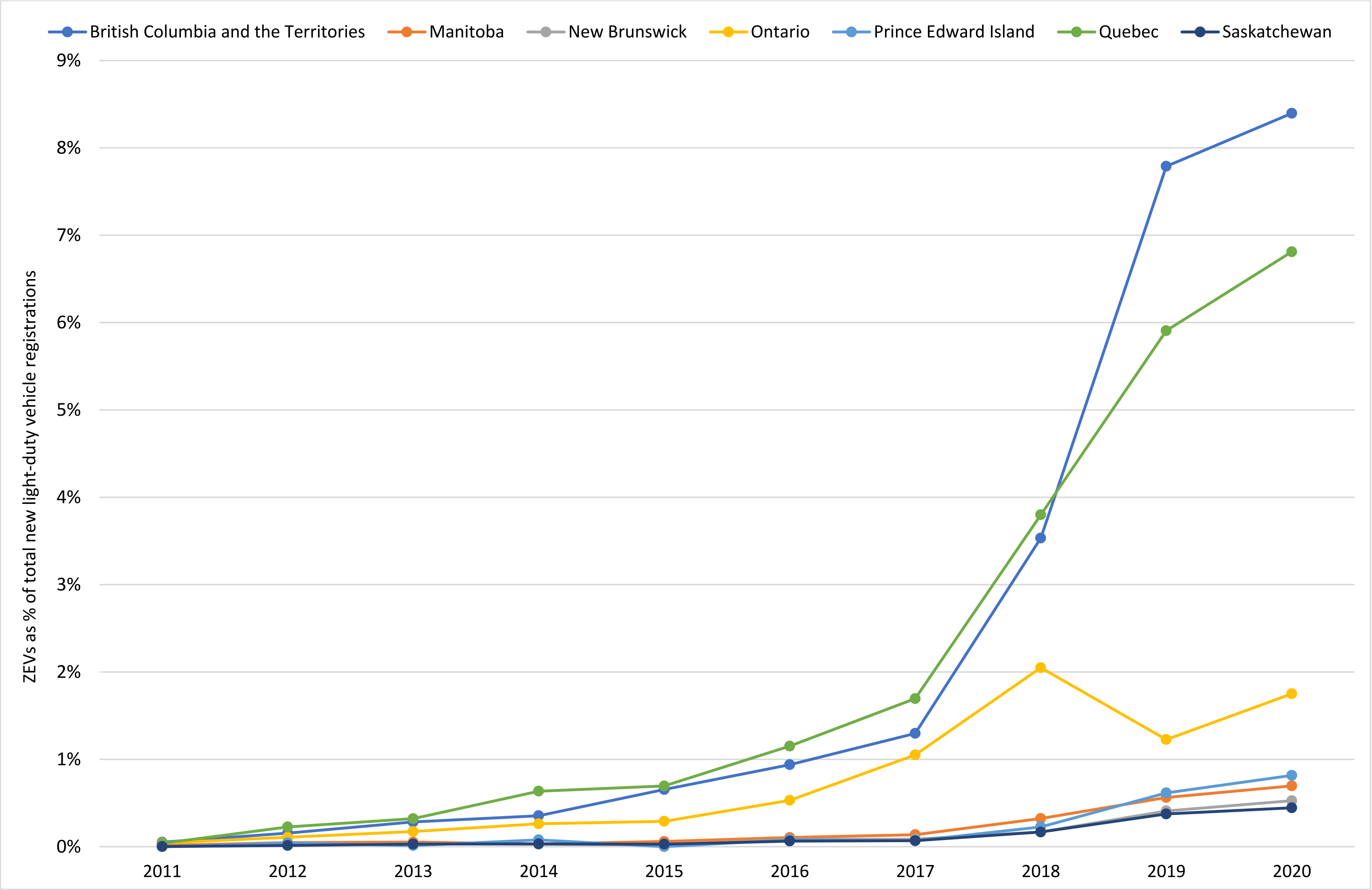


Table 7: Timeline of ZEV Regulations and Subsidies in Select Canadian Jurisdictions, 2011-2020

Province	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
QC		Subsidy				Act	Regulation			
BC	Subsidy								Act	Regulation
ON						Subsidy		Subsidy Ends		
FED									Subsidy	

Legend

(green shading)	ZEV Requirements

Sources: (Statistics Canada 2021; Government of British Columbia 2021; Legislative Assembly of British Columbia 2019; Government of British Columbia 2018; 2020; Government of Quebec 2021; National Assembly of Quebec 2016; Government of Quebec 2017a; Government of Ontario 2016; Bickis 2018; Transport Canada 2020)

Note: British Columbia and the Territories (i.e. Yukon, Northwest Territories and Nunavut) are aggregated in the Statistics Canada ZEV registration data. Both ZEV adoption and the total light-duty vehicle market of the territories are relatively small. Therefore, the outcome of aggregating British Columbia with the territories is that the percentage of ZEV registrations in the former are slightly diluted by the latter.

6.2. United States

Figure 7 shows ZEVs as a percentage of new light-duty vehicle sales from 2008 to 2020 in twelve US states. As per Table 8, California, Colorado, New York, Oregon and Vermont all have adopted ZEV regulations and are among the many other states have established ZEV purchase subsidies.

The perceivable impact of subsidy programs on ZEV adoption is inconsistent between states considered in Figure 7 and Table 8. There was a notable increase in ZEV adoption following the introduction of a subsidy program in California in 2010 and an even more notable increase in ZEV adoption in 2018 with the introduction of the Clean Vehicle Assistance Program available for low- and moderate-income households. Colorado's ZEV adoption also increased in 2012 with its first subsidy program coming online and an increase in 2017 with its second subsidy program being launched. However, the impact of subsidies is less obvious in some other states. New York experienced a rise in ZEV uptake with the introduction of its subsidy in 2017 and during subsequent years. However, ZEV adoption was already on the rise in 2016. Similarly, Oregon did have a sustained increase in new ZEV sales when its subsidy was launched in 2019 but ZEV adoption was already on a steady upward trajectory since 2016. Texas and Virginia both introduced a subsidy program in 2014 and saw a relatively small increase in ZEV adoption that year followed by a decrease in 2015. In both states, ZEV adoption started to pick up in 2017 and subsequent years. However, neither states introduced new regulation or subsidies which suggests that other factors have greater influence on ZEV adoption. The impact of some subsidy programs cannot be assessed since they were introduced prior to the availability of sales data. This includes the federal tax credits starting in 2008 and 2010, the Washington tax credit starting in 2009, and the Vermont rebate starting in 2010.

There is some evidence that regulations are having an impact on new ZEV sales. States with regulations had greater new ZEV sales on average than states without regulations. The seven states with the highest market share of new ZEV sales all adopted regulations, namely California, Washington, Oregon, Colorado, Vermont, New York, and Virginia. Similarly, none of the five states with the lowest new ZEV sales have adopted regulations, namely Michigan, Montana, Wisconsin, Texas, and Minnesota. Furthermore, ZEV sales did increase in some states following the introduction of regulations. California had a notable increase in ZEV adoption following its 2012 regulation and then another increase in uptake in 2018. This second increase coincides with the enforcement of the ZEV sales requirements for 2018 and subsequent years applicable for intermediate and large vehicle manufacturers. Similarly, Oregon had a significant increase in ZEV sales after adopting the latest iteration of California's regulation in 2013. New ZEV sales then plateaued for the following two years before picking up again in 2016 and becoming among the states with the highest market share of new ZEV sales. Vermont adopted the latest iteration of California's regulation in 2014 and experienced a steady increase in ZEV uptake starting in 2016. Lastly, Colorado did have a notable increase in new ZEV sales the same year it adopted its regulation in 2018.

However, there are several inconsistencies in this pattern. To begin with, numerous states without regulations had upward trends in new ZEV sales like states with regulations in place. Washington had a trend of increasing ZEV sales similar to Oregon, and yet it did not adopt California's regulation until 2020. Colorado had a similar trend of new ZEV sales as Vermont and only adopted the regulation in 2018. Virginia just adopted the regulation in 2021 and yet it had a ZEV adoption rate similar to New York which was the first adopter of California's latest regulation in 2012. In fact, Virginia had a greater market share of new ZEV sales than New York in 2018 and 2019. The similar trends in ZEV adoption between states with and without regulations suggests two things. First, this suggests that some states did not have greater ZEV adoption because they introduced regulations, but rather they adopted regulations in a context of already strong ZEV adoption. This is exemplified by Washington, Colorado and Virginia which all had relatively high market share of new ZEV sales long before adopting a regulation. Second, this suggests that other factors have a greater impact on ZEV adoption than government regulations and subsidies.

A key example of other factors impacting ZEV adoption is the rapid increase of ZEV sales in 2018 which was present in many states with and without regulations. From looking at the national plug-in electric vehicle sales statistics, it seems clear that the dramatic ZEV uptake in 2018 is mainly due to the launch of the Tesla Model 3 the year before (U.S. Department of Energy 2020a). The plug-in electric vehicle sales increased by nearly 85 percent across the US from 2017 to 2018 (2020a). The Model 3 accounted for 83 percent of that growth and made up nearly 39 percent of total plug-in electric vehicle sales in 2018 (2020a). This suggests that the growth in ZEV adoption during that period has more to do with ZEV manufacturers like Tesla gaining greater market share as opposed to the impact of state regulations on ICEV manufacturers.

Overall, like the Canadian market, American jurisdictions with a regulation in place seem to experience higher rates of ZEV registrations on average than their counterparts without such regulations. However, there are too many inconsistencies and insufficient evidence to be able to determine to what extent the changes in ZEV uptake are linked to regulations as opposed to other factors such as the release of new electric vehicles or variations in consumer preferences.

Figure 7: ZEV Adoption in Select US States, 2008-2020

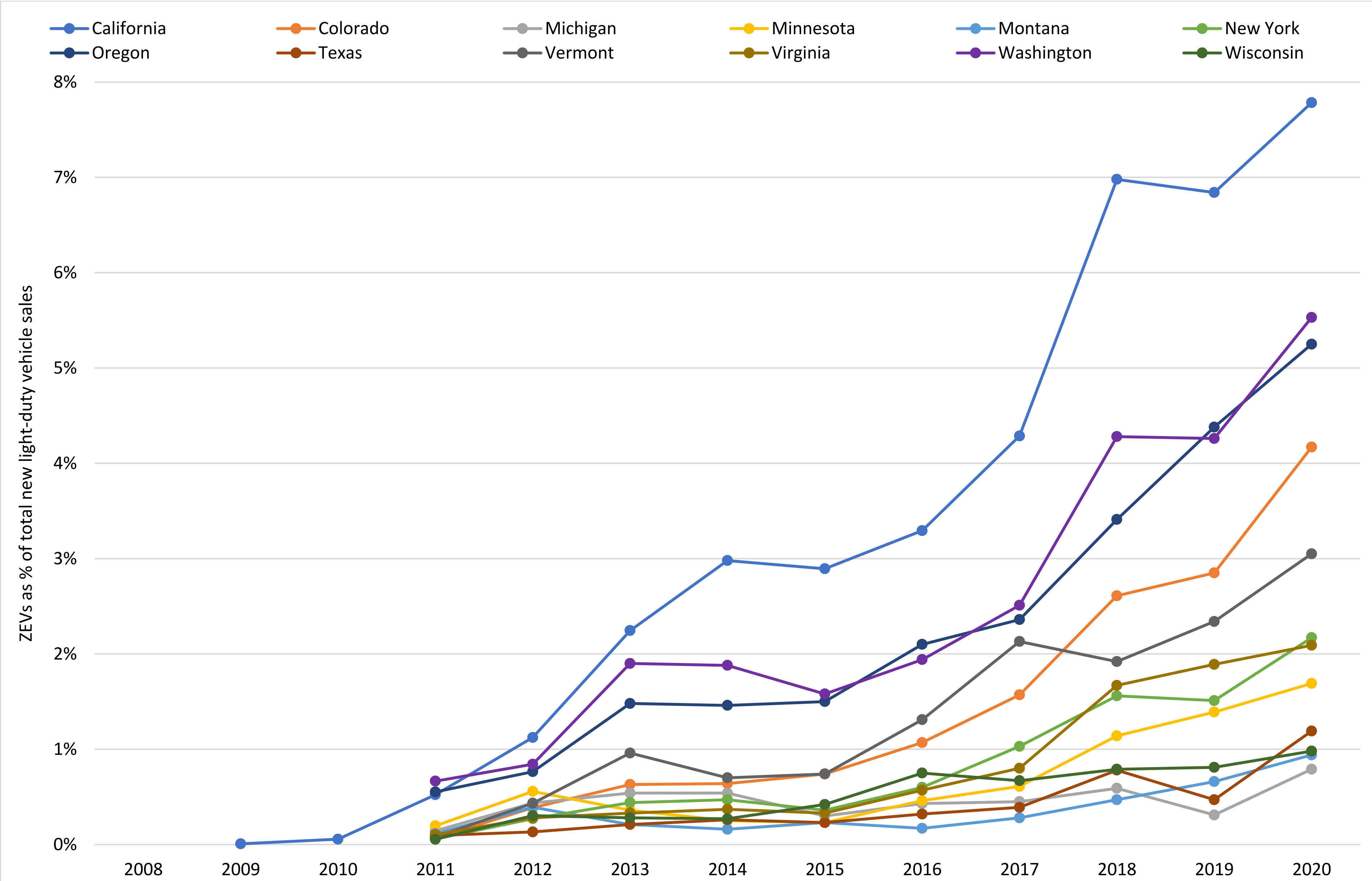


Table 8: Timeline of ZEV Regulations and Subsidies in Select US Jurisdictions, 2008-2020

State	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CA	S.1962.1		Subsidy		S.1962.2						Subsidy		
NY			S.1962.1		S.1962.2					Subsidy			
VT	S.1962.1		Subsidy				S.1962.2						
OR						S.1962.1-2						Subsidy	
CO					Subsidy					Subsidy	S1962.2		
WA		Subsidy											1962.2
TX							Subsidy						
VA							Subsidy						
FED	Subsidy		Subsidy										

Legend

S.1962 ZEV Requirements	S.1962.1 ZEV Requirements	S.1962.2 ZEV Requirements

Sources: (Alliance for Automotive Innovation 2021; California Energy Commission 2021; U.S. Department of Transportation 2020a; California Air Resources Board 2008; 2012; California Clean Vehicle Rebate Project 2021b; New York Department of State 2011; 2013; New York State Energy Research and Development Authority 2020; Vermont Department of Environmental Conservation 2008; 2014; Drive Electric Vermont 2021; Oregon Department of Environmental Quality 2013; 2021; Colorado Regional Air Quality Council 2021; Colorado Department of Revenue 2019; Colorado Department of Public Health and Environment 2018; Washington State Department of Revenue 2019; Texas Commission on Environmental Quality 2021; Virginia Clean Cities 2018; U.S. Internal Revenue Service 2008; U.S. Department of Energy 2021)

7. ZEV Availability

7.1. Canada

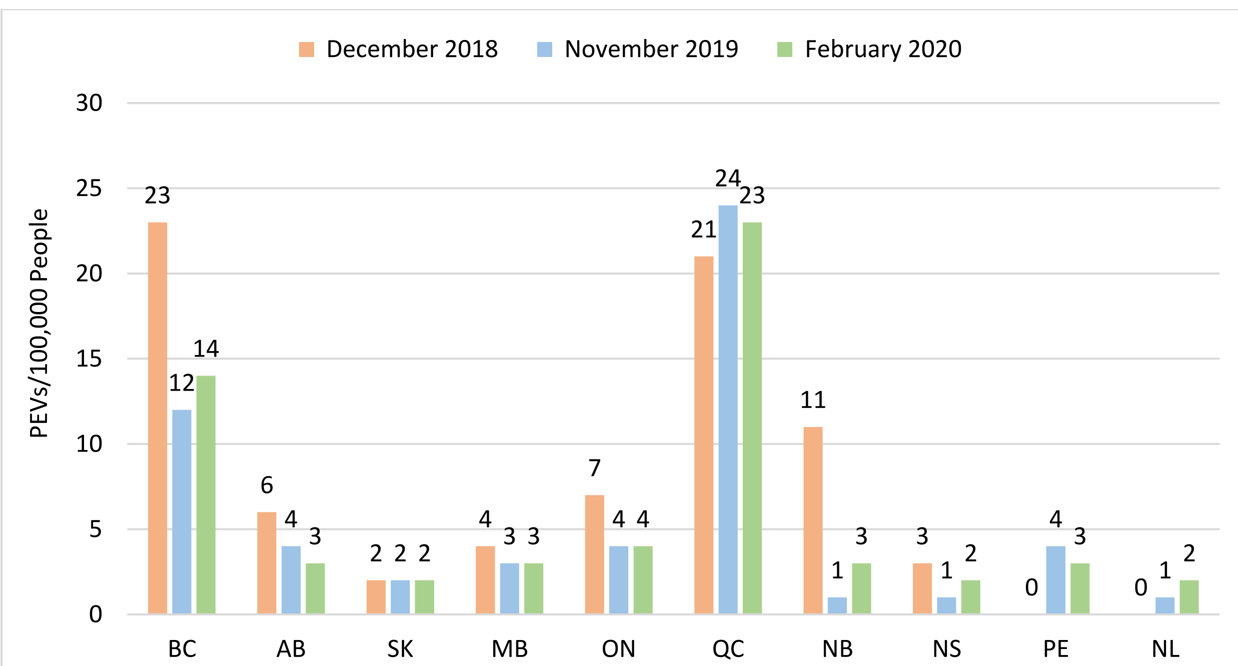
ZEV availability remains a consistent barrier to greater adoption in Canada. In 2018, only 26 models of electric vehicles were on offer and only nine were trucks, SUVs or minivans (Canada Energy Regulator 2019). Similarly, limited ZEV dealership inventory remains an impediment to greater adoption. In a survey of plug-in electric vehicle inventory across Canada, only 33 percent of dealerships had at least one of these vehicles in stock (Dunsky Energy Consulting 2020, 5). However, this scarcity of plug-in electric vehicles is not distributed evenly across jurisdictions. As demonstrated in Table 9, Quebec, British Columbia and Ontario have consistently far greater numbers of plug-in electric vehicles available for purchase (2020, 3). However, while Ontario does have the third largest market share of ZEVs, it is also the largest population and vehicle market. When adjusting for population size, Quebec and British Columbia come out far above other provinces in terms of plug-in electric vehicle dealership inventory as shown in Figure 8. Available stocks fluctuate from month-to-month but these yearly snapshots do suggest that vehicle manufacturers are concentrating electric vehicle inventory in the two provinces with ZEV regulations while maintaining relatively lower stocks per capita in the remaining provinces. It is also interesting that electric vehicle stocks have halved in British Columbia in 2019 and 2020 relative to the 2018 snapshot. This is consistent with the spike in new ZEV registration in BC which more than doubled in terms of market share during this period. However, this could also mean that vehicle manufacturers and dealerships in Quebec and British Columbia are stocking greater electric vehicles mainly because the market demand is greatest. This is made clear by the higher ZEV registrations in 2018 in both provinces relative to other parts of Canada (see Figure 6). Similarly, ZEV registrations were increasing in Ontario until 2018 and have begun decline in 2019 following the cancellation of its generous subsidy program. It seems that dealership inventory has adjusted with the decline in demand. Once again, ZEV availability appears consistently greater in provinces with regulations. A clear example is Quebec which accounts for over half of Canada's electric vehicle inventory (Dunsky Energy Consulting 2020, 3). Since the adoption of Quebec's ZEV Act in 2016, the percentage of ZEV models available in California that are also available in Quebec increased from 66 to 92 percent (Smith 2020). However, there is no clear attribution to regulations since this can also be caused by a variety of factors, namely greater consumer demand for ZEVs in Quebec and British Columbia.

Table 9: Comparison of 2018 and 2019 Inventory Levels by Province, 2018-2020

	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL	Total
Dec. 2018	1,118	253	19	57	1,043	1,789	81	29	-	2	4,391
Nov. 2019	595	115	22	37	543	2,010	10	12	6	6	3,356
Feb. 2020	692	164	26	36	536	1,944	21	22	4	8	3,453

Source: (Dunsky Energy Consulting 2020, 3)

Figure 8: Plug-In Electric Vehicle Available for Purchase in Canadian Provinces, 2018-2020

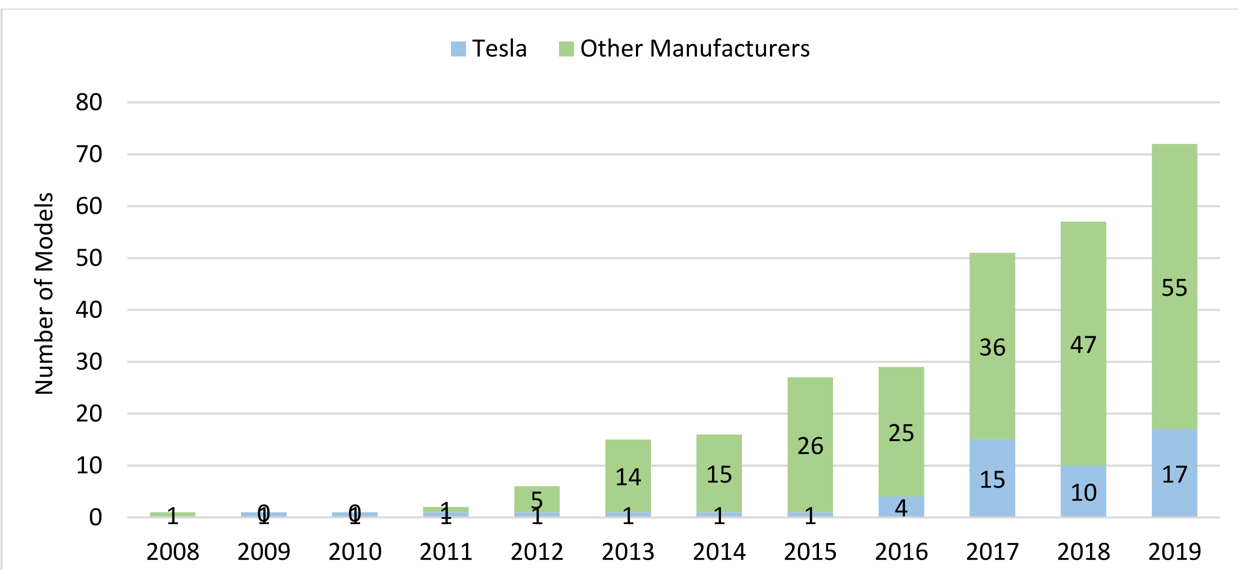


Source: (Dunsky Energy Consulting 2020, 4)

7.2. United States

Like in Canada, lack of availability still poses significant challenges for greater ZEV adoption in the US. However, the national data in Figure 9 shows that plug-in electric vehicle model offering has greatly increased starting in 2012. Since this data is not specific, this change cannot be attributed to the increased adoption of ZEV regulations in the US. However, it is possible to identify the proportion of plug-in electric vehicle models on offer in the US that are produced by Tesla, the main exclusively electric vehicle manufacturer. What this shows is that the proportion of ZEV models offered by ICEV manufacturers has greatly expanded over the past decade. Furthermore, this sudden acceleration in model offering does coincide with the adoption of California's latest ZEV regulation introduced in 2012 (S.1962.2) which was adopted thereafter by twelve other states. Together, these ZEV states accounted for over 30 percent of the total US automobile registrations in 2019 (U.S. Department of Transportation 2020b).

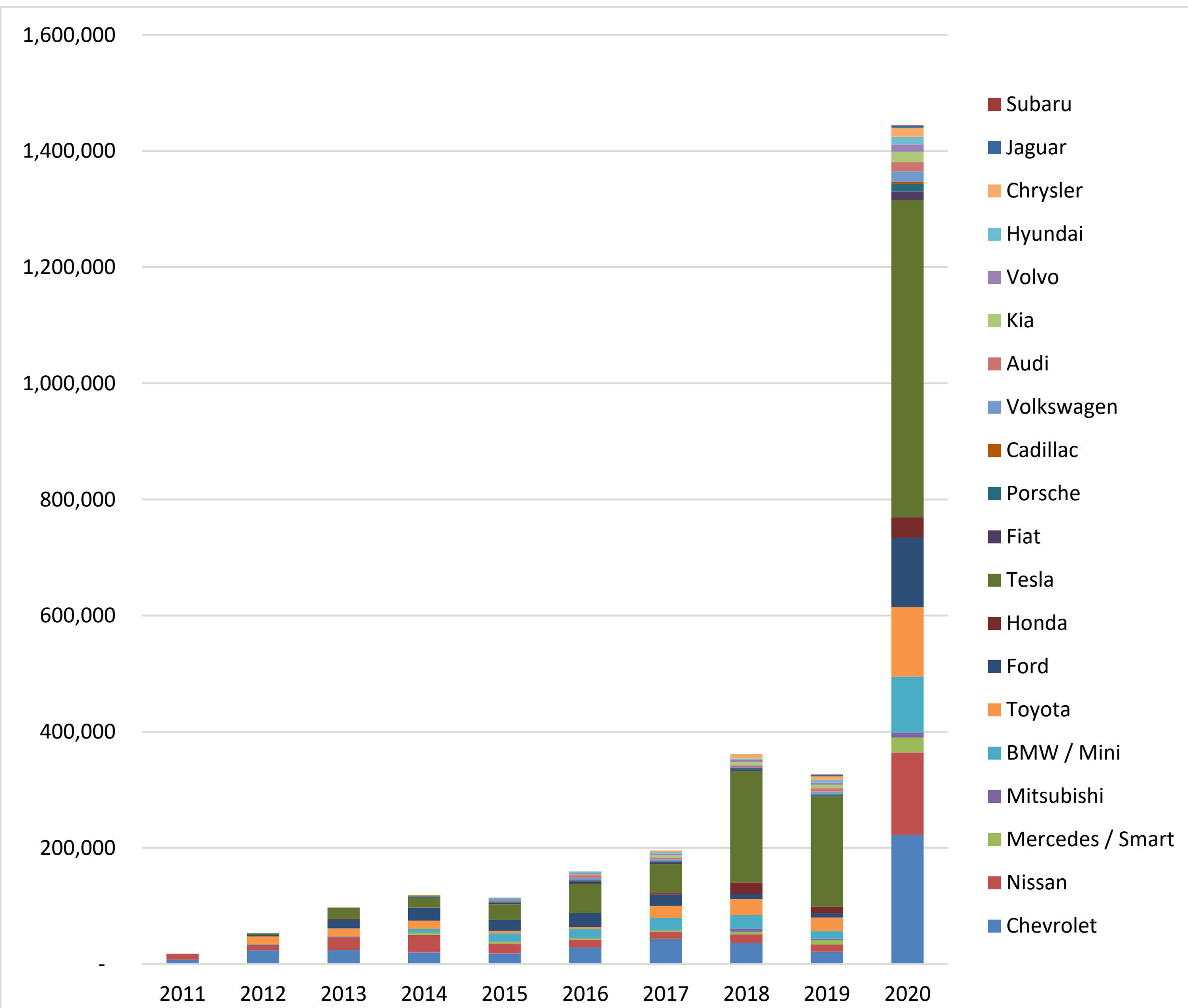
Figure 9: Plug-In Electric Vehicle Model Offering in the US, 2008-2019



Sources: (U.S. Department of Energy 2020b; 2020c)

However, even though other manufacturers are increasingly offering different models of ZEVs, Tesla is still responsible for more ZEV adoption in the US than any other vehicle manufacturer. As show in Figure 10, Tesla accounted for only 5 percent of ZEV sales in 2012, but it has since grown to account for 58 and 38 percent of ZEV sales in 2019 and 2020. Chevrolet and Nissan, the second and third manufacturers in terms of sales volume, accounted for 15 and 10 percent of ZEV sales in 2020. While other mnufacturers are increasing their ZEV model offering, they are selling in smaller numbers in comparison to Tesla.

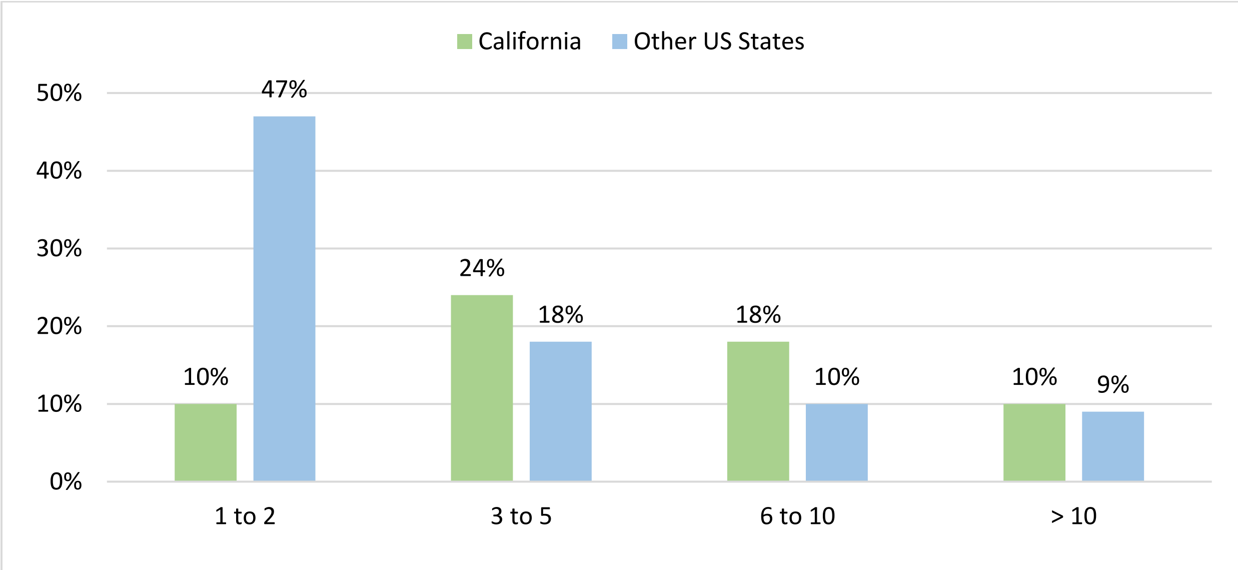
Figure 10: Plug-In Electric Vehicle Sales by Manufacturer in the US, 2011-2020



Source: (U.S. Department of Energy 2020a)

State-specific information on ZEV dealership inventory in the US is also challenging to find. However, the Sierra Club has conducted a study between May and July 2019 on the electric vehicle shopping experience across the US which contained some relevant findings. A significant difference was found in electric vehicle availability between US states that have adopted a ZEV regulation and those that did not (Le and Linhardt 2019). Among the dealerships that did offer electric vehicles in non-ZEV states, 52 percent of them only had one to two vehicles in stock (2019, 12). In ZEV states, 53 percent had more than two electric vehicles: 27 percent offered three to five, 13 percent offered from six to ten, and 12 percent offered more then ten (2019, 12).The differences are even more pronounced between California, where ZEV regulations originated, and the rest of the US. In California, among the dealerships that offered electric vehicles, 52 percent had three or more available on their lot (2019, 14). In other states, 63 percent of dealerships that do offer electric vehicles had two or less on their lot (see Figure 9). Aside from inventory this study also found that, in California, 75 percent of dealerships with electric vehicles displayed them prominently while only 40 percent did so in other states (2019, 14). In California, 73 percent of dealers with electric vehicles had vehicles that were fully charged for a test drive and 10 percent had vehicles that were partially charged (2019, 14). In other US states, 34 percent of dealers with electric vehicles had vehicles that were fully charged for a test drive, 9 percent had vehicles that were partially charged, and 3 percent had vehicles that were not charged at all (2019, 14). Overall, there does appear to be a pattern of greater availability in US states that also have ZEV regulations in place. However, greater electric vehicle inventory in California and other ZEV states, does not demonstrate that ZEV regulations necessarily leads to greater dealership inventory. It just shows that ZEV availability tends to be higher in states with regulation. Also, since this study is based on a single three-month sample, it cannot be assumed that these patterns are consistent over time. A longitudinal study of dealership availability would be required to make proper observations about the differences in ZEV availability between California, other ZEV states, and the rest of the US.

Figure 11: Electric Vehicle Stocks of Dealerships in California and Other US States, May-July 2019



Source: (Le and Linhardt 2019, 14)

8. Conclusion

A growing trend in ZEV adoption and availability is clearly underway in Canada and the US. Many large ICEV manufacturers announced targets for greater ZEV production. General Motors, Honda, Volkswagen, have all made public commitments to make either the entirety or majority of their productions dedicated to ZEVs within the next fifteen years (The Associated Press 2021; Honda Global 2020; Beresford 2021). One potential explanation for this progressive reorientation of the automobile industry toward ZEVs is that private and public forces have exerted mounting pressure on ICEV manufacturers. On one hand, growing demand for ZEVs enables new competitors (e.g. Tesla) to gain a greater share of the market which is threatening the future competitiveness of ICEV manufacturers. On the other hand, the increasing public support for climate action has led governments to adopt a growing number of policies to mitigate GHG emissions, including ZEV regulations, which are making current ICEV productions less and less sustainable. To wrap up, some of the key findings and limitations of this study are discussed below.

8.1. Findings

This study provides several findings that help answer the question of whether ZEV mandate regulations have been effective at promoting ZEV adoption and availability in subnational jurisdictions in Canada and the US. First, this analysis has shown that jurisdictions with ZEV regulations do have on average higher ZEV adoption and availability than their counterparts without such regulations in place. However, there is insufficient evidence to establish a clear link between regulations and ZEV adoption and availability. Moreover, some jurisdictions have high rates of ZEV adoption long before they adopt a regulation. For example, British Columbia in Canada as well as Colorado, Washington, and Virginia in the US. Second, there appears to be some increase in ZEV adoption following the adoption and implementation of a ZEV regulation. In Canada, Quebec, and British Columbia both appear to have experienced a significant increase in ZEV adoption following the adoption of their respective regulations. This was also a pattern in the US where California, Oregon, Vermont and Colorado all saw rises in ZEV sales within two years following the adoption of California's 2012 regulation. However, there are several inconsistencies with this pattern, namely that states without regulations experienced similar trends of ZEV uptake. Moreover, there are likely many other factors that have a potentially greater impact on ZEV adoption and availability, including the introduction of popular new ZEV models (e.g. the Tesla Model 3 in 2017), varying consumer preferences and other environmental policies. Third, jurisdictions with more stringent regulations may experience greater ZEV adoption and availability in the long term, namely due to the difference in compliance requirements between California, Quebec, and British Columbia. However, the ZEV regulations in the US have similar stringency since all other states have adopted California's regulation with only small amendments. Also, British Columbia adopted its regulation in 2020 and the added stringency of its compliance requirements only take effect starting in 2026. Since this study looked at data up to 2020, it is unlikely that ZEV adoption and availability in British Columbia was impacted by the added stringency of its regulation relative to other jurisdictions. Future studies will be needed to investigate if there is a difference in impact between British Columbia's regulation and that of other jurisdictions.

8.2. Limitations

This study has several limitations. As mentioned before, the data on ZEV adoption in Canada and the US is from a convenience sample of sources that have made their data publicly available. This makes it harder to determine if ZEV adoption is consistently greater in jurisdictions that have implemented a ZEV mandate regulation. Similar limitations apply for ZEV availability since the data is mostly national and does not cover a very large timespan. Data on dealership inventory in the US that covers several years and is disaggregated by jurisdiction could really help future studies in determining supply-side trends.

Beyond data limitations, there are several methodological issues with this project. The main one is that ZEV adoption analysis does not properly meet the requirements for the use of a difference-in-differences assessment method. First, many ZEV jurisdictions and non-ZEV jurisdictions already had diverging trends prior to the adoption of regulations by the former, which goes against the “equal trends” assumption discussed in the methods section. Second, ZEV adoption trends are potentially skewed by purchase subsidies since some jurisdictions have adopted subsidies and others have not. This goes against the consistency in trends assumption of the method. Third, it is not clear where a baseline should be placed to make the difference-in-differences assessment since most jurisdictions have adopted several iterations of the ZEV regulation and/or purchase subsidies which could each have had an impact on vehicle adoption. Fourth, normally the difference-in-differences will be quantifiable by subtracting the change from the baseline to the adoption year in a ZEV jurisdiction from the change over the same period in a non-ZEV jurisdiction. It was not useful to do a quantitative analysis because the delay for the presumed impact of a ZEV regulation was often more than one year and varied from one ZEV jurisdiction to the next.

Another potential inaccuracy of this impact assessment is that regulations remain challenging to evaluate due to the complexity of their credit systems. The number of credits required on a given year from manufacturers of different sizes is based on a manufacturer’s three-year sales average. Also, different types of ZEVs sold earn different amounts of credits depending on their electric ranges and other factors. Two simple changes to ZEV regulations could go a long way in making these credit systems more transparent and easier to evaluate. First, instead of calculating the required credits based on a three-year sales average, the number of credits could be based on the total number of vehicles sold during the compliance year. This is what is being done under the current British Columbia regulation. This makes it far simpler to identify the ZEV sales required on a given year. Second, one credit could be allocated per sale of a ZEV regardless of which type it is. This new approach would allow ZEV compliance requirements to accurately represent the percentage of vehicles that need to be sold on a given year, as opposed to the current abstract number of credits. This change was originally proposed for the British Columbia regulation starting in 2025 but seems to have been abandoned during consultations on the regulation (Government of British Columbia 2019, 6–7).

Lastly, this study has mostly measured changes in ZEV adoption and availability in anticipation of ZEV compliance requirements. Compliance requirements began in 2018 in Quebec and 2020 in British Columbia. Similarly, the compliance requirements were reset in the US following the most recent iteration of California's ZEV regulation in 2012 (see Section 4.1) which is only effective starting in 2018. Therefore, only the last three years of the available data indicate with greater certainty if manufacturers are stepping up to meet ZEV requirements. Future retrospective impact studies will be required to confirm if these trends continue to evolve in the next decades.

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