Canada's future vehicle emissions standard (2024-2035):

Impacts on vehicle size and GHG emissions

PREPARED FOR ENVIRONMENTAL DEFENCE, EQUITERRE, AND THE DAVID SUZUKI FOUNDATION BY:

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About the Sustainable Transportation Action Research Team (START)

We take an interdisciplinary approach to low-carbon transportation solutions, integrating relevant insights from quantitative and qualitative research methods, such as statistical analyses, energy-economy modeling, consumer and citizen surveys, stakeholder interviews, media analysis and policy analysis. Our current research focus centers around four main themes:

About Environmental Defence Canada

Environmental Defence is a leading Canadian environmental advocacy organization that works with government, industry and individuals to defend clean water, a safe climate and healthy communities. For over 40 years, Environmental Defence has worked at the municipal, provincial and federal level to safeguard our freshwater, create livable communities, decrease Canadians' exposure to toxic chemicals, end plastic pollution, tackle climate change and build a clean economy.

About Équiterre

Équiterre seeks to make the necessary collective transitions toward an equitable and environmentally sound future more tangible, accessible, and inspiring. Since 1993, Équiterre has been helping to find solutions, transform social norms, and encourage ambitious public policies through research, support, education, mobilization, and awareness-building initiatives. This progress is helping to establish new principles for how we feed ourselves, how we get around, and how we produce and consume, that are designed for our communities, respectful of our ecosystems, in line with social justice, and of course, low in carbon.

About the David Suzuki Foundation

Founded in 1990, the David Suzuki Foundation is a national, bilingual non-profit organization headquartered in Vancouver, with offices in Toronto and Montreal. Through evidence-based research, education and policy analysis, we work to conserve and protect the natural environment, and help create a sustainable Canada. We regularly collaborate with non-profit and community organizations, all levels of government, businesses and individuals.

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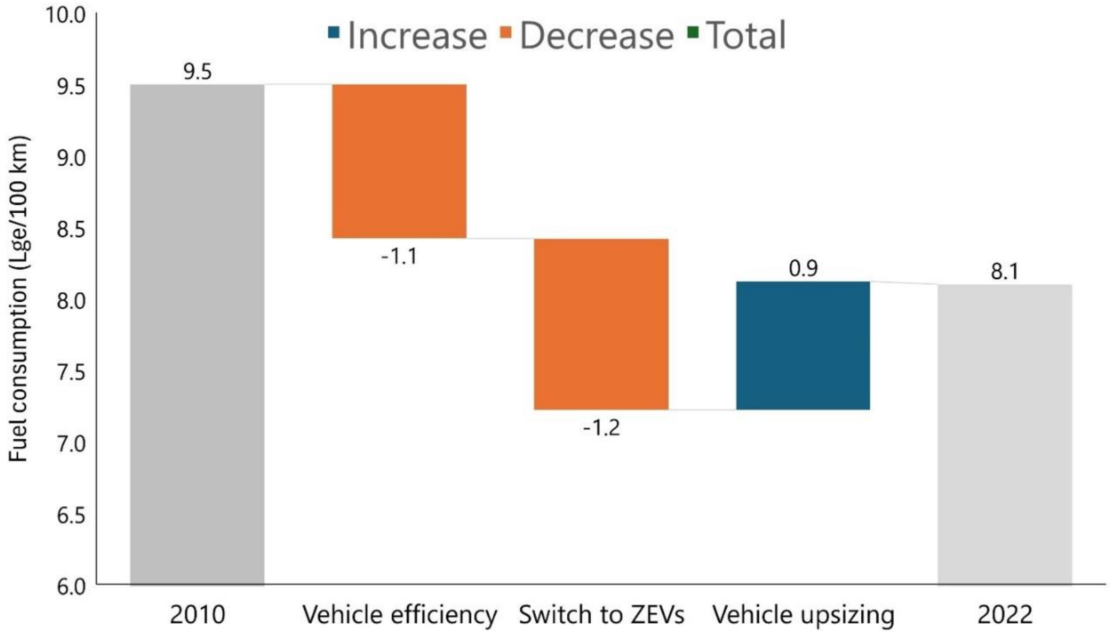
Executive summary

Background

In Canada and globally, the growing market share of sport utility vehicles (SUVs) and other light-duty trucks in the passenger vehicle market is challenging various sustainability goals, especially efforts to decarbonize the transportation system. Larger and heavier vehicles require more energy per km, emit more greenhouse gas (GHG) emissions, and present increased safety risks compared to smaller vehicles. Since 2005, emissions from light-duty trucks (mostly SUVs and pickup trucks) has been the top contributor to Canada's transportation emissions, accounting for 27% of the sector's emissions in 2022.[1] This trend is largely driven by an increase in the share of passenger vehicles that are trucks, growing from about 50% of sales in 2010 to 70% in 2022.[i]

We can isolate the negative role of vehicle upsizing in efficiency trends among Canada's new vehicles sold in 2010 versus 2022 (Figure ES1). On the positive side, overall fuel consumption (per km traveled) decreased by 15% in total. There was a 12% reduction in new vehicle fuel consumption due to improvements in engine and vehicle technology, and a 13% reduction due to the switch from internal combustion engine (ICE) vehicles to electric vehicles. However, during that same period there was a 9.5% increase in new fuel consumption due to the trend towards larger vehicle sales, notably light-duty trucks. **In other words, 39% of the reductions in fuel consumption Canada would have seen from increased ZEV sales and fuel economy improvement during this period (2010-2022) has been wiped out by vehicle upsizing.**

Figure ES1: Fuel consumption trends in Canada (2010-2022, see report for sources)



[i] Various data sources report different values for Canada's 2022 car/truck split of new light-duty vehicle sales, in the range of 70 to 80%. The higher values (~80%) typically include medium and heavy-duty vehicles as well. See Appendix A for more discussion.

In this report, we explore how climate policy design can influence this trend of passenger vehicle upsizing in Canada, focusing on the design of the national Vehicle Emissions Standard (VES). As of April 2024, the US Environmental Protection Agency (EPA) has announced new VES requirements for light-duty vehicles sold in 2027 to 2032. As with past versions of North American VES policy, the new EPA VES contains relatively less stringent reduction requirements for trucks, and especially for trucks with a larger footprint (sq. ft.). Because Canada is likely to adopt this same VES, we simulate the impacts of it and alternative policy designs on future trends in Canada's vehicle size, sales, and other impacts.

Method

We use the AUtomaker-consumer Model (AUM) to simulate the impacts of different climate policy designs and mixes on Canada's light-duty vehicle sector from 2023 to 2035. AUM is unique in that it simulates interactions between behaviorally-realistic consumers and an aggregate profit maximizing automaker. Consumer preferences are based on empirical survey data collected from Canadian car-buyers. AUM endogenously represents multi-year foresight for a profit-maximizing automaker, including decisions about: (i) increasing ZEV model variety, (ii) setting prices and profit margins on different vehicle models (by class and drivetrain), and (iii) investing in R&D to reduce future ZEV costs. Parameters are drawn from the literature, and model performance is calibrated with current sales and with forecasts from other models and studies. We represent uncertainty by running simulations with "median", "optimistic", and "pessimistic" parameters.

Policy Scenarios

We start with the existing mix of climate policies in Canada (including carbon pricing, ZEV purchase subsidies, and provincial regulations), and add 10 policy scenarios. The first four scenarios consider new and old versions of the VES:

1. **"Old VES"**: The current version of the national VES, which does not extend beyond 2025. In "Old" and "New" versions of the VES, requirements vary by vehicle class (car versus truck) and by vehicle size within a class (footprint).
2. **"New VES":** The US EPA version of the VES as announced in March 2024, with annual emissions reductions required until 2032.
3. **"Old VES + ZEV"**: adds the national ZEV Availability Standard requiring 100% ZEV sales by 2035.
4. **"Comprehensive Baseline":** includes all Canadian climate policies, the national ZEV sales standard, and the New VES announced for the US.

Building from the "Comprehensive Baseline" (Scenario #4), we then simulate several alternate versions of the VES that have potential to induce downsizing of light-duty vehicle sales:

5. **"Single VES":** applies a single GHG reduction standard for all vehicles (no differences based on vehicle class or footprint).
6. **"SUV=Car":** maintains different requirements by vehicle class, but with the "smaller SUV/truck" class having the same emissions requirements (based on footprint) as the car class.
7. **"Truck=Car":** puts all SUV/trucks ("smaller" and "larger") on the same footprint-based emissions requirement curve as the car class.

8. **“Truck Multiplier”:** follows the “New VES”, but applies a “multiplier” that more heavily weighs the impact of emissions from SUVs and trucks.

The final two policy scenarios keep the new EPA VES (as present in Scenario #4), but simulate two alternative downsizing policies outside the VES structure:

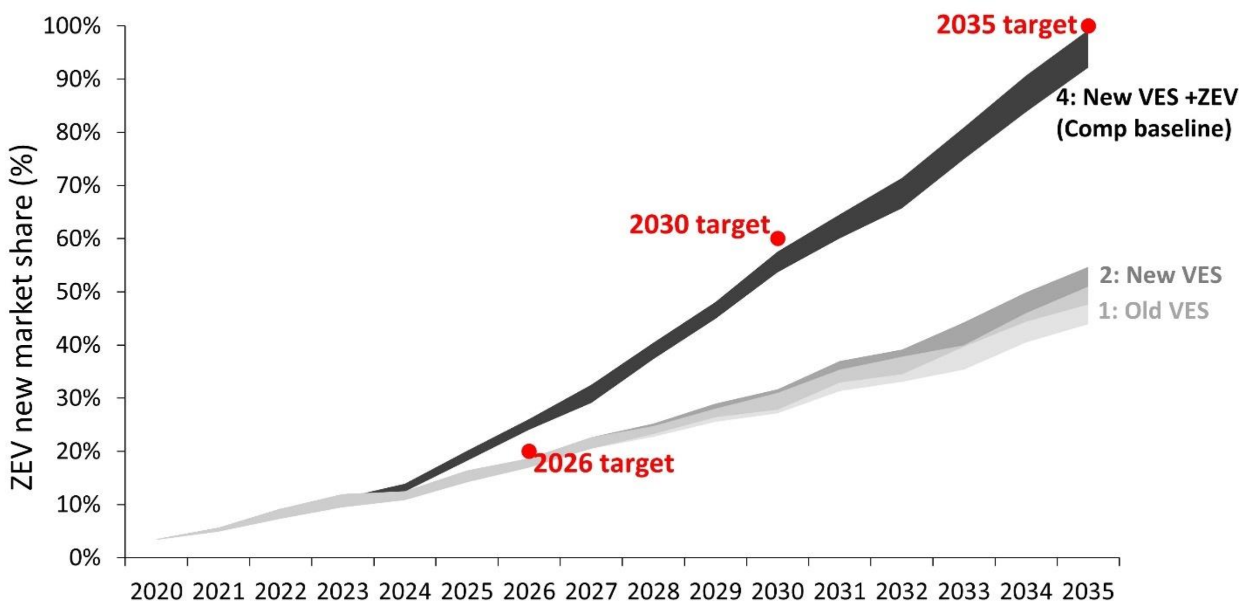
9. **“Truck Tax”**: adds to Scenario #4 a purchase tax on light-duty trucks based on GHG emissions (g/km), only for ICE vehicles and hybrids (not ZEVs). The value changes by year, but averages to a purchase of about $1800 per ICE truck.
10. **“ZEV Efficiency”** adds to Scenario #4 a VES-style efficiency standard for new ZEV sales, requiring improved ZEV efficiency (Wh/km). Financial penalties are imposed for every Wh/km that the fleet is over the required average.

Key findings

Full results are provided in the report, but we provide some highlights here.

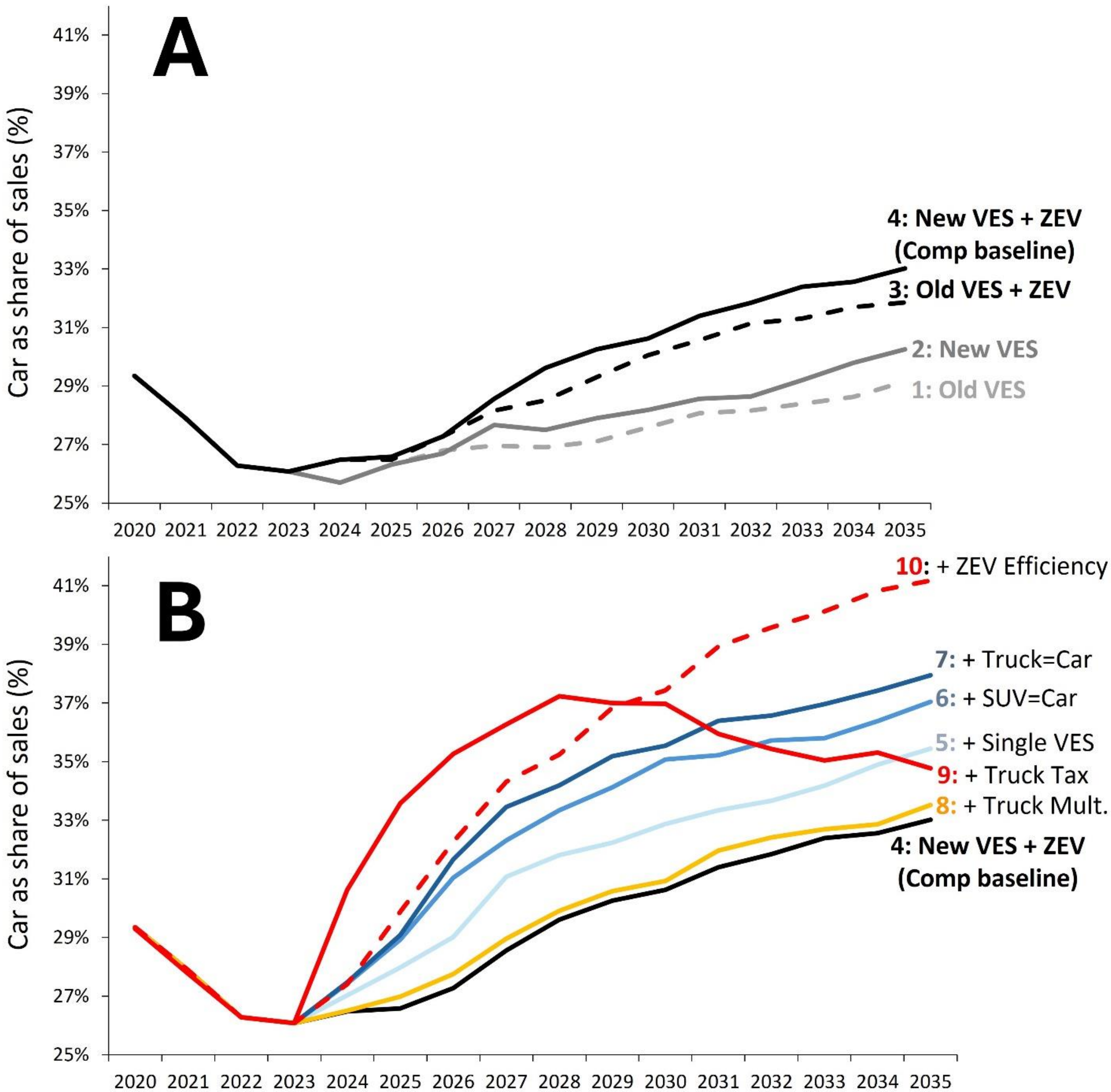
1. ZEV sales: due to the strength of Canada’s national ZEV Availability Standard, its presence in a policy mix has the dominant impact on ZEV sales. The Comprehensive Baseline includes this ZEV standard (Scenario #4 in Figure ES2), where the additional policy scenarios (#5-#10) have nearly identical impact on ZEV sales (not shown due to visual overlap). In contrast, the new VES standard (from the US EPA) has a much smaller impact on ZEV sales from 2025-2035.

Figure ES2: ZEV market share in new vehicle sales (individual policies, uncertainty range)



2. SUV sales: in all policy scenarios, there is an increase in the share of car sales (and a corresponding reduction in truck sales share) in future years past 2024 (Figure ES3). Part A depicts how the addition of the New VES and national ZEV mandate individually and in combination increase the share of new cars by up to four percentage points (to a median of 33% sales share in 2034). The reason is that stringent regulations lead to proportionally higher compliance costs for larger vehicles, which induces a slight downsizing of the light-duty vehicle fleet.

Figure ES3: Overall car/truck sales share for all policy scenarios (ICE vehicles and ZEVs, median parameters only)

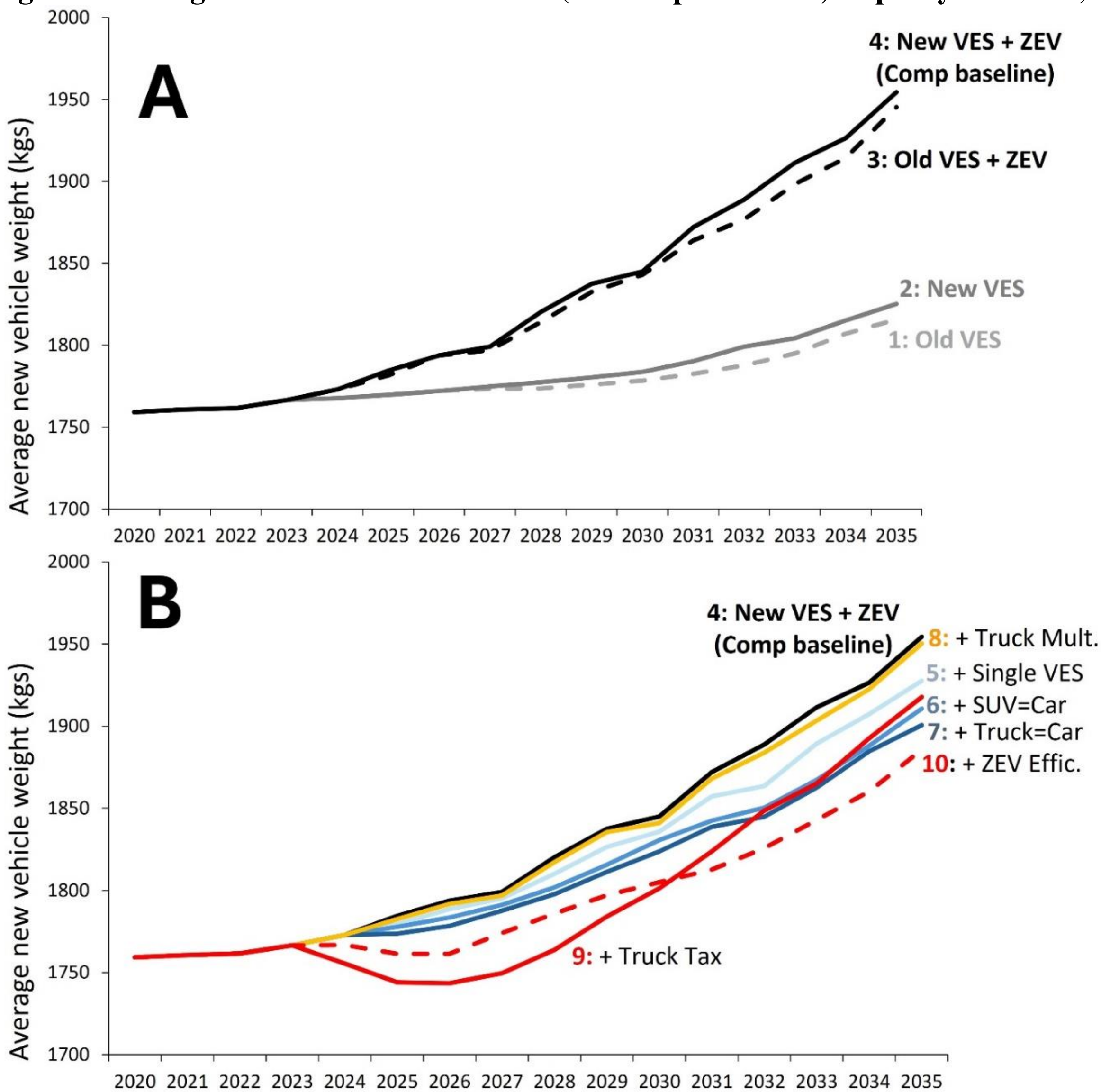


All the added policy scenarios (#5 to #10) lead to further increases in the sales share of cars above the Comprehensive Baseline (Part B of Figure ES3). One particularly useful comparison is the "Single VES" scenario (#5) that applies the same average GHG requirement as the new VES, but with neutrality towards vehicle class or size. This size-neutral VES induces an increase of car sales share by 2 percentage points, which is consistent for each year from 2026 to 2035. The more stringent VES scenarios that require trucks to be meet same standards as cars (#6 and #7) further increase the 2035 car sales share by 2%-points and 3%-points, respectively.

Two scenarios have particularly large impacts on car/truck sales shares. First, the "Truck Tax" (#9) leads to the strongest short-term impacts, increasing car share to 37% for 2028-2030. However, the tax is less impactful beyond 2030 because ZEV sales increasingly dominate the market (the tax only applies to ICE vehicles and hybrids). Second, the "ZEV efficiency" standard (#10) increases car sales share to 41% of new vehicle sales by 2035 (8 percentage points above the Comprehensive Baseline), which is the largest impact of any policy scenario we simulate.

3. Light-duty vehicle weights and footprint: although the future sales shares of trucks decrease in all scenarios, the average weight of new vehicles sold increases from 2023-2035 in all scenarios due to the transition to increasing ZEV sales (Figure ES4). ZEVs are heavier due to large batteries. However, the additional policy scenarios (#5-#10) can slow the increase in new vehicle weight relative to the Comprehensive Baseline. The "ZEV Efficiency" scenario (#10) induces the largest reduction in the 2035 average weight (3.5% or 69kg).

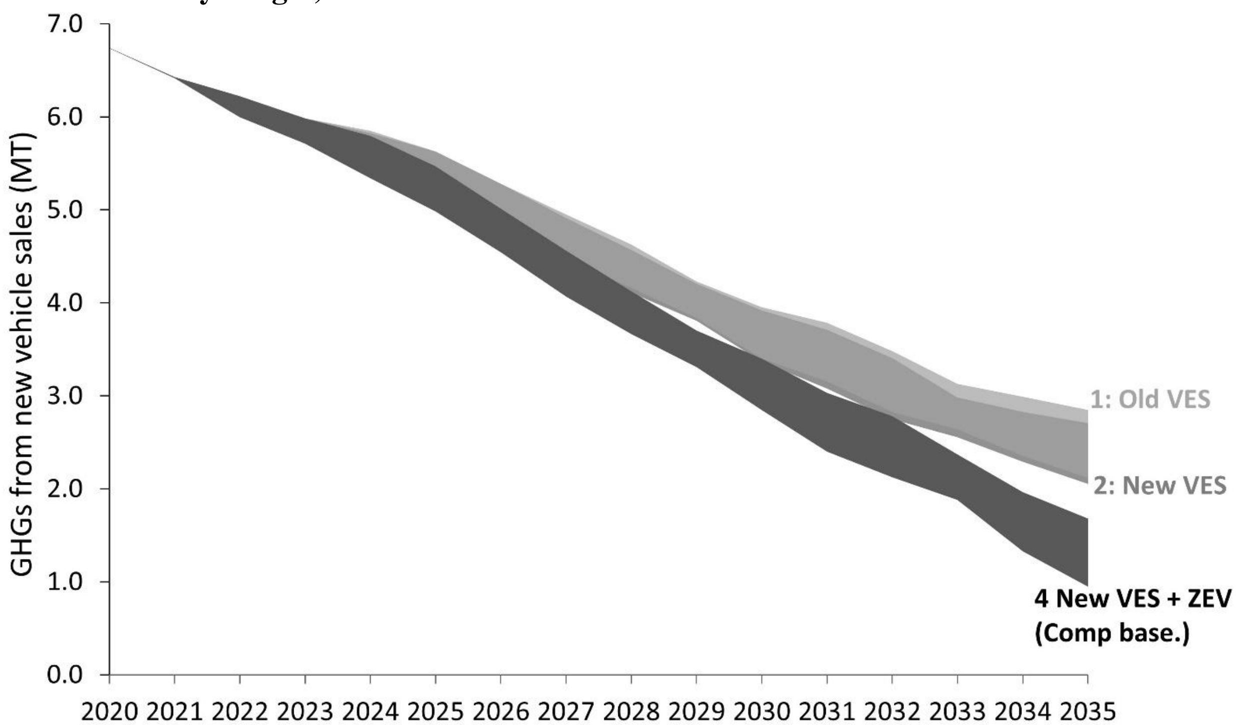
Fig ES4: Average mass of new vehicles sold (median parameters, all policy scenarios)



The average footprint of new vehicles decreases in future years in all scenarios, while all the added policy scenarios (#5-#10) induce further downsizing over time. Again, the "ZEV Efficiency" scenario induces the largest reduction (1% or 0.5 sq. ft.) among 2035 light-duty vehicle sales.

4. GHG emissions: the fuel consumption and GHG emissions from new light-duty vehicles are mostly influenced by the share of ZEV sales, so these results align with the ZEV sales patterns in Figure ES2. The Comprehensive Baseline substantially lowers emissions compared to the Old VES or New VES alone (Figure ES5). The comparison demonstrates the particular importance of the national ZEV Availability standard (scenario #4) which leads to cumulative 2024-2035 GHG emissions that are 12% lower than the "New VES" alone (scenario #2). The added policy scenarios (#5-10) have some additive impacts beyond the Comprehensive Baseline (see Table 10 of report). Emissions from new vehicles sold in 2035 are an additional 4-8% lower with more stringent versions of the VES (scenarios #4 to #7), and 13% lower with the "ZEV Efficiency" standard (scenario #10).

Figure ES5: GHG emissions of new vehicles sold in a given year (Scenarios #1, 2, and 4; with uncertainty ranges)



5. Automaker profits: in all 10 policy scenarios, automaker profits in 2035 are substantially higher in real terms than in 2023. The additional policy scenarios (#5-#10) reduce profits in 2035 by 0.2% to 4.0%, but those profits are still 16-24% higher than profits in 2023. Further details on profits and vehicle pricing are summarized in Section 6.6.

Policy recommendations

All results should be interpreted with care, especially policy scenarios #5-#10. The relative magnitudes of the reported impacts are mostly a function of the stringency of the selected policy (standard, requirement, or tax). For example, a larger truck tax (and/or tax that applies to ZEV trucks also) would induce even larger reductions in the truck sales share. Further, the simulated "ZEV Efficiency" standard could be more or less impactful with more or less stringent requirements set in each year (and the magnitude of the penalty applied for non-compliance).

That said, we can draw several broad results from this analysis:

1. **The national ZEV Availability Standard will play a dominate role in several key sustainability goals**, including increased ZEV sales, decreased fuel consumption and GHG emissions from new light-duty vehicles, and a slight decrease in average new vehicle size. Without the ZEV mandate, the New (US EPA) VES alone would have only a slight impact in increasing ZEV sales and decreasing GHG emissions.

2. **The new US EPA VES offers slightly improved sustainability impacts over the old VES**, including slight reductions in GHG emissions, increases in ZEV sales share, and vehicle downsizing.

3. **In addition to the ZEV standard and new EPA VES, a number of additional policies (or design adjustments to the VES) can induce further vehicle downsizing.** As an illustration, the two VES designs that put trucks in the same requirements category as cars can increase the sales share of cars by 4%-points to 5%-points over the Comprehensive Baseline with the NEW VES.

4. **A stringent version of a "ZEV Efficiency" standard could be particularly effective**. The version we simulate (scenario #10) results in the following changes in 2035 (compared to the Comprehensive Baseline in 2035):
    - A 9-percentage point increase in car (versus truck) sales share
    - A 13% decrease in GHG emissions from new vehicles sold in that year
    - A 3.5% decrease in the average weight of vehicles sold (69 kg)
    - A 1% decrease in average footprint of vehicles sold (0.5 sq. ft.)
    - A 7% decrease in needed battery capacity sold for ZEVs (with similar reduction for metals/minerals used in battery production).

    In terms of cumulative GHG emissions impacts from vehicle stock (2024-2035), the ZEV Efficiency standard has about the same reduction impacts as the "Truck Tax" (which has an average charge of ~$1800 per new internal combustion engine truck).

5. All these policies (ZEV standard, new VES, and additional policies) can be implemented and **still result in substantial growth in automaker profit over time**.

This study is not set up as a comprehensive policy analysis. We focus on major impacts regarding key sustainability goals (mainly GHG emissions, fuel consumption, and vehicle size), but do no presently evaluate additional policy evaluation criteria such as policy cost-effectiveness, equity impacts, or political acceptability. However, we do identify numerous additional policy pathways that can have positive impacts if added to the current policy mix in Canada (including ZEV Availability Standard and new VES):

- **Design adjustments to new VES:** given the numerous reasons to reduce vehicle size (and the trend towards larger vehicles over the last decade), it is wise to consider adjusting the VES towards requirements to be "neutral" regarding class (car versus truck) and footprint. With this adjustment, vehicle downsizing would then become a viable VES compliance pathway for automakers, and would yield additive reductions in GHG emissions, fuel consumption, vehicle size, and battery requirements.
- **ZEV efficiency standard:** we demonstrate the potential efficacy of an efficiency standard on new ZEV sales, which can shift the sale of new ZEVs towards smaller, lighter versions. Of course, such as standard would also have to be neutral in regards to vehicle class, weight, and footprint.
- **Truck tax:** a purchase tax on light-duty trucks (or by weight) can also be effective at reducing vehicle weight and/or footprint, if the price signal is large enough. However, we demonstrate that if the tax is only applied to conventional ICE and hybrid trucks there will be little impact post-2030 (with the national ZEV standard in place). Further, it is highly likely that political and public opposition to a purchase tax will be quite strong—typically larger than that observed for a VES or ZEV standard.

1. Background

In Canada and globally, the growing market share of sport utility vehicles (SUVs) and other light-duty trucks in the passenger vehicle market is challenging various sustainability goals, especially efforts to decarbonize the transportation system. Larger and heavier vehicles require more energy per km, emit more greenhouse gas (GHG) emissions, and present increased safety risks compared to smaller vehicles. Since 2005, emissions from light-duty trucks (mostly SUVs and pickup trucks) has been the top contributor to Canada's transportation emissions, accounting for 27% of the sector's emissions in 2022.[1]

A major concern is that increasing vehicle size and weight is cancelling out a substantial portion of the efficiency and decarbonization gains induced by Canada's climate policy mix. There are also concerns regarding the added mineral requirements of a fleet of larger ZEVs, which would need bigger batteries with more energy storage capacity than a fleet of smaller ZEVs. A larger, heavier fleet of vehicles reduces safety in the transportation system, increasing the risks of injury and fatalities from collisions.

In this report, we explore how climate policy can influence this trend of passenger vehicle upsizing in Canada, focusing on the design of the national Vehicle Emissions Standard (VES). As of April 2024, the US Environmental Protection Agency (EPA) has announced new VES requirements for light-duty vehicles sold in 2027 to 2032. As with past versions of North American VES policy, the new EPA VES contains relatively less stringent reduction requirements for trucks, which are even less stringent for trucks with a larger footprint (sq. ft.). Because Canada is likely to adopt this same VES, we simulate the impacts of it and alternative policy designs on future trends in vehicle size, sales, GHG emissions, and other impacts.

1.1 Vehicle upsizing is inconsistent with climate (and safety) goals

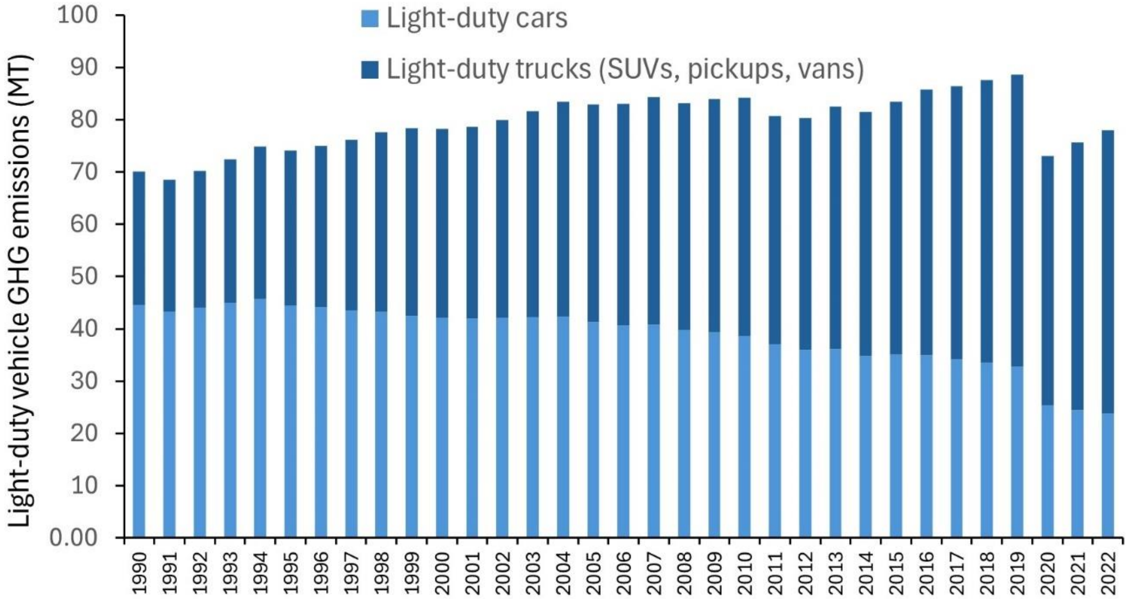
Canada has set firm goals to reduce emissions by 40-45% by 2030 (relative to 2005 levels) and net zero by 2050.[ii] The transportation sector represents 22-28% of greenhouse gas emissions in Canada.[1] Although national emissions have decreased by 7% from 2005-2022, emissions from the transport sector have increased by 3%, with 8% growth in road transport emissions from 2020 to 2022 as transportation patterns return towards pre-pandemic levels.[1]

As portrayed in Figure 1, light-duty passenger trucks (which include SUVs, minivans, and pickup trucks) is one of the fastest growing sources of GHG emissions in Canada's transport sector. Canadian GHG emissions from light-duty cars went down 47% from 1990 to 2022—while emissions from light-duty trucks went up 112%.[1] This trend is largely driven by an increase in the share of light-duty trucks among passenger vehicles sales, growing from about 50% of sales in 2010 to 70% in 2022.[iii] As of 2020, about 62% of the light-duty vehicles on Canada's road were trucks (the total "stock"), compared to 27% in 1990.

[ii] Canada has not identified specific decarbonization goals for the light-duty vehicle sector.

[iii] Various data sources report different values for Canada's 2022 the car/truck split of new light-duty vehicle sales, in the range of 70 to 80%. The higher values (~80%) typically include medium and heavy-duty vehicles as well. See Appendix A for more discussion.

Figure 1: Growing GHG emissions in Canada's transportation sector, 1990-2022 (Source: Environment and Climate Change Canada, 2024)[1]



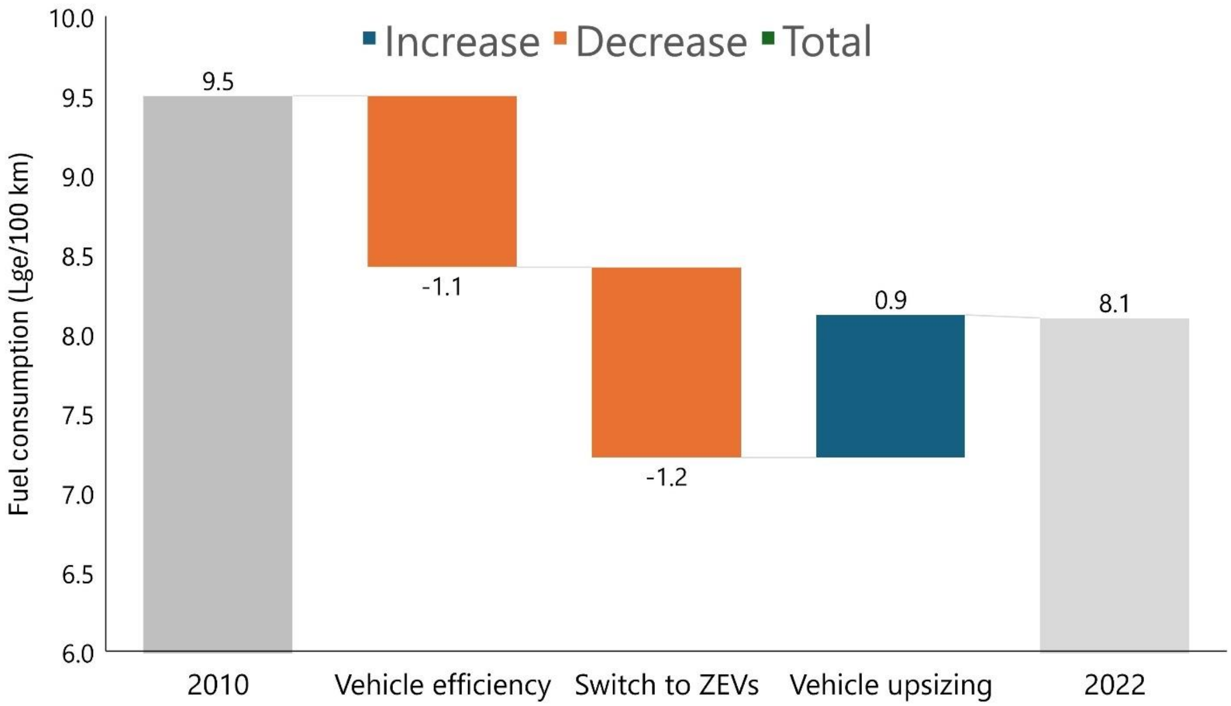
These trends are occurring globally as well, where the proportion of SUVs has grown from 22% of light-duty vehicle sales in 2005 to over 50% in 2022.[2] Correspondingly, the average weight and footprint of new vehicles sold has steadily increased from 2010 to 2022.[2] During this same time period, SUVs represented the second fastest growing source of GHG emissions globally, after the power sector—higher than heavy industry, heavy-duty trucks, and aviation.[3]

The problem climate mitigation goals is that light-duty trucks are less efficient than cars. In Canada, light-duty trucks emitted about 30% more GHGs per km than cars in 2018.[4] Globally, SUVs use on average 25% more energy (per km) than midsized cars.[3] SUVs have also been getting heavier over time, with a 7% increase (136 kg) in average weight since 1990.[5] The implication is that increased SUV and truck usage can counteract the GHG benefits of improved vehicle efficiency and increased electric vehicle sales.

Figure 2 quantifies this trend for Canada's new vehicle sales in 2010 versus 2022. Overall fuel consumption (per km traveled) for new vehicles decreased by 15% during this time, which can be separated into three factors. On the positive side, there was a 12% improvement due to the improved technical efficiency of internal combustion engines (ICEs), and a 13% improvement in average efficiency due to switching from ICE vehicles to electric vehicles. However, there was a 9.5% increase in fuel consumption due to the trend towards increasing light-duty truck sales (away from smaller car sales). **In other words, 39% of all the reduction in fuel consumption Canada would have seen from increased ZEV sales and fuel economy improvements has been wiped out by vehicle upsizing.**

Put another way, without the 0.9 Lge/100km increase in average fuel consumption observed from upsizing of the light-duty vehicle fleet from 2010-2022, the GHG emissions from 2022 new vehicle sales would be 0.7 Mt/year lower (all else held constant).

Figure 2: Fuel consumption trends in Canada (2010-2022)[iv]



An increasing share of SUVs also reduces the safety of the transportation system.[5] SUVs are disproportionately more likely to injure or kill pedestrians relative to cars.[6] In a collision between an SUV and smaller vehicle, the driver and passengers in the smaller vehicle are significantly more likely to be killed.[7,8] Pedestrians that are struck by heavier vehicles are also at higher risk.[9,v]

Frustratingly, although increasing the mass of the vehicle fleet reduces the safety of the overall transportation system, consumers typically perceive themselves as being safer inside SUVs. This can be described as the difference between the "passive safety" offered by SUVs (hitting or getting hit by something), while smaller cars are better at "active safety": handling, braking, and avoiding collisions.[10,11]

[iv] Authors' calculation based on:
1 https://www.iea.org/articles/fuel-economy-in-canada
2 https://www.globalfueleconomy.org/data-and-research/publications/trends-in-the-global-vehicle-fleet-2023
3 https://www150.statcan.gc.ca/n1/pub/71-607-x/71-607-x2021019-eng.htm
4 NRCan
https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=ca&year=2020&rn=32&page=0

[v] More details on SUV and pickup impacts on safety are detailed here:
https://windsorlawcities.ca/oversized-danger-report-on-the-lethal-danger-of-pickups-and-large-suvs/

1.2 Climate policy and vehicle size: The role of the Vehicle Emissions Standard (VES)

Three broad types of actions can reduce GHG emissions from transportation: switching to low-carbon fuels or electricity ("fuel switching"), otherwise improving the efficiency of vehicles, and reducing vehicle travel (which includes reduced demand, and switching to low-carbon modes such as public transit). This report focuses more on the second category (efficiency), though the simulation model we utilize (AUM) represents how policy can impact all three mitigation categories.

For the most part, Canada's climate policies do not directly address or try to counteract the observed trend towards light-duty truck sales. Following the US, Canada's vehicle emissions standard in particular has weaker requirements (in terms of gCO_2e per km) for larger vehicles.[12] More neutrally, both the national ZEV Availability Standard and low-carbon fuel standard (LCFS) focus on fuel-switching, with no emphasis on reducing vehicle size.

Canada's current transportation decarbonization strategy focuses mostly on switching to zero-emissions vehicles (ZEVs). The national target is for ZEVs to make up 20% of annual light-duty vehicle (LDV) sales by 2026, 60% by 2030, and 100% by 2035.[vi] These targets have been translated into legal requirements via the ZEV Availability Standard (which we call the "ZEV Standard" in this report), supported by complementary policies that include ZEV purchase subsidies and charger deployment.

In theory, a technology-neutral policy such as Canada's national carbon pricing program should incentivize consumers to shift towards more efficient vehicles in general (leading to reductions in size and mass). Yet, so far, most consumers are found to have low responsiveness to increases in gasoline or carbon prices—at least when it comes to their decisions about vehicle type.[11]

One of these policies has the potential to play particularly strong role in trends of vehicle size and class: the national Vehicle Emissions Standard (VES). A VES is often viewed as an "efficiency" standard, though it includes requirements for automakers to reduce the per km fuel consumption, air pollution emissions, and GHG emissions of new light-duty duty vehicles sold each year. Although such a policy could be designed to induce the sale of smaller and lighter vehicles, it has had the opposite effect. Since the first version of this policy was deployed (CAFE standards in the US in the early 1980s), "loopholes" were added to provide less stringent requirements (gCO_2e/km) for larger vehicles. These loopholes initially included more lax standards for light-duty trucks (relative to cars), and have progressed in Canada, the US, and numerous other countries to include less stringent standards for vehicles with a larger footprint (the area between the four wheels).

The newly announced US Environmental Protection Agency (EPA) VES requirements will follow this same pattern, as announced in April 2024 (Figure 3). For each model year, the average emissions requirements (gCO_2e per km) are higher for light-duty trucks relative to cars, and are even less stringent for trucks with a larger footprint (sq. ft.). For example, in the year 2027, a smaller truck (50 sq. ft. footprint) has a requirement of 173 gCO_2e per mile (108 g/km),

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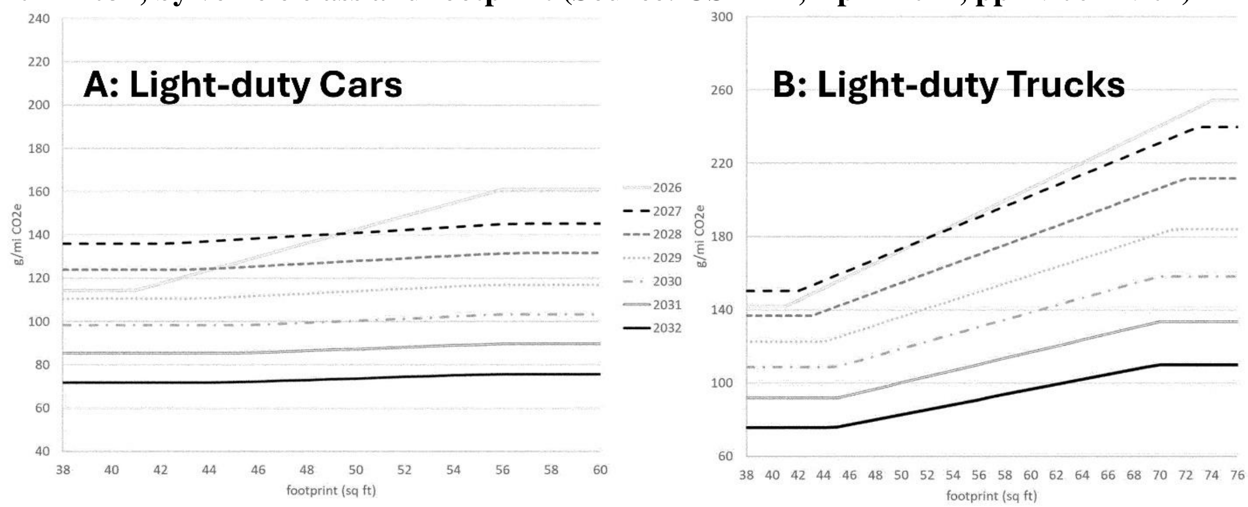
[vi] https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/canada-s-zero-emission-vehicle-zev-sales-targets

while a larger truck (56 sq. ft.) has a more relaxed requirement of 191 gCO_2e/mile (119 g/km). In the same year, cars with footprint ranging from 39 to 45 sq. ft. have much more stringent requirements of achieving 134-138 gCO_2e/mile (83-87 g/km). Clearly, such a policy design is not meant to induce vehicle downsizing as a compliance strategy. In fact, the design induce "gaming" among automakers, inducing them in the long-term to more on manufacturing, marketing, and selling larger vehicles than they would otherwise.

Figure 3: "Final" requirements for the US Vehicle emissions standard for model years 2027-2032, by vehicle class and footprint (Source: US EPA, April 2024, pp27906-27907)[vii]



Such loopholes clearly play a strong role in recent light-duty vehicle trends towards higher SUV market share, and larger vehicles in general. As VES requirements become more stringent overall, automakers have shifted towards selling more light-duty trucks (SUVs and pickup-trucks) relative to cars, and within each class the average footprint of vehicles has increased. Numerous scholarly analyses demonstrate that this trend is at least partially driven be the VES design, as summarized in the next section.

2. Literature review: Vehicle emissions standards and vehicle size

Numerous economic studies have quantified the impact of VES design on light-duty vehicle usage and impacts in different countries. Some studies analyze past data (ex-post) to uncover trends in countries that have a VES in place. For example, Greene et al. study the US experience with the original CAFE standard, finding that the standards (combined with oil supply shocks) induced an initial average weight loss for new light-duty vehicles of about 1000 lbs (~450 kg) from 1975-1982.[13] However, with later policy changes to have less stringent requirements for larger vehicles, vehicle weight increased over the following decades. Light-duty vehicles sold in 2019 were on average heavier than those in 1975. Lipman provides a similar evaluation,

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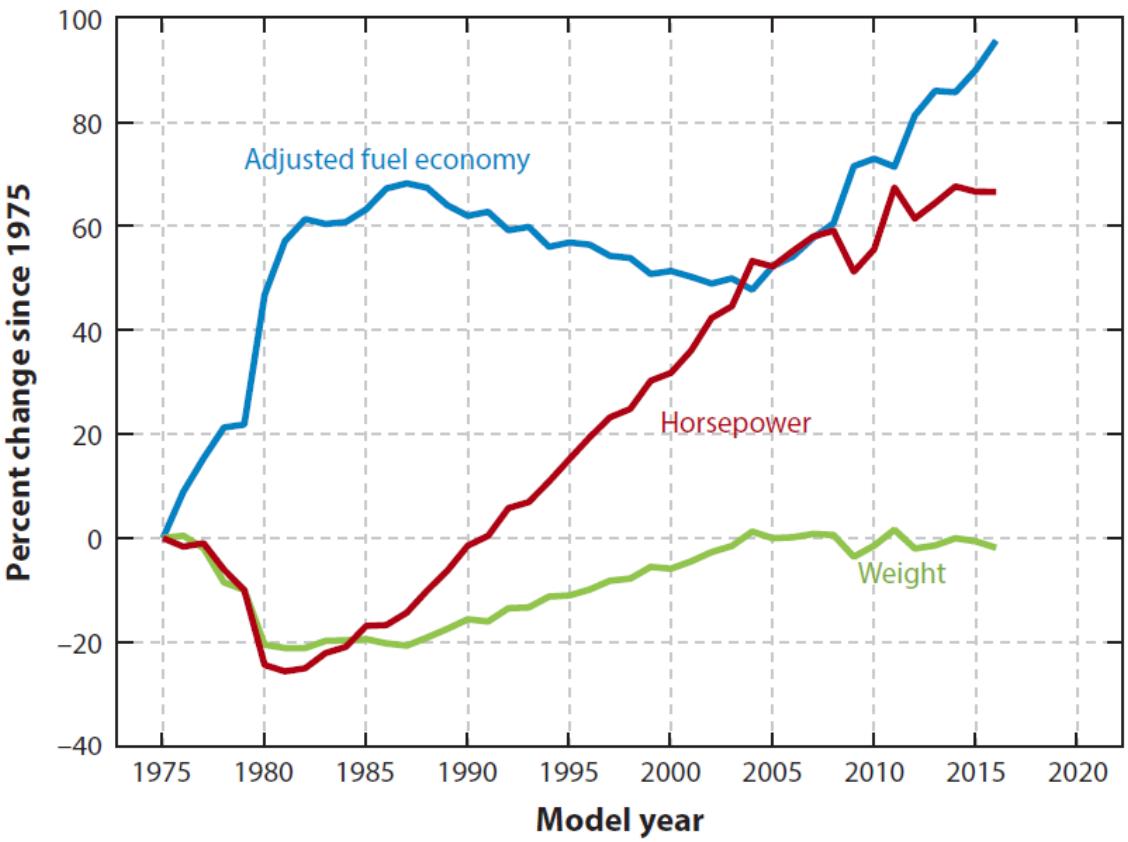
[vii] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-passenger-cars-and

depicting trends in fuel economy, horsepower, and weight from 1975 to 2016 (Figure 4).[14] Knittel (2011) finds that increases in vehicle weight and horsepower from 1980-2006 have substantially detracted from potential improvements in vehicle fuel economy.[15] Although these studies point to an alarming dynamic, each misses the even more dramatic recent increases in SUV new market share to about 70% sales in the US and Canada (notably 2020-2023).

Figure 4: Changes in new US light-duty vehicle sales, 1975-2016 (Source: Lipman, 2018)[14]



Several studies focus on the impacts of a VES that provides "attribute-based" requirements for fuel economy emissions. Typically, this design feature means that new vehicles have less stringent requirements if they are heavier (mass), larger in area (footprint), and/or of a particular vehicle class (light-duty trucks versus light-duty car). **Nearly every rigorous study on this topic finds that having an "attribute-based" VES (compared to having the same gCO_2e/km standard applied to all light-duty vehicles), leads to weaker emissions reductions, with unintended distortions to the light-duty vehicle market due to automaker "gaming".[16]**

The reasoning is as follows. Because larger vehicle (footprint) or heavier vehicles (in mass) have a less stringent emissions and fuel economy standard, automakers have no incentive to downsize vehicles as a compliance strategy.[16,17] Perversely, such a VES design incentivizes automaker to shift their vehicle production and sales (based on pricing, model offerings, and marketing) towards the larger vehicles (in footprint, mass, or class) that have less stringent requirements.[18,19]

Further, a footprint-based (or weight-based) VES favours any automakers that already focus on producing larger vehicles, such as SUVs and pickup trucks, and encourages other automakers to move in that direction.[20]

Several countries provide case studies of weight-based and footprint-based standards, including the US which switched from weight to a footprint focus in 2011. One study compared the light-duty vehicles sold in the US before (2009) and after (2011-2012) this policy change, finding a statistically significant increase in average vehicle footprint following the revision.[21] Other studies report similar findings,[22] where footprint-based VES designs (like those in the US and Canada) induce automakers to switch towards the provision of larger, less efficient vehicles.

More sophisticated studies use quantitative models to simulate the effects of VES design on emissions, fuel economy, and technological change over time. Whitefoot and Skerlos (2012) provide a particularly well-cited simulation of the US auto sector using an equilibrium model that represents automaker decision-making as an oligopoly.[18] Their analysis finds that compared to a neutral VES, having a footprint-based VES leads to an increase in vehicle size by 2-32%, as a well as increasing average vehicle weight, increasing the share of light-duty trucks, and increasing GHG emissions by 5-15% . The authors recommend that VES design should instead move towards a “flatter” curve for vehicle footprint requirements—essentially with little to no variation across vehicle sizes (mass or footprint).

Similar patterns were found in a study of Japan’s weight-based VES, which after implementation led to an average increase in vehicle weight of 10% (from 2001 to 2013).[19] The weight-based VES design also led to a less efficient policy (higher policy costs), and an increase in traffic fatalities. The authors conclude that the main drawback of an attribute-based VES is “that it creates an implicit incentive for market participants to manipulate the secondary attributes”, in this case increasing vehicle weight for new vehicles sold.

In summary, there is clear evidence from past data and from forward-looking models that the inclusion of attribute-based requirements in a stringent VES can influence the composition of the light-duty vehicle sold each year, including changes in the average footprint, mass, and share of light-duty cars versus trucks (SUVs and pickup trucks).

However, there are several important gaps in this literature that this present analysis seeks to address. The cited studies do not consider long-time horizons (beyond a few years), and they do not represent larger technological changes such as the ongoing transition to ZEVs. These studies also do not consider the case of Canada, and they don’t consider the role of a VES in the broader climate policy mix, such as Canada’s mix that includes carbon pricing, ZEV sales standards (provincially and nationally), LCFS, and ZEV purchase subsidies. Next, we address our present research objectives, and usage of the AUM to simulate policy impacts, while filling these research gaps.

3. Research objectives

The primary goal of this study is to simulate the impacts of a national vehicle emissions standard (VES) within Canada's broader mix of climate polices. Specifically, we explore how different VES designs can steer automakers and consumers towards larger and heavier light-duty vehicles (SUVs and pickup trucks), or towards smaller and lighter vehicles. Our scenarios include Canada's "baseline" policies, notably carbon pricing, zero-emissions vehicle (ZEV) purchase subsidies, charger deployment, the national ZEV Availability standard, and the national the low-carbon fuel standard. We break down our objectives into simulations of:

1. The "baseline" policies, including the relative impacts of the current VES, the recently announced US EPA version of the VES, and Canada's national ZEV standard.
2. The additive impact of several alternative versions of the EPA VES that seek to induce some degree of vehicle downsizing, including versions that are neutral regarding size and/or vehicle class.
3. Two alternate policy approaches to influence car versus truck sales share: a purchase tax on conventional ICE light-duty trucks, and an efficiency standard for new ZEVs.

Key outputs for each policy simulation include the following:

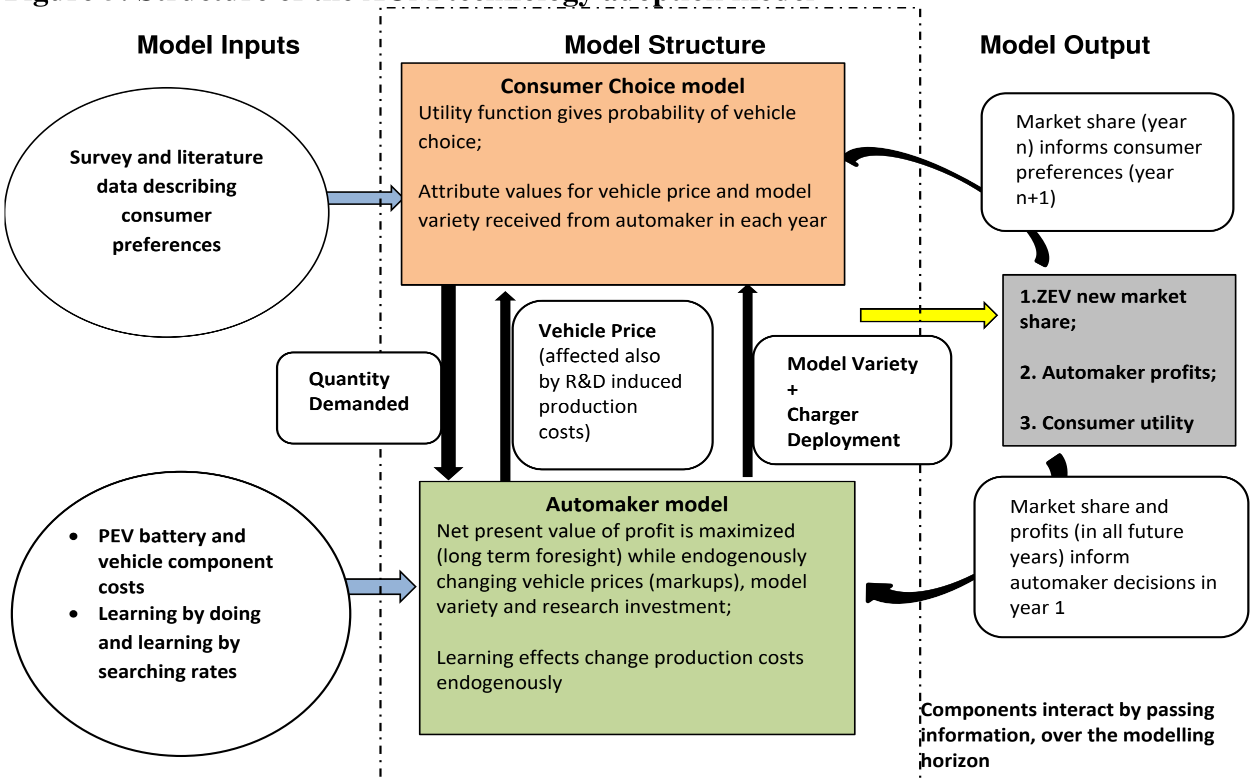
- Canada's ZEV new market share for light-duty vehicles (2023-2035, percentage)
- Split of light-duty vehicle sales by SUV/truck versus car (2023-2035, percentage)
- GHG emissions from Canada's new sales, and stock of light-duty vehicles (2020-2035, MT, including % and absolute increase and decrease compared to baseline)
- Total capacity of batteries sold each year for new LDVs (aggregate kWh)
- Automaker profits (2020-2035, aggregate $CDN)
- Median price of conventional vehicles and ZEVs (2020-2035, $CDN)
- Uncertainty analysis: each policy scenario is run with "median" parameter assumptions, as well as "pessimistic" and "optimistic" parameter values (see Section 4.5.

For each simulation we also conduct a form of uncertainty analysis, where each policy scenario is run with "median" parameter assumptions, as well as "pessimistic" and "optimistic" parameter values. However, because many of these uncertainty ranges are overlapping, we depict most results figures using the "median values" to permit visual comparisons.

4. The AUtomaker-consumer Model (AUM)

We use the AUtomaker-consumer Model (AUM) to simulate the impacts of different VES designs (and additional policies) on Canada's light-duty vehicle sector, including the sales shares of cars versus trucks. AUM is unique in that it simulates interactions between behaviorally-realistic consumers and an aggregate profit maximizing automaker, as depicted in Figure 5.[23] Specifically, the automaker (or vehicle supply) model and the consumer model interact by passing data in each one-year time period. AUM endogenously represents multi-year foresight for the automaker, including decisions about: (i) increasing ZEV model variety, (ii) intra-firm pricing for different vehicle types (cars versus trucks, ICE vehicles versus ZEVs), and (iii) investing in R&D to reduce future ZEV costs.

Figure 5: Structure of the AUM technology adoption model



As examples, the automaker model selects prices and number of vehicle models available, while in each year consumers demand a certain number of vehicles. For a given year, the main outputs of the model are ZEV sales (as a proportion of light-duty vehicle sales), car versus truck market share, automaker profits, and consumer utility. AUM also accounts for the stock of vehicles, and estimates well-to-wheels GHG emissions for the fleet of light-duty vehicles in each year.

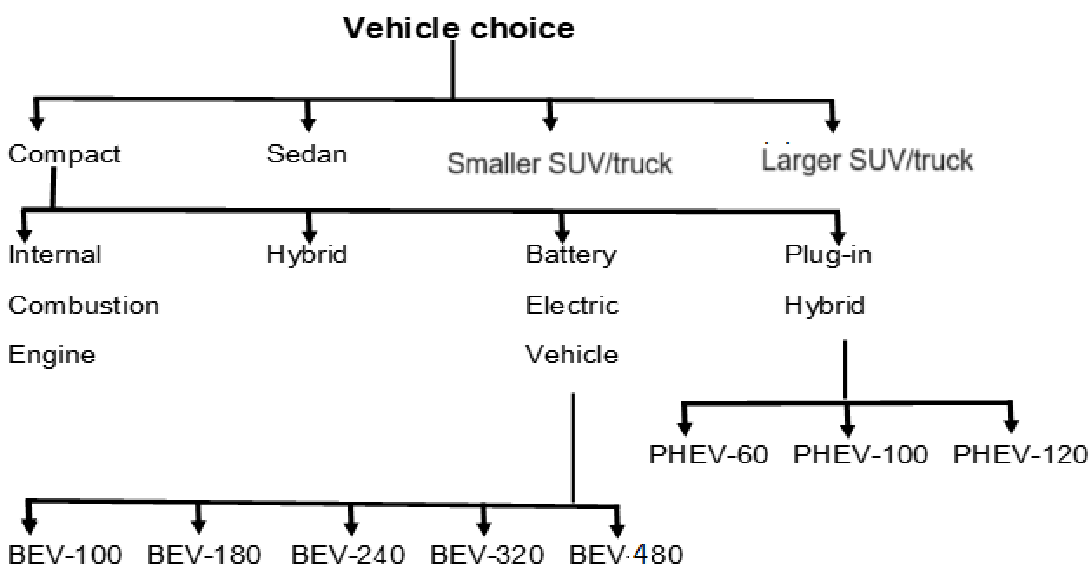
In the following subsections, we summarize the demand-side and supply side models, the method used to calculate policy costs, and the validation process used to calibrate AUM.

4.1 Demand-side model

The consumer choice model simulates annual light-duty vehicle sales and market share in Canada from 2020 to 2035. Total vehicle sales are in turn affected by prices generated by the automaker model using own-price elasticities (that is, for every 1% increase in average vehicle purchase price, what is the percentage decrease in annual vehicle sales). In each year, consumers choose from the available options to satisfy the demand for new vehicles, generating annual light-duty vehicle sales which are split between cars and trucks, and between conventional internal combustion engine vehicles, hybrid vehicles, PHEVs, and BEVs.

The consumer model is a nested discrete choice model (Figure 6). At the first level of the nest, a consumer makes a choice between different vehicle classes (compact, sedan, smaller SUV/truck, and larger SUV/truck). At the second level, the consumer chooses between different vehicle drivetrain technologies (conventional internal combustion engine, hybrid, PHEV, and BEV) within each class. Though, as detailed next, the availability of a given drivetrain in a given year is determined by the automaker model. For certain drivetrains (PHEV and BEV), the third level of the nested discrete choice hierarchy is a choice of vehicle electric-driving range. PHEVs can include electric ranges of 60, 100 and 120 km, and BEVs can include ranges of 100, 180, 240, 320 and 480 km.

Figure 6: Nesting of consumer choices in AUM



Consumers choose the vehicle technology which provides the highest utility, based on a utility function. The utility function indicates the utility a consumer derives from the purchase of vehicle technology i, and draws largely from the LAVE-Trans model is as follows:[24]

$$U_i = ASC + \beta_{PP}X_{PP} + \beta_{FC}X_{FC} + \beta_{CA}X_{CA} + \beta_R X_R + \beta_{MV}X_{MV} \quad (1)$$

Where the utility of the consumer is influenced by the vehicle technology's purchase price (PP), fuel costs (FC), electric driving range (R), recharging access (CA), and vehicle model variety (MV). Purchase price indicates the vehicle price (vehicle cost + markup added by automaker) as observed by consumers. Fuel cost indicates the annual running costs of a vehicle. Electric driving range indicates the number of kilometres a vehicle can run without needing recharging. Recharging access is the percentage of filling/recharging stations with electric charging, relative to gasoline stations.[25]

Model variety, expressed as natural logarithm of the percentage of models relative to conventional vehicles, captures the idea that availability of models for battery electric and plug-in hybrid electric vehicles (n_j) is limited, affecting consumers' purchase decisions. The value of model variety is given by the logarithm of the ratio (nj /N, N is the number of models of conventional vehicles).[26]

The ASC, or Alternative Specific Constant, contains the component of utility not captured by other attributes.

The probability $P_{i|j}$ (indicating the market share, MS) of a consumer choosing a technology 'i' is then given by:

$$P_{i|j}(MS) = \frac{e^{U_i}}{\sum_{k=1}^{n} e^{Uk}} \qquad (2a)$$

The probability that technology i will be selected is the product of the probability of choosing a nest j (where j represents a nest at Level 1or 2 in Fig. 2) and the probability of choosing i, given that a choice will be made from the nest j: $Pij = Pi|j*Pj$.

We use empirical data sources to inform our consumer utility equation. ASC base-year values and the base year weights for the other attributes in equation (1) are empirically derived largely from the Canadian Plug-in Electric Vehicle Study (CPEVS) and Canadian Zero Emissions Vehicle Study (CZEVS) survey data,[27,28] and in part from international literature.[29-31] Consumers' base year willingness to pay for the different attributes are listed in Table 1. The CPEVS included a three-part survey completed by a representative sample of 1754 new vehicle buying Canadian households in 2013 while the CZEVS 2017 survey is essentially an updated version of the previous study. Both studies contain responses to survey questions on PEV awareness, weekly driving distance, vehicle class for the next planned vehicle purchase, and preferences for vehicle attributes. The latent-class choice model was used to identify five heterogeneous consumer classes in the sample for both surveys, discussed further below.

Table 1: List of attributes and the corresponding estimated Willingness to pay values of their coefficients

Attribute	WTP (in CAD$)			Range in literature (CAD$)	Sources with comparable values of WTP
	ZEV - Enthusiasts (15%)	Mainstream (50%)	ZEV Resistors (35%)		
Purchase price	-	-	-		Axsen et al. [27]; Kormos et al. [28]
Fuel cost (per $1k a year in fuel savings)	6000	4000	2000	(1000,7000)	Brand et al.[29]
Driving range (per km increase in electric range)	30	15	15	(20,200)	Ferguson et al. [31]; Dimitripoulos et al. [30]
Model variety (natural log of per 1% increase in number of PEV models, relative to CVs)	3500	3500	3500	(0,10000)	Brand et al.[29]; Green [26]
Recharging access (per 1% increase in recharging stations)	550	550	550	(100,1000)	Ferguson et al. [31]; Hackbarth and Madlener [25]
ASC for SUVs/trucks (relative to cars)	0	12000	12000		
ASC in 2020				(-50000, 8000)	Axsen et al. [27]; Kormos et al. [28]
PHEV	5000	-10000	-30000		
BEV	8000	-15000	-40000		
HEV	3000	-3000	- 5000		
ASC in 2035 (optimistic, median, pessimistic)					
PHEV	(2275, 2030, 1800)	(0, -2400, -3050)	(0, -8954, -15k)		
BEV	(4020, 2750, 2150)	(0, -3850, -5535)	(0, -13500, -20k)		
HEV	(0,0,0)	(0, 0, 0)	(0, 0, 0)		

To simulate dynamics in consumer preferences, the ASC parameter changes endogenously over time as a function of cumulative vehicle sales of drivetrain technology k (either conventional, battery electric or plug-in hybrid electric) as follows:

$$ASC_{tk} = ASC_{ok} \times e^{b(\,cumulative\ sales\ of\ drivetrain\ technology\ k\ in\ Canada)} \quad (3)$$

Where the ASC_{ok} represents the value of the ASC parameter at time *t=0* for technology *k*; b = constant (as used in National Research Council).[24]

While the data for all attributes in equation (1) for the first modelling year is exogenously specified, the data for each attribute for the remaining years are determined either exogenously (for fuel prices and charger availability, Table 2) or endogenously as inputs from the automaker model. As shown in Figure 5, vehicle purchase price and model variety values are endogenously taken from the automaker model. However, model variety also has an exogenous component, to represent the global increase in the number of models. The exogenous assumptions regarding model variety are also listed in Table 2.

To represent heterogeneity in consumer preferences, we include three consumer segments: "ZEV Enthusiasts" (15% of consumers), "Mainstream" (50%) and "Resistors" (35%). These proportional splits are exogenous and constant across the modelling horizon. Dynamics in preferences are instead represented via changes in the ASC for a given segment. As noted, these three classes are drawn from the five consumer classes identified in past Canada-based consumer research. [9,10] First, “ZEV Enthusiasts”, have a high positive valuation (negative risk aversion) for electric vehicles. The “Resistors” segment favour the conventional vehicles and have a high negative valuation for electric vehicles. The third segment, “Mainstream”, represents consumers with an initial, moderate bias against ZEVs.

Table 2: Optimistic, Median and Pessimistic values for key model parameters

	2020	2022	2023	2030			2035			
Parameters	**Values**			**Median**	**Optimistic**	**Pessimistic**	**Median**	**Optimistic**	**Pessimistic**	**Source**
Model variety (relative to CVs)	10%	20%	25%	70%	90%	40%	100%	100%	60%	Authors' judgement,
Recharging access (%, relative to gas stations)	10%	15%	20%	70%	90%	50%	100%	100%	60%	Authors' judgement
Gasoline price ($CDN/litre, exclusive of carbon price)	0.83	1.78	1.6	1.02	1.70	0.70	0.65	1.70	0.51	National Energy Board [32], US EIA [33], IEA [34]; Knuemo [35]
Battery costs (CDN$/kWh in 2020)	189	180	175	110	70	130	70	40	100	ICCT[36]; Lutsey et al.[37]; IEA[38]; Bloomberg[39]
Consumer own-price elasticity for vehicle purchase (2020-2035)	-0.6	-0.6	-0.6	-0.6	-0.3	-1	-0.6	-0.3	-1	Fouquet [40]; Holmgren [41]
Consumer elasticity for travel demand (2020-2035)	-0.2	-0.2	-0.2	-0.2	-0.15	-0.25	-0.2	-0.15	-0.25	Small and van Dender [42]
Automaker rate of learning (%) (2020-2035)	8	8	8	8	10	6	8	10	6	Weiss et al. [43]; Barreto and Kypreos [44]
Automaker discount rate (%) (2020-2035)	10	10	10	10	8	15	10	8	15	Jagannathan et al. [45]
Vehicle stock turnover rate (%) (2020-2035)	7	7	7	7	10	5	7	10	5	National Energy Board [32]; Author's judgement

4.2 Supply-side model

The vehicle supply model is designed to be a representation of the Canadian auto industry at the aggregate level. While it would be interesting to simulate and observe the behaviour of a heterogenous set of automakers (in future applications of this model), the present study is more concerned with the overall industry-wide impacts of policies (not impacts to specific automakers).

The objective for the aggregate automaker is to maximize the net present value of profits over the planning horizon, which we can set as any number of years within the modeling time horizon (in this case, from 2020 to 2035). In AUM, in a given year, the automaker looks forward with their planning horizon (currently the full time horizon to 2035), and makes several decisions relating to all drivetrain technologies, namely:

i. R&D investment,[44] which includes any investment costs (including capital and labour) that can contribute to lower ZEV costs nationally over time, apart from the global exogenous decline in battery and other component costs;
ii. the number of ZEV models available for sale;
iii. charger deployment, where the automaker can endogenously partly contribute to the exogenous increase in charging infrastructure; and
iv. the price of all vehicles sold where the automaker adjusts relative prices of vehicles (e.g. by subsidizing ZEVs and adding a premium to conventional vehicles) while trying to maximize profits subject to policy.

The automaker seeks to maximize profits over the planning horizon T for all technologies 1 to K, specified as:

$$Profits = \sum_{t=1}^{T} \frac{1}{(1+i)^t} \sum_{k=1}^{K} [Q_{tk}(P_{tk}, n_{ctk}, CA_{ctk}). P_{tk} - C_{Ptk} - C_{Rtk} - C_{Itk}] \quad (4)$$

Where, $Q_{tk}(P_{tk}, n_{ctk}, CA_{ctk})$ is the quantity of each vehicle type *k* produced in t^{th} time period and quantity is a function of price P_{tk}, and number of models n_{ctk} of the vehicle type *k*. n_{ctk} is endogenously added by the Canadian automaker, in addition to the exogenous increase in the number of models globally. Similarly, CA_{ctk} is the Canadian automaker's endogenous contribution to charging access (in %), in addition to the exogenous increase in charging access. The discount rate is 8%, which reflect the opportunity cost of capital for private firms.[46] The automaker thus adjusts P_{tk}, $n_{ctk,}$ CA_{ctk} and C_{Itk} in equation (4) to maximize profits. The quantity of vehicles of each type produced is assumed to equal the quantity demanded in the consumer choice model. The inclusion of model variety feedback and endogenous charging deployment are additional novelties of AUM. The profit equation (4) also includes three cost terms ($C_{Ptk}, C_{Rtk}, C_{Itk}$), each of which is described briefly next.

First, C_{Ptk} is the total cost of production of a vehicle technology type *k* in time *t*. given by the following equation. The quadratic cost curve equation indicates the effect of diseconomies of scale as follow:

$$C_{Ptk} = C_{0tk} * Q_{tk}(P_{tk}, n) + a * Q_{tk}(P_{tk}, n)^2 \quad (5)$$

Where C_{0tk} is the cost of production of a single vehicle of type k in time t, a is a scaling constant (Table 3) and $Q_{tk}(P_{tk}, n)$ represents the total quantity of vehicles of type k produced in time t.

Table 3: Exogenous parameters used in the automaker model

Parameters	Value	Source
Scaling parameter, a (equation 5) conventional vehicles (CVs)	0.01	Authors' judgement, based on model calibration to 2020actual CV market share
Scaling parameter, a (equation 5) PEVs	0.02, decreasing linearly to 0.015 in 2030	Authors' judgement, based on model calibration to 2020 actual PEV market share;
Cumulative capacity (*CC*) CVs in 2020	25 million	Statistics Canada (2020)
Cumulative capacity (*CC*), PEVs in 2020	100,000	Statistics Canada (2020)
Knowledge Stock (*KS*), CVs in 2020	500 billion $CAD	Authors' calculation; based on Barreto and Kypreos (2004)[44]
Knowledge Stock (*KS*), PEVs in 2020	3 billion $CAD	Authors' calculation; based on Barreto and Kypreos (2004) [44]

The second cost term in equation (4), C_{Rtk}, indicates the total regulation costs related to policy. We endogenously model the ZEV standard and VES as part of the profit function. The regulation cost associated with the ZEV standard is then modelled as $\rho_{ZEV} * (\emptyset_{ZEV} * Q_{Total} - Q_{ZEV})$, where ρ_{ZEV} is the penalty per ZEV credit below the stipulated quota, $\emptyset_{ZEV}$ is the minimum ZEV credits required by the quota (e.g., 4%), Q_{Total} is the total number of vehicles sold by the automaker, and Q_{ZEV} is the total number of zero emission vehicles sold by the automaker. For vehicle emission standards, similarly, the regulation cost is $\rho_{FE} * Q_k * (Z_{FE} - Z_k)$, where ρ_{FE} is the penalty, Q_k is the number of vehicles of drivetrain technology k that are sold, Z_{FE} is the fuel economy limit, and Z_k is the fuel economy of vehicle k. The total regulation cost is given by:

$$C_{Rtk} = \rho_{ZEV} * (\emptyset_{ZEV} * Q_{Total} - Q_{ZEV}) + \rho_{FE} * Q_k * (Z_{FE} - Z_k) \qquad (6)$$

The third cost component in equation (4) above, C_{Itk} represents the Canadian automakers' R&D investment. We assume that the cost of production (C_{0tk}in equation 5 above) of vehicles produced in Canada can be in part influenced by the investment in research, C_{Itk} made by automakers nationally over time (apart from the exogenous decline in vehicle costs due to global efforts), as follows:

$$C_{0tk} = \{\gamma_k * C_{0t-1,k} * [CC_{t-1k}{}^{-LBD} + KS_{t-1,k}{}^{-LBS}]\} \qquad (7)$$

The cost of production for each drivetrain technology, C_{0tk} has two separate components affecting the evolution of costs over time. First, capital costs can decline as a result of production occurring elsewhere in the world, where γ_k represents the annual rate of exogenous (global) decline in the cost of production. Therefore, a vehicle's costs can still decline over time despite little to no production or investment occurring in Canada. Second, production costs decline endogenously as a result of an increase in the cumulative production and research investment in that technology in Canada. The cost of production of each drivetrain technology C_{0tk} in time *t* is affected (endogenously) by the cost of production in the previous year $C_{0t-1,k}$, cumulative capacity CC_{t-1k} (total number of vehicles of technology k produced up to time *t-1*in Canada) as well as knowledge stock $KS_{t-1,k}$ (synonymous with cumulative R&D investment in Canada) achieved up to period *t-1*.

Thus, while on the one hand, investing in research increases automaker's costs in the present, on the other hand, such investment potentially reduces future production costs. When optimizing over the planning horizon, the automaker can trade-off between increased research costs in the present versus benefits from lower costs of production at a later date. The initial capital costs, initial knowledge stock, initial cumulative capacity, learning by doing (LBD), and learning by searching (LBS) values are exogenously specified in the model (Table 3).

4.3 Vehicle class details

For the present research objectives and policy scenarios, we adapted how AUM represents four vehicle classes to provide more detailed class-level outputs. Those vehicle class archetypes are summarized in Table 4.

We calibrate these car and truck sales shares to recent years in Canada. Note that there is some inconsistency in the data sources reporting light-duty car versus truck market share in Canada. Some data sources do not separate light-duty truck sales from commercial, medium-duty, or heavy-duty trucks. When considering only *passenger* light-duty vehicles, we estimate the share of light-duty trucks in new vehicle sales in recent years is around 70%. So, we calibrated AUM to new market shares (sales) in the range of 70 to 75% light-duty trucks in the 2020-2023 time period. By doing so, we exclude light-duty trucks used for freight or commercial purposes. This focusing on passenger vehicles aligns with Canadian reporting of GHG emissions.[viii] Appendix A provides more details on the different ways that car and truck market shares are calculated in Canada.

For the vehicle classes, Table 4 summarizes our updated assumptions. AUM now includes two archetypes for cars, and two archetypes for light-duty trucks. For each class, we specify different weights for each drivetrain (representing different battery and electronics components). Footprint is the same for most drivetrains of a given class, though we assume BEV versions of the smaller and larger trucks have a slightly smaller footprints, as has been seen in BEV light-duty truck sales to date. Table 4 also reports battery sizes for each vehicle archetype.

[viii] For example Table 1 (passenger transport) of the following https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/automobile-truck-emission-regulations-discussion.html

Table 4: Vehicle model details

	Compact car	Sedan	Smaller SUV/truck	Larger SUV/truck
Tech details				
Footprint, m^2 (sq.ft)				
ICE, Hybrid, PHEV	3.6 (39)	4.2 (45)	4.6 (50)	5.2 (56)
BEVs	3.6 (39)	4.2 (45)	4.4 (47)	5.0 (53)
Curb weight, (kg, including battery)[a]				
Conventional ICE	1000	1300	1680	2200
Hybrid	1000	1300	1680	2200
PHEV 60km	1100	1350	1700	2300
100km	1150	1400	1800	2400
120km	1200	1450	1900	2450
BEV 100km	800	1100	1500	2200
180km	900	1300	1650	2300
240km	950	1400	1750	2400
320km	1100	1550	1900	2500
480km	1200	1700	2000	2600
Fuel consumption[b]				
Base ICE fuel efficiency, Lge/100km	6.1	7.5	8.0	11.0
PHEV Lge/km	3.7	3.7	4.4	4.4
BEV Lge/km	2.0	2.4	2.4	3.0
Battery size (total kWh)[c]				
Hybrid	0.9	1.0	1.1	1.2
PHEV 60km	12	15	20	24
100km	30	33	42	51
120km	36	40	50	61
BEV 100km	20	24	28	34
180km	32	37	42	56
240km	41	50	57	70
320km	56	67	77	94
480km	88	105	119	144
Electric efficiency (kWh/km)[d]				
PHEV 60km	0.24	0.26	0.34	0.40
100km	0.24	0.26	0.34	0.41
120km	0.24	0.27	0.34	0.42
BEV 100km	0.16	0.19	0.22	0.27
180km	0.16	0.19	0.22	0.27
240km	0.17	0.20	0.23	0.28
320km	0.17	0.20	0.24	0.29
480km	0.18	0.22	0.25	0.30
Cost details				
Manufacturing cost, $CDN	24,729	25,155	27,129	30,291
For Efficiency improvement[e]				
Median cost increase for 1% improvement	2%	2%	2%	2%
Median cost increase for 5% improvement	15%	15%	15%	15%
PHEV-40 (2023 incremental cost)[f]	30,699	31,313	37,834	43,085
BEV-300 (2023 incremental cost)[f]	28,365	28,635	44,411	52,756

[a] Following IEA GFEI 2023[2] report/database and IEA GFEI 2021 https://www.iea.org/articles/fuel-economy-in-canada. Examples: Ford Escape weighs 1400 to 1700 https://www.caranddriver.com/ford/escape/specs. Toyota Highlander, highest selling large SUV in Canada, weighs 1800 to 2000. https://www.toyota.ca/toyota/en/vehicles/highlander/models-specifications
[b] Following IEA 2021 https://www.iea.org/articles/fuel-economy-in-canada and IEA GFEI 2023 database[2]
[c] Following ICCT 2022[47]
[d] Sources: Table 5 of https://theicct.org/wp-content/uploads/2022/10/ev-cost-benefits-2035-oct22.pdf
ACEEE: 2023 BEV efficiencies range from 0.15 kWh/km to 0.33 kWh/km https://www.aceee.org/blog-post/2023/04/boosting-ev-efficiency-would-cut-emissions-and-reduce-strain-grid
EV database: 0.14 to 0.30 kWh/km, with an average of 0.20 kWh/km https://ev-database.org/cheatsheet/energy-consumption-electric-car

[e] For reference Whitefoot and Siskios[18] use a linear curve . 1% increase in manufacturing costs for every 1% improvement in fuel economy.
[f] These are production costs, updated using ICCT's 2023 analysis of Canada[36]

4.4 Calculating GHG emissions

We follow several additional steps to calculate total light-duty vehicle GHG emissions. We calculate the total stock of vehicles, the usage of those vehicle and then finally assign GHG values to those vehicles.

First, the total stock (S_{tk}) of vehicles of each technology type k surviving from year t to year $t+1$ is given by:

$$\sum_{k=1}^{N} S_{t+1,k} = \sum_{k=1}^{N} S_{t,k}\,(1-d_{t,k}) + \sum_{k=1}^{N} Q_{t,k} \qquad (8)$$

where $d_{t,k}$= stock turnover rate in time t for technology k; Q_{tk} is the quantity of new vehicles of technology k at time t.

Second, vehicle use (or travel demand) depends upon fuel costs. An increase in fuel costs (e.g. due to a tax) can decrease travel demand, while a reduction in fuel costs (e.g. due to fuel economy improvement) can increase travel demand. We use elasticity (e) to represent how consumers adjust vehicle usage rates as a result of changes to the cost of driving. The elasticity of travel demand is depicted in Table 2. The vehicle use under policy (V_p) is a function of the projected travel demand in the reference no policy case (V_0), the elasticity parameter (e), and the changes to the fuel cost in the policy scenario relative to the reference case, given by

$$V_p = V_0 \left(\frac{fuel\ cost_P}{fuel\ cost_0}\right)^e \qquad (9)$$

where $fuel\ cost_P$ is the fuel cost under policy, while $fuel\ cost_0$ is the fuel cost in the reference no policy case. The reference case vehicle use (V_0) in Canada is assumed to be 16,000 km a year, based on data from Statistics Canada.

Once the vehicle stock and vehicle use values are known, the total GHG emissions are calculated by multiplying the product of vehicle stock and vehicle use values with the energy consumption per vehicle and fuel carbon intensity. The vehicle energy intensity for each drivetrain is set exogenously for each drivetrain as already shown in Table 4.

For PHEVs, we assume that consumers use electricity to run the PHEVs 70% of the time and use gasoline for the remaining 30% -- which translates to a 70% "utility factor". Plotz et al.[48] calculate this utility factor from real world driving data across several countries, and find that utility factors vary with the electric range, and across countries (e.g., for a 100km electric range PHEV, utility was about 70% in Canada and Norway, but only 40% in China and Netherlands). To account for uncertainty in our sensitivity analysis, we assume the utility factor is 50% in the pessimistic case, and 90% in the optimistic case – however, in each scenarios the split is exogenous and does not respond to changes in fuel or electricity prices.

Table 5 summarizes our exogenous assumptions about the WTW carbon intensity of each fuel, which include the GHGs emitted in the process of producing a fuel and transporting it to the point at which it enters a vehicle for consumption in Canada, based on GHGenius (version 5.05b) model and other literature cited above (National Energy Board, 2019; EIA, 2020). Carbon intensity decreases over time under the effect of the Clean Fuel Standard. For electricity, it is assumed that the contribution of low-carbon, renewable sources in electricity production will increase in the future in Canada, stimulated by national policies to replace coal and natural gas fired power plants in the electricity sector.[32]

Table 5 Fuel carbon intensity (Canadian) assumptions

Carbon intensity (gCO2/MJ)	2020	2035	Source
Gasoline (with Clean Fuel Standard)	88.1	76	Government of Canada (2021)
Electricity	19.5	14	National Energy Board (2019); GHGenius

4.5 Uncertainty analysis

We follow multiple steps to explore and depict uncertainty in results, namely we: (i) identify key parameters (listed below) causing the most uncertainty in model outputs; and (ii) depict some results as uncertainty bans with pessimistic and optimistic value assumptions of the input parameters determining the boundaries of these uncertainty bands. We test the effect of pessimistic and optimistic estimates drawn from literature (optimistic/pessimistic values are listed in Tables 2).

The key parameters affecting model results are:

1. **Battery pack costs**: as seen by car manufacturers (including markups from battery manufacturers), costs are 189 CDN $/kWh in 2020, and 180 CDN$/kWh in both 2022 and $175 in 2023.[38,39] The higher 2022 and 2023 prices reflect the past supply chain issues observed for advanced automotive batteries. For the uncertainty analysis, we assume values of 40 CDN$/kWh (optimistic) and 100 CDN$/kWh (pessimistic) in 2035,[38] similar to Lutsey et al.[37]
2. **Price elasticity** of demand, determining how vehicle ownership is affected in response to vehicle prices, assume values of -0.3 (optimistic) and -1 (pessimistic), corresponding to the low and high values suggested in literature.[40,41]
3. **Discount rate** used by the automaker assumes values of 8% (optimistic) and 15% (pessimistic), corresponding to the low and high values suggested in Jagannathan et al. (2016).[45]
4. **Fuel prices** (gasoline price, exclusive of carbon price) are taken to be $0.83 per Litre (CDN) in 2020, $1.78/L in 2022, and $1.60/L in 2023. For 2035 we include a range of prices from $0.65 to $1.70. [32-35,49]
5. The **Consumer preferences** parameter, representing the endogenous change of ASC over time, varies across consumer segments (Table 1). As an example, the consumer preference for BEVs among the "Resistors" consumer segment is -40k CDN$ in 2020, and assume a base value of -13k CDN$, with -20k CDN$ as pessimistic and 0k CDN$ as optimistic values in 2035.

6. The exogenous global increase in **Model variety** for ZEVs is assumed to grow from 10% (relative to model availability for conventional vehicles) in 2020, to assume values of 60% (pessimistic) and 100% (optimistic) in 2035.
7. The **Recharging access** parameter, indicating the locational availability of public charging infrastructure, relative to existing gasoline infrastructure, is 10% in 2020. The 2030 values are 70% in the median scenario, 50% in the pessimistic scenario, and 90% in the optimistic scenario. Values in 2035 range from 60% (pessimistic) to 100% (median and optimistic).
8. The **Domestic Rate of learning** Parameter, which in AUM determines the rate at which technology improves in Canada, partly (in addition to global efforts) affecting how quickly domestic vehicle manufacturing costs drop over time, in response to increased domestic production (learning by doing) or domestic investment in R&D (learning by searching) (see equation 8 for reference). Since part of the decline in vehicle costs is assumed to be exogenous (due to global factors), this rate of learning can be understood to be the domestic learning rate. The Rate of Learning parameter assumes values of 6% (pessimistic) and 10% (optimistic), +/-25% relative to the median value of 8%.[43] These values are constant from 2020 to 2035.The stock turnover rate indicates the exogenous rate at which existing vehicles are assumed to retire annually. We assume it varies between 5% (pessimistic) and 10% (optimistic) between 2020 and 2035.
9. The **stock turnover rate** indicates the exogenous rate at which existing vehicles are assumed to retire annually. We assume it varies between 5% (pessimistic) and 10% (optimistic) between 2020 and 2035.
10. **VKT (vehicle kilometres travelled) elasticity of demand**, determining how vehicle travel is affected in response to fuel costs, assume values of -0.15 (optimistic) and -0.25 (pessimistic) between 2020 and 2035.
11. **Carbon intensity of gasoline (in gCO2e/MJ),** assumes values of 76 gCO2e/MJ (optimistic) and 82 gCO2e/MJ (pessimistic)

5. Policy scenarios

We simulate a total of ten policy scenarios. All ten scenarios include current policies in place in Canada, namely:

- **Carbon tax:** $50 in 2022, increasing by $15 annually until it reaches $170 in 2030, where is stays until 2035.
- **Clean Fuel Standard (CFS):** exogenously simulated as a 13% reduction in carbon intensity of liquid fuels by 2030 (relative to 2016); reduction of 2.4 gCO2e/MJ in 2022; gradual increase to reach 12gCO2e/MJ by 2030.(i.e. Fuel Carbon Intensity = 90.4 gCO2e/MJ in 2021 and 2022; 89.2 in 2023; 81 gCO2e/MJ in 2030).[ix] We will also account for the BC low-carbon fuel standard, which is more stringent than the CFS by 2030 (76 gCO2e/MJ). Including that, the total Canada-wide requirement would be 80.5 gCO2e/MJ)
- **Provincial ZEV sales standards (BC and Quebec):** we translate provincial ZEV mandates to national equivalent (update to 100% for 2035 in BC and Quebec).

[ix] Parameters published in December 2020 (see Table 1 on the reference CI values): https://gazette.gc.ca/rp-pr/p1/2020/2020-12-19/html/reg2-eng.html

Equivalent to 21% national ZEV mandate in 2030, 36% national ZEV mandate in 2035.

- **Purchase incentives:** National/provincial ZEV purchase incentives in terms estimated amount and duration (and total population weighted average for Canada). See Appendix B.
- **Charging deployment:** we assume existing ZEV charging infrastructure initiatives lead to 70% of consumers having access to charging by 2030. Uncertainty analysis considers ranges from 50% to 90%.
- **Impacts from US Inflation Reduction Act (IRA):** we expect the IRA to have very minimal impact on key outputs in the Canadian light-duty ZEV market.[x] To account for IRA, we add a slight reduction in ZEV production costs in the long run (from US production subsidies), and a slight increase in ZEV valuation among Canadian consumers (spillover valuation from increased ZEV advertising/marketing in USA).[xi] We anticipate that battery suppliers and automakers are likely to capture most or all of the US production subsidy.

The ten policy scenarios can be split into three broad categories. In the first category are four variations of the **baseline**:

1. "Old VES": An "old" baseline scenario with current policies that are in place, but without updates to the national VES or ZEV mandate. Canada's VES is current version from the first "Biden era". Table 6 provides the schedule for the overall light-duty fleet, and broken down by the four vehicle class archetypes we are using in AUM. Average requirements progress from 140 gCO_2e/km in 2021 to 107 gCO_2e/km in 2025. For 2026-2035, the VES stays at 102 gCO_2e/km (starting in this year, fuel economy is held constant for non-ZEVs)

2. "New VES": replaces the "Old VES" with the new EPA VES standard as summarized in Table 6 using the final standards announced in March 2024 (and graphs shown in Section 1.2). Under the new VES, carbon emissions requirements continue to ramp down from 2026-2032.

3. "Old VES + ZEV": we use the original Biden VES baseline (scenario #1), but add the announced national ZEV sales standard (Electric Vehicle Availability Standard), with details simulated as follows:[xii]

- Annual compliance to sales targets requiring 20% ZEV sales by 2026, 60% by 2030 and 100% LDV ZEV sales by 2035.
- Credit system:

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[x] The short and long-term impacts are also highly uncertain, as the IRA provides both production subsidies (that could lower long-term ZEV production costs in the USA), and consumer purchase subsidies for certain ZEVs, for consumers that are not high-income. One ICCT study finds that the IRA might increase ZEV light-duty market share by about 5-10 percentage points by 2030-2032. https://theicct.org/publication/ira-impact-evs-us-jan23/

[xi] On the supply side, the production subsidies by IRA are assumed to translate to 1% reduction in battery costs in Canada. On the demand side, consumer neighbour effect coefficient is improved by 5%, to reflect increased consumer uptake of ZEVs in US. Both effects combined lead to a less than 1% impact on overall results

[xii] Source: https://www.canada.ca/en/environment-climate-change/news/2023/12/canadas-electric-vehicle-availability-standard-regulated-targets-for-zero-emission-vehicles.html

- BEV and long-range PHEV: 1 credit per sale
- PHEV 16-49km: 0.15 credits
- PHEV 50-79km: 0.75 credits
- Short-range PHEVs can only earn credits until 2028
- PHEVs can only make up 45% of credits until 2026, 30% in 2027, and 20% in 2028 and beyond
- Credits can be banked for up to 5 years (but all credits due in 2035)
- Penalty: $20k per ZEV credit[xiii]

Table 6: VES scenario details (Policy Scenarios #1, #2, #4)

	Compact car	Sedan	Smaller SUV/truck	Larger SUV/truck
Scenario #1: Base with "Old EPA" "Old/original EPA" VES Policy details				
2021 avg. gCO_{2e}/km (140 avg.)	110	131	143	160
2023 avg. gCO_{2e}/km (125 avg.)	105	120	130	146
2025 avg. gCO_{2e}/km (107 avg.)	95	105	112	134
2026-2035 avg. gCO_{2e}/km (102 avg.)	78	87.5	100	128
Scenarios #2 + #4: "New EPA"[a]				
2023 average gCO_{2e}/km (125 avg.)	105	120	130	146
2025 avg. gCO_{2e}/km (107 avg.)	95	105	112	134
2027 avg. gCO_{2e}/km (101 avg.)	84	86	101	126
2030 avg. gCO_{2e}/km (72 avg.)	60	66	74	84
2032 avg. gCO_{2e}/km (51.25 avg.)	43.75	46.9	52	58

[a] As of March 2024, EPA has chosen Alternative 3 targets as the final rule (page 194 of the EPA final rule 2024). The emissions targets for intermediate years were reduced but the target for 2032 remains the same as the proposed targets.

4. "Comprehensive Baseline": this is the most relevant baseline, including all base policies in Canada, the new EPA, and the national ZEV standard. In other words, all policies from scenarios #1, #2, and #3. The Comprehensive Baseline scenario is the baseline of comparison for most of the next six "additional" policy scenarios.

The next four scenarios demonstrate the impacts of alternative designs of the VES. Each variation is intended to induce some amount of vehicle downsizing as a compliance option.

5. "Single VES" (class neutral, footprint neutral): this variation of the new US EPA VES is designed to be class and footprint neutral, as depicted in Table 7. A single VES requirement (gCO_2e/km) is applied to for all LDVs. For each year, this single value uses the average gCO_2e/km expected by the EPA (e.g., 51.25 g/km in 2032). The overall VES is not any more stringent than Scenario #4, but is expected to induce more switching of sales towards smaller vehicle segment. The main purpose of this scenario is to

[xiii] Canada's ZEV Availability Standards is written to have "criminal sanction" as the penalty for non-compliance, rather than a financial penalty. In theory, that is meant to be a hard constraint. However, we simulate this as a strong financial penalty ($20k per ZEV credit), which is similar in magnitude to the flexible compliance mechanism that automakers can invest in $20k of charging infrastructure in lieu of a missed ZEV credit.

demonstrate a "proof of concept" of the impact of introducing vehicle downsizing as a compliance pathway via a class-neutral and footprint-neutral VES.

Table 7: Additional VES scenario details (Scenarios #5, #6, #7)

	Compact car	**Sedan**	**Smaller SUV/truck**	**Larger SUV/truck**
Scenario #5: "Single VES" EPA with one avg (all sizes/classes)				
2023 average gCO_{2e}/km (125 avg.)	105	120	130	146
2025 avg. gCO_{2e}/km (107 avg.)	107	107	107	107
2027 avg. gCO_{2e}/km (101 avg.)	101	101	101	101
2030 avg. gCO_{2e}/km (72 avg.)	72	72	72	72
2032 avg. gCO_{2e}/km (51.25 avg.)	51.25	51.25	51.25	51.25
Scenarios #6: "SUV=Car" EPA with (smaller) SUVs on car curve				
2023 average gCO_{2e}/km (125 avg.)	105	120	130	146
2025 avg. gCO_{2e}/km (105 avg.)	95	105	110	134
2027 avg. gCO_{2e}/km (100 avg.)	84	86	88	126
2030 avg. gCO_{2e}/km (70 avg.)	60	66	71	84
2032 avg. gCO_{2e}/km (48 avg.)	43.75	46.9	47.5	58
Scenarios #7: "Truck=Car" EPA with all light trucks on car curve				
2023 average gCO_{2e}/km (125 avg.)	105	120	130	146
2025 avg. gCO_{2e}/km (103 avg.)	95	105	110	112.5
2027 avg. gCO_{2e}/km (98 avg.)	84	86	88	101
2030 avg. gCO_{2e}/km (69 avg.)	60	66	71	73
2032 avg. gCO_{2e}/km (46.5 avg.)	43.75	46.9	47.5	48

6. "SUV=Car": this variation of the new VES maintains different requirement by vehicle class. However, the "Smaller SUV/Truck" category is put on the same emissions curve (requirement per footprint) as cars (Table 7). The transition starts in 2025, and is fully implemented in 2027. The overall stringency of this scenario is higher than that of scenario #5, and is thus expected to have more impact on decreasing GHG emissions and SUV/truck market share.

7. "Truck=Car": this VES variation again differentiates requirements by vehicle class. However, both "SUV/Truck" classes ("Smaller" and "Larger") are put on the car emissions curve, based on footprint (Table 7). The overall stringency is again higher than that in Scenario #6, and is expected to have more impact on decreasing GHG emissions and SUV/truck market share.

8. "Truck Multiplier": returns to the new EPA VES design (Scenario #4), but adds a multiplier to the VES to increase the impact of ICE and HEV light-duty trucks. The specific multipliers (2025-2032) are:

- Smaller SUV/Truck: 1.2
- Larger SUV/Truck: 1.4

The expected impact is to induce more vehicle downsizing than Scenario #4.

The final two scenarios again return to the Comprehensive Baseline of Scenario #4, and add policy mechanisms outside the new EPA VES structure.

9. "Truck Tax": adds to Scenario #4 a purchase tax on light-duty trucks based on GHG emissions (g/km), starting in 2025. The tax is based on g/km above the new EPA VES fleet-wide average for that year (Table 8). The tax value is $15 per g/km over the light-duty fleetwide EPA/VES requirement for that year. On average across the timeline, this works out to an average tax of about $1800 per ICE truck. The tax is expected to have a larger impact in earlier years, when ICE vehicle sales are substantial. However, as national ZEV standard requirements increase towards 100% ZEV sales, the truck tax will apply to fewer new vehicles.

Table 8: Tax details (g/km for vehicles, and tax per vehicle)

	ICE SUV/truck		Hybrid SUV/truck	
	Smaller	**Larger**	**Smaller**	**Larger**
Baseline g/km				
2025	178	248	113	133
2027	174	244	110	129
2030	169	239	108	124
2032	165	235	105	120
Tax per vehicle (based on $15 per g/km over the annual VES average)[a]	based on rate x number of g/km over the avg noted in each year[a]			
2025 (107 avg)	$1,072	$2,121	$86	$396
2027 (95 avg)	$1,183	$2,232	$231	$507
2030 (63.75 avg.)	$1,583	$2,632	$665	$907
2032-35 (51.25 avg.)	$1,705	$2,750	$801	$1,025

[a] To convert fuel consumption (in lge/100km) to CO2 emissions (in g/km) https://www.unitjuggler.com/convert-fuelconsumption-from-lper100km-to-gperkmgasoline.html

10. "ZEV efficiency" (class-neutral, footprint neutral): adds a VES-style efficiency standard for new ZEV sales, requiring improved ZEV efficiency (kWh/km) each sales year. A $50 penalty is imposed for every kWh/km that the fleet is over the required average. The policy is class-neutral and footprint-neutral). See Table 4 for details of ZEV efficiency for each vehicle class archetype. The schedule of kWh/km requirements is:

- 2025: 0.22 kWh/km
- 2027: 0.21 kWh/km
- 2030-35: 0.20 kWh/km

6. Results and discussion

Tables 9 and 10 provides summaries of several key outputs for each policy scenario. Both tables have only median outputs, which don't account for the uncertainty ranges described in Section 4.5. These tables summarize the broad impacts of each policy scenario, and some of the trade-offs involved in selecting one scenario over another.

The following sections provide further details regarding ZEV sales, car versus SUV/truck market share, vehicle attributes (weight and footprint), fuel consumption and GHG emissions, automaker impacts (profits and vehicle sales prices), and needs for ZEV battery usage.

Table 9: ZEV new market share in each policy scenario (median scenario)

	2026	2030	2035
Emission Reduction Plan Sales Target	**20%**	**60%**	**100%**
No national ZEV standard			
Scenario #1: Old VES	18%	29%	47%
Scenario #2: New VES	18%	30%	51%
With national ZEV standard			
Scenario #3: Old VES + ZEV	25%	55%	95%
Scenario #4: New VES + ZEV (Comp. baseline)	25%	56%	96%
Scenario #5: Comp + Single VES	25%	56%	96%
Scenario #6: Comp + SUV=Car VES	25%	56%	96%
Scenario #7: Comp + Truck=Car VES	25%	56%	96%
Scenario #8: Comp + Truck multiplier	25%	56%	96%
Scenario #9: Comp + Truck tax (g/km)	25%	56%	96%
Scenario #10: Comp + ZEV efficiency (kWh/km)	25%	56%	97%

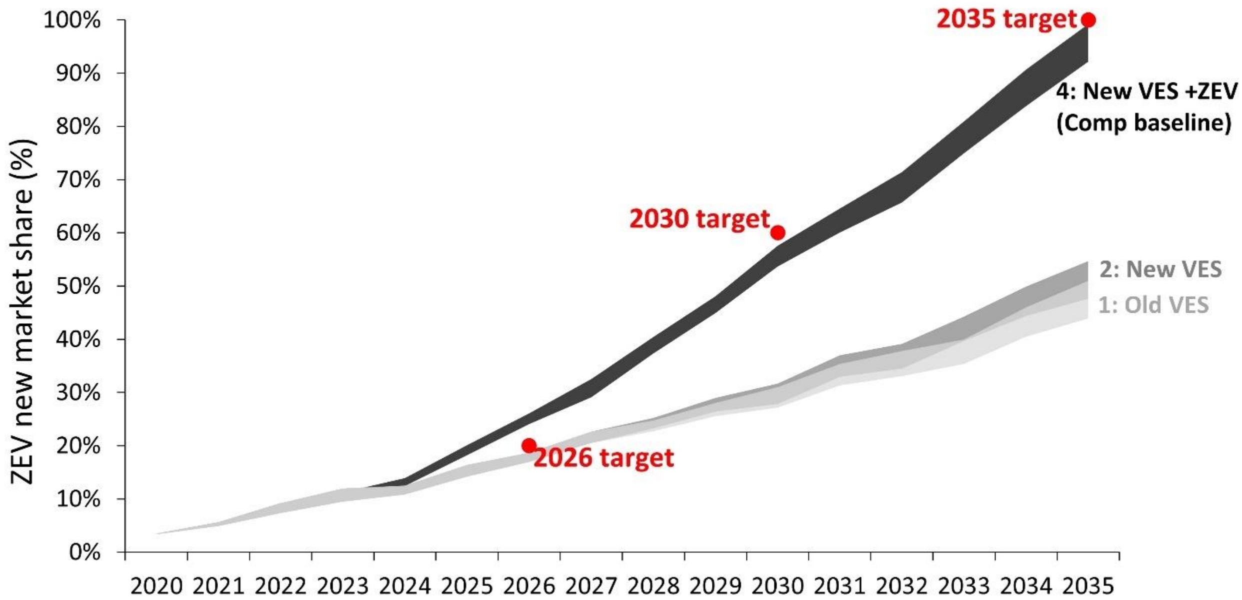
6.1 ZEV Sales

Figure 7 portrays results for ZEV new market share in three of the "baseline" scenarios: "Old VES" (scenario #1), "New VES" (scenario #2), and the "Comprehensive Baseline" that includes the New VES and national ZEV Standard (Scenario #4). Each shaded area incorporates the uncertainty analysis described in Section 4.5, where the upper ZEV sales boundary utilizes the "optimistic" parameter assumptions, and the lower boundary utilizes the "pessimistic" assumptions. Tables 9 and 10 provides numerical values for all 10 scenarios.

Table 10: Policy scenario summary (median scenario)

	Vehicles sales		GHG emissions			Vehicle attributes			
	ZEV sales share	Car sales share	New sales	Stock		Average weight	Average footprint	Automaker profits	Battery needs
	2035 %	2035 %	2035 Mt	2035 Mt	2024-35 Mt	2035 kg	2035 sq. ft.	2023-35 % increase	2035 GWh
No national ZEV standard									
Scenario #1: Old VES	47%	29%	2.48	47.3	700	1816	49.6	42%	80
Scenario #2: New VES	51%	30%	2.13	45.3	688	1825	49.5	39%	86
With national ZEV standard									
Scenario #3: Old VES + ZEV	95%	32%	1.34	35.5	606	1945	48.7	27%	152
Scenario #4: Comp. Baseline	96%	33%	1.31	35.4	605	1954	48.6	24%	157
Scenario #5: + Single VES	96%	35%	1.26	35.4	604	1928	48.5	22%	152
Scenario #6: + SUV=Car VES	96%	37%	1.22	35.3	603	1911	48.4	19%	150
Scenario #7: + Truck=Car VES	96%	38%	1.21	35.3	603	1901	48.3	18%	148
Scenario #8: + Truck multiplier	96%	34%	1.30	35.4	604	1950	48.6	24%	154
Scenario #9: + Truck tax (g/km)	96%	35%	1.29	35.3	601	1918	48.4	20%	152
Scenario #10: + ZEV efficiency	97%	41%	1.15	35.0	601	1886	48.1	16%	146

Figure 7: ZEV market share in new vehicle sales (individual policies, uncertainty range)



ZEV sales share is simulated to increase each year under all scenarios, though the Old VES and New VES scenarios do not achieve ZEV sales goals for 2026, 2030, or 2035. The New VES provides a slight increase in ZEV sales, by about 1 percentage point in 2030, and by 4 percentage points in 2035 (median values). These three policy scenarios cover the range of outcomes observed for all 10 policy scenarios.

As shown in Table 9, ZEV sales share is dominated by the presence of a national ZEV mandate. Scenarios #3 to #10 (all with a ZEV standard) have nearly identical ZEV sales trajectories, which are substantially higher than ZEV sales in Scenarios #1 and #2 from 2024 to 2035. All scenarios with a national ZEV standard induce ZEV sales that exceed the 2026 target, and come close to (but don't quite meet) the 2030 and 2035 sales targets.[xiv]

6.2 Car versus truck sales

Figures 8-10 depict the impacts of each policy scenario on the split of car versus SUV/truck new market share in the light-duty vehicle sector. In all scenarios, there is an increase in light-duty truck sales from 71% in 2020 to 74% in 2022 and 2023 (median values), and then a reduction in

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[xiv] The ZEV scenarios can fall short of the sales goals in 2030 or 2035 by several percentage points for two possible reasons: i) automakers are banking credits from over-compliance in earlier years to comply with later requirements (applies to 2030 only), and/or ii) automakers choose to pay the penalty of $20k/credit for non-compliance, as this is cheaper than further subsidizing their ZEVs (or following other compliance pathways) to the amount needed to sell ZEVs this last few percent of consumers. Due to the heterogeneity among consumer preferences, it is difficult to sell ZEVs to a small segment of the "resistors" (See Section 4.1). Although automakers can increase the price of conventional vehicles, increasing price too much will reduce overall vehicle sales and profits. Automakers consider the trade-off between foregoing profits due to lost sales and paying fines, choosing to pay fines for a small portion of non-complying sales relative to the requirement.

truck sales in future years. Correspondingly, the sales share of cars is about 26% in 2023 and 2024.

Figure 8: Overall car/truck share for baseline scenarios #1-4 (all drivetrains, ICE vehicles + ZEVs, with uncertainty)

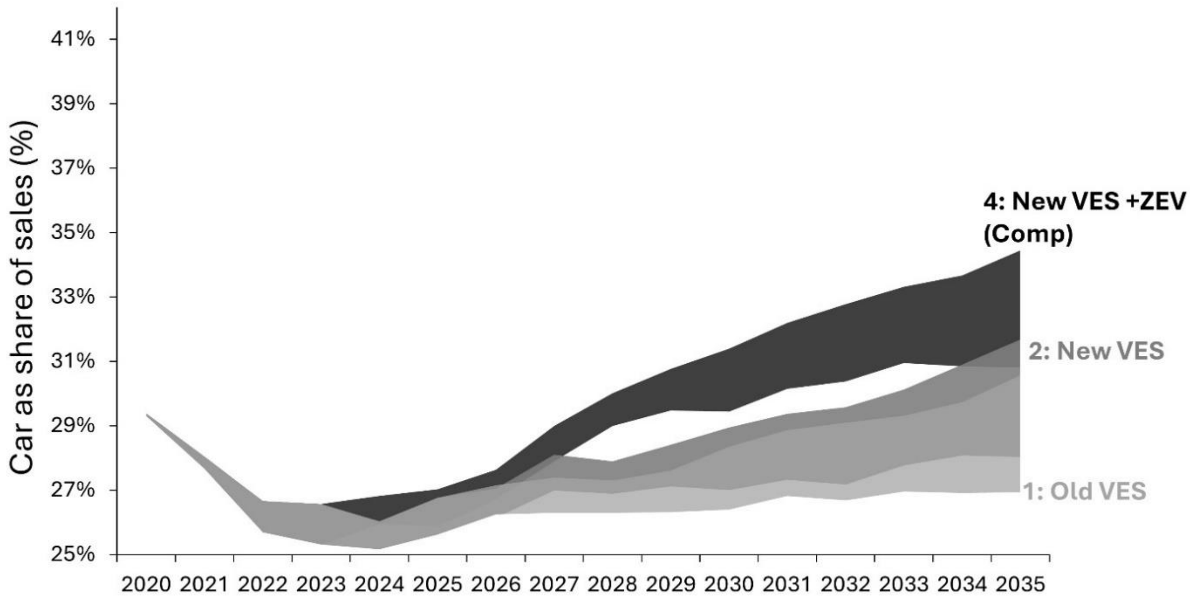
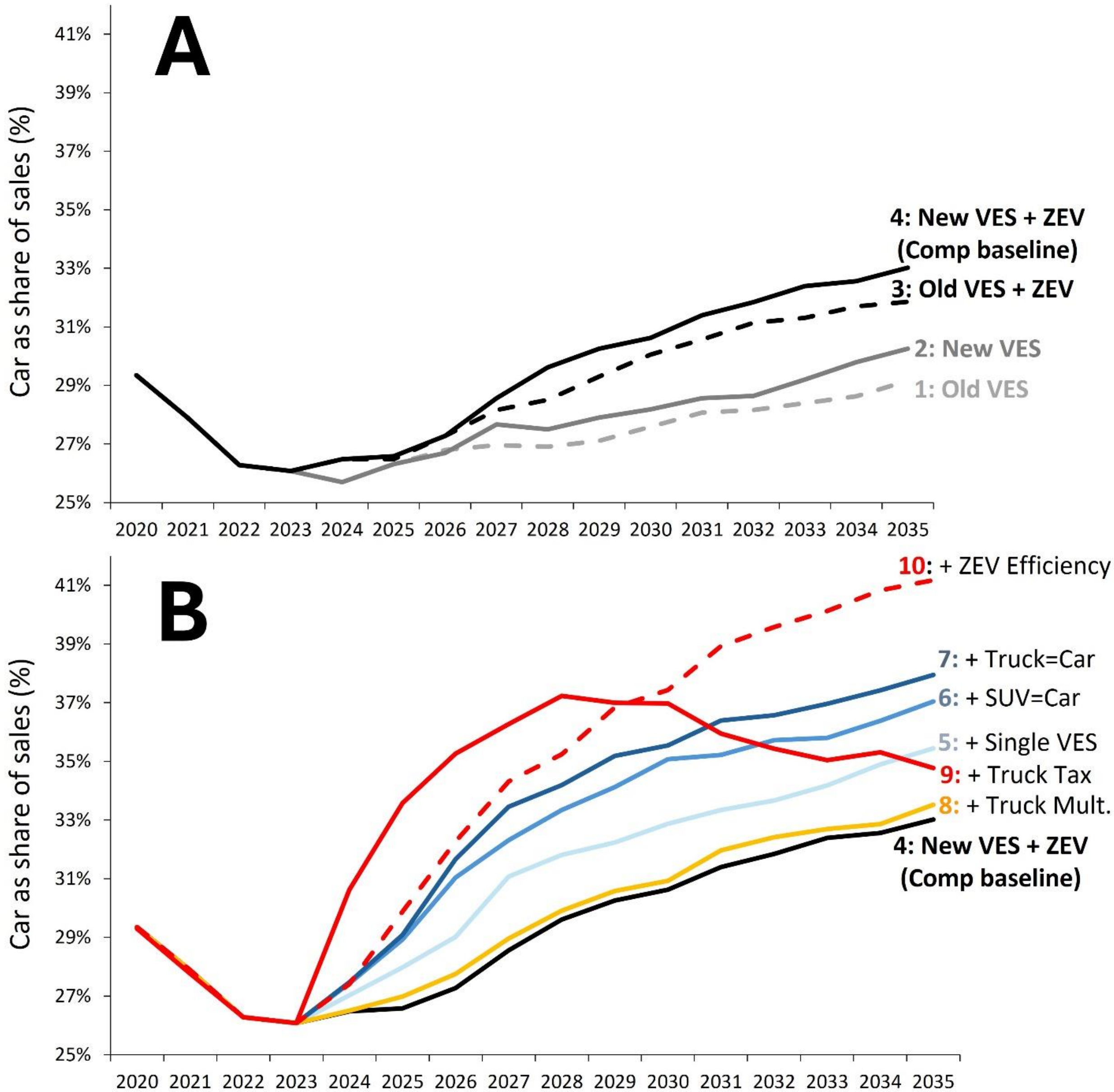


Figure 8 summarizes the baseline scenarios with uncertainty, while Figure 9A portrays these trajectories as median values. The "Old VES" scenario (#1) leads gradually to 29% car new market share in 2035, while the "New VES" (#2) slightly increases car market share to 30% in that year. The addition of the national ZEV Availability standard (#4) further increases 2035 car sales to 33%.

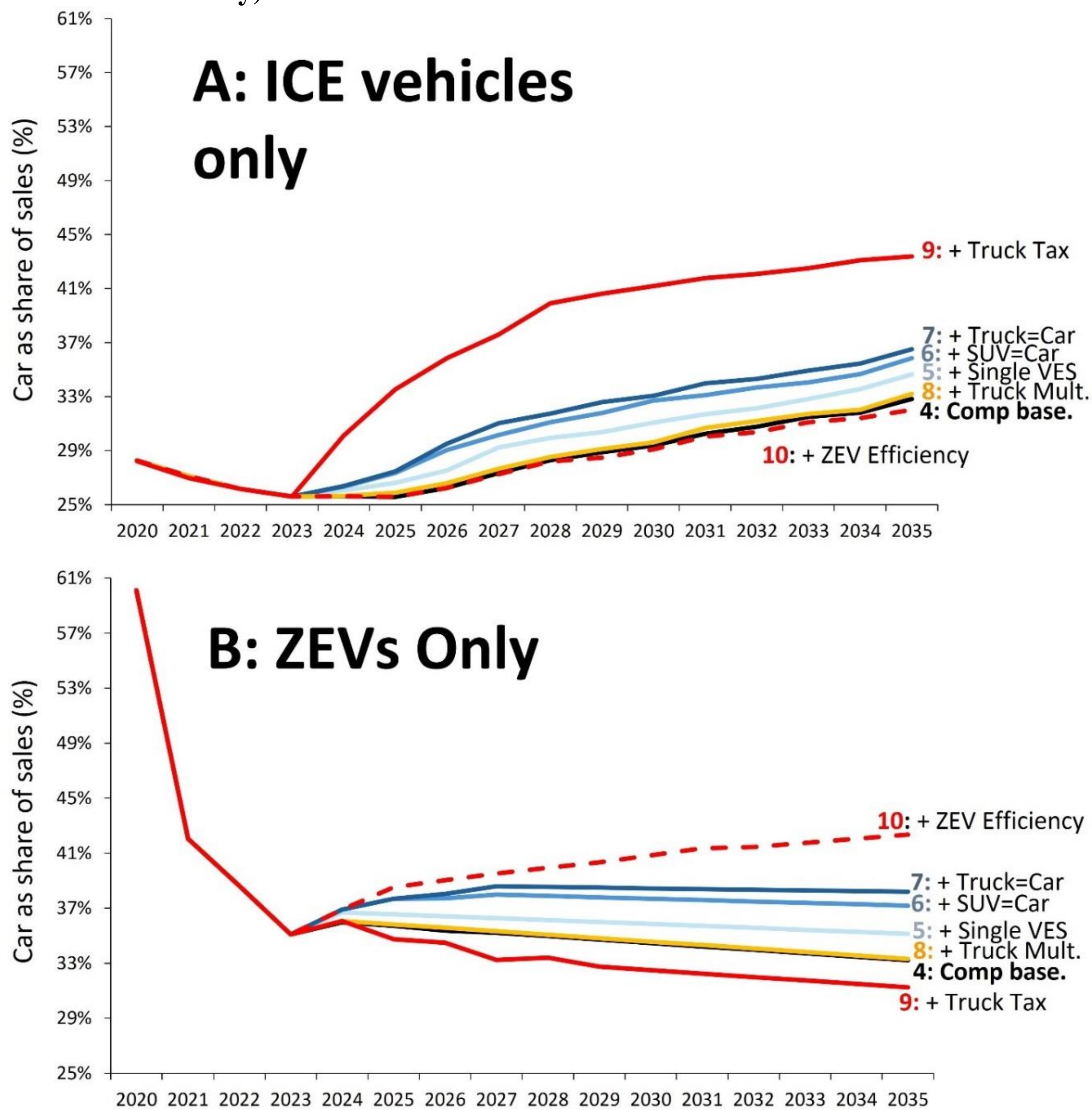
Figure 9: Overall car/truck share for all policy scenarios (ICE vehicles and ZEVs, median parameters only)



All the added policy scenarios (#5 to #10) lead to further increases in car sales share above the 33% comprehensive baseline (Figure 9B). As expected, the three variations of the VES lead to reduced truck shares: the "Single VES" leads to 35% car sales share in 2035, the "SUV=Car" version leads to 37% share, and the "Truck=Car" leads to 38% share. The "Truck Multiplier" version (Scenario #8) only leads to a slight reduction in truck sales, though higher multiplier values would surely be more effective.

The "Truck Tax" (applied only to ICE and hybrid trucks) leads to the strongest short-term impacts, increasing new car sales share to 37% for 2028-2030. The car sales share decreases again to 35% by 2035 because ZEV share gradually increases towards 100% (and ZEV trucks are not taxed in this scenario). Figure 10 provides an alternate perspective by separating trends in car/truck share for ICE vehicles only (Figure 10A), and ZEVs only (Figure 10B). From that view, the "Truck Tax" (Scenario #9) induces a consistent annual increase in car sales share among ICEs (to 43% in 2035). Among ZEVs, there is actually a slight increase in truck sales share, as some SUV/truck consumers switch from a ICE truck (which is taxed) to a ZEV truck (which is not).

Figure 10: Car/truck share for ICE vehicles only (A) and ZEVs only (B) (median values, scenarios #4-10 only)



Finally, the "ZEV Efficiency" standard (#10) leads to the highest post-2030 car market share in this study, which reaches 41% of new sales by 2035 (8 percentage points above the

Comprehensive Baseline). Scenario #10 demonstrates the potential magnitude of influence that policy can have on future car/truck market share. Figure 10 shows that the ZEV Efficiency standard induces an increase in car sales share among new ZEVs only, with no substantial impact to the sales share among ICE vehicles.

The simulated effects of these policy scenarios on car/truck share should be interpreted with caution. The magnitude of impact is mostly a function of the stringency of the selected standard, requirement, or tax. One of the most “fair” or useful comparisons is between the two versions of the VES with the same overall stringency the “New VES” in the comprehensive baseline (#4), and the “Single VES” that is class-neutral and footprint-neutral (#5). That change in policy design effectively adds downsizing as a VES compliance option, and reduces 2035 truck share by about 2.4 percentage points (in the median scenario).

The other differences across scenarios are largely a consequence of policy stringency. The additional VES variations (#6 and #7) have more stringent VES requirements overall, and thus have more impact on reducing truck sales share. The “Truck Multiplier” scenario (#8) has little impact, but larger multiplier values would surely have more impact. The “Truck Tax” of $15 per g/km above the required emissions level would likewise have different impacts at $5 versus $50 per g/km (or at $600 versus $6,000 per ICE truck). The relative success of the “ZEV efficiency" scenario (#10) is also a function of stringency. In other words, one should not simply interpret these results as an indication that any ZEV Efficiency standard is “better” than a tax or VES design.

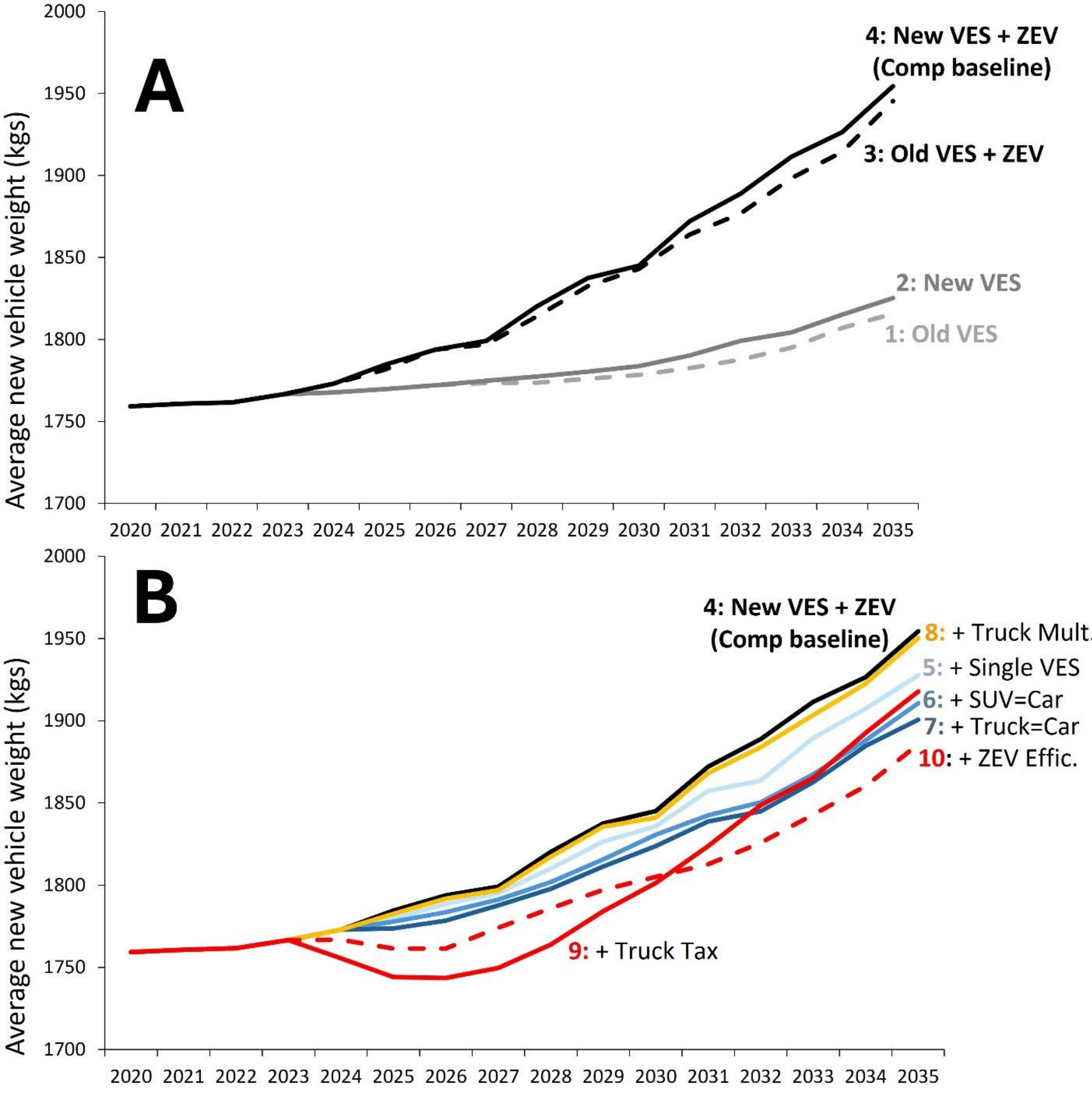
6.3 Vehicle attributes: Weight and Footprint

As expected, the policy scenarios have different impacts on the weight (kg) and footprint (sq. ft.) of new vehicles sold each year. Though, the trends are a bit at odds—with vehicle weight increasing in all scenarios, and footprint decreasing in all scenarios.

New vehicle weight increases in all scenarios due to the transition to increasing ZEV market share (Figure 11). As summarized in Table 4 (Section 4.3), we assume that all PHEVs and BEVs are heavier than their conventional version, due to the added weight from advanced batteries. So, the transition towards increased ZEV sales leads to vehicles of increased weight, and weight increases faster if the ZEV sale mandate is included (e.g., Scenario #4).

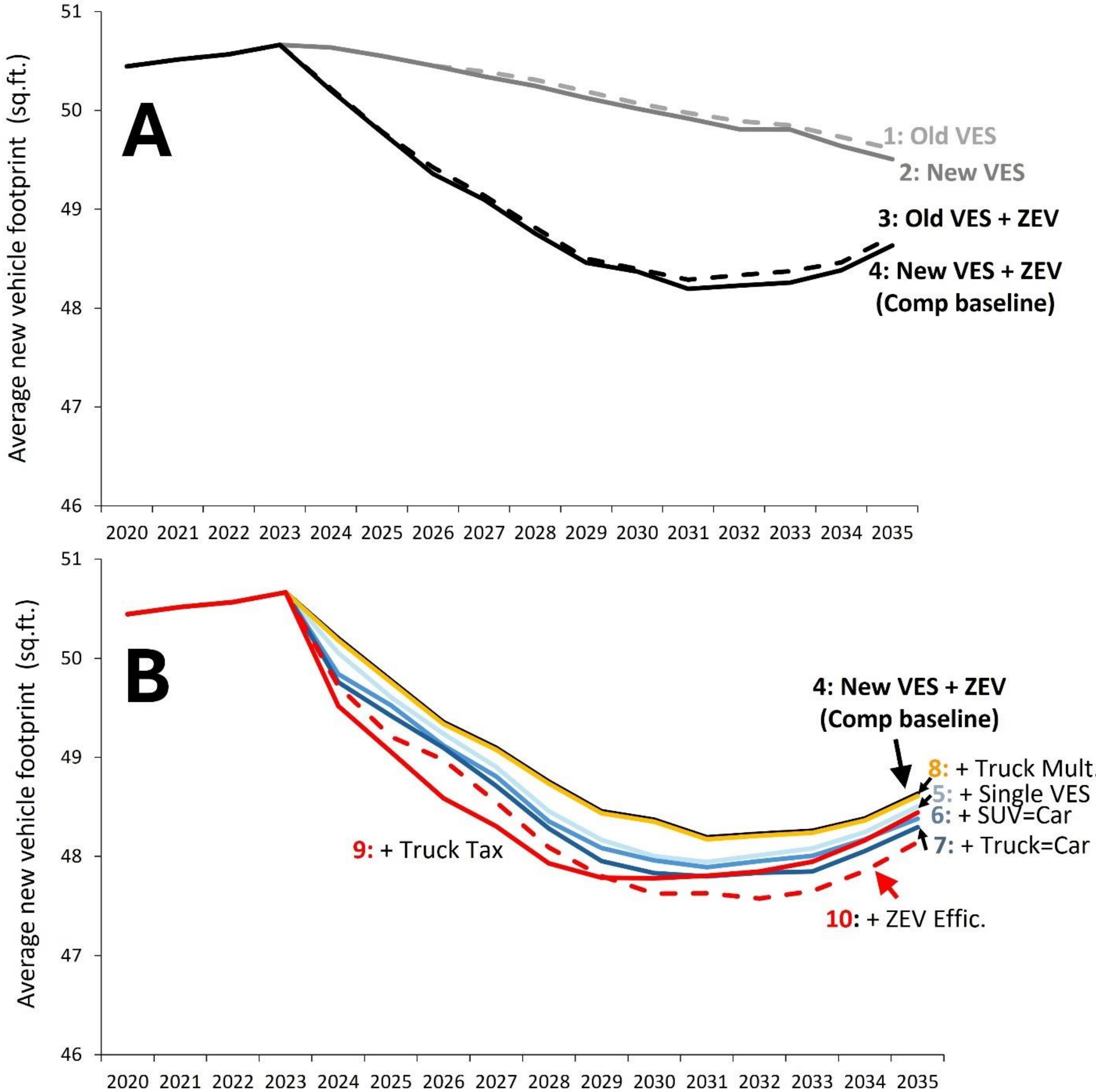
However, all additional policy scenarios (#5-#10) lead to a decrease in new vehicle weight relative to the Comprehensive baseline. Reductions in the 2035 sales year range from 0.2% (4 kg) in the “Truck multiplier” scenario to a high of 3.4% reduction (69kg) in the “ZEV Efficiency” standard scenario. Note that the “Truck Tax” scenario (#9) has a stronger down-weighting effect in the earlier years (2024-2030), until ZEV sales (untaxed) dominate the somewhat downsized ICE sales.

Fig 11: Average vehicle mass of new vehicles sold (median parameters, all policy scenarios)



In contrast, the average footprint of new vehicles decreases in future years in all policy scenarios (#1-10). The main reason is that each VES design ("Old" and "New") and the ZEV standard all lead to an increase in the relative costs of larger vehicles, leading slightly to downsizing across vehicle classes (Figure 12). Second, the BEV versions of the two truck classes are assumed to be slightly smaller, following BEV sales trends to date (Table 4). The added policy scenarios (#5 to #10) all induce further downsizing over time. Compared to the Comprehensive Baseline, reductions in 2035 new vehicle averages are negligible for Scenario #8 (Truck multiplier), but otherwise range from reductions of 0.3% (or 0.12 sq. ft.) in the "Single VES" scenario to 1% (0.5 sq. ft.) in the "ZEV Efficiency" scenario.

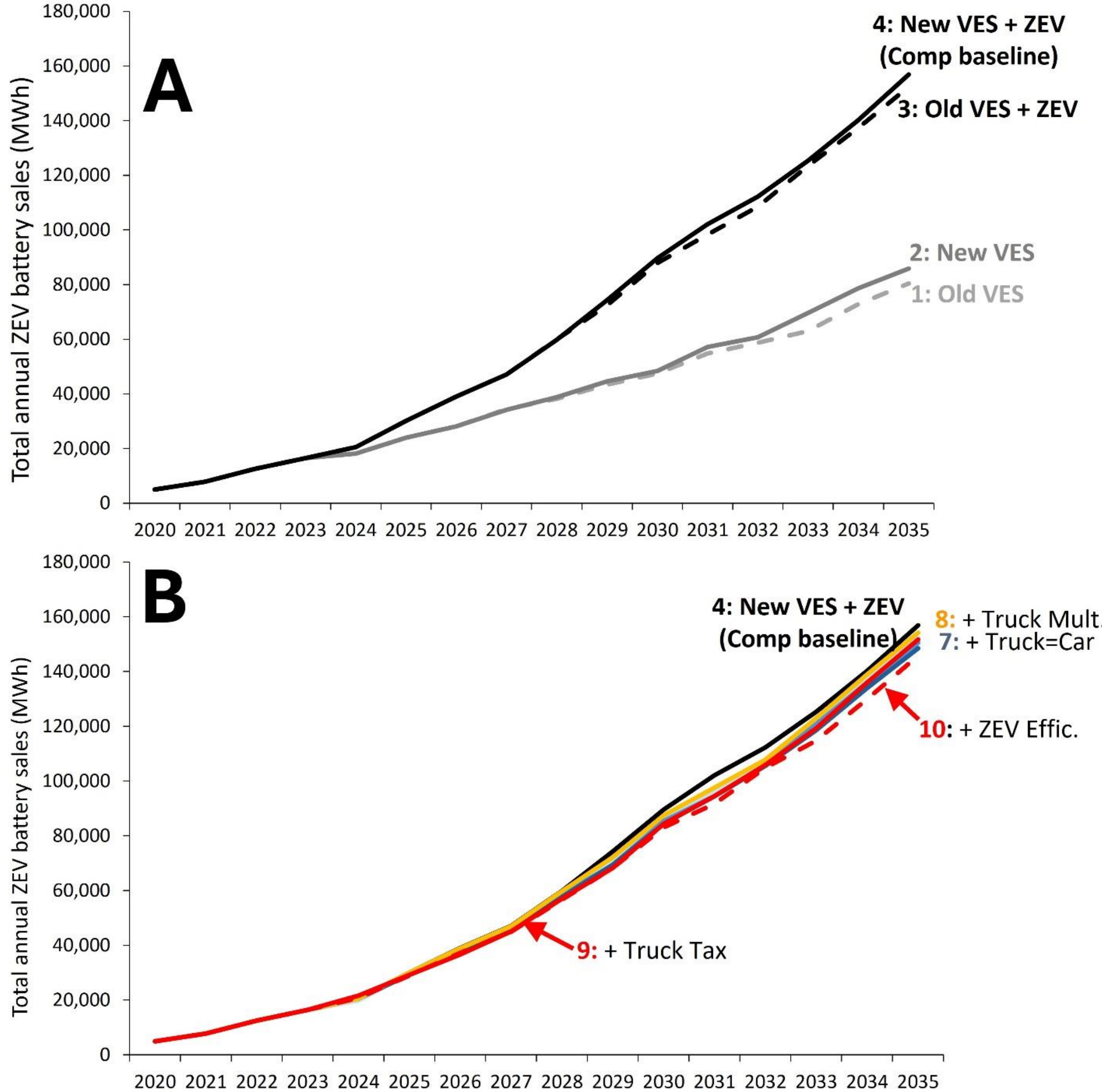
Fig 12: Average vehicle footprint (median parameters, all policy scenarios)



6.4 Battery usage for ZEVs (and associated metals)

Figure 13 depicts the total battery sales required for the annual ZEV sales simulated in each scenario. Battery sales are proportional to the total ZEV sales in each year, as well as the distributions of battery sizes needed by vehicle class and PHEV or BEV range (see Table 4). As expected, trends in Figure 13 largely follow trends observed for ZEV new market share (Section 6.1), with the largest increase in battery needs being induced by the presence of a national ZEV standard. The ZEV standard approximately doubles Canadian battery sales by 2035, compared to scenarios without the ZEV standard.

Figure 13: Total battery sales in Canada for new ZEVs sold in that year (total MWh)

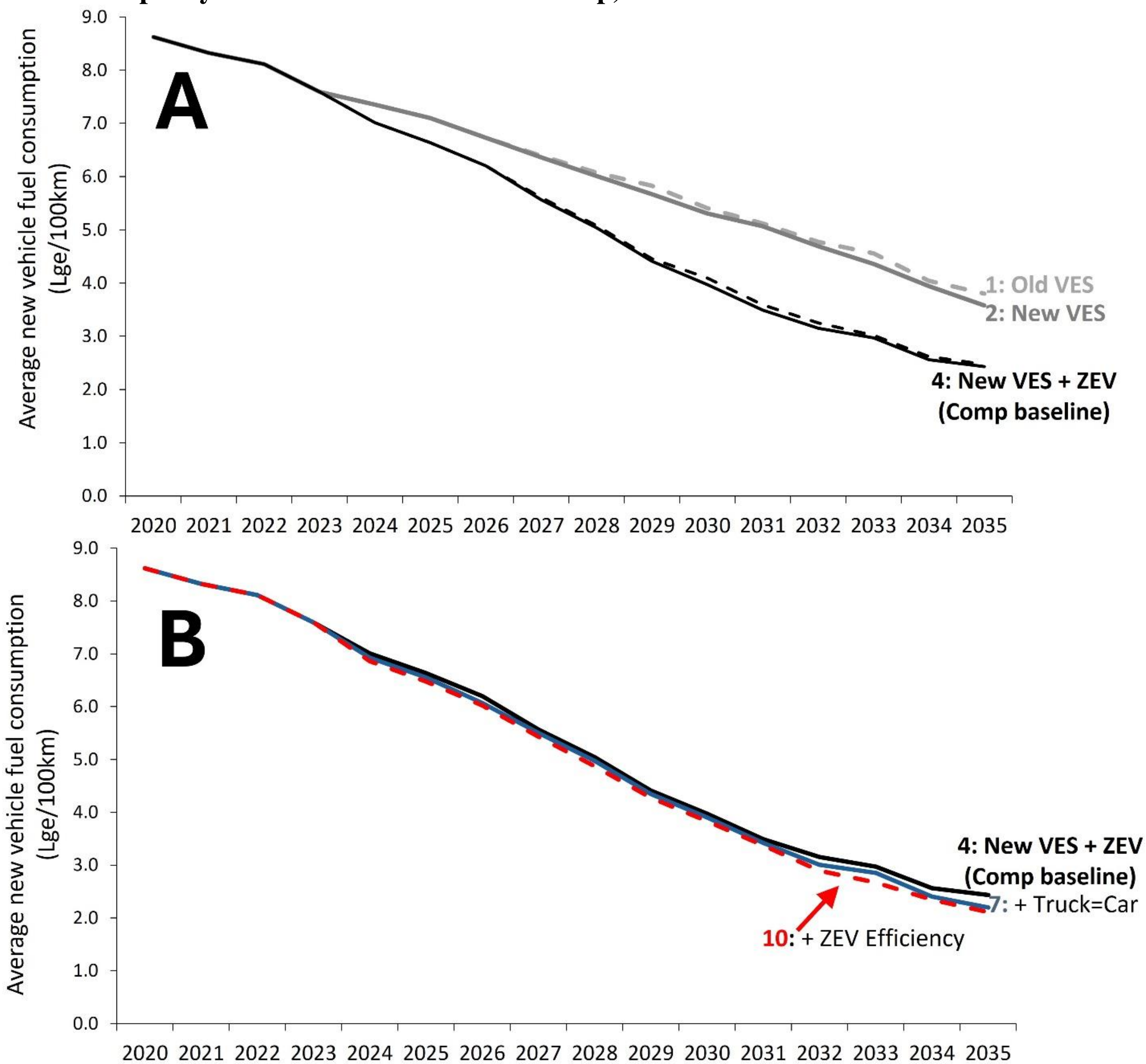


Because each of the additional policy scenarios (#5-#10) induces some amount of downsizing of the light-duty vehicle fleet, each scenario induces a slight reduction in battery demand relative to the Comprehensive Baseline. Reductions among 2035 ZEV sales range from 1.7% (#8: "Truck Multiplier") to 7.1% (#10: "ZEV Efficiency" standard). If future ZEV batteries are made using the same distribution of metals as those sold in 2023 (e.g., lithium, cobalt, and nickel), then one can assume a proportional reduction in demand for those metals (for ZEV batteries) by 2035.

6.5 Fuel Consumption and GHG emissions

The fuel consumption and GHG emissions from new light-duty vehicles are mostly influenced by the share of ZEV sales, so results again mostly follow those of Section 6.1. Figure 14A depicts the fuel consumption (Litres of gasoline equivalent or Lge/100km) of the baseline scenarios, where the more stringent Comprehensive Baseline leads to lower fuel consumption levels past 2023. Scenarios #5-10 only slightly improve upon the Comprehensive Baseline (Figure 14b), reducing 2035 fuel consumption by 4-10% among the VES variations (scenarios #5-7), and by as much as 13% in the ZEV efficiency standard (#10).

Figure 14: Fuel consumption of new vehicle sold in each year (median parameters, only illustrative policy scenarios shown due to overlap)



The trajectories for GHG emissions from new vehicles sold each year are nearly identical to fuel consumption trajectories. The Comprehensive Baseline leads to substantially lower emissions than the Old VES or New VES alone (Figure 15). Using median parameters, the Comprehensive Baseline leads to emissions from new vehicles in 2035 being 81% lower than new vehicles sold in 2020 (Figure 16A). The added policy scenarios (#5-10) have little further impact (Figure 16B); 2035 emissions are only 0.8% lower ("Truck multiplier") to 7.8% lower ("Truck=Car" VES) than the Comprehensive Baseline among most scenarios. The "ZEV efficiency" scenario has the largest impact, with 2035 emissions being 13% lower than the Comprehensive Baseline in that year.

Figure 15: GHG emissions of new vehicles sold in a given year (Scenarios #1, 2, and 4; with uncertainty ranges)

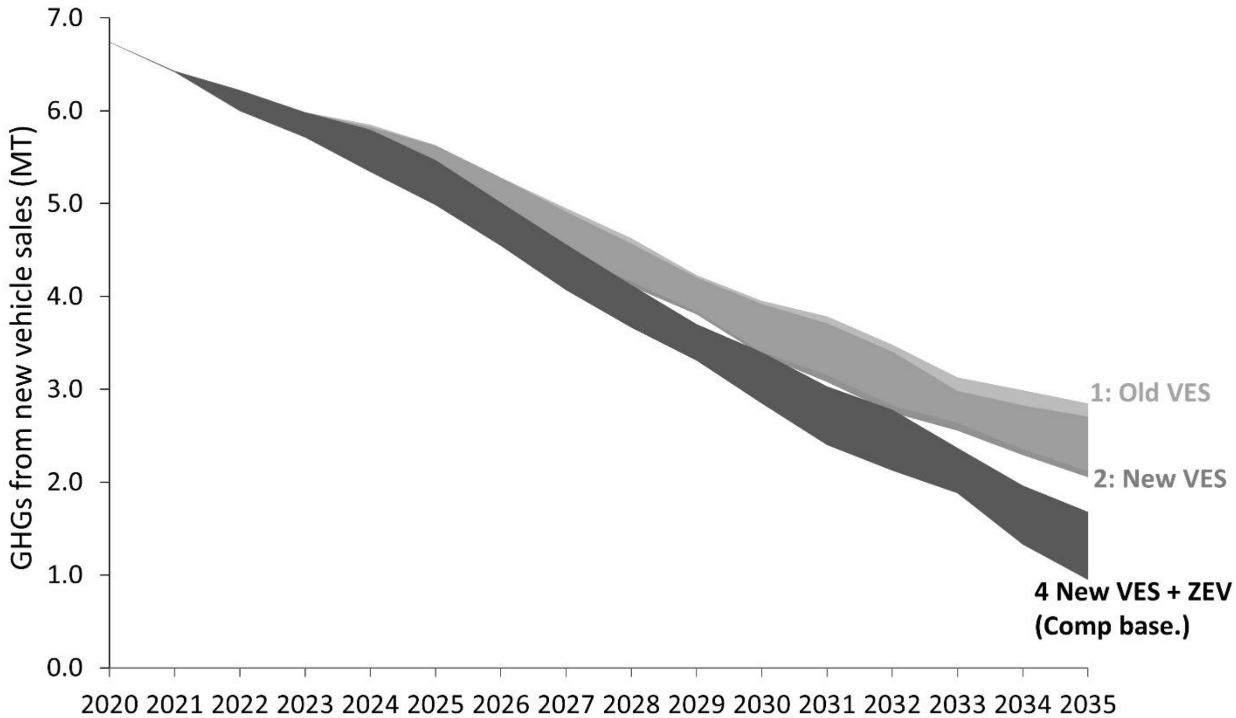
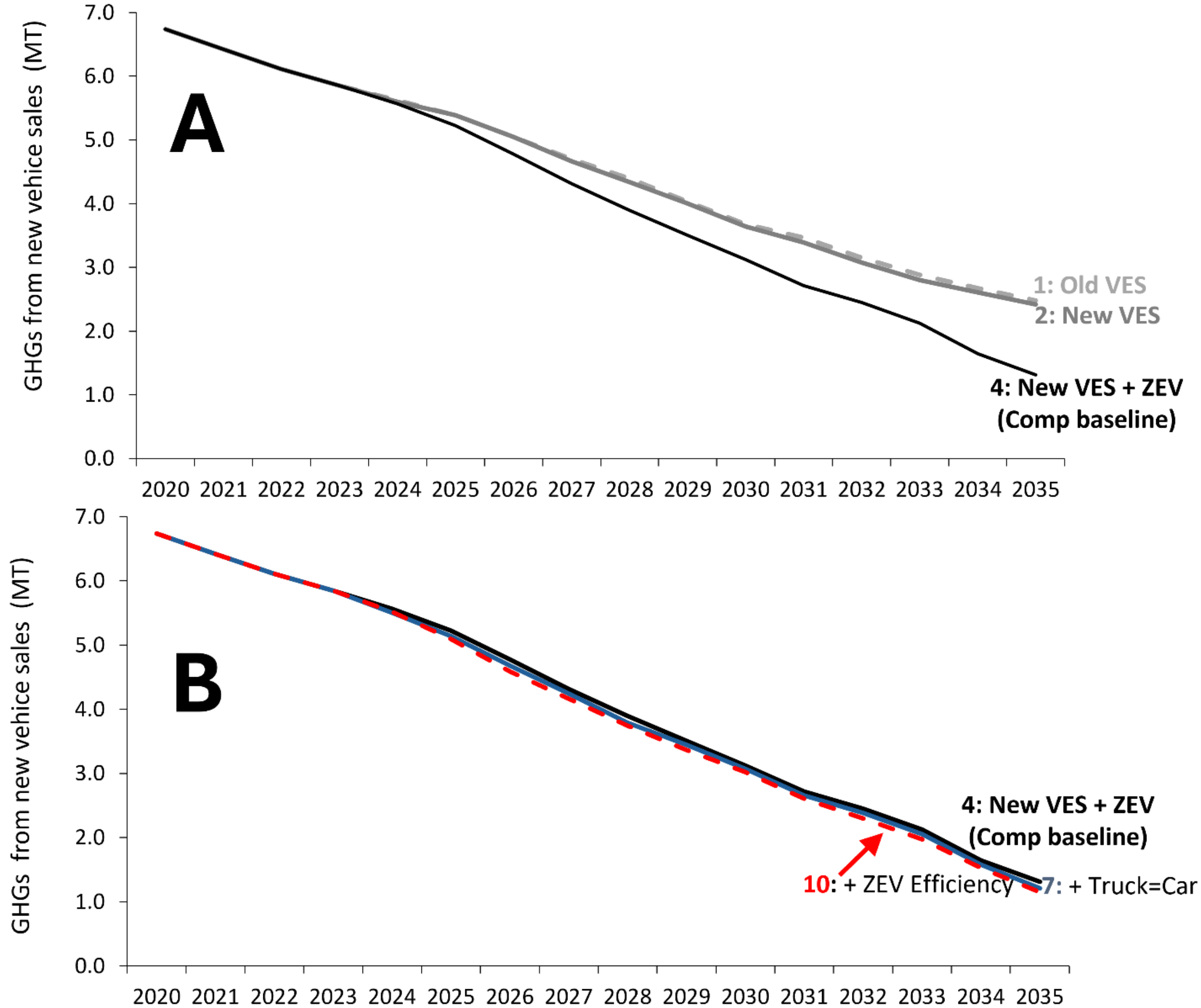
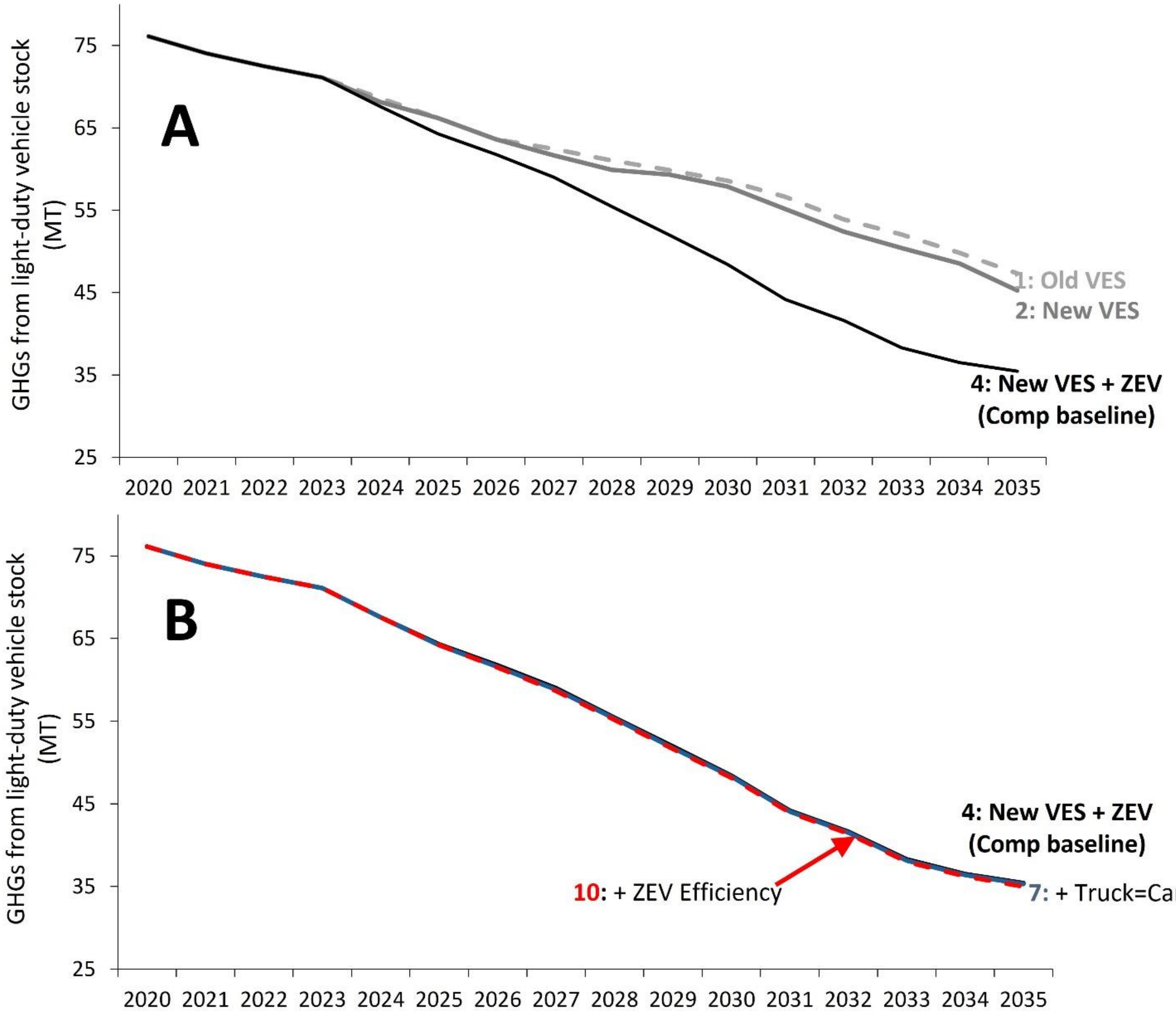


Figure 16: GHG emissions from new vehicles sold in a given year (All policy scenarios; median parameters)



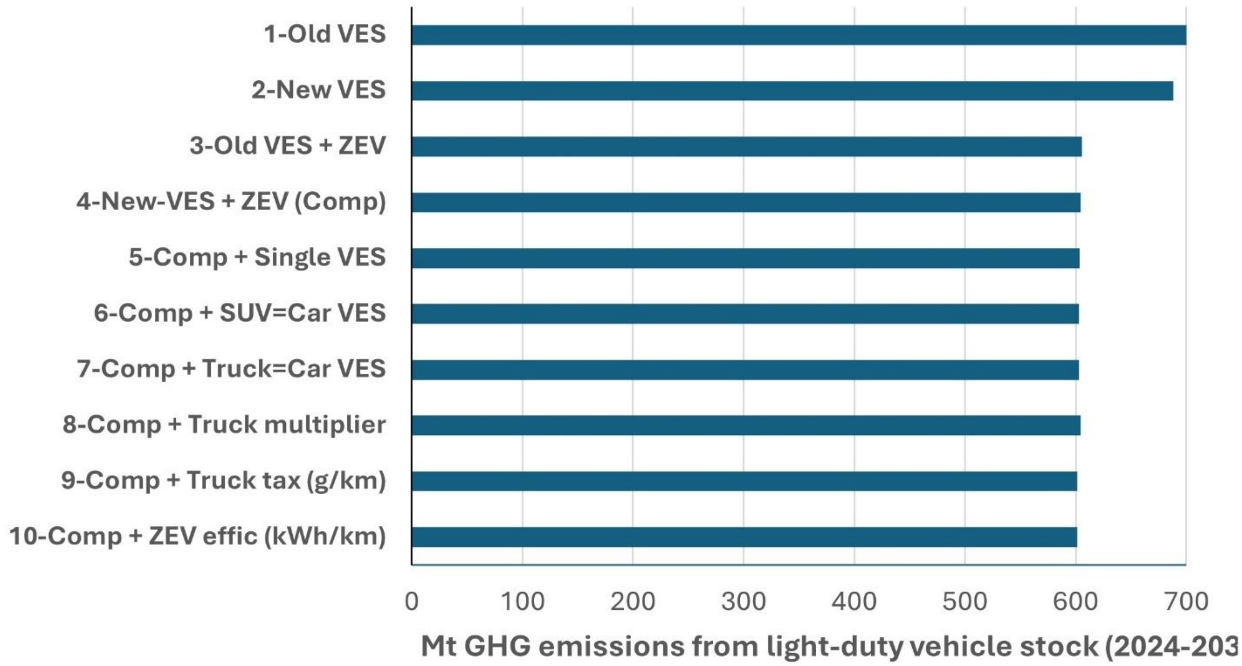
Simulated GHG reductions are more conservative when considering the full stock of Canada's light-duty vehicles (Figure 17). For each scenario with a ZEV standard, total GHG emissions from light-duty passenger vehicles in 2035 are 53-54% lower than those in 2020 (Figure 17A). Variation is small among those policy scenarios, where stock GHG emissions in 2035 are 0.2% to 1.2% lower (for policy scenarios #5-#10) compared to the Comprehensive baseline (Figure 17B).

Fig 17: GHG emission from total stock of light-duty passenger vehicles (All policy scenarios; median parameters)



In terms of cumulative GHG emissions from the stock of light-duty vehicles for the 2024-2035 simulation period (Table 10 and Figure 18), the bulk of reductions occur from the addition of the ZEV standard (84 to 95 Mt lower than scenarios without a ZEV standard). Compared to the Comprehensive baseline, the additional policy scenarios reduce cumulative emissions (2024-2035) by 0.1 Mt ("Truck multiplier") to 3.3 Mt ("Truck Tax").

Fig 18: GHG emission from total stock of light-duty passenger vehicles, 2024-2035 (All policy scenarios; median parameters)

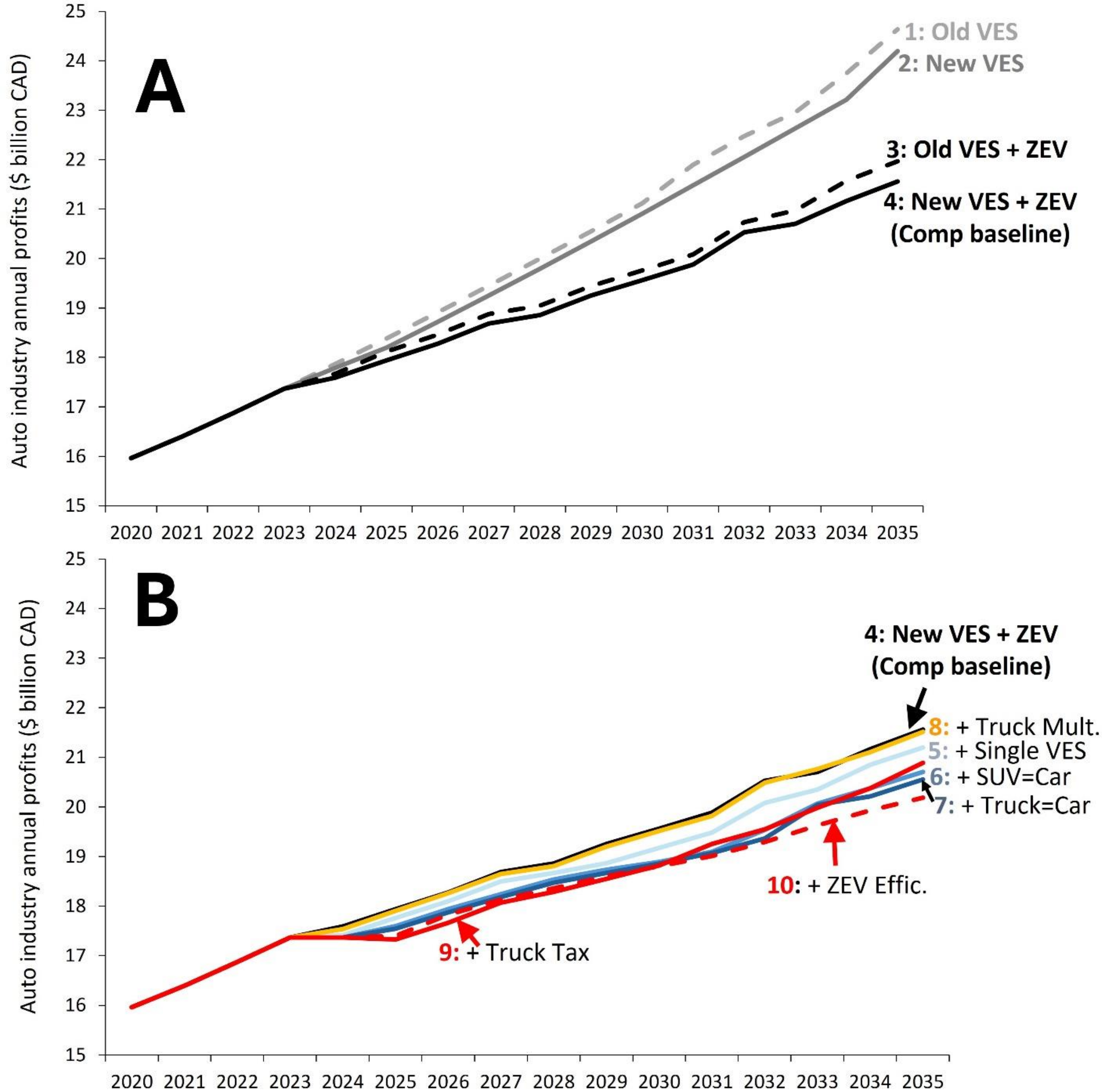


6.6 Automaker impacts: Profits and vehicle prices,

In all scenarios, median automaker profits are higher in 2035 compared 2023 (Figure 19), though all policy scenarios lead to a decrease in profits relative to any baselines with less stringent policy. The Comprehensive Baseline (scenario #4) induces a 7% decrease in cumulative profits (2024-2035) relative to the "Old VES" scenario with no ZEV standard (#1) (Figure 19A). Profit losses result from the automaker changing their practices (pricing, R&D investment, and other strategies) relative to the baseline, as well as due to fewer vehicles sales, lower ZEV profit margins for the initial years, and additional R&D costs in the initial years. Though, as noted, annual automaker profits in the Comprehensive Baseline still increase by 24% from 2023-2035 in real terms.

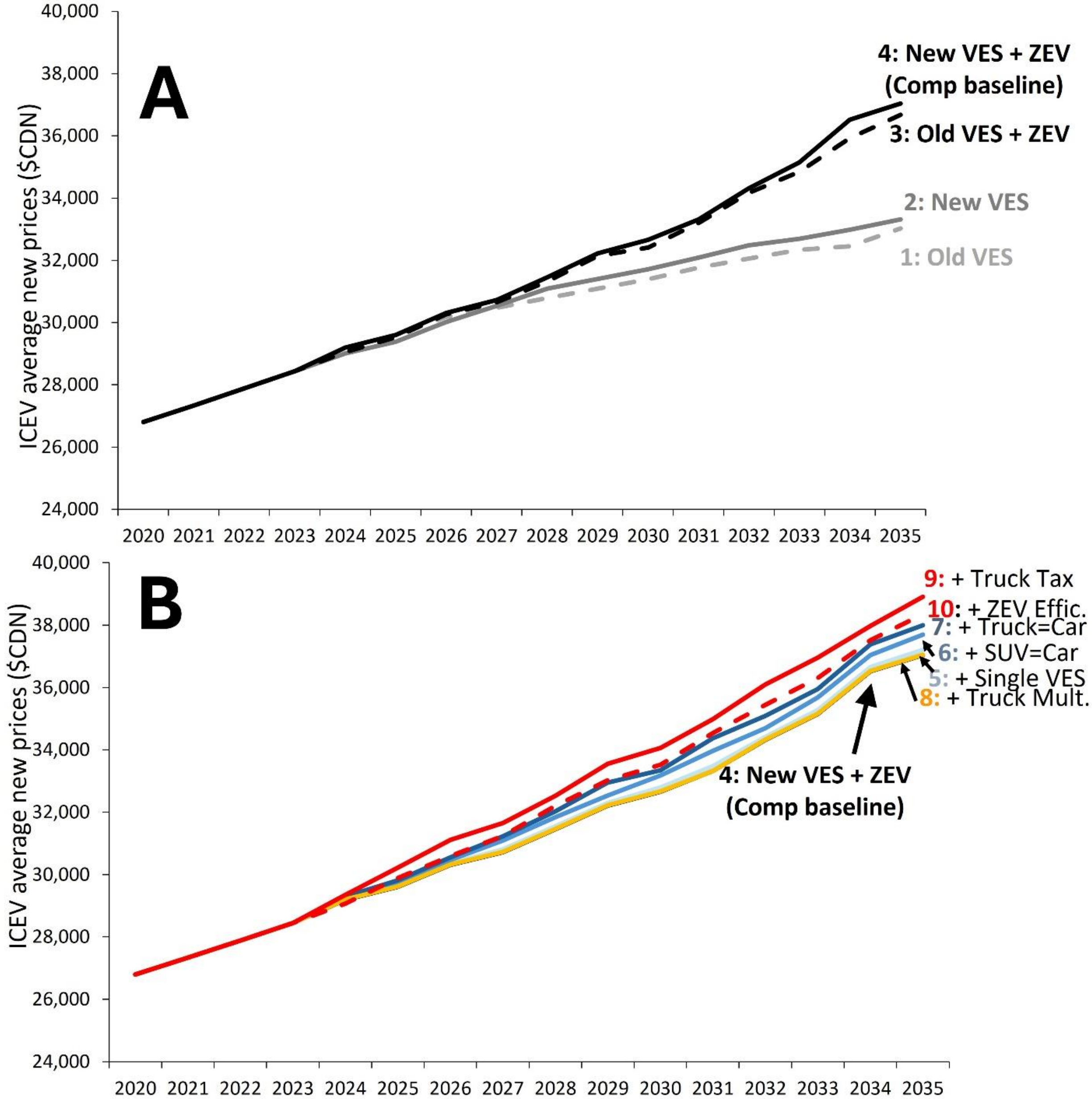
Relative to the Comprehensive Baseline, additional policy scenarios lead to reductions in cumulative profits (2024-2023) ranging from 0.2% (#8: "Truck Multiplier") to 4.0% (#10: "ZEV Efficiency" standard) (Figure 19B). Though, even in the more impactful ZEV efficiency scenario, 2035 profits are 16% higher than those in 2023.

Figure 19: Automaker profits (median simulations).



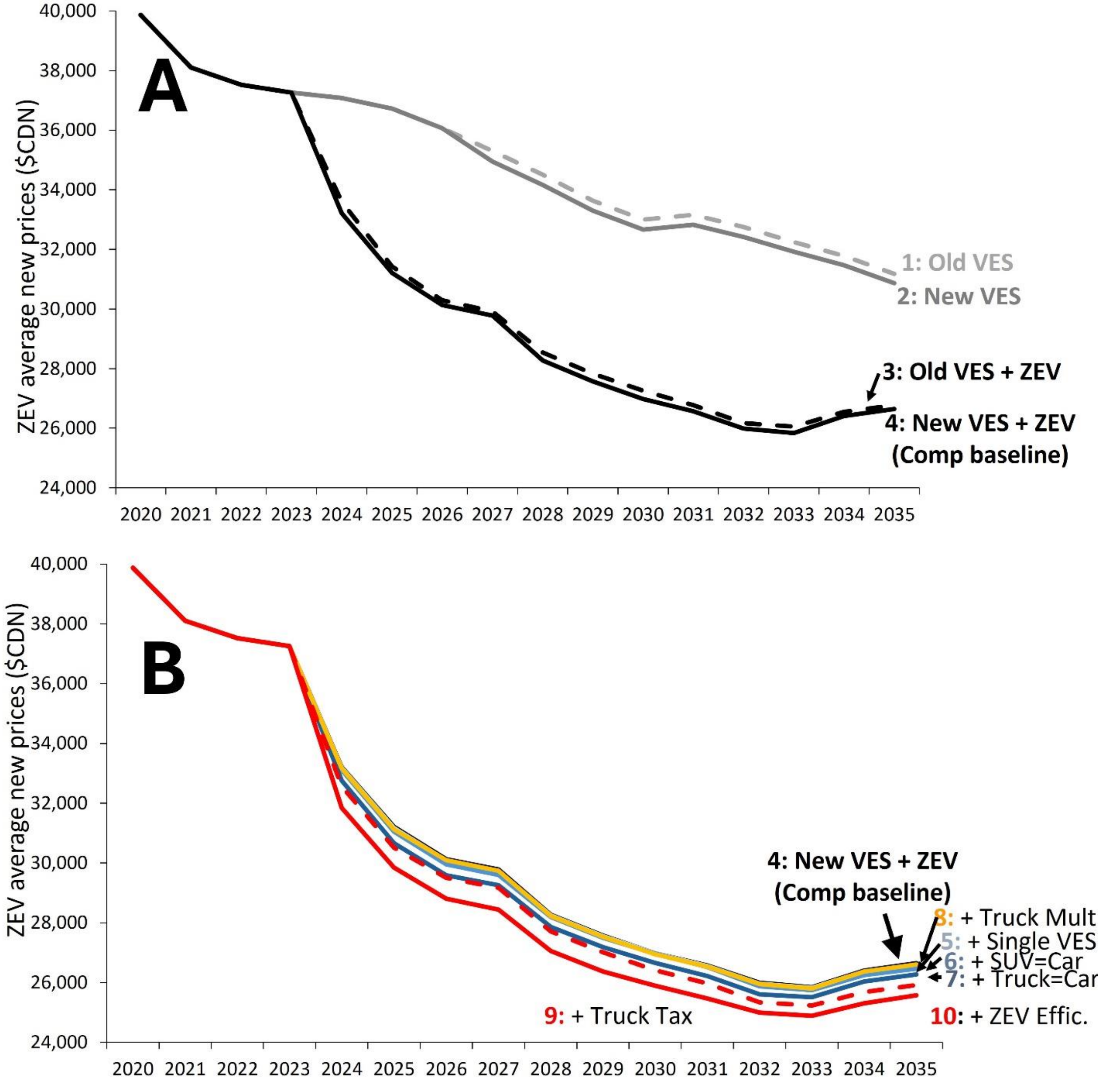
Trends in ICE new sales prices (Figure 20) and ZEV new sales prices (Figure 21) are again mostly driven by the presence of a ZEV standard. The depicted values are illustrative, showing only the average price for vehicles in the "larger car" vehicle class, without any "upgrades" or add-ons, such as a higher trim level. AUM also does not at this time explicitly represent a "luxury" vehicle segment. Taken together, the ICE and ZEV prices shown in these figures are significantly lower than the actual average sales prices in Canada, once luxury vehicles, larger vehicles, and vehicle upgrades/trims are accounted for. However, the dynamics and proportional changes are still relevant for our present analysis.

Figure 20: New ICEV average prices (median simulations, base price, sales-weighted average price of "larger car" class, with no add-ons or upgrades)



As has been demonstrated in past research,[23,50] a stringent ZEV standard induced automakers to implement an intra-firm, cross-price subsidy as the main strategy to comply with the ZEV sales requirements. That means that the profit margins (and sales prices) are raised on ICE vehicles, and dropped on ZEVs. In the Comprehensive Baseline (which includes a 100% national ZEV standard), new ICE vehicle prices on average increase by 30% from 2023 to 2035 (Figure 20A), while new ZEV prices drop by 28% over the same time frame (Figure 21A).

Figure 21: New ZEV average prices (median simulations, base price, sales-weighted average price of "larger car" class, with no add-ons or upgrades)



The additional policy scenarios (#5-#10) are more stringent, and thus lead to (slightly) further increases in ICE vehicle prices (Figure 20B), and slight decreases in ZEV sales prices (Figure 21B). For example, the most stringent policy (#10: "ZEV efficiency" standard) leads to an additional increase in 2035 new ICE vehicle prices by 3.5% (compared to the Comprehensive Baseline) and a further decrease in ZEV prices by 4%.

7. Key findings and policy recommendations

All results should be interpreted with care, especially comparisons of policy scenarios #5-#10. The magnitudes of each scenario's impacts are mostly a function of the stringency of the selected standard, requirement, or tax. For example, a larger truck tax (and/or tax that applies to ZEVs only also) would induce even larger reductions in the truck sales share. Further, the simulated "ZEV Efficiency" standard could be more or less impactful, depending on the required stringency set in each year (and the magnitude of the penalty applied for non-compliance). In other words, our present results do not demonstrate that a truck tax, VES design, or ZEV efficiency standards are "better" or "best" compared to the other policy types.

That said, we can draw several broad results from this analysis:

1. **The national ZEV Availability Standard will play a dominant role in several key sustainability goals**, including increased ZEV sales, decreased fuel consumption and GHG emissions from new light-duty vehicles, and a slight decrease in average new vehicle size. Without the ZEV mandate, the New (US EPA) VES alone would have only a slight impact in increasing ZEV sales and decreasing GHG emissions.

2. **The new US EPA VES offers slightly improved sustainability impacts over the old VES**, including slight reductions in GHG emissions, increases in ZEV sales share, and vehicle downsizing.

3. **In addition to the ZEV standard and new EPA VES, several additional policies (or design adjustments to the VES) can induce further vehicle downsizing.** The three VES designs that put trucks in the same requirements category as cars (Scenarios #5, #6, and #7) can have several beneficial impacts. The "**Single- VES" scenario (#5)** has the following changes in 2035 (compared to the Comprehensive Baseline in 2035):
    - A 2-percentage point increase in car (versus truck) sales share
    - A 4.1% decrease in GHG emissions from new vehicles sold in that year
    - A 1.4% decrease in the average weight of vehicles sold (27 kg)
    - A 0.3% decrease in average footprint of vehicles sold (0.13 sq. ft.)
    - A 3.0% decrease in needed battery capacity sold for ZEVs (with similar reduction for metals/minerals used in battery production).

    The more stringent **"SUV=Car VES" scenario** (#6) has the following 2035 impacts (relative to the Comprehensive Baseline):
    - A 4-percentage point increase in car (versus truck) sales share
    - A 6.9% decrease in GHG emissions from new vehicles sold in that year
    - A 2.2% decrease in the average weight of vehicles sold (44 kg)
    - A 0.5% decrease in average footprint of vehicles sold (0.25 sq. ft.)
    - A 4.1% decrease in needed battery capacity sold for ZEVs (with similar reduction for metals/minerals used in battery production).

    The further stringent **"Truck=Car VES" scenario** (#7) has the following 2035 impacts (relative to the Comprehensive Baseline):

    - A 5-percentage point increase in car (versus truck) sales share
    - A 7.8% decrease in GHG emissions from new vehicles sold in that year
    - A 2.8% decrease in the average weight of vehicles sold (54 kg)
    - A 0.7% decrease in average footprint of vehicles sold (0.34 sq. ft.)
    - A 5.4% decrease in needed battery capacity sold for ZEVs (with similar reduction for metals/minerals used in battery production).

4. **A stringent version of a "ZEV Efficiency" standard could be particularly effective**. The version we simulate (scenario #10) results in the following changes in 2035 (compared to the Comprehensive Baseline):
    - A 9-percentage point increase in car (versus truck) sales share
    - A 13% decrease in GHG emissions from new vehicles sold in that year
    - A 3.5% decrease in the average weight of vehicles sold (69 kg)
    - A 1% decrease in average footprint of vehicles sold (0.5 sq. ft.)
    - A 7% decrease in needed battery capacity sold for ZEVs (with similar reduction for metals/minerals used in battery production).

    In terms of cumulative GHG emissions impacts from vehicle stock (2024-2035), the "ZEV Efficiency" standard scenario induces the same reductions as the "Truck Tax" (which has an average charge of ~$1800 per new internal combustion engine truck).

5. All these policies (ZEV standard, new VES, and additional policies) can be implemented and **still result in substantial growth in automaker profit over time**.

This study is not set up as a comprehensive policy analysis. We focus on major impacts regarding key sustainability goals (mainly GHG emissions, fuel consumption, and vehicle size), and do not evaluate additional policy evaluation criteria such as policy cost-effectiveness, equity impacts, or political acceptability. However, we do identify numerous policy pathways that can have positive impacts if added to the current policy mix in Canada (including ZEV Availability Standard and new US EPA VES). Three broad directions are worth mention:

- **Design adjustments to new VES:** given the numerous pro-societal justifications to reduce vehicle size (and the unfortunate trend towards larger vehicles over the last decade), it is wise to consider adjusting the VES towards requirements to be "neutral" regarding class (car versus truck) and footprint. With such an adjustment, vehicle downsizing would then become a viable VES compliance pathway for automakers, and would yield additive reductions in GHG emissions, fuel consumption, vehicle size, and ZEV battery requirements.

- **ZEV efficiency standard:** we demonstrate the potential efficacy of an efficiency standard on new ZEV sales, which can shift the sale of new ZEVs towards smaller, lighter versions. Of course, to be effective in downsizing effects, such as standard would also have to be neutral in regards to vehicle class, weight, and footprint.

- **Truck tax:** a purchase tax on light-duty trucks (or by weight) can also be effective at reducing vehicle weight and/or footprint, if the price signal is large enough. However, we demonstrate that if the tax is only applied to conventional ICE and hybrid trucks there will be little impact post-2030 (with the national ZEV standard in place). Further, it is highly likely that political and public opposition to a purchase tax will be quite strong—typically larger than that observed for a VES or ZEV standard.[51-53]

Although we have simulated these three policy pathways in different policy scenarios, they need not be mutually exclusive. For example, an effective policy mix in Canada could include a class- and footprint-neutral VES, a ZEV efficiency standard, and a purchase tax system on new trucks, or by vehicle weight.

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Appendix A: Counting light-duty truck sales share

We've learned that this split varies widely by sources, and that reporting of data and data analyses are often imprecise and inconsistent. Table A3 summarizes some different estimates from different sources. The major differences include:

- Mixing of light-, medium-, and heavy-duty trucks
- Mixing of light-duty trucks for passenger and freight usage. (For example, many urban delivery trucks would qualify as class 2b/3 light trucks.)
- Reporting of sales/registrations by calendar or fiscal year.

In short, in the 2020-2022 time period we see higher "light truck" markets shares of 75-80% when more types of trucks are included in vehicle sales, typically all sizes, for passenger and freight uses. When considering only passenger light-duty vehicles, the market share for those years is 68-70%. As another one point of comparison, US analyses focus more on a 60/40 or 55/45 split between light-duty trucks and light-duty cars.[xv]

AUM is designed to focus on passenger light-duty vehicles, so we are currently calibrating the model to **market shares in the range of ~70% light-duty trucks**. That means we are excluding light-duty trucks used for freight or commercial purposes. A precise definition is provided here.[xvi]

[xv]See page no. 74440 (7 of 93 pages) US EPA Final Rule 2021 "states that "The combined car/truck CO2 targets are a function of projected car/light truck shares, which have been updated for this final rule (MY 2020 is **44 percent car and 56 percent light trucks** while the projected mix changes to 47 percent cars and 53 percent light trucks by MY 2026)." The US EPA assumes an approximate 60%/40% truck/car split for future years (p29240).

[xvi] According to Government of Canada: "*A passenger vehicle is a motor vehicle that is owned by the taxpayer (other than a zero-emission vehicle) or that is leased, and is designed or adapted primarily to carry people on highways and streets. It seats a driver and no more than eight passengers. Most cars, station wagons, vans and* ***some*** *pick-up trucks are passenger vehicles. They do* ***not*** *include:*

- *a van, pick-up truck or similar vehicle that seats* ***no more than the driver and two passengers*** *and that, in the tax year you bought or leased it, was used more than 50% to transport goods and equipment to earn income*
- *a van, pick-up truck or similar vehicle that, in the tax year you bought or leased it, was used 90% or more to transport goods, equipment or passengers to earn income*
- *a pick-up truck that, in the tax year you bought or leased it, was used more than 50% to transport goods, equipment or passengers to earn or produce income at a remote work location or at a special work site that is at least 30 kilometres from the nearest community with a population of at least 40,000*."

Table A1: Comparing light-duty truck share calculations by source

	Notes	Source
NRCan	Canada vehicle sales data up to 2020. Cars are just one category, but trucks are helpfully broken down into: passenger light-trucks, freight light-duty, medium-duty, heavy-duty. **2020 light-duty truck market share:** 68% if passenger vehicles only 74% if light-duty freight trucks included 76% if medium-duty trucks also included	**Cars:** **https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=ca&rn=32&year=2020&page=4** **Trucks:** **https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=ca&year=2020&rn=60&page=0**
Stats Can annual sales	2020: 80% Truck market share 2021: 81% 2022: 82% But "Truck" includes minivans, SUVs, light and heavy trucks, buses and vans	**https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010000201**
Stats Can quarterly sales	**Quarterly new vehicle registrations.** Doesn't specify passenger vs. freight. Has Car, Pickup truck, multi-purpose vehicle (SUV/crossover), Van. 2020 Truck/SUV/Van share is 79%	**https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002401&pickMembers%5B0%5D=1.1&pickMembers%5B1%5D=3.5&cubeTimeFrame.startMonth=01&cubeTimeFrame.startYear=2020&cubeTimeFrame.endMonth=10&cubeTimeFrame.endYear=2020&referencePeriods=20200101%2C20201001**
GFEI	p17 of the 2023 GFEI report states that "SUV" market share is 79% for Canada in 2022. I have downloaded the data to confirm this calculation, where 2020 "SUV" new market share is ~75%. This seems to align with NRCan estimate (with light-duty freight included).	https://www.globalfueleconomy.org/data-and-research/publications/trends-in-the-global-vehicle-fleet-2023
US EPA	In model year 2022, 37% of all new vehicles were cars and 63% of all new vehicles were trucks under EPA's light-duty GHG regulations.	https://www.epa.gov/automotive-trends/highlights-automotive-trends-report

Appendix B: National and provincial ZEV purchase subsidy assumptions

Table A2: Assumed baseline ZEV purchase subsidies (weight by vehicle sales per region)

BEVs	2020	2021	2022	2023	2024	2025	2026	2027	2028-35
Canada	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	
BC	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000		
QC	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000	$8,000		
Nova Scotia	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,300		
PEI	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750		
NFL	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500		
Yukon	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000		
Sales-weighted total	$7,425	$7,425	$7,425	$7,425	$7,425	$7,425	$7,425	$5,000	$0
PHEVs									
Canada	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	
BC	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500		
QC	$4000	$4000	$4000	$4000	$4000	$4000	$4000		
Nova Scotia	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000		
PEI	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750		
NFL	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500	$2,500		
Yukon	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000	$4,000		
Sales- weighted total	$3,770	$3,770	$3,770	$3,770	$3,770	$3,770	$3,770	$2,500	$0