Preliminary Cost Benefit Analysis (CBA) Assessing Alternate Policies to Achieve Equality in Moving to Clean Transportation

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Summary

Electric vehicles have been promoted for some time as important fin reducing greenhouse gas (GHG) emissions. This includes ongoing generous incentives since 2019 from the current federal government. At the same time, an unaddressed problem is increasingly evident, namely social inequality associated with electric vehicles. Electric vehicles of all types, even after a decade in the market, remain overly expensive, too dear for most Canadians. Prices are indeed increasing despite declining battery costs. The Tesla Model 3 is a classic example, announced with much fanfare as the affordable "every-person" car, but now, in reality, with a starting price in excess of $60,000.

Profiles of electric vehicle buyers in the U.S. consistently show them to be: overwhelmingly male; 40 to 55 years old; and with incomes exceeding $100,000. For Canada, this suggests federal EV incentives of $2.2 billion are going to the top 16 per cent income bracket, a privileged group less in need of assistance. A dichotomy is developing. High-income consumers can purchase high-end electric vehicles and acquire virtue-signal advantages for "saving the planet." Meanwhile, lower-income consumers are stuck with conventional vehicles, if they can afford them, and "vilified." Such perceptions ignore economic and social realities.

How can social inequality with electric vehicles be addressed? MBA students studying sustainability economics at the I.H. Asper School of Business, considered this question earlier in the year, reaching an unexpected conclusion. Rather than promoting individual electric vehicles for lower-income consumers, the answer appears to lie with having better public transit. For evaluation, a series of cost-benefit analysis calculations were undertaken, assessing four options. For this purpose, lower-income consumers are considered to represent roughly 10 per cent of the population, about 3.8 million Canadians, or about 1.5 million households.

The first option involves the federal government providing targeted purchase incentives for lower-income households sufficient to bridge the total cost of ownership gap between

a modest new electric car versus a modest new conventional car. Given costs are balanced for consumers, the benefits involve externalities: GHG reductions, based on a social cost of carbon at about $50 per tonne (i.e., present value of future damages from releases today); and air quality improvements. The latter are often over-exaggerated, with modest estimates in this case based on the American Lung Association. The cost to government works out as $30 billion. The result is an overall net cost of about $20 billion. This option does not work, with excessive electric vehicle prices the key constraint.

The second option is based on an idea popularized by some in Manitoba, namely interest-free, pay-as-you-save (PAYS) loans from the federal government for lower-income households. This option, however, imposes an even higher overall net cost of about $35 billion, and does not work. Contrary to expectations, no actual net annual savings are achieved, again because of excessive electric vehicle prices. In a cruel twist, lower-income consumers are left paying extra costs they can ill afford.

The last two options involve the federal government fully-funding new transit buses to meet transportation needs of lower-income households. Calculating the exact number requires more in-depth investigation, but preliminary estimates suggest around 30,000 new buses nationally, tripling the number across the country, and thus a big change. Benefits include externalities of GHG reductions and air quality improvements, as above, but also congestion relief. To this is added economic savings to households after first covering costs for transit operators and delivered energy/fuel for transit buses.

The third option considers 30,000 additional diesel buses across Canada. The cost to government is about $20 billion. The result is a significant positive overall net benefit of about $30 billion. There are also significant emission reductions, due to modal shift. The last option instead considers 30,000 additional electric or hydrogen fuel cell buses across Canada. The cost to government is higher at $38 billion. The result is a positive overall net benefit of about $17 billion; smaller but still positive. Emission reductions are larger than for diesel buses, with both options showing relatively consistent unit reduction costs.

Using a combination of these two approaches is possible too, with intermediate emission reductions and net benefits, in all cases positive.

Public transit provides a good way to simultaneously reduce GHG emissions and ensure equality in moving to clean transportation, warranting more attention. None of this, however, can happen on a mere whim. There are no magic wands, with many difficult challenges. For example, the hard limit constraining Winnipeg Transit to only about 100 new electric buses (Free Press, City issues RFP for first round of green buses, September 16, 2022), is electricity capacity, beyond which requires massive and costly infrastructure. Statistics Canada also confirms public transit is still suffering badly from the outfall of COVID; needing more assistance, but with little in the offing from the current federal government. Public transit solutions show significant promise, but transit still urgently needs more help over the near future to recover.

1. Introduction

Electric vehicles have been prominently identified for some time as an important means to achieve greenhouse gas (**GHG**) emission reductions. This includes recognition at a national level within Canada, e.g., EMC (2010), Axsen et al. (2016), Poovanna et al. 2018 or Electrifying Canada (2022), as well as at an international level, e.g., EEA (2018), Leard and McConnell (2020), or ITF (2021).

Electric vehicles are particularly important for developed economies, like Canada. In such cases, personal light-duty passenger cars and trucks are ubiquitous, and overwhelmingly dominated by conventional fossil fuels, especially gasoline. At the same time, governments around the world, including Canada, have made commitments to reduce carbon footprints in order to meet requirements of the 2015 Paris Agreement. For targets to be achieved, electric vehicles are anticipated to provide an important contribution (Gielen 2021).

For Canada, there is significant anticipated promise with electric vehicles, both economically and environmentally (Sharp et al. 2020). This is, firstly, because Canada's electric grid already exhibits relatively low GHG-intensity overall compared to the rest of the world, and, secondly, because of significant opportunities in manufacturing and/or provision of components for zero-emission vehicles of many types. The Government of Canada announced goals to achieve 40% to 45% GHG reductions by 2030, and further to achieve a "net-zero" status for the Canadian economy by 2050. Such goals have already been described by some as "ambitious" (e.g., Clean Energy Canada 2022). From a more practical perspective, identified by others as overly optimistic and not necessarily realistic in terms of achievement. The range of concerns is outlined by many including for example Bulowski (2022), Booth (2022), Blaze Baumen and Walsh (2022), or Tasker (2022). There are a host of problems to be overcome if Canada is to achieve a successful transition and reach desired reduction targets.

At the same time, equality regarding electric vehicles, across income-levels, genders, ethnic/racial groups, etc., is emerging as an important concern in Canada, and elsewhere. Economic inequality is particularly evident, as discussed in more detail later, given, firstly, that electric vehicles remain very expensive, only practically available to the already well-off, and, secondly, that electric vehicles require ongoing access to charging, also most readily available to the already well-off (Hardman et al. 2021). Further, infrastructure, programs and incentives, as implemented by governments, intended to accelerate adoption, end up overwhelmingly benefiting the already well-off. In the rush and the enthusiasm to embrace electric vehicles as an environmental panacea, the third essential "social" pillar of sustainability appears to have been largely overlooked, in particular as part of government policies and programs.

Transitioning away from fossil fuels needs to be successfully accomplished for all segments of our society, not just the well-off. This latter point is aptly identified in a recent report by the International Council on Clean Transportation (ICCT) (Bauer et al. 2021):

> As governments seek to integrate decarbonization policy with environmental justice goals, it will be critical to ensure equal access to clean technology … There are critical unanswered questions about when electric vehicles will provide benefits for lower-income households, and how the magnitude of these benefits will vary ...

As a means to address a potential problem with real world implications, MBA students at the I.H. Asper School of Business, University of Manitoba, studying sustainability economics during the Winter term of 2022, undertook an independent cost benefit analysis (CBA). The purpose of this analysis, recognizing the problems and perspectives outlined above, is to review equality concerns regarding electric vehicles within Canada, and then to identify and economically assess possible alternative policy options in order to enhance equality in the transition toward cleaner transportation. This analysis is based on a review of available literature from the public domain. A compendium of results for the options considered is presented in this report, along with recommendations.

Figure 1. Photograph side-by-side of the modestly-priced Mitsubishi iMiEV (~$28,000) and luxury-priced Tesla Model S (~$120,000+) electric vehicles, both driven by the first author (June 2013 by R. Parsons)

2. Background on Electric Vehicles

Relevant background on equality concerns with electric vehicles are summarized in the following sections.

2.1 Electric Vehicle Promise versus Electric Vehicle Realities

Electric vehicles are not, per se, a new concept, having existed for some time, and, indeed being a major contending option when private vehicles were first conceived as a major consumer product more than a century ago. They largely faded into obscurity for some time, but re-emerged. Modern commercial models began to reappear around 2010 (TETF 2018). These included the Mitsubishi iMEV (seen in photograph on page 2) and the Nissan Leaf, which are both categorized as battery electric vehicles (**BEV**), and the Chevrolet Volt, which is categorized as a plug-in hybrid electric vehicle (**PHEV**).

A further relevant zero-emission approach involves the use of hydrogen in fuel cell electric vehicles (**FCEV**), such as the Toyota Mirai, however, the numbers of these vehicles remain extremely small. So far these have only been available in a very few selected locations. As such, the focus in this case is on BEV and PHEV.

Two key technologies improvements are important for the practical resurgence of electric vehicles: (1) modern lithium-ion batteries for energy storage; and (2) regenerative braking systems. The advantages of electric vehicles, including both BEV and PHEV, as compared to conventional internal combustion engine vehicles (**ICEV**) result from three main characteristics. Firstly, operating systems of electric vehicles are inherently simpler and more efficient. Secondly, the motive energy for electric vehicles comes from electrical grids, meaning that energy inputs can be both less expensive and involve much lower GHG emissions. Thirdly, use of regenerative braking for energy capture further enhances efficiency.

Initially when modern electric vehicles were introduced, now roughly a decade ago, purchase prices were significantly higher than ICEV. Indeed, this was expected, given both new technologies and very small numbers of units involved. Importantly, it was anticipated, both as battery efficiency increased over time and production volumes continued to ramp up, that the market prices for electric vehicles would decline, and indeed would ultimately match those of ICEV (e.g., Qualey 2014).

In proportional terms, the numbers of electric vehicles have grown significantly. Yet total electric vehicle registrations have lagged significantly behind aspirations and projections. Notable in this regard was the projection by NRCan (2009) that 500,000 such vehicles could be on the road in Canada by 2018 (based on 2008 as a starting point). The actual number in 2018 turned out to be approximately 100,000.

Over-optimism on electric vehicle progress, unfortunately, tends to be distorted to some degree by the reporting of annual sales proportions, which, of course, have been rising. However, emissions are determined by the entire fleet in place, not just new entrants. This is illustrated by results for 2021 showing roughly 1.6 million new sales of light-duty vehicles of all types, with approximately 5.2% classified as zero-emissions (Statistics Canada 2021). Yet total sales for 2021, including ICEV, represent less than 7% turnover of the entire light-duty fleet within Canada, which has been estimated earlier as about 23.5 million (Statistics Canada 2019a).

Electric vehicles in total appear to have not yet gone higher than the target of 500,000 identified in 2009, but likely could by 2025, meaning 16 years to reach the originally defined target, rather than in less than 10 years. Even so, this same target of 500,000 still represents only about 2.2% of the total fleet of light-duty vehicles. Electric vehicles thus still only represent only a relatively small fraction of total vehicles today, not just in Canada, but around the world. The consequence is that numbers are still insufficient to make any consequential contributions to emission reductions in Canada (Parsons 2021). Much higher numbers are needed. Transitioning to electric vehicles is thus a long-game, one not likely to result in any rapid and decisive reductions in the near term, as obviously hoped for by government.

The key drawback of high prices for electric vehicles has continued to be a major hurdle limiting their application. For example, a major poll undertaken by Ipsos (Markusic 2020) as part of its Global Mobility Navigator Syndicated Study and involving 20,000 consumers worldwide, showed "price" to be the primary barrier, regardless of the type of vehicle in question. The same study confirmed "price" to be the most important single factor considered overall when consumers are purchasing or leasing a new vehicle of any type. Recent collaborative survey work in Canada, involving BNN Bloomberg (Shmuel 2021), suggests "high cost" also remains the dominant reason Canadian consumers continue to defer from purchasing electric vehicles.

There has been significant discussion about reducing the costs of electric vehicles, with the key focus of attention for some time being on batteries (Nykvist and Nilsson 2015). Battery packs represent the single largest cost component for electric vehicles, in the range of 25% to 30%. In 2010 the cost of batteries was very high, roughly $1,100 USD per kWh, but by 2020 had declined to approximately $137 USD per kWh, and anticipated to reduce further, close to $100 USD per kWh, by about 2023 (Boudway 2020).

Battery costs have been declining, at least up to the present. However, this has not directly translated into more-affordable electric vehicles becoming available. Indeed, quite the opposite has been true, with electric vehicle prices generally increasing appreciably (Malloy 2022). Data presented by Hardman et al. (2021) shows for the five-year period up to 2020, average BEV prices in the U.S. steadily rose by more than $6,000 annually. A much-identified "holy grail" of electric vehicles has been a lower-cost model priced around $35,000 that could be broadly affordable, and as such, significantly expand mass market sales. This, however, has not worked out so far, with the most blatant cautionary tale surrounding Elon Musk and Tesla.

Earlier Tesla commercial models, including the Roadster, Model S, and Model X, were all deliberately "high-end". The original (first generation) Roadster was Tesla's opening commercial offering from 2008 through 2012, a high-performance sportscar with price in the range of

$100,000 to $160,000 (i.e., $80,000 to $120,000 USD) at the time (Wikipedia 2022). The Model S was Tesla’s second commercial model, introduced in 2012 and continuing to the present. It is classified as an executive/luxury car, and has an indicated purchase price ranging from $120,000 to $170,000 (Tesla 2022a). The Model X followed in 2015, also continuing to the present. It is classified as a luxury cross-over vehicle, and has an indicated purchase price ranging from $130,000 to $180,000 (Tesla 2022b).

Tesla’s intended high-volume “every-person” car is the Model 3. This sort of vehicle was articulated early on by Musk (2006), with descriptions consistently emphasizing “affordable” and “family car.” A price target of $35,000 USD, prior to incentives, was noted prominently and attracted significant media attention. The Model 3 became available starting in 2017, continuing to present, and is classified as a compact executive car. It is also, obviously, Tesla’s most common vehicle.

Doubts regarding Tesla’s commitment to and ability to deliver their ambitious price goal began early (Davis 2016), and persisted. By 2019, the “$35,000 vehicle” goal was quietly dropped, with much less fanfare than original announcements (O’Kane 2019). Musk and Tesla’s stipulated rationale was simply that the “$35,000 vehicle” was simply not sufficiently profitable. Currently, the purchase price indicated for the Model 3 in Canada ranges from $60,000 to $80,000, confirming it as a luxury vehicle (Tesla 2022c). These events have not prevented Musk, the preeminent showman, from alluding to an even more ambitious “$25,000 vehicle,” although Tesla later recently confirmed it is not being pursued at this time (Haselton 2022). Meanwhile, other vehicle manufacturers are crowding into the up-scale luxury EV space.

Newer problems are also emerging, that will tend to push up the prices of electric vehicles. The cost of batteries, which had heretofore been in steady decline, in 2022 began to surge upward. This turn of events had been precipitated primarily by a shortage of minerals and materials needed for batteries (LeBeau 2022). Similarly, the global shortage of semiconductor chips, caused by pandemic-related supply-chain problems, has affected electric vehicles too, indeed proportionately worse, given such vehicles tend to be more electronic and incorporate a larger number of chips (Hiar 2021). A key point is that those who are already well-off are better able to accommodate price increases, but not lower-income citizens.

A dichotomy appears to be developing whereby high-income consumers are able to purchase high-end electric vehicles, often with incentive support from governments, as discussed later, and through this acquiring “virtue-signal” advantages of “saving the planet.” At the same time, lower-income consumers are becoming effectively stuck with conventional vehicles, primarily based on high prices. Through this process they are also effectively becoming “vilified” from an environmental perspective. These perceptions, however, ignore economic and social realities, and are largely becoming self-fulfilling constructs.

2.2 Electric Vehicle Incentives and Who Ends up Benefiting

The use of financial purchase incentives of various forms has broadly demonstrated effectiveness all over the world for accelerating the uptake of electric vehicles (Xue et al. 2021). Incentives, though, can vary quite significantly between countries, including direct subsidy payments to purchasers, and various forms of tax relief. The most prominent mechanism used within Canada, both federally and by specific provincial governments, has involved direct subsidy payments.

Despite apparent effectiveness, however, concerns are increasing about such incentives. This obviously includes social equality, but also economic efficiency in the transition to new technologies and new markets. These concerns suggest that in Canada it may be time to re-evaluate purchase subsides, whether by eliminating them outright (Ragan et al. 2020), or significantly altering their nature.

The principals behind incentive subsidies come from two distinct but linked perspectives. The first is technology-related, in advancing a technology adoption cycle, as outlined in general for example by Roumani et al. (2015). The second is market-related, in enhancing consumer interest and accelerating market uptake, in particular addressing concerns in being able to bridge the so-called “chasm” from narrow niche introduction of products to broad adoption (Moore 1991). The market aspects are discussed specifically for electric vehicles by Larson et al. (2014). Both of these perspectives tie to new technology adoption, also related to the well-known concept of Technology Readiness Level (Industry Canada 2018), with in this case the intent being to deliberately transition away from ICEV to electric vehicles in order to address and mitigate environmental GHG emissions, which is a legitimate and desirable policy outcome.

In the early 2010s when commercial models were being introduced, the arguments for incentive subsidies were entirely valid, given higher prices due both to battery costs and small numbers. This was exemplified through considering the Total Cost of Ownership (TCO), and was a specific motivating factor in implementation of electric vehicle incentive subsidies in diverse jurisdictions to help bridge the TCO gap. This situation was recognized within Manitoba, as outlined by the EVAC (2012), although Manitoba did not in the end implement any incentive program, as was undertaken most notably in Quebec and British Columbia, for a period of time within Ontario, and later by the federal government beginning in 2019.

The automotive industry continues to emphasize the TCO, and hence that there is a need to continue, if not accelerate, incentive subsidies in order to achieve higher adoption levels to meet climate goals. Indeed, in the lead-up to the recent Canadian federal budget, Canadian automobile manufacturers and dealers through their “Road to 2035” (2022) initiative, called for electric vehicle incentives to be increased to as much as $15,000. The situation now, however, is quite different from a decade ago. As noted earlier by Lee and Clark (2018) dramatic declines in battery costs per kWh are making it increasingly difficult for governments to justify purchase incentive subsidies for vehicles. Price-premiums for electric vehicles now appear to be due more to vehicle manufacturer “up-scaling,” rather than any technology-readiness constraints, such as high battery-costs. In this case, the use of incentive subsidies appears increasingly to represent a form of self-serving “rent-seeking” behaviour by the automotive industry.

At the same time, recent analysis by McKinsey (Baik et al. 2019) clearly illustrates the rationale behind the stance of the automotive industry; they need to stop losing money on electric vehicles. Enhanced profitability also explains the automotive industry’s current emphasis on conventional trucks, vans, SUVs and CUVs over conventional passenger cars. In order to remain profitable overall, and thus stay in business, they need to sell vehicles with margins that are at least adequate and hopefully higher, which has not been happening so far with electric vehicles. As outlined by Baik et al. (2019), two factors have led to low profitability relative to conventional ICEV. Firstly, they so far remain more expensive to produce, about 1.4× to 1.6× more costly than conventional ICEVs, this also given the need to recoup enormous investments made in research and development. Secondly, consumers possess only a limited “willingness-to-pay” more for just basic vehicles. Hence the obvious trend to more-valuable, up-market versions. A variety of tactics for the automotive industry were identified by Baik et al. (2019) to increase profitability, but, even so, they suggest some increment of higher cost for electric vehicles is likely to remain. The upshot for consumers and manufacturers alike is that electric vehicles remain costly.

This leads directly to considering equality concerns regarding electric vehicle incentives. Since 2019, roughly $589 million has been spent by the federal government alone on its iZEV incentive program, providing upwards of $5,000 per eligible vehicle, with the recent Budget 2022 allocating a further $1.7 billion for such incentives up to March 2025 (Rabson 2022). This does not even include incentive expenditures provided in BC, Quebec, and for a time Ontario, nor incentives for electric vehicle charging stations. A key question arises as to who precisely have been the recipients of such incentives?

While answers regarding beneficiaries are not directly available for the programs in question, these can be inferred based on extensive available profiling of electric vehicle owners in the U.S. (Ricardo 2021), a country reasonably similar to Canada. Data for the U.S. suggests, for 2019, the average annual household income of electric vehicle buyers was more than $100,000. Further, electric vehicles buyers tend to be overwhelmingly male and 44 to 50 years of age. Such results suggesting well-off owners is corroborated specifically for California earlier by Turrentine et al. (2018).

These characteristics of electric vehicles owners suggest a rather “privileged” background. Considering Canada, a convenient article by Rendaje (2022), based on recent census data, indicates that about 15.7% of Canadians have an annual income of $100,000 or more. This suggests that present and future electric vehicle incentives that will total over $2.2 billion are being directed, overwhelmingly, to privileged individuals within the top 16% of income earners. Incentives, as provided within Canada, have ended up being relatively perverse in nature, a situation needing to be corrected, in particular ensuring equality, hence this work.

3. Analysis Methods

The intent of this report is to analyze alternative approaches to address inequality in the move toward clean transportation. Methods are outlined in the following sections.

3.1 Who are Lower-Income Canadians

In considering lower-income Canadians, the first relevant question to ask is, “Who are they?” Definitions of “low income” have always tended to be relatively non-uniform, and inherently subjective in nature. Up until 2019, the Government of Canada had no official definition of poverty, although with three main metrics monitored (ESDC 2016):

- Low-income cut-off (LICO), defined as the income threshold below which a family must devote a larger share of its income on the necessities of food, shelter and clothing than an average family, typically deemed as 20%, with data available as far back as 1976;
- Low-income measure (LIM), defined as income threshold below 50% of median household income, thus a relative measure, with data available as far back as 1976, and also frequently compared internationally as a relatively standard measure; and
- Market basket measure (MBM), defined as income threshold below which a family has insufficient income to buy a specific set of goods and services that represent a basic standard of living, as such an absolute measure, with data available as far back as 2002.

In 2019, the Government of Canada officially adopted the MBM methodology to define the “poverty line” (ESDC 2021). Relevant values for all three measures above covering two representative years (2014 and 2019) are summarized in Table 1, with sources presented.

Table 1. Relevant Lower-Income Populations for Representatives Years

“Poverty” Metric Considered	**2014 (ESCD 2016)**	**2019 (ESDC 2021)**
Low-income cut-off (LICO)	8.8% (~ 3.0 million)	Not presented
Low-income measure (LIM)	13.0% (~ 4.5 million)	12.1% (~ 4.4 million)
Market basket measure (MBM)*	11.3% (~ 3.9 million)	10.1% (~ 3.7 million)
* Value selected by Government of Canada as official measure in 2019		

Some further changes in poverty level did occur as a result of the COVID pandemic, e.g., reductions due to short-term Canada Emergency Response Benefit (CERB) provided. While more recent data is thus available, it is not considered for this analysis given the uniqueness of circumstances during the pandemic. For analysis purposes, an MBM-based rough measure of 10% of the population being lower-income is assumed, or roughly 3.8 million people, based on the current population.

Further, most recently available total number of light-duty vehicle registrations is indicated to be about 23.5 million in 2019, this compared to an estimated population of 37.6 million in the same year (Statistics Canada 2019, Statistics Canada 2019b). From these values, the average number of vehicles per capita in Canada is approximately 0.63. Assuming that lower-income families maintain a relatively consistent proportion of vehicles compared to the national average, i.e., similar proportion but likely lower value or used vehicles, this translates to approximately 2.4 million relevant light-duty vehicles within lower-income households.

3.2 Comparative Options Selected for Analysis

To ensure reductions of GHG emissions from transportation involving lower-income Canadians, but also address equality of access to "cleaner" transportation options, three major alternatives are assessed in this report, and summarized in Table 2.

Table 2. Summary of Comparative Options Selected for Analysis
Option Titles and Subsequent Brief Descriptions
Option 1: Purchase Subsidy Incentives Targeted to Lower-Income Households This option involves transitioning individual vehicles toward BEV and PHEV for lower-income households through a targeted purchase subsidy incentive. In this case the incentive is based on value required in order to achieve comparable Total Cost of Ownership between a modest current electric vehicle and a modest new conventional vehicle.
Option 2: Interest-Free Pay-As-You-Save Loans for Lower-Income Households This option uses a so-called "pay-as-you-save" or PAYS approach to transition lower-income households. This involves interest-free loans for lower income-consumers, with a broad intent that fuel savings (hopefully) should balance reasonably against higher vehicle purchase costs.
Option 3: Focus on Adequate Public Transit to Meet Transportation Needs This option involves transitioning lower-income households to "cleaner" transportation but through the use of public transit, rather than via individual vehicles, requiring sufficient new transit buses to ensure transportation needs for this target population can be fulfilled.

Regarding Option 1, Sharpe and Bauer (2021) specifically in the context of Canada, recommend two approaches to address lower-income consumers: firstly, allowing pre-owned electric vehicles to be eligible for purchase subsidy incentives; and/or, secondly, creating a tiered subsidy funding approach that corresponds to consumer income levels, i.e., giving more funding to lower income users. Both approaches still maintain the use of purchase subsidy incentives, but differ from current practice in how administered. The former involves effectively increasing incentives to cover further "stages" of vehicle ownership, although a bit tricky given that both vehicle condition and usage become important, albeit highly variable, factors affecting vehicle value. The latter approach has already been adopted by the Government of British Columbia (2022), but still maintains the basic use of a purchase subsidy incentive.

Option 2 differs significantly from the first in how the program operates and in how associated costs are calculated. This approach notably has been promoted for some time by caucus members of the Manitoba provincial New Democratic Party (NDP), and indeed was advanced in some detail as part of their 2017 Shadow Throne Speech, including outlining a variety of specific parameters (Pursaga 2017).

Option 3 differs significantly from the others given a focus on public transit rather than individual vehicles. Success in this case requires ensuring sufficient public transit bus availability to meet transportation requirements. This is considered whether new buses may be diesel or involve electrification, i.e., through use of battery electric buses (**BEB**) and/or fuel-cell electric buses (**FCEB**). A recent Issue paper by CUTA (2021a) continues to emphasize the key role of public transit for GHG reductions, with significant potential benefits identified. Public transit is also well known, as outlined in a variety of recent papers, to be already important for lower-income households, e.g., Allen and Farber (2019), Cui et al. (2020).

Earlier work by Parsons et al. (2017) confirmed two mechanisms are involved in the reduction of GHG emissions via transit buses: (1) modal shift, which is the more traditionally recognized approach of getting consumers out of individual vehicles and onto public transit; and (2) transitioning transit buses themselves from conventional diesel to BEB or FCEB. Importantly, given that the prices for zero-emission bus models remain at least twice that for conventional diesel, transit authorities have options in how to reduce overall emissions, i.e., more diesel buses to increase modal shift versus a smaller number of zero-emission buses to fully reduce emissions, but not provide a good a coverage. As such, two sub-options are included in analysis to permit quantifying the extent of respective opportunities:

> **Option 3a**: Focus, on additional conventional diesel buses, at least as a starting point, with lower emission reduction potential but much lower costs per bus; and
>
> **Option 3b**: Full shift to electric (zero-emission) for all proposed additional buses, in order to achieve full GHG reductions, albeit with higher costs per bus.

While representing legitimate option(s), problematically, as described by Larson et al. (2022), public transit of all types was literally crippled by the COVID pandemic, with ridership plummeting. Some interim support was provided by the Government of Canada, but as reiterated by CUTA (2021b) additional support is still absolutely necessary. A more recent update of ridership numbers by Statistics Canada (2022), continues to show ongoing severe impacts. As such, for any transit-based option to work toward reducing emissions, returning public transit to normal operational capacity must be a priority.

3.3 Cost Assumptions for Analysis

Cost assumptions for the three options are outlined in the following subsections.

3.3.1 Cost Assumptions for Option 1 (Purchase Incentives Targeted to Lower-Income)

For this option the essential comparison is between the present value of benefits from moving to electric, i.e., externality benefit values of GHG reductions and air quality improvements, versus the present value costs to government in the form of purchase subsidy incentives to equip lower-income households with electric vehicles. The amount of the incentive is calculated based on a achieving a breakeven total cost of ownership (TCO) between a modest electric vehicle and a modest conventional vehicle. As such, in this case the costs for consumers are balanced.

As outlined earlier, there are an estimated 3.8 million lower-income Canadians, representing approximately 1.5 million households, and translating to approximately 2.4 million relevant light-duty vehicles. The analysis assumes households making new vehicle purchases to replace existing conventional vehicles, with the comparison for such new purchases involving a modest electric versus modest conventional vehicle.

Approximate purchase costs assumed for the analysis are summarized as follows:

- Modest conventional car price of approximately $18,000, based on considering four currently available models: Chevrolet Spark; Mitsubishi Mirage; Hyundai Elantra; and Nissan Versa.
- Modest electric car price of approximately $38,000, based on considering five currently available models: Nissan Leaf (BEV); Chevrolet Bolt (BEV); Mini Cooper SE (BEV); Toyota Prius Prime (PHEV); and Hyundai IonIQ Plug-in (PHEV).

Assumed average operational characteristics and costs for respective electric and conventional vehicles are provided in Table 3.

Table 3. Operational Characteristics and Costs Assumed for Option 1 Analysis

Parameter	Assumed Value
Effective vehicle lifespan	12 years
Approximate consumer discount rate (i.e., consumer car loan)	6.2%
Resulting PVIFA value	8.29
Approximate annual travel distance	15,000 km
Average modest vehicle gasoline consumption	8.6 Litres per 100 km
GHG emissions per Litre of gasoline	2.3 kg CO_2e per Litre
Average modest vehicle electricity consumption (incl. winter)	25 kWh per 100 km
GHG emissions per kWh of electricity (Canadian average)	0.10 kg CO_2e per kWh
Approximate future price of gasoline (12 years)	$1.18 per Litre
Approximate price of electricity (residential based rate)	$0.155 per kWh

There are two major externality benefits in this case. The primary benefit is GHG emission reductions and is relatively straightforward. This benefit is estimated using a social cost of carbon (SCC) value of approximately $50 per tonne CO_2e, consistent with ECCC (2016). This value reflects an estimate of the present value of future damages from emission releases today. While the comparison of costs is based on a modest conventional vehicle, the result of the initiative would be to remove existing, and less efficient existing vehicles. NRCan (2014) suggests an average existing light-duty vehicle consumes about 2,000 Litres annual, resulting in emissions of about 4.6 tonnes (i.e., 2,000 Litres × 2.3 kg CO_2e per Litre). The corresponding fue consumption in this case is 13.3 Litres per 100 km rather than the modest new vehicle at 8.6 Litres per 100 km.

The secondary benefit is air quality improvements. Unfortunately, such benefits have often been over-exaggerated. A useful and reasonable source is the American Lung Association (2022), which estimates the public health benefits associated with eliminating criteria air contaminants (i.e., smog pollutants) from vehicles in the U.S. to be $1.2 trillion USD over 30 years, or approximately $43 billion USD annually. Based on roughly 276 million vehicles within the U.S., this translates to approximately $145 USD per vehicle annually. A significant difference in such analyses between the U.S. and Canada is the statistical value of life (SVL) as employed in the respective countries: $10 million USD per SVL in the U.S.; versus $6.5 million CAD in Canada (TBS 2018). Using this as a simple conversion factor, the savings per vehicle translates to approximately $94 CAD per vehicle annually, and is employed for analysis. Noting the physical nature of such impacts, no discounting is employed in the calculation of benefits over vehicle lifespan.

3.3.2 Cost Assumptions for Option 2 (Interest-Free PAYS Loans for Lower-Income)

For this option the essential comparison is between the present value of benefits from moving to electric, i.e., externality benefit values of GHG reductions and air quality improvements, versus the costs to government in the form of providing interest-free PAYS loans to lower lower-income households for electric vehicles. At the same time, the present value of operational benefits for consumers (if savings exceed vehicle payments) or operational costs (if savings are insufficient to fully cover payments) need to be considered.

As outlined above, the number of relevant light-duty vehicles involved is approximately 2.4 million, with the price for a modest new electric vehicle assumed as approximately $38,000. Importantly, this value is well within the $50,000 loan limit suggested by the Manitoba NDP for such a program (Pursaga 2017), and is assumed to be fully covered.

Applicable operational characteristic and cost parameters outlined in Table 3 are employed as necessary, although with a few additional parameters:

- Borrowing period for interest-free loan assumed to be 12 years, consistent with the effective lifespan of the vehicle, with this being longer than a loan period of 8 years suggested by the Manitoba NDP for such a program (Pursaga 2017).
- Borrowing cost for the basic PAYS loan by the Government of Canada is assumed as 3.2%, based on approximate longer-term (ten-year) bond rate outlined by Bank of Canada (2022).
- In this case, rather than comparing to a modest new conventional car, a more typical average existing vehicle is assumed to be replaced, involving higher annual fuel use of approximately 2,000 Litres, translates to a consumption rate of about 13.3 Litres per 100 km, much higher than the 8.6 Litres per 100 km assumed for Option 1.
- The future-forward price of gasoline is assumed as $1.18 per Litre, excluding any carbon tax, and the price of electricity is assumed as $0.155 per kWh, also excluding carbon tax.
- For vehicle payment costs not covered by operational savings compared to conventional, individual households are assumed to be required to pay the remainder at the same rate as the car loan outlined for Option 1, i.e., 6.2%.

3.3.3 Cost Assumptions for Option 3a and Option 3b (Enhanced Public Transit)

The target population of lower-income households, as noted represents about 3.8 million people, and translates to about 2.4 million conventional vehicles. Estimating the number of transit buses needed to adequately fulfill transportation requirements is tricky given differences in distances, timeframes and extents of operations (i.e., idle time) between transit buses versus private vehicles, and even accessibility to a vehicle as an alternative. As such, this calculation is not straightforward and certainly will require more in-depth investigation and confirmation. As a very preliminary estimate, the following approach is employed:

- Typical transit buses travel approximately 50,000 km annually at rough speeds of 20 km per hour, and on average are operational approximately 40% of a day, or close to 10 hours.
- Private vehicles travel approximately 15,000 km annually at variable speeds, and are operational only about 5% of the time, about 70 to 75 minutes daily involved in actual travel.
- Transit buses operating at any given time carry approximately 10 passengers who would otherwise be driving single occupancy vehicles (SOV) concurrently (Parsons et al. 2017).

The derived estimate of buses needed is thus as follows:

Estimated buses = private vehicles × 0.05 active / (10 SOV per bus × 0.40 active)
Estimated buses = 2.4 million vehicles × 0.05 / (10 × 0.40) = 30,000 new transit buses

To put the numbers in context, the current number of transit buses in Canada is approximately 15,000 (Wallcraft 2021). The proposed approach thus would involve essentially tripling the number of transit buses across the country, which is a significant effort.

For this option, the essential comparison is between costs for the Government of Canada to fully cover purchase of the incremental transit buses required across the country to provide approximately comparable transportation for lower-income households, based on the number of buses as outlined, versus the present value of benefits.

The benefits in this case involve three externalities, namely (1) GHG reductions and (2) air quality improvements, as outlined earlier for Option 1 and Option 2, as well as (3) congestion relief. Evaluating congestion relief benefits is more complex, but can be approximated on a preliminary basis using analysis based on Aftabuzzaman et al. (2010). In this case the rough congestion relief benefit is estimated at about $0.40 per marginal vehicle-km travelled. Congestion relief, though, is most relevant and valuable for peak periods that are most congested. Conservatively, the applicable marginal travel during peak periods is assumed to involve 10% of the travel involved by the light-duty vehicles in question. Finally, to this is added the economic savings for households from reduced vehicle operation, net after first covering the costs for operators and energy/fuel for transit buses. The latter represent the most significant incremental costs for transit aside from the purchase cost of vehicles.

The purchase prices for relevant transit buses are as outlined from Parsons et al. (2020), and involve:

- Conventional diesel bus price of approximately $675,000 per unit for Option 3a;
- BEB price of approximately $1.2 million per unit, assumed to represent 80% of zero-emission buses for Option 3b; and
- FCEB price of approximately $1.6 million per unit, assumed to represent 20% of zero-emission buses for Option 3b.

Additional operating characteristics and costs for Option 3 alternatives include:

- Cost of money for transit authorities of approximately 4.5%;
- Lifespan for buses of 12 years, which is consistent with electric and conventional cars and also consistent with the lifespan employed by U.S. Federal Transit Administration (FTA), although with longer lifespans known for various transit authorities within Canada;
- Resulting PVIFA value of 9.12;
- Operator cost of $50,000 per full-time equivalent annually, with 1.25 operators per transit bus assumed;
- Conventional bus fuel consumption of 60 Litres diesel blend per 100 km;
- GHG emissions of 2.7 kg CO_2e per Litre diesel fuel blend;
- BEB energy consumption of 130 kWh per 100 km;
- Average GHG grid-intensity level across Canada considered, namely about 100 g per kWh;
- Electricity cost at dispenser based on Canadian average of $0.221 per kWh, including energy fee, demand fee, and capital coverage for charging systems;
- FCEB energy consumption of 10 kg hydrogen per 100 km;
- Two options for hydrogen production, including, (1) “electrolysis” hydrogen with assumption of 50 kWh required to produce 1 kg hydrogen, with emissions as per electricity above, and (2) “SMR” hydrogen from steam methane reforming of natural gas with assumption of four m3 of natural gas required, with associated emissions of 7.6 kg CO2e per kg hydrogen; and
- Hydrogen cost at nozzle, given uncertainty potentially ranging from $6 per kg to $12 per kg, with mid-range cost of $9 per kg used for calculations.

Further terms of costs and benefits:

- Existing vehicle fuel costs, emissions and air quality costs are assumed as outlined for Option 2;
- Social cost of carbon (SCC) level of $50 per tonne maintained consistently as used for other options; and
- Air quality related costs for diesel buses assumed as representing a present value cost of about $3,900 per diesel buse, based on 50,000 km travel, as outlined in Parsons et al. (2017).

3.4 Sensitivity Analysis

Analyses of light-duty electric vehicles and zero-emission transit already have demonstrated strong sensitivity to zero-emission vehicle purchase costs and to the prices of fossil fuels, with much lower sensitivity to the price of electricity. In order to more fully understand sensitivity, two specific variables are considered further in this case:

- Carbon taxation levels, given this is already a major policy within Canada, and assessed primarily through determining carbon tax levels required to achieve break-even;
- Number of buses required for Option 3 to adequately support transportation needs of lower-income Canadians, with in this case two sensitivity evaluations considered, (1) cost benefit analysis based on 45,000 new buses, rather than 30,000, and (2) calculating program breakeven to evaluate the numbers of addition transit buses that could be involved with the program imposing no net cost.

3.5 Limitations of Analysis

The analysis undertaken as part of this work is preliminary in nature and will definitely require more in-depth investigation to confirm results. Identified constraints include the following:

- Analysis is based solely on a review of available literature from the public domain;
- There are specific limitations in relevant data availability, with assumptions employed in some instances that may not necessarily be reasonable in all circumstances or locations;
- Specifically, various assumptions are based on U.S. experience and data, and may not necessarily entirely reflect the situation within specific Canadian locations, for example taking account of colder conditions;
- Data for Canada primarily focusses on national-average value, for example national average grid-mix GHG intensity; however, circumstances are known to vary significantly across the country;
- Costs for electricity reflect solely approximate equivalent energy prices, and may not adequately reflect the demand fees, as can be important, particularly for heavy-duty vehicles such as buses; and
- Performance factors and costs associated with hydrogen-based technology are particularly uncertain, and subject to variation.

4. Calculations and Results

Calculations of costs and benefits for the three main options (and sub-options) are provided in the following sections, with then comparisons of final results, including sensitivity.

4.1 Results for Option 1 (Purchase Incentives Targeted to Lower-Income)

For Option 1, it is important to first work out the necessary incentive in order to fully bridge the TCO for lower-income households. Based on operational characteristics and costs in Table 3:

- Present value higher price of electric vehicle translates to $20,000 (i.e., $38,000 - $18,000);
- Annual gasoline consumption per vehicle translates to 1,290 Litres (i.e., 8.6 Litres per 100 km × 15,000 km) with annual cost of $1,522 (i.e., 1,290 Litres × $1.18 per Litre);
- Annual electricity consumption per vehicle translates to 3,750 kWh (i.e., 25 kWh per 100 km × 15,000 km) with annual cost of $582, based on average residential cost of $0155 per kWh, this meaning more than 60% reduction in fuel costs;
- Resulting future annual savings are approximately $940 (i.e., $1,522 - $582), which translates to a present value of approximately $7,790 (i.e., $940 per year × PVIFA of 8.29 for consumer otherwise needing to use commercial loan); and
- Resulting approximate present value shortfall in TCO, needing to be bridged by purchase subsidy incentive translates to $12,210 per vehicle (i.e., $20,000 - $7,790).

The overall cost for the Government of Canada to support this initiative by providing the necessary incentives to bridge the TCO for lower-income households, and transition an estimated 2.4 million existing vehicles, translates to $29.3 billion (i.e., 2.4 million vehicles × $12,210 per vehicle incentive to balance TCO). Given more targeted funding for households lacking resources to otherwise support such vehicles, a high level of incentive is appropriate.

The primary externality benefit is the reduction of GHG emissions from the vehicles, approximated using SCC at $50 per tonne. As noted, while cost calculations involve comparison to modest new conventional vehicles, the result of the program would be to remove less-efficient existing vehicles, with higher emissions, approximately 4.6 tonnes annually each. At the same time, electric vehicles using an average Canadian grid-mix produce emissions of about 0.4 tonnes (i.e., 25 kWh per 100 km × 15,000 km × 0.10 kg CO_2e per kWh), meaning net reduction per replaced vehicle of about 4.2 tonnes annually. From this relatively optimistic assumption, total emission reductions over lifespan total 121.0 million tonnes (i.e., 2.4 million vehicles × 4.2 tonnes per vehicle annually × 12 years). This benefit thus translates to approximately $6.1 billion (i.e., 121.0 million tonnes × $50 per tonne).

The secondary externality benefit is air quality improvement through the reduction of criteria air contaminants, or smog pollutants. Based on an value of about $94 per vehicle, the overall benefit translates to about $2.7 billion (i.e., 2.4 million vehicles × $94 per vehicle annually × 12 years). Proportionately, this value is roughly about 45% of the benefit value for GHG reductions, which appears generally appropriate.

The resulting overall externality benefits total to $8.8 billion. Program costs to the Government of Canada, however, are about $29.3 billion. The result translates to an overall net present value cost of about $20.5 billion. This means the program is not viable and does not work. As a useful note, the present value of benefits per vehicle translates to approximately $3,670.

The analysis, as noted, does not consider carbon taxation. Impacts of a carbon tax are presented in Figure 2, outlining carbon tax levels required in order to reduce the necessary purchase subsidy progressively down, ultimately to zero. The purchase incentive value presented reflects the amount per vehicle, with the value of $12,210 per vehicle applicable for zero carbon tax, calculated earlier.

As can be seen from this plot, high carbon tax levels, with associated high burdens, are necessary to make any consequential differences in incentive levels and the cost of the program to government. In order to match existing federal incentives of $5,000 per BEV and $2,500 per PHEV, carbon tax levels must be $142 per tonne and $191 per tonne, respectively. To match the overall average benefit derived per vehicle, of $3,670 as noted, a carbon price of $168 per tonne is required. In order for the program to have no cost, the carbon tax must be astronomically high at $241 per tonne.

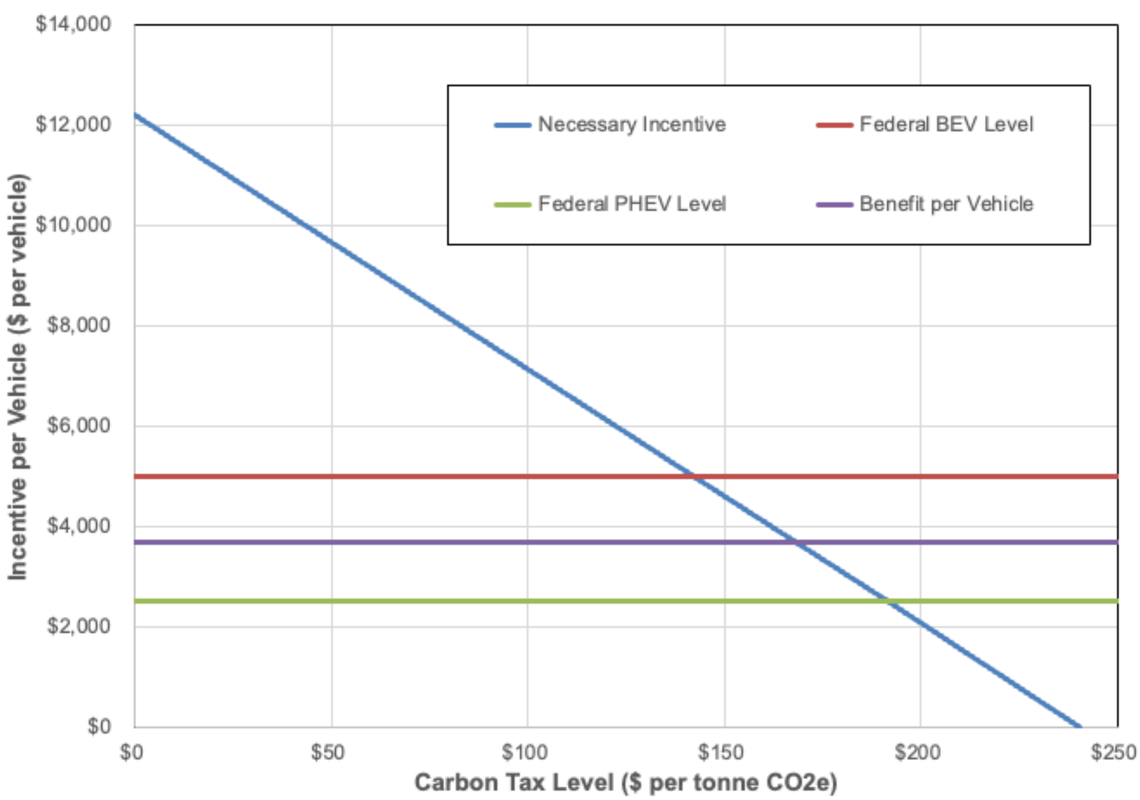

Figure 2. Impacts of Carbon Tax on Purchase Incentives and Program Costs (Option 1).

4.2 Results for Option 2 (Interest-Free PAYS Loans for Lower-Income)

As described earlier, the approximate price for a modest electric vehicle is $38,000, which is within the suggested practical loan limits, and is thus assumed fully covered for the interest-free PAYS loan. Simply dividing this price by a lifespan of 12-years, principal payments by lower-income households translate to about $3,170 annually. For the Government of Canada, covering interest, a discount rate of 3.2% is assumed, which for 12-year lifespan translates to PVIFA value of 9.86. As such, total annual costs to the Government of Canada translate to $3,854, meaning that annual interest costs, not covered by consumers, are thus $684 (i.e., $3,854 - $3,170). The present value of this portion, which reverts back to government, translates to approximately $6,750 (i.e., $684 × 9.86).

For the overall program, based on funding for 2.4 million vehicles relevant to lower-income Canadians, the costs to the Government of Canada to support the program total $16.2 billion (i.e., $6,750 per vehicle × 2.4 million vehicles). Yet this is not the complete cost, given potential further costs to consumers.

Future year savings per existing vehicle replaced represent approximately $1,780 annually (i.e., 2,000 Litres gasoline annually × $1.18 per Litre - $582 for electricity). This is lower than the annual principal payment of $3,170, meaning that fuel savings do not actually compensate for the cost of the electric vehicle for lower-income households. Lower income households thus are left responsible for further annual costs of $1,390 per vehicle. Given this would need to be financed using a conventional car loan, with approximate rate of 6.2% and with PVIFA for 12 years of 8.29, this translates to an additional present value cost per vehicle of approximately $11,520. Resulting costs borne by consumers for the overall program thus translate to about $27.6 billion (i.e., 11,520 × 2.4 million vehicles).

The overall combined cost of the program, for the Government of Canada and for consumers, is thus $43.8 billion. Externality benefits for GHG reductions and air quality improvements are the same as for Option 1, namely $8.8 billion in total. The result is thus an overall net cost of approximately $35 billion, meaning the program is not viable and does not work.

Problematically the net costs in this case are significantly more expensive than Option 1. At the same time, it is true that the costs borne by government are lower, i.e., $16.2 billion for Option 2 versus $29.3 billion for Option 1. What ends up happening is that significant additional costs are foisted onto lower-income consumers who likely cannot afford them. As can be seen, while the intent of the PAYS approach is for annual savings to cover costs, this is not actually achieved, specifically because of the high prices of electric vehicles. While certainly well-intentioned, a PAYS approach ends up being neither useful nor practical.

As with Option 1, the analysis does not include carbon taxes. For Option 2, in order to achieve a PAYS-based breakeven, the required carbon tax would need to be at least $330 per tonne (i.e., $1,390 remaining annual costs ÷ 4.2 tonnes annual reduction). Such a level is astronomically high and impractical.

4.3 Results for Option 3a and 3b (Enhanced Public Transit)

The cost to the Government of Canada, i.e., covering the purchase capital for additional buses to meet the transportation needs of lower-income households, is straightforward, based on the assumed requirement for additional buses:

- For Option 3a (additional diesel buses), the cost is $20.3 billion (i.e., $675,000 × 30,000); and
- For Option 3b (zero emission buses), the cost is $38.4 billion (i.e., 0.8 × 30,000 × $1.2 million + 0.2 × 30,000 × $1.6 million = $28.8 billion for BEB and $9.6 billion for FCEB).

The GHG reductions via removing light-duty vehicles are similar to Option 1 and Option 2, and come to 132.5 million tonnes (i.e., 4.6 tonnes per vehicle × 2.4 million vehicles × 12 years). From this must be subtracted emissions associated with operation the buses, which can vary depending on the technology involved. Associated emissions are outlined in Table 4.

Table 4. Emissions for Alternative Bus Options to Support Lower-Income Households

Option	Emissions	Calculation
Option 3a (100% diesel buses)	29.2 million tonnes	30,000 buses × 60 Litres per 100 km × 50,000 km × 2.7 kg CO2e per Litre × 12 years
Option 3b (80% BEB and 20% FCEB using SMR)	4.6 million tonnes (i.e., 1.9 + 2.7)	24,000 buses × 130 kWh per 100 km × 50,000 km × 0.1 kg CO2e per kWh × 12 years + 6,000 buses × 10 kg per 100 km × 50,000 km × 7.6 kg CO2e per kg × 12 years
Option 3b (80% BEB and 20% FCEB using electrolysis)	3.7 million tonnes (i.e., 1.9 + 1.8)	24,000 buses × 130 kWh per 100 km × 50,000 km × 0.1 kg CO2e per kWh × 12 years + 6,000 buses × 10 kg per 100 km × 50,000 km × 50 kWh per kg × 0.1 kg CO2e per kg × 12 years

Based on these values, the net GHG reduction externality benefits can be calculated:

- For Option 3a using conventional diesel buses, the benefit is about $5.2 billion (i.e., (132.5 milliion tonnes - 29.2 million tonnes) × $50 per tonne);
- For Option 3b using 80% BEB and 20% FCEB based on SMR hydrogen, the benefit is about $6.4 billion (132.5 milliion tonnes – 4.6 million tonnes) × $50 per tonne); and
- For Option 3b using 80% BEB and 20% FCEB based on electrolysis hydrogen, the benefit is also about $6.4 billion (132.5 milliion tonnes – 3.7 million tonnes) × $50 per tonne).

As can be seen from these results, there are negligible differences in emission reduction benefits between the two alternatives for Option 3b, so the same value is thus employed.

In terms of air quality improvement externality benefits, the same benefits for removing light duty vehicles apply as for Option 1 and Option 2, already noted as $2.7 billion. In the case of Option 3a, there are some air quality costs still associated with diesel buses, which translate to about

$0.1 billion ($3,900 present value cost per bus × 30,000 buses). As such, the air quality benefit for Option 3a is about $2.6 billion, while for Option 3b about $2.7 billion.

An additional externality benefit, as noted, not appliable for Option 1 or Option 2, is congestion relief, this irrespective of the type of bus involved. The benefit translates to about $17.3 billion (i.e., 2.4 million vehicles × 12 years × 15,000 km × 10% travel most relevant to congestion × $0.40 per km). Given based on physical parameters, this cost is not discounted.

The final benefit of moving to transit is economic, which is the net savings to lower-income consumers after first covering the costs for transit operators and for energy/fuel for buses. These two are the largest operating costs for transit operations and likely to be embedded in fare costs. As noted, in this case the discount rate for transit agencies is employed. Calculations for individual components are summarized as follows:

- Fuel cost savings from private vehicles for consumers translate to $52.1 billion (i.e., 2.4 million × 2,000 Litres annually × $1.18 per Litre future-forward price × 9.19);
- Transit operator costs translate to $17.2 billion (i.e., $50,000 per operator annually × 1.25 operators per bus × 30,000 buses × 9.19);
- Fuel costs for buses for Option 3a, involving additional diesel buses, translate to $9.5 billion (i.e., 30,000 buses × 50,000 km × 60 Litres per 100 km × $1.15 per Litre × 9.19);
- Fuel costs for buses for Option 3b, involving 80% BEB and 20% FCEB, translate to $5.6 billion (i.e., 24,000 buses × 50,000 km annual × 130 kWh per 100 km × $0.221 per kWh (for energy, demand and charging equipment) × 9.19 + 6,000 buses × 50,000 km annual × 10 kg per 100 km × $9 per kg (for production, delivery and dispensing) × 9.19).

As such, the net economic savings involved then can be calculated as follows:

- Option 3a savings translate to $25.4 billion ($52.1 billion - $17.2 billion - $9.5 billion); and
- Option 3b savings translate to $29.3 billion ($52.1 billion - $17.2 billion - $5.6 billion);

The final overall results, combining costs to government, externality benefits and net economic savings to lower-income consumers then can be calculated as follows:

- Option 3a provides an overall positive net present value benefit of about $30.3 billion (i.e., externality benefits of $5.2 billion for GHG reductions, $2.6 for air quality improvement and $17.3 for congestions relief, plus economic net savings of $25.4 billion to consumers, less costs to government of $20.2 billion to support purchase of additional buses).
- Option 3b provides an overall positive net present value benefit of about $17.3 billion (i.e., externality benefits of $6.4 billion for GHG reductions, $2.7 for air quality improvement and $17.3 billion for congestions relief, plus economic net savings of $29.3 billion to consumers, less costs to government of $38.4 billion to support purchase of additional buses).

These results in all cases are positive, very different from the overall net costs encountered with Option 1 or Option 2, both involving a focus on individual electric vehicles. Importantly, congestion relief benefits and economic net savings for consumers are significant; not present for Option 1 or Option 2, and also larger than respective externality benefits for GHG reductions and air quality improvements. Unexpectedly, the overall net benefits are roughly twice larger for Option 3a, involving additional buses that are all conventional diesel.

Carbon taxes are not included in the analysis, as the case with the other earlier options. For Option 3a and Option 3b, carbon taxes favour transit and would further enhance benefits. Given that both options already provide positive overall net benefits, quantifying sensitivity in this regard is thus less useful. Much more important in terms of sensitivity in these cases is the number of buses necessary to practically support travel requirements of lower-income households.

For sensitivity purposes, the impact of increasing the number of additional buses necessary to fulfill lower-income household transportation needs is considered, in two ways: firstly, evaluating the relative impacts if the number of additional buses is increased to 45,000, meaning the overall number of transit buses in Canada is quadrupled rather than tripled; and secondly, calculating the number of additional transit buses that could be implemented respectively for Option 3a and Option 3b, yet still provide breakeven on the overall cost/benefit assessment. Results are presented in Table 5 and Table 6 comparing impacts on benefits and costs by moving to a larger number of additional buses for Option 3a and Option 3b respectively, i.e., 45,000 versus 30,000 as used in the preliminary estimate.

Table 5. Impact of Increasing Added Buses to 45,000 for Option 3a (i.e., Diesel)

Cost or Benefit Factor	**45,000 Added Buses**	**30,000 Added Buses**
Cost for additional bus purchase	-$30.4 billion	-$20.3 billion
GHG reduction benefit	$4.4 billion	$5.2 billion
Air quality improvement benefit	$2.5 billion	$2.6 billion
Congestion relief benefit	$17.3 billion	$17.3 billion
Consumer savings benefit	$12.0 billion	$25.4 billion
Net overall benefit (or cost)	$5.8 billion	$30.3 billion

Table 6. Impact of Increasing Added Buses to 45,000 for Option 3b (i.e., BEB and FCEB)

Cost or Benefit Factor	**45,000 Added Buses**	**30,000 Added Buses**
Cost for additional bus purchase	-$57.6 billion	-$38.4 billion
GHG reduction benefit	$6.3 billion	$6.4 billion
Air quality improvement benefit	$2.7 billion	$2.7 billion
Congestion relief benefit	$17.3 billion	$17.3 billion
Consumer savings benefit	$17.9 billion	$29.3 billion
Net overall benefit (or cost)	-$13.5 billion	$17.3 billion

As the number of transit buses required to meet lower-income travel needs is increased, so too does the cost of the program increase, in this case in a linear fashion. If the level of buses required increases to 45,000, there is still an overall positive benefit provided if using diesel buses. For zero-emission buses (BEB and FCEB) on the other hand, the result is a net cost. This makes sense given the much higher purchase prices for the latter.

These observations lead naturally to estimating breakeven points for both Option 3a and Option 3b, determining the largest number of buses, whether conventional diesel or zero-emission, that can be supported such that the result of the program is still not a net cost. These estimated breakeven levels are summarized in Table 7.

Table 7. Breakeven Transit Bus Levels Whereby Overall Program Not a Net Cost	
Option Considered	**Breakeven Bus Number**
Option 3a using conventional diesel buses	Approximately 48,700 added buses
Option 3b using zero-emission buses (BEB and FCEB)	Approximately 38,500 added buses

The results show that the use of conventional diesel buses is more flexible and less sensitive to the many buses required in order to meet travel requirements.

4. Discussion and Conclusions

The overall results for the evaluation, based on assumptions as outlined, are summarized in Figure 3. The overall results show stark differences, with Option 1 and Option 2, focused on different targeted ways of providing light-duty personal electric vehicles to lower-income households, showing significant net costs. As such, neither of these programs is viable, and they should not be considered further. On the other hand, Option 3a and Option 3b, focused on public transit to fulfill transportation needs of lower-income households, show significant positive net benefits, and are worthwhile considering further.

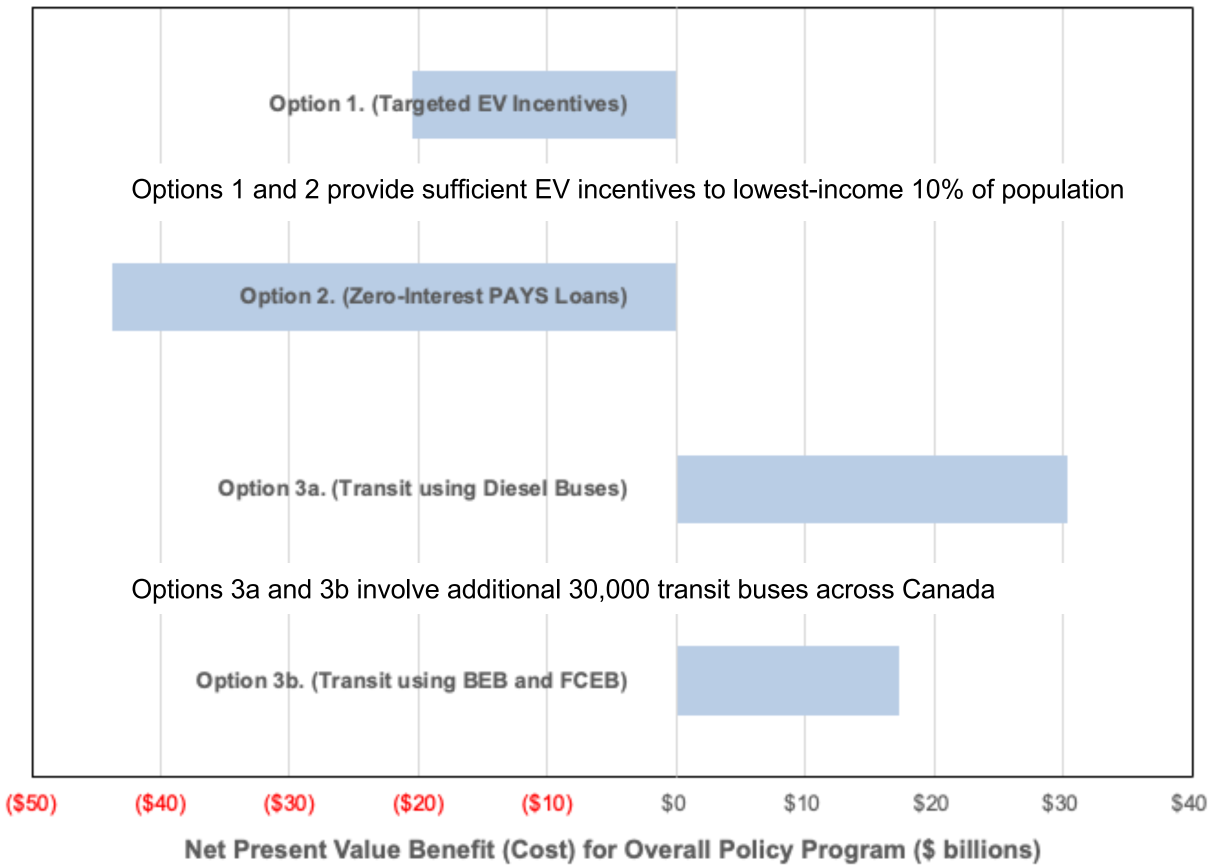

Figure 3. Summary of Cost/Benefit Analysis Results for Different Policy Options.

The poor results for Option 1 and Option 2 both come down to the persistent problem that prices for electric vehicles continue to remain excessively high. Under Option 1, the incentive necessary in order to make them realistically viable for lower-income households, pushes program costs to exorbitantly high levels, much larger than the externality benefits to be gained. Particularly disappointing is Option 2, based on using zero-interest PAYS loans. Overall costs are much higher in this case, even than Option 1, although with costs to government being somewhat lower. The problem, again, stems from excessively high electric vehicle prices, which mean annual savings gained by moving away from conventional cars, even optimistically, do not actually cover the annual vehicle costs to consumers, even with no interest. In a cruel twist, what ends up happening is that additional costs for electric vehicles are foisted onto consumers who are not really in a position to afford them. As such, extreme caution needs to be undertaken for any government considering such an option. While it may sound good in theory, in practice this approach could backfire spectacularly.

One factor considered in terms of sensitivity is implementation of carbon taxes. For Option 1 and Option 2, it is found that in order to significantly improve the results in both cases, carbon taxes must be excessively high. For Option 1, a carbon tax of roughly $168 per tonne is required to ensure the incentive value matches the externality benefits gained. For Option 2, a carbon tax of roughly $330 per tonne is required in order to breakeven. On the other hand, for the two transit-based options, Option 3a and Option 3b, calculations show a positive benefit already, with carbon taxation further favouring transit, such that further sensitivity assessment is less important to consider.

Results tend to show carbon taxation as inconsequential, emphasizing the ineffectiveness of this policy on its own to motive any actual changes. Given this policy makes so little difference, the question is raised as to why bother? The results, as such, suggest carbon taxation should be at least downplayed or more desirably eliminated if Canada is to move toward achieving necessary emission reductions into the future.

The two transit-based options produce positive net benefits. Importantly in these cases there are additional benefits associated with congestion relief and economic net savings for consumers. These benefits are larger than externality benefits associated with GHG reductions or air quality improvements. Such benefits also are not provided by either Option 1 or Option 2. The results make sense, in that dramatically increasing public transit would have a direct positive impact on congestion, and further the efficiency of public transit offers potential for economic savings for consumers too.

Of the two transit-based options, Option 3a, just using additional conventional diesel buses, shows the best results. The net benefit, unexpected, is roughly twice that for Option 3b, using zero-emission buses. This too makes sense given diesel buses cost less than half the price of zero-emission models, yet diesel buses still yield significant GHG reduction savings, given they get a large number of light-duty vehicles off the road.

In terms of sensitivity, much more relevant for Option 3a and Option 3b, is the number of additional buses necessary to practically support travel requirements of lower-income households. Implementation of 30,000 additional buses, as employed in this analysis, has been based only on a preliminary estimate method.

Comparative results show Option 3a, based on conventional diesel buses, is significantly less sensitive regarding the number of buses needed. Looking at the program breakeven levels for the two options show that very large numbers of transit buses can be supported in both cases, just more with Option 3a. For Option 3a, based on conventional diesel buses, transit could be increased across Canada by almost 325% and still breakeven, while for Option 3b, based on zero-emission buses, transit could be increased across Canada by more than 250%, and still breakeven. These changes are very significant.

The results show that public transit represents a potentially viable option to provide equality in access to clean transportation for lower-income households, whereas attempting to target support for individual light-duty electric vehicles is not viable, whatever option is employed.

Results for sensitivity suggest the importance of further research and analysis in order to better understand and confirm how many transit buses would be realistically required to adequately fulfill transportation needs of lower-income households. The results also illustrate the importance and the value of diesel buses.

Conventional diesel buses, even though they run on fossil fuel, succeed in getting significant numbers of light-duty vehicles off the road, producing significant net emission reductions. Currently, they remain significantly less expensive than zero-emission buses, BEB or FCEB. As such, diesel buses need to be recognized as an important intermediate or interim solution for achieving emission reductions.

Environmental purists may scoff at diesel buses, considering only BEB or FCEB as acceptable. However, like light-duty electric vehicles, zero-emission bus models still remain overly expective. This situation also suggests an obvious potential transitional approach, emphasizing more diesel buses to start, while moving progressively toward zero-emission buses as their prices continue to decline.

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