SHIFTING GEARS

CLIMATE SOLUTIONS FOR TRANSPORTATION IN CITIES

Metro Vancouver case study

November 2019

David Suzuki Foundation, Sustainable Transportation Action Research Team (SFU) and Navius Research

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BULLITT FOUNDATION

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SERIES

This is the first in a series of reports and case studies investigating challenges and opportunities for reducing carbon pollution from the transportation sector in Canadian cities.

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FOREWARD:
RESPONDING TO THE CLIMATE CRISIS, AFFORDABILITY AND QUALITY OF LIFE

As municipalities throughout Canada declare climate emergencies, the need to transition quickly to low- and zero-carbon transportation solutions has never been greater. Reducing greenhouse gas emissions from the highly polluting transportation sector is proving to be one of the most promising climate responses for cities and regions. Decarbonizing this sector also improves everyone's health and quality of life, provides more transportation choices and helps the economy by easing traffic. The wins are enormous and the opportunities plentiful to transition to clean transportation choices.

This report reviews best practices for low-carbon transportation policy and strategies that would be most effective in achieving B.C. and Metro Vancouver's 2030 and 2050 emissions goals. It offers proven, cost-effective, politically acceptable policy recommendations to forward-thinking decision-makers and communities moving toward healthier, more livable communities with better-connected transportation systems.

The report is the first in a series the David Suzuki Foundation is spearheading to delve into some of the most pressing transportation challenges and opportunities facing Canadian cities. We're thrilled that Navius Research and Jonn Axsen, director of Simon Fraser University's sustainable transportation research team, partnered with us on this first policy blueprint. They're recognized in transportation circles for their authoritative and innovative research and interdisciplinary approach to emissions-free transportation systems and solutions.

Focusing on climate-friendly approaches to transportation is part of the Foundation's bigger push to support cities with the solutions they need to tackle the climate crisis while improving people's well-being. With more than 80 per cent of Canadians living in urban areas, fast reliable public transit and active and shared transportation options have never been better investments. The Foundation is a leading research and non-profit voice advocating for efficient and affordable transportation options throughout Canada, focusing on electric vehicles, public and active transportation, clean fuel standards and smart city design.

Canada needs transportation solutions informed by best practices, motivated by climate action and led by public and stakeholder buy-in. Along with climate imperatives, momentum is growing to fix transportation gridlock and call for long-term transit funding.

Transportation touches us all, every day. It is the backbone of city design. Good systems keep us connected and working, with more time to do what we love. Clean systems keep us healthy. The choices we make now will determine our quality of life for generations to come, so informing them by the best and most innovative practices is essential. The Foundation is looking forward to continuing the discussion on how our best climate solutions may also be our best city-building choices.

Ian Bruce
Director of Science and Policy, David Suzuki Foundation

PHOTO Alesia Kazantceva, Unsplash

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EXECUTIVE SUMMARY

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BACKGROUND AND GOALS

Stringent climate policy is needed to avert the most dangerous impacts of climate change. To do their part, British Columbia and Metro Vancouver must implement a set of policies that have the ability to achieve their stated goals of reducing greenhouse gas emissions by 40 per cent (relative to 2007) by 2030, and 80 per cent by 2050. This report focuses on the transportation sector, which represents about 40 per cent of British Columbia's GHG emissions, and about 45 per cent of emissions in Metro Vancouver.

The purpose of this report is to review the available evidence for "best practices" for low-carbon transportation policy and initiatives. Our primary consideration is effectiveness in achieving these 2030 and 2050 GHG goals. However, good policy will also need to be cost-effective (meeting goals in an efficient way), politically acceptable and administratively feasible. We also consider a range of "secondary" social goals for transportation systems, namely improving health and equity, as well as reducing congestion and improving economic activity.

In effect, we hope to build public and organizational support for effective transportation policies and investment, which in turn can encourage leaders to implement these initiatives. The report summarizes evidence (research and analysis) to help stakeholders identify and champion best practices appropriate for Metro Vancouver, and potentially other regions. Metro Vancouver currently has an opportunity to develop a transportation GHG mitigation plan that could be effective in meeting its goals while also being an inspiring, innovative model and blueprint for other cities and metropolitan regions. In this context, this report aims to explore the following questions:

- Based on available evidence, what policies and initiatives can help British Columbia and Metro Vancouver meet 2030 and 2050 GHG reduction targets in the transportation sector?
- What additional sustainability benefits or impacts can we expect from these policies and initiatives? (Where some policies or initiatives may be desirable even if they don't substantially contribute to GHG mitigation goals.)
- Which selection of policies should British Columbia and Metro Vancouver include in a comprehensive transportation climate plan?[1]

OUR APPROACH

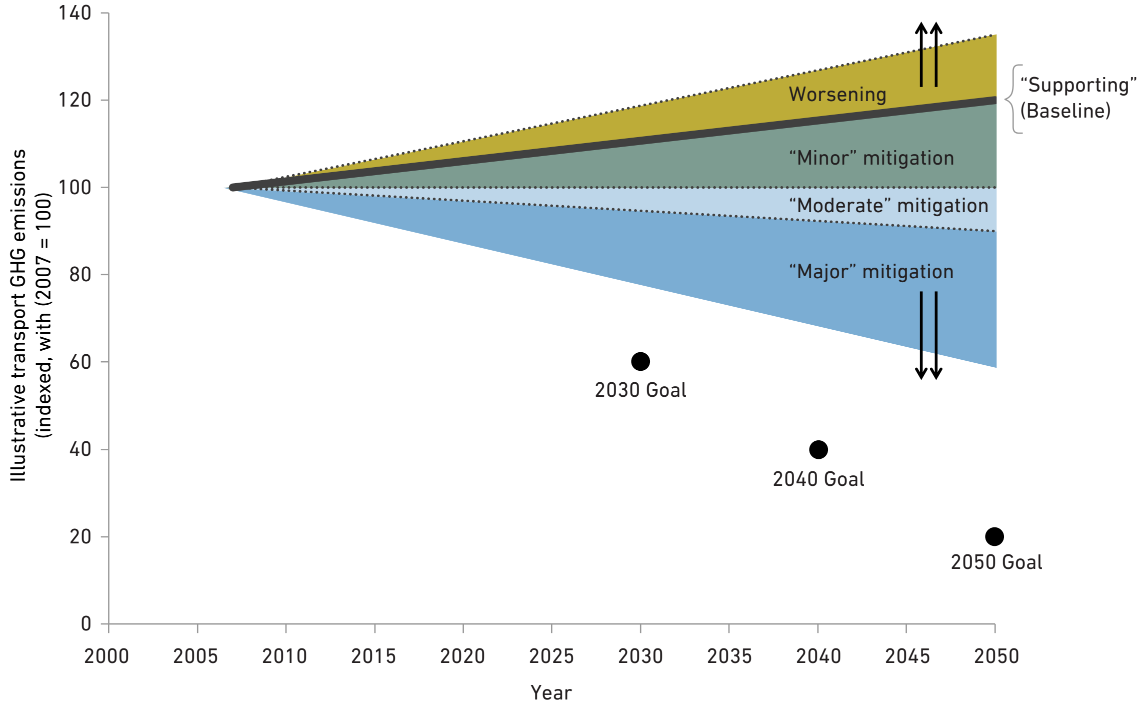
The core of this analysis is a summary and synthesis of available literature. While multiple sources are considered, we prioritize insights according to comprehensiveness, rigour and applicability to the case region of British Columbia. We organize our summary around several categories, in part relating to the "three legs of the stool" of transportation GHG mitigation: low-carbon fuels, vehicle efficiency and travel reduction (vehicle-km travelled or VKT). We also consider specific insights for GHG mitigation related to "new mobility" options (car-share, ride-hailing and vehicle automation), as well as heavy-duty vehicles.

For each policy or initiative, we draw from available evidence in the literature to assess its role in achieving 2030 and 2050 GHG targets, while accounting for expected population growth in Metro Vancouver (which could be about 45 per cent more people than today's population, or 70 per cent more than the 2007 population). For each category of policy or initiative, we frame our assessment according to the following impact levels (conceptually illustrated in Figure E1):

- **Worsening:** refers to actions or policies that would lead to transportation GHG emissions that exceed the current trajectory. In our current evaluation, this would only occur from removal of existing climate policies, or failure to keep infrastructure investment in line with population growth (e.g., for public transit or active travel).
- **Supporting:** can help to hold the "baseline" of projected GHG emissions out to 2050.
- **Minor GHG mitigation:** can help to slow the growth of transportation GHG emissions, but not actually decrease them relative to 2007.
- **Moderate GHG mitigation:** can decrease transportation GHG emissions by one to 10 per cent relative to 2007, accounting for population growth.
- **Major GHG mitigation:** can decrease GHG emissions by over 10 per cent relative to 2007, accounting for population growth.

1 We do not presently focus on GHG emissions from air, marine or rail, which make up about 15 per cent of Metro Vancouver's transportation GHG emissions.

Figure E1: Categories of GHG mitigation potential for evaluated policies (illustrative, shown for 2050 goals only).



Where information is available, we also consider a range of "secondary" benefits and impacts for different transportation policies and strategies, including:

- **Cost-effectiveness:** which may include the direct financial costs of a given policy, government expenditure, economists' estimates of social welfare or "efficiency" impacts, or impacts to economic activity (e.g., as measured through GDP or job growth).
- **Innovation:** does the policy send a signal to channel innovation into low-carbon technologies or practices, elsewhere called a "transformative signal"?
- **Health impacts:** including improved health through physical activity, as well as negative impacts, including injuries and exposure to air pollution.[2]
- **Social impacts:** such as citizen happiness and well-being.
- **Equity impacts:** addresses the distribution of policy costs and benefits among different groups, which might differ by household income and region.
- **Political acceptability:** considers if a given initiative is likely to be accepted by different stakeholders, including citizens (i.e., voters), industry and civil society.

2 There are important (and more specific) air quality considerations that are beyond the scope of this report but that will be supported by many of the recommendations that reduce vehicle travel (VKT) and GHG emissions.

Finally, we provide recommendations for each policy category, accounting for both GHG reductions and secondary benefits. The assessment options are as follows:

- **Complementary measures:** can help support the baseline GHG emissions while providing important secondary social benefits, including improved health, social and equity impacts. Such policies may also ease implementation of the more impactful GHG mitigation policies, easing compliance and/or improving political acceptability.
- **Important mitigation measures:** can have a minor to moderate impact on GHG mitigation, and should be seriously considered as climate policies.
- **Priority mitigation measures:** can have a major impact on GHG mitigation, where stringent versions are likely necessary to lead the way to 2030 and 2050 GHG mitigation goals in the transportation sector.

SUMMARY OF EVIDENCE FOR LOW-CARBON VEHICLES AND FUELS

Table E1 provides a summary of the overall assessment for each policy category, including 2030 and 2050 GHG impacts, and potential secondary benefits. We identify several priority mitigation policies, each with the potential to play a moderate to major role in 2030 and 2050 GHG targets. These policies include the low-carbon fuel standard (LCFS), zero-emissions vehicle (ZEV) mandate, and vehicle efficiency/emissions standards. This potential for large GHG impact applies to both light-duty (e.g., for passengers) and heavy-duty vehicles (e.g., for freight). All three policies fit into the efficiency and low-carbon fuels “legs” of the stool.

Within the third “leg,” a comprehensive VKT reduction strategy is identified as an important mitigation policy, with the potential to play a minor role in achieving 2030 and 2050 targets. Of these measures, road-pricing mechanisms offer the highest potential for GHG impacts, notably a system with strong pricing applied per VKT or unit of fossil fuel used. Initiatives focused on built environment, public transit and active travel are identified as complementary and can play supporting to minor roles in GHG mitigation. These VKT reduction strategies can offer substantial secondary social benefits, including improved health and equity and expanded travel options.

Table E1: Summary of GHG impacts and secondary benefits for the reviewed transportation policies and initiatives

		Potential role in GHG targets for...		
	Overall assessment	...2030 targets (40% below 2007)	...2050 targets (80% below 2007)	Potential secondary benefits:
Leg #1: Low-carbon fuels				
Low-carbon fuel standard	**Priority**	**Major**	**Major**	**Innovation, air quality**
Zero-emissions vehicle (ZEV) mandate	**Priority**	**Moderate to Major**	**Major**	**Innovation, air quality**
Other ZEV policy	Complementary	Supporting to Minor	Supporting to Minor	
Leg #2: Vehicle efficiency				
Vehicle emissions/ efficiency standards	**Priority**	**Major**	**Major**	**Innovation, air quality**
Leg #3: Travel (VKT) reduction				
Road pricing	**Important**	**Minor**	**Minor**	**De-congestion, health**
Built environment	Complementary	Supporting	Supporting	Health, travel options
Active travel (cycling, walking, etc.)	Complementary	Supporting to Minor	Supporting to Minor	Health, travel options
Public transit	Complementary	Supporting	Supporting	Health, equity, travel options
Heavy-duty vehicles and freight				
ZEV mandate	**Priority**	**Minor**	**Major**	**Innovation, air quality**
Low-carbon fuel standard	**Priority**	**Minor**	**Major**	**Innovation, air quality**
Vehicle emissions/ efficiency standards	**Priority**	**Minor**	**Moderate to Major**	**Innovation, air quality**

Drawing from our evaluation, we offer 14 main findings:

Evidence for low-carbon vehicles and fuels

1. A low-carbon fuel standard (LCFS) is a priority mitigation policy and can play a major role in meeting 2030 and 2050 GHG targets, especially in the freight sector. However, the policy needs to be significantly more stringent than existing or proposed levels to achieve 2050 targets.

    - In addition: LCFS policies have driven innovation into low-carbon fuels and appear to be politically acceptable to people in Canada.

2. A stringent and well-designed ZEV mandate is a priority mitigation policy and can play a moderate to major role in 2030 GHG reduction goals and a major role in 2050 GHG reduction goals. British Columbia's ZEV legislation for passenger vehicles is amongst the most stringent in the world.

    - In addition: ZEV mandates have driven innovation into low-carbon vehicle technology and can be cost-effective compared to other policy options.

3. Other ZEV policies can be complementary, notably purchase incentives and home-charging building codes — though either is only expected to play a supporting to minor role in 2030 and 2050 GHG targets.

Evidence for vehicle efficiency

4. The existing vehicle efficiency standard is a priority mitigation policy and can play a major role in meeting 2030 and 2050 GHG targets (if Canada holds to the 2025 requirements). Increased policy stringency beyond 2025 could further contribute to 2050 GHG mitigation (e.g., following the EU's 2030 standards).

    - In addition: vehicle efficiency standards have driven innovation into efficient vehicle technology and can be cost-effective if implemented with other market-oriented policy (namely carbon pricing).

Evidence for VKT reduction

5. In a region expecting significant population growth (like Metro Vancouver), a mix of well-designed VKT reduction initiatives could be an important mitigation strategy and play a minor role in 2030 and 2050 GHG mitigation targets. Of the individual strategies, road-pricing strategies can have the largest impact on VKT reduction.

    - In addition: VKT reduction can reduce traffic congestion while increased active travel and public transit service can help to achieve other desirable social goals, including improved health, accessibility and equity.

6. Road pricing alone is an important mitigation policy and can play a minor role in meeting 2030 and 2050 GHG targets, if strong and implemented to directly discourage GHG emissions (not just congestion), ideally charged per kilometre driven or per unit of fossil fuel consumed.

    - In addition: road pricing can reduce congestion, support mode shift to active travel and associated health benefits, and generate funds to further support compact development, public transit and active travel. The impact of road pricing will likely be limited by political acceptability, though some research suggests that public opposition can be potentially overcome through careful design (to avoid inequity) and clear communication of acceptable goals.

7. Actions to improve the built environment (including increased density, diversity and transit-oriented development) are complementary and can play a supporting role in mitigating transport GHGs. Failure to sustain existing density levels in the face of population growth could lead to a worsening of GHG impacts.

    - In addition: improvements to the built environment can offer a variety of other social benefits, including improved health (by supporting active travel), affordability and support for economic activity.

8. Initiatives to increase cycling and walking are complementary and can play a supporting to minor role in 2030 and 2050 GHG targets, though they can complement a larger strategy to reduce VKT and GHGs. Failure to increase active travel infrastructure in the face of population growth could lead to a worsening of GHG impacts.

    - In addition: increasing the share of active travel offers clear health and social benefits.

9. Improved public transit service is expected to play a supporting role in 2030 and 2050 GHG abatement. Failure to increase public transit service and infrastructure in the face of population growth could lead to a worsening of GHG impacts.

    - In addition: a well-designed public transit system can provide equity and accessibility to the broader population, and complement a broader package of policies to reduce VKT.

Evidence for “new mobility”

10. The emergence of car-sharing programs, ride-hailing, automated vehicles and other forms of “new mobility” could have a range of positive and negative social impacts, notably for GHG mitigation. Important and priority mitigation policies are needed to increase the probability of positive social impacts, including GHG mitigation.

11. Car-share programs provide a useful travel option for some households, though the present and future impacts on vehicle ownership, VKT and GHG emissions are uncertain. GHG and social benefits could be improved if coordinated with VKT reduction measures, such as road pricing and improved transit.

12. Ride-hailing is providing a competitive transportation mode in many cities that it enters, though its present and future impacts on VKT and GHG emissions are variable and uncertain. Important and priority mitigation policies are likely needed to guide ride-hailing in a low-carbon direction, including the road pricing and regulations noted above.

    - In addition: careful policy design could increase the use of "pooled" ride-hailing (multiple travellers per vehicle), and better complement (rather than compete with) public transit and active travel.

13. Automated vehicles present a very wide range of potential benefits and threats to sustainable transportation goals, with scenarios demonstrating their potential to halve or double GHG emissions. Important and priority mitigation policies are needed to guide development in a low-carbon direction, particularly the regulations and pricing policies noted in previous findings.

Evidence for freight

14. GHG emissions from heavy-duty vehicles (primarily involved in freight transportation) are just as significant as the emissions from passenger vehicles, yet policy is weaker in this sector. As with passenger vehicles, important and priority mitigation policies are needed to have major GHG reductions in this sector, notably a ZEV mandate, LCFS and vehicle efficiency standards.

Recommendations for Metro Vancouver

As a final component to this report, we consider how the insights from this broad evidence base may suggest specific recommendations for British Columbia and Metro Vancouver in achieving 2030 and 2050 GHG mitigation goals. We split these recommendations based on policy jurisdiction: i) policies that are likely to be led at the provincial or national level, and ii) policies that would likely be led at the municipal or metro level.

To be clear, we do not believe that one or two priority policies is enough. Rather, evidence suggests that a cohesive mix of policies is needed to induce a low-carbon transition, likely a combination of pricing mechanisms, subsidies, regulations and infrastructure implementation. Therefore, we view our collection of priority and important policies as a sort of menu that policy-makers ought to prioritize for their region, as part of a broader, comprehensive policy mix. Likely, several priority and important policies will need to be implemented together, along with several complementary polices, to support the low-carbon transition.

Most of the identified priority (major impact) mitigation policies for transportation concern the "low-carbon fuels" and "vehicle efficiency" legs of the transportation stool, where such policies are implemented at the provincial and federal level. With 2030 and 2050 GHG mitigation targets in mind for the transportation sector, Metro Vancouver and other stakeholders should support such policies:

> **Recommendation 1:** Support British Columbia's recently announced ZEV mandate (with the 2030 requirement of 30 per cent ZEV sales by 2030 and 100 per cent by 2040). This stringency is already sufficient to play a moderate role in 2030 targets and a major role in 2050 climate targets for transportation.

> **Recommendation 2:** Support the low-carbon fuel standard in British Columbia and the LCFS under development for Canada. However, both policies will need to become more stringent beyond 2030 to play a major role in 2050 climate targets.

> **Recommendation 3:** Support Canada's vehicle emissions standard (CAFE) for light-duty vehicles, keeping with the 2025 requirements as they currently stand. Increasing stringency beyond 2025 would further improve the policy's contribution to 2050 mitigation goals.

> **Recommendation 4:** Heavy-duty vehicles need strong regulations as well, which could include a stringent mix of a vehicle emissions standard (like CAFE), ZEV mandate (like that in B.C. for light-duty vehicles) and LCFS.

> **Recommendation 5:** The province should support Metro Vancouver and city and municipal governments in efforts to reduce VKT, especially by implementing road-pricing mechanisms, as well as improvements to the built environment, infrastructure for active travel and improvements to public transit service.

City and Metro governments are more likely to have the capacity to lead the "VKT reduction" leg of the stool, as well as the deployment of "new mobility" options. We offer the following recommendations to Metro Vancouver and other stakeholders, while noting that national and provincial support would greatly aid efforts to reduce VKT:

> **Recommendation 6:** Seriously pursue road pricing as the lead mechanism to reduce VKT, ideally through a system based on VKT, gasoline and diesel use or GHG emissions (not just congestion-focused). Road pricing can also be one of the most effective ways to responsibly guide the rollout of car-sharing, ride-hailing and vehicle automation, to assure they lead to GHG reductions and avoid "rebound effects" from cheaper travel modes. Road pricing can also fund the other VKT reduction strategies noted below (active travel and public transit), which can boost political acceptability.

> **Recommendation 7:** Support active travel, primarily for the health benefits that are consistently shown to lead to a net social benefit. Increase active travel infrastructure to at least match or exceed population growth while providing more travel choices (complementing road pricing).

Recommendation 8: Support improved public transit, also primarily from a health and social equity perspective. Increase transit infrastructure and service to at least match or exceed population growth while providing more travel choices (complementing road pricing). Also, support TransLink's plans to fully electrify its bus fleet by 2040, to further contribute to GHG mitigation.

Recommendation 9: To avoid worsening impacts from population growth, maintain or improve the quality of the built environment, including density, diversity and transit-oriented development. Improvements to the built environment can help support the uptake of active travel and public transit, and may help to achieve other secondary benefits, including health, equity in access and housing affordability.

Recommendation 10: Support shared mobility (including car-share and ride-hailing programs) to improve the variety of transport options. However, important and priority mitigation policies (regulation and pricing) are likely needed for shared mobility modes to effectively contribute to GHG goals. Further, planning of these modes should be coordinated with other transport efforts (active travel, public transit, built environment) to sustain a robust system of travel modes and achieve a range of sustainability goals.

Recommendation 11: The emergence of automated vehicles presents a wide range of opportunities and threats to sustainable transportation goals. Metro Vancouver should carefully monitor progress in AV technology to consider and address its potential in policy-making and planning. Most of the important and priority mitigation policies summarized above will help to support pro-societal AV scenarios, including low-carbon vehicle regulations and road pricing. With large-scale deployment of AVs, other policies may become even more important, such as maintaining or improving the built environment (e.g., to avoid scenarios where AVs lead to excessive suburban and rural sprawl). Additional policies will be needed to steer AV technology toward the achievement of secondary sustainability goals, such as equity and health.

Recommendation 12: To achieve 2030 and 2050 GHG targets, governments must effectively plan for and coordinate all the various transportation and climate policies. This includes not only the various VKT reduction policies but how they may interact with efficiency and low-carbon fuels regulations, as well as adaptation to "new mobility" options. The task will be challenging and needs regular review, consultation and updating.

1. INTRODUCTION

PHOTO Metro Transit, Flickr CC BY-NC-ND 2.0

Although our present transportation systems provide numerous benefits, the negative societal impacts are enormous. Globally, the transportation sector is responsible for almost one-quarter (23 per cent) of total energy-related carbon dioxide equivalent emissions (IPCC 2014), while road traffic is a major contributor to fatalities and injuries, and in many countries a leading cause of death among young adults (WHO 2018). In numerous cities and developing countries, vehicles remain a major source of air pollutants that cause significant health impacts, especially among children and elderly people (WHO 2018). Despite decades of progress for alternative and low-carbon fuels and technologies, and some incremental improvements taken up in the mass market, most countries remain locked in to the use of privately owned, petroleum-powered vehicles, frequently driven with a single occupant (Sperling 2009; Melton, Axsen et al. 2016).

Stringent climate policy is needed to avert the most dangerous impacts of climate change. To do their part, British Columbia and Metro Vancouver must implement a set of policies that have the ability to achieve their stated goals of reducing greenhouse gas emissions by 40 per cent (relative to 2007) by 2030, and 80 per cent by 2050. Metro Vancouver has adopted these same goals and is in the process of developing climate road maps for 2019 and 2020, which will serve to implement the Climate 2050 Strategic Framework published in 2018. More recently, the City of Vancouver, as well as other Metro Vancouver municipalities, declared a “climate emergency” and identified a number of priority actions, including efforts to increase the proportion of walkable communities, provide safe and convenient active transportation and public transit, and support zero-emissions vehicles.

This report focuses on the transportation sector, which represents about 40 per cent of British Columbia's GHG emissions and about 45 per cent of emissions in Metro Vancouver, including emissions for passenger vehicles (light-duty cars and trucks), heavy-duty trucks used for goods movement (or freight) and buses.[3] There are a wide range of technologies, actions and policies that can reduce GHG emissions in this transportation sector, commonly split into three categories or "three legs of the stool" (Sperling and Eggert 2014):

1. Low-carbon fuels (e.g., switching to low-carbon electricity, biofuels and hydrogen);
2. Efficiency (e.g., improving the efficiency of vehicles); and
3. Travel (vehicle-km travelled, VKT) reduction (e.g., through road pricing, changes to the built environment, and promotion of active travel and transit).

A carbon price is known as being technology-neutral, in that it can induce changes in any of these three legs, and other sectors. However, most other policies and initiatives are more specific and tend to focus on one leg. This report focuses on policies that are specific to transportation (not carbon pricing, aside from its inclusion as a potential type of road pricing).

The purpose of this report is to review the available evidence for "best practices" as to which policies can be the most effective in reducing GHG emissions in the long-term to meet 2030 and 2050 mitigation goals within the transportation sector. In addition to GHG mitigation, good transportation policy will also need to be cost-effective (meeting goals in an efficient way), politically acceptable, and administratively feasible. Further, beyond climate change goals, stakeholders seek additional pro-societal objectives for the transportation sector, namely in improving health (e.g., through reduced air pollution, increased active travel and improved safety) and equity (e.g., in providing access to a range of affordable transportation modes), as well as reducing congestion and improving economic activity. While we focus on evidence for the stated 2030 and 2050 GHG mitigation goals, we also note evidence for these secondary impacts and "co-benefits" as well, where available.

In effect, we hope to build public and organizational support for effective transportation policies and investment, which in turn can encourage leaders to implement these initiatives. The report summarizes evidence (research and analysis) to help stakeholders identify and champion best practices appropriate for Metro Vancouver, and potentially other regions.

The next section provides more background details for British Columbia and Metro Vancouver, while Section 3 summarizes our approach. Sections 4 through 8 then summarize evidence for different aspects of the transportation sector: low-carbon fuels, vehicle efficiency standards, travel (VKT) reduction, "new mobility" options and heavy-duty vehicles. Section 9 summarizes these insights, while Section 10 provides more specific policy recommendations for British Columbia and Metro Vancouver.

3 We do not presently focus on GHG emissions from air, marine or rail, which make up about 15% of Metro Vancouver's transportation GHG emissions.

2. BACKGROUND: BRITISH COLUMBIA'S TRANSPORTATION GHG EMISSIONS

PHOTO Aditya Chinchure Unsplash

In this section we summarize the relevant transportation trends, goals and initiatives from several different perspectives in British Columbia, including the province, Metro Vancouver, and TransLink. We also acknowledge the variety of potential goals for transportation planning, including health, equity and congestion reduction. We end with the argument that transportation initiatives, including climate policy, need to be carefully considered and coordinated across the different levels of government, and different actors.

The major focus of this report is the GHG mitigation goals set by the Province of British Columbia in May 2018, relative to the 2007 baseline (64 Mt CO2e):

- 40 per cent reductions by 2030 (~25 Mt CO2e less than 2007).
- 60 per cent reductions by 2040 (~38 Mt CO2e less than 2007).
- 80 per cent reductions by 2050 (~51 Mt CO2e less than 2007).

Transportation is a major component of province wide GHG emissions and an even larger component of Metro Vancouver's emissions, so policy and investment targeting this sector is necessary. In 2016, B.C.'s transportation sector accounted for about 39 per cent of total GHG emissions (24 Mt CO2e). Between 2007 and 2016, provincial passenger vehicle emissions increased by 15 per cent, and heavy-duty truck emissions increased by 7.7 per cent (Government of British Columbia, 2018). This growth is tied to population and economic growth during that time (11 per cent and 19 per cent, respectively), as well as the lack of stringent climate policy in the sector.

Provincial GHG policy development is already underway. In December 2018, the province released an updated climate plan, "Clean BC", focusing on policies and strategies that would help to achieve the 2030 goals. Notably, the listed initiatives only added up to reductions of 18.9 Mt GHG relative to 2007, rather than the required 25 Mt. The province listed the following initiatives for the transportation sector, which they estimate would together account for six Mt of reductions by 2030:[4]

- A zero-emissions vehicle mandate that would require 10 per cent of new vehicle sales to be ZEVs by 2025, 30 per cent by 2030, and 100 per cent by 2040 (expected to reduce 2030 emissions by 1.3 Mt GHG).[5]
- ZEV purchase incentives, for light-duty vehicles, clean buses and heavy-duty vehicles (expected to reduce 2030 emissions by 0.3 Mt GHG).
- Expanding the network of vehicle charging and hydrogen refuelling (no listed impact).
- Extending the low-carbon fuel standard to reduce the (life cycle) carbon intensity of fuels sold in the province by 20 per cent by 2030 (expected to reduce 2030 emissions by 4.0 Mt GHG).
- Improved vehicle efficiency standards for light-duty vehicles post 2025 (expected to reduce 2030 emissions by 0.4 Mt GHG).
- Improving active transportation and commuting solutions (no listed impact).
- Notably, the provincial carbon tax is expected to reduce 2030 emissions by 1.8 Mt, though this would likely be spread across multiple sectors.

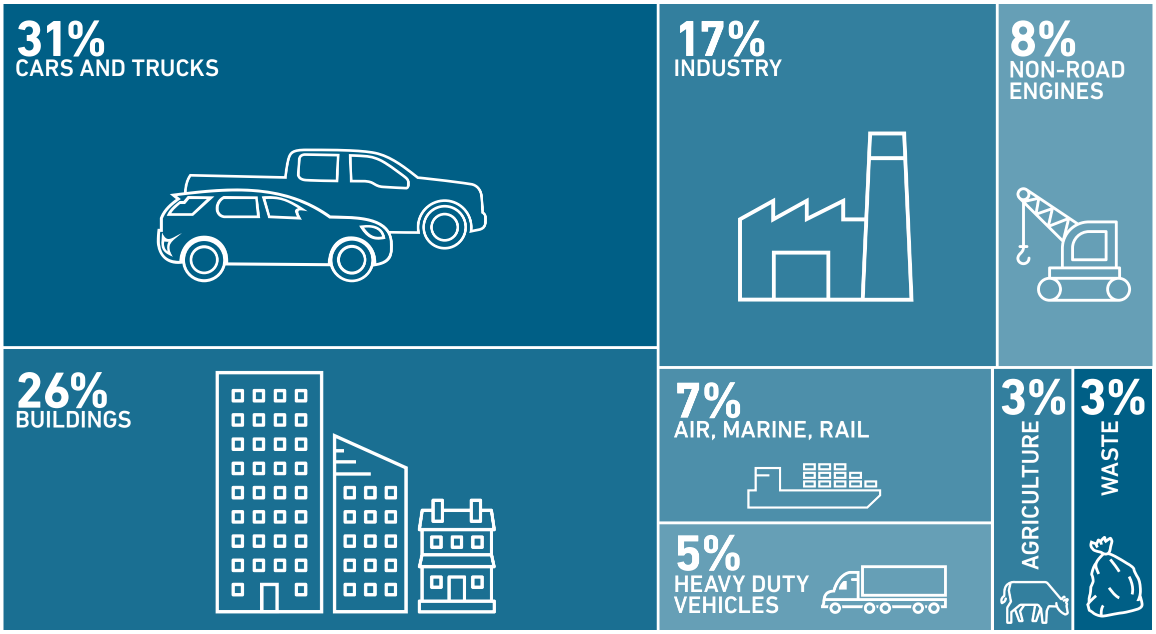
In Metro Vancouver, transportation accounts for about 43 to 45 per cent of GHG emissions. Figure 1 depicts how this beaks down between on-road cars and trucks (31 per cent), heavy-duty vehicles (five per cent), and air, marine and rail (seven per cent).[6]

4 All estimates of expected reductions were conducted by the Province – not necessarily from the present report.

5 In addition, as of May 2019, Canada, British Columbia and the City of Vancouver have signed the "Drive to Zero Pledge", which targets the domination of ZEVs in commercial and heavy-duty vehicles. https://globaldrivetozero.org/about/pledge/

6 We do not presently focus on GHG emissions from air, marine or rail, which make up about 15% of Metro Vancouver's transportation GHG emissions.

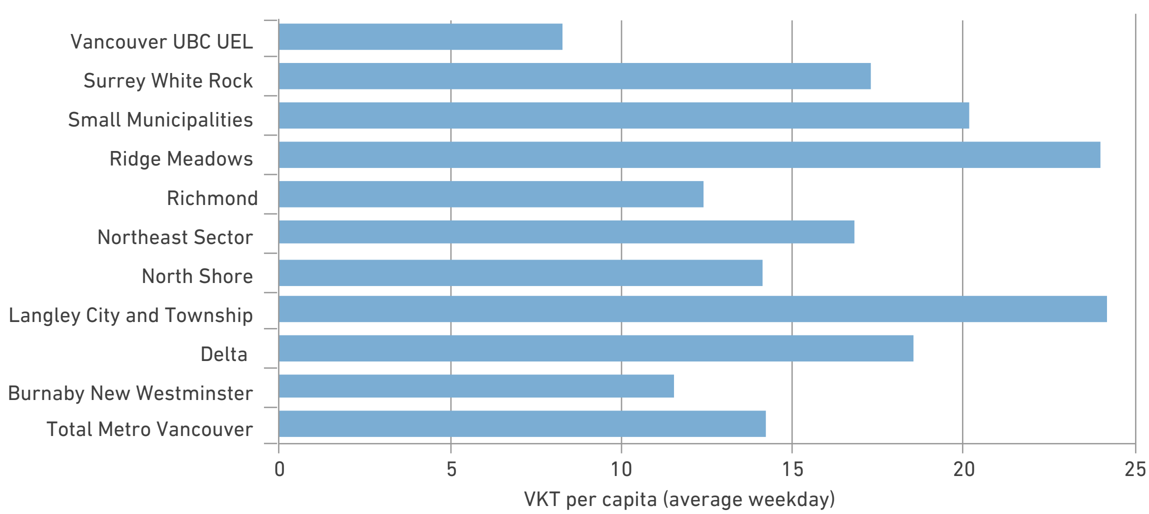
Figure 1: Summary of GHG emissions sources in Metro Vancouver, adding up to 14.7 Mt GHG



Source: Climate 2050: Strategic Framework

It is also important to consider Metro Vancouver's trends in population growth and travel demand (vehicle km travelled, or VKT). In 2011, residents on average drove personal vehicles about 14.2 VKT per weekday, per capita. (Figure 2 splits this up by municipality.) Notably, Metro Vancouver's population has been growing at about 30,000 residents per year, and is expected to reach 3.6 million by 2050, which would be about 45 per cent more people than in 2016. If driving patterns continue per capita, 2050 VKT would increase to be 45 per cent higher than 2016 levels, and 70 per cent higher than 2007 levels. With the same vehicle efficiency and fuels, such an increase in VKT would proportionally translate to increased GHG emissions.

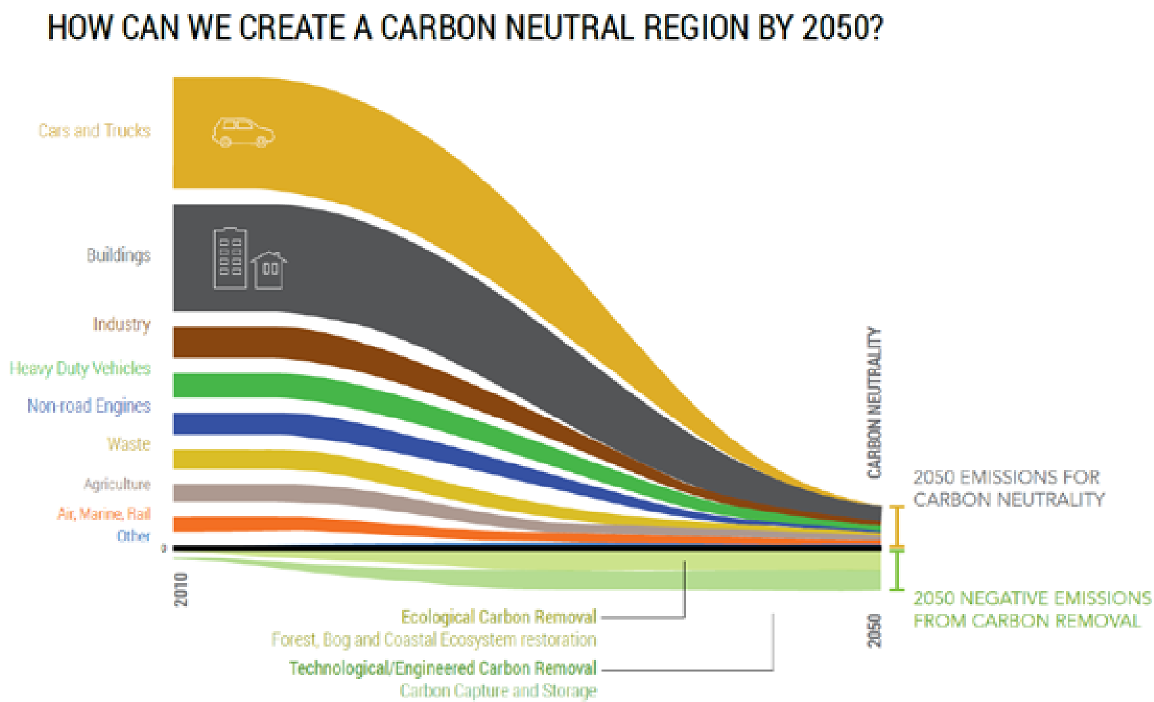
Figure 2: Vehicle km travelled (VKT) per capita, by municipality in Metro Vancouver, 2012



Source: 2012 Metro Vancouver Regional Trip Diary Survey, TransLink, http://www.metrovancouver.org/metro2040/sustainable-transportation/vehicle-movement/vehicle-km-travelled/Pages/explore-vkt-per-capita-data.aspx)

Similar to the province, Metro Vancouver is pursuing a goal of reducing GHG emissions by 80 per cent by 2050 (relative to 2007 levels). Its Climate 2050 initiative is meant to guide climate change policy and action for the region over the next 30 years. According to Climate 2050: Strategy Framework (September 2018), Metro Vancouver intends to eliminate GHG emissions from passenger transportation by 2050 through a combination of i) having "most" trips made by active travel or transit, and ii) having "almost all" cars and trucks be low-carbon vehicles. Today, about 70 per cent of personal trips in the region are made by vehicles, compared to 13 per cent by walking and cycling, and 14 per cent by transit. Figure 3 illustrates one potential scenario for achieving 2050 goals, where, strikingly, light-duty vehicle emissions are reduced to nearly zero by 2050 (beyond 80 per cent). Such a trajectory would require a profound transition in technology and behaviour, especially given the expected population growth noted above.

Figure 3: Illustration of one possible scenario to achieve 2050 targets in the Metro Vancouver region



Source: Climate 2050: Strategic Framework

For its part, TransLink is planning to invest in several public transit initiatives to help increase transit ridership over the next decade (2018-2017 Investment Plan, released June 2018). With the current system, transit trips are expected to increase from 250-million journeys per year in 2018 to 274-million journeys per year by 2027. However, TransLink's proposed "Phase 2" would aim to increase 2027 transit journeys to 316-million, through projects such as:

- Building new rapid transit (extending SkyTrain, adding light rail);
- Upgrades to existing passenger rail services (SkyTrain and West Coast Express);

- Increasing overall bus and HandyDART service (including "B-Line or Better" bus service);
- Increased funding for walking and cycling infrastructure; and
- Funds to pilot different shared mobility services (e.g., commuter van-pooling and demand-responsive transit systems).

Notably, "Phase 2" proposes adding some form of road pricing to "reduce congestion and overcrowding, improve fairness and support transportation investment." This rationale does not mention GHG emissions reduction as a primary motive. We further discuss road-pricing options in Section 6.

Across these different governments and actors, there is a clear need for coordination of transportation climate policies and initiatives — a need that has yet to be fulfilled. As noted in Section 1, transportation GHG mitigation measures are typically split into three categories: low-carbon fuels, efficiency and travel (VKT) reductions. Most of the climate policies implemented at the national and provincial levels address the first two "legs of the stool", namely low-carbon fuels and vehicle efficiency. In contrast, metro areas and municipalities tend to be limited to influencing travel demand through built environment, public transit, active travel and, potentially, road pricing. However, these different policies are inevitably co-dependent; careful coordination is needed to make sure that, together, they achieve 2030 and 2050 GHG goals in B.C. and Metro Vancouver.

In addition to meeting GHG reduction goals, a "sustainable transportation" system needs to address other societal goals (Litman 2017). For example, the City of Vancouver's Transportation 2040 Vision supports a thriving economy, increasing affordability and healthy citizens. Trends of increased traffic congestion provide a particular concern. In April 2019, the Metro Vancouver Mayors' Council released a call for a national congestion relief fund (Cure Congestion: 2019 Federal Election Platform), which would help to support investments in public transit. While such aims are not the primary focus of this report, we will consider potential impacts in our review of evidence (detailed further in the next section).

A further consideration of future transportation trends in British Columbia and Metro Vancouver relates to various aspects of what is sometimes called "new mobility," including the potential for shared mobility and vehicle automation. For shared mobility, while the City of Vancouver is already a leader in car-sharing programs in North America (Vancity 2018), it has been a laggard in the use of ride-hailing programs (i.e., Uber or Lyft). The province has recently introduced legislation to allow ride-hailing in the next year, which could substantially affect passenger travel and mode share — especially taxis and public transit (Clewlow and Mishra 2017). Vehicle automation is still a decade or more away by some estimates, but it may have an even more transformative impact on the transportation system, for better or worse (Wadud, MacKenzie et al. 2016). While the potential success and impacts of such "new mobility" options are highly variable and uncertain, they need to be considered in long-term transportation plans. Section 7 provides further insights regarding the impacts of "new mobility".

In short, Metro Vancouver has an opportunity to develop a transportation GHG mitigation plan that could be effective in meeting its goals, while also being an inspiring, innovative model and blueprint for other cities and metropolitan regions. In this context, this report aims to explore the following questions:

- Based on available evidence, what policies and initiatives can help British Columbia and Metro Vancouver meet 2030 and 2050 GHG reduction targets in the transportation sector?
- What additional benefits or impacts can we expect from these policies and initiatives? (Where some policies or initiatives may be desirable, even if they don't substantially contribute to GHG mitigation goals.)
- Which selection of policies should British Columbia and Metro Vancouver include in a comprehensive transportation climate plan?

3. APPROACH

PHOTO Kyle Thacker Unsplash

The core of this analysis is a summary and synthesis of available literature. We use our experience and expertise in this field to identify helpful and robust studies, to evaluate their findings and to extract evidence and insights relevant to British Columbia and Metro Vancouver's plans for GHG mitigation.

The literature includes peer-reviewed journal articles, as well as so-called "grey literature" reports, some of which are peer-reviewed and others not. These studies use a wide range of methods, including statistical analyses of real-world data, simulation models of how policies or technology scenarios might affect future transportation systems and surveys and interviews with consumers, citizens and stakeholders. Typically, the most robust and useful studies are literature reviews or systematic analyses that pull together insights from dozens of previously published studies.

Although multiple sources are considered, we prioritize insights according to comprehensiveness, rigour and applicability to the case region of British Columbia. While studies can vary considerably in quality and relevance, we generally find that peer-reviewed studies can provide more careful insight than the grey literature (though there are exceptions), and that systematic reviews provide a broader evidence base than a single case study. In the summary of evidence sections (Sections 4 through 8), we include footnotes for pieces of evidence that are based on particularly high-quality and/or relevant sources, namely:

- Systematic reviews that collect insights from many other studies;
- Studies published in international, peer-reviewed journals; and/or
- Studies focusing on (and thus relevant to) the case of Metro Vancouver, British Columbia or Canada.

We organize our summary around several categories, in part relating to the "three legs of the stool" noted above: low-carbon fuels, vehicle efficiency and travel reduction (i.e., VKT reduction). Based on the literature, we have compiled our insights into the following sections and subsections covering the "legs of the stool":

- **Section 4**: Low-carbon fuels (low-carbon fuel standard, ZEV mandate and other ZEV policy).
- **Section 5:** Vehicle efficiency.
- **Section 6:** VKT reduction (road pricing, built environment, active travel and public transit).

There are two additional sections that somewhat overlap with the above categories:

- **Section 7:** "new mobility" options (car-share, ride-hailing and vehicle automation), which could affect car ownership and VKT and interact with efficiency and low-carbon fuels policies.
- **Section 8:** Freight and heavy-duty transportation, where GHG emissions are also affected by low-carbon fuels, efficiency and travel (tonne-km travelled), though the relevant policies and insights may be different than for personal travel.

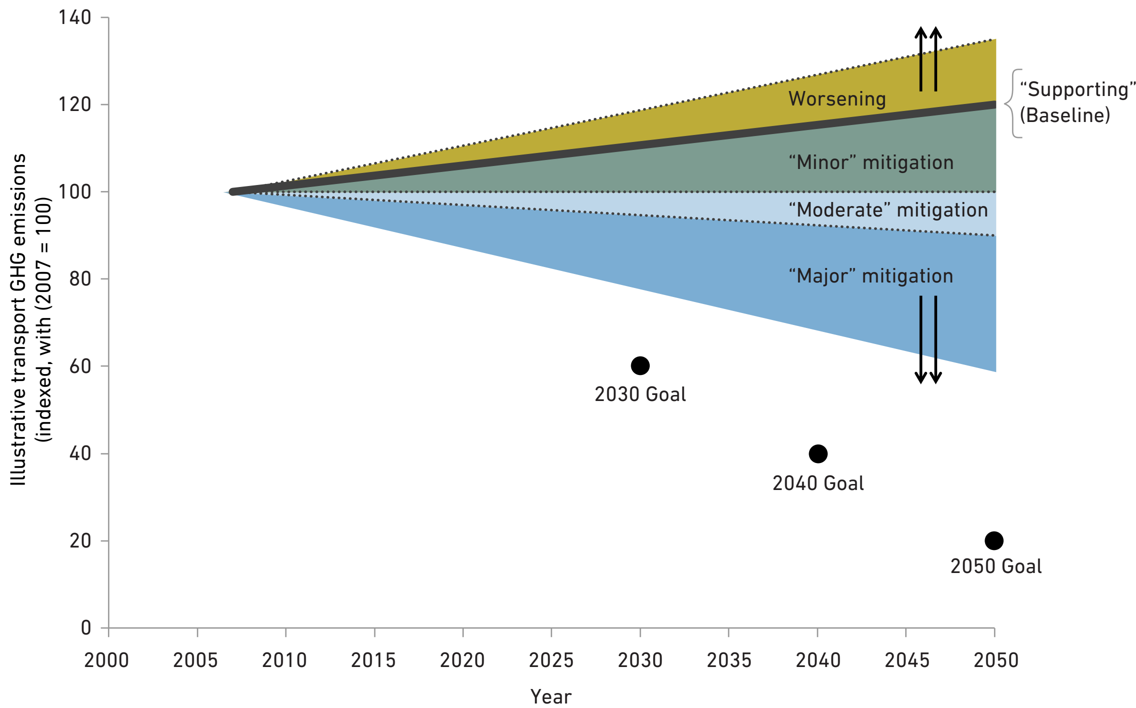
Each of our results sections begins with a summary statement of primary findings, which focus on evidence for the potential of policy or initiatives in that category to contribute to GHG mitigation targets for the transportation sector. Namely, we consider British Columbia's two GHG targets relative to the 2007 baseline: a 40 per cent reduction by 2030 and an 80 per cent reduction by 2050. We assume that because transportation makes up 39 per cent of total emissions in British Columbia, GHG reductions would likely need to be at least proportional in this sector. As noted by a scenario in one Metro Vancouver report (Figure 3), transportation GHG emissions might actually need to be more than 80 per cent less than in 2007 to account for slower GHG abatement in other sectors (e.g., buildings).

For each policy or initiative, we draw from available evidence in the literature to assess its role in achieving 2030 and 2050 GHG targets, while accounting for expected population growth in Metro Vancouver (which could be about 45 per cent more people than today, or 70 per cent more than in 2007). While many of the studies we review provide specific numbers for GHG mitigation potential, they vary considerably by method, assumptions, region and context. For each category of policy or initiative, we frame our assessment according to the following impact levels (conceptually illustrated in Figure 4):

- **Worsening:** refers to actions or policies that would lead to transportation GHG emissions that exceed the current trajectory. In our current evaluation, this would only occur from the removal of existing climate policies, or failure to keep infrastructure investment in line with population growth (e.g., for public transit or active travel).
- **Supporting:** can help to hold the "baseline" of projected GHG emissions out to 2050.
- Minor GHG mitigation: can help to slow the growth of transportation GHG emissions but not actually decrease them relative to 2007.
- **Moderate GHG mitigation:** can decrease transportation GHG emissions by one to 10 per cent relative to 2007, accounting for population growth
- **Major GHG mitigation:** can decrease GHG emissions by over 10 per cent relative to 2007,

accounting for population growth.

Figure 4: Categories of GHG mitigation potential for evaluated policies (illustrative, shown for 2050 goals only)



We further distinguish between expected impacts in 2030 versus 2050. The rate at which vehicles are retired and replaced will constrain the near-term impacts of some policies, as will any policy schedules with rising stringency through time. For example, the announced ZEV mandate will impact less than 10 to 15 per cent of the stock of passenger vehicles by 2030 but could apply to 90 per cent of vehicles by 2050. The slow turnover of transportation infrastructure and the built environment in general will similarly constrain the near-term impact of some policies aimed at reducing VKT.

Where information is available, we also consider a range of secondary benefits and impacts for different transportation policies and strategies, including:

- **Cost-effectiveness:** which may include the direct financial costs of a given policy, government expenditure, economists' estimates of social welfare or "efficiency" impacts, or impacts to economic activity (e.g., as measured through GDP or job growth). As one example, policy that reduces traffic congestion is expected to have economic benefits, due to reduced travel time.
- **Innovation:** does the policy send a signal to channel innovation into low-carbon technologies or practices, elsewhere called a "transformative signal" (Melton, Axsen et al. 2016).
- **Health impacts:** including improved health through physical activity, as well as negative impacts including injuries and exposure to air pollution.

- **Social impacts:** such as citizen happiness and well-being.
- **Equity impacts:** addresses the distribution of policy costs and benefits among different groups, which might differ by household income and region. In particular, careful consideration is needed for impacts (added costs, or lack of benefits) to marginal groups, such as low-income households.
- **Political acceptability:** considers if a given initiative is likely to be accepted by different stakeholders, including citizens (i.e., voters), industry and civil society.

Finally, we provide recommendations for each policy category, accounting for both GHG reductions and secondary benefits. The assessment options are as follows:

- **Complementary measures:** can help support the baseline GHG emissions while providing important secondary social benefits, including improved health, social and equity impacts. Such policies may also ease implementation of the more impactful GHG mitigation policies, easing compliance and/or improving political acceptability.
- **Important mitigation measures:** can have a minor to moderate impact on GHG mitigation, and should be seriously considered as climate policies.
- **Priority mitigation measures:** can have a major impact on GHG mitigation, where stringent versions are likely necessary to lead the way to 2030 and 2050 GHG mitigation goals in the transportation sector.

Throughout this process, we acknowledge that 2050 is sufficiently far in the future and that much can change in technologies, lifestyles, values and economic conditions. Although we present our best assessment of the available research, we see a strong need for ongoing research, collaboration across sectors, experimentation and learning from other regions. We welcome contributions of state-of-the-art research findings and data from fellow academics and practitioners.

4. EVIDENCE FOR LOW-CARBON VEHICLES AND FUELS

Photo: Oregon Department of Transportation, Flickr CC BY 2.0

The first category of transportation GHG mitigation concerns low-carbon vehicles and fuels, which we split into three subsections. We first discuss the low-carbon fuel standard (LCFS), which requires fuel suppliers to lower the life cycle GHG emissions associated with the fuels they sell. Next, we summarize insights for a ZEV mandate, a policy that requires automakers to sell ZEVs. Finally, we provide a short summary of other policies that can support ZEV uptake, including incentives and deployment of chargers.

4.1 Low-carbon fuel standard (LCFS)

PHOTO Nabeel Syed, Unsplash

Main finding 1: A low-carbon fuel standard (LCFS) is a priority mitigation policy and can play a major role in meeting 2030 and 2050 GHG targets, especially in the freight sector. However, the policy needs to be significantly more stringent than existing or proposed levels to achieve 2050 targets.

In addition: LCFS policies have driven innovation into low-carbon fuels, and appear to be politically acceptable to Canadian citizens.

A low-carbon fuel standard is a policy that requires fuel suppliers to progressively decrease the average GHG intensity of their fuels on a life-cycle basis. An LCFS focuses on the life-cycle emissions of each fuel, which is commonly referred to its "carbon intensity" and measured in grams of carbon dioxide equivalent per megajoule (gCO2e/MJ). Life cycle in this case refers to all GHG emissions resulting from fuel feedstock production, refining, distribution and consumption. An LCFS is regulation-based in the sense that there is a carbon intensity target (or limit) that fuel providers must comply with, and it is market-based in that fuel suppliers can trade and bank emission credits. The latter component is meant to improve the policy's cost-effectiveness (Farrell and Sperling, 2007).

California pioneered the LCFS in 2007 as part of enacted legislation requiring the state to reduce its GHG emissions by 80 per cent below 1990 levels by 2050. Specifically, the California LCFS requires fuel suppliers to reduce the carbon intensity of transportation fuels sold in the state by 10 per cent by 2020 (Farrell and Sperling, 2007). Versions of an LCFS have also been used in British Columbia, Oregon and Europe. In 2008, British Columbia implemented its own LCFS, largely based on California's policy with the same 2020 target, and has recently proposed a 20 per cent reduction in carbon intensity by 2030 (Government of British Columbia, 2018). Federally, Canada is developing a Clean Fuel Standard, which follows similar principles to the LCFS policies noted above. Here we consider the CFS as a type of LCFS.

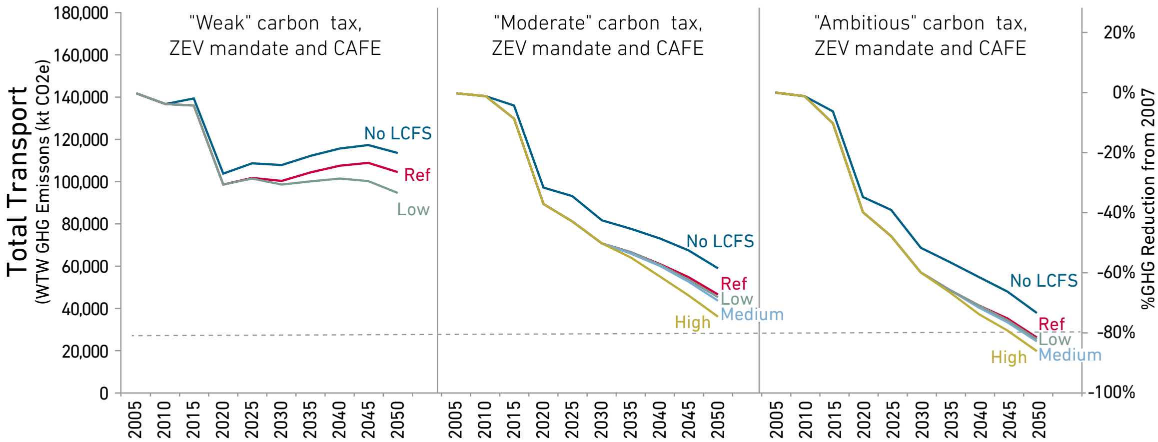
Two recent studies have quantitatively modelled the long-term GHG impacts of an LCFS in British Columbia and Canada. Their results yield the following conclusions:

- When combined with other stringent policies, a strong LCFS could be responsible for about 12 to 20 per cent of the GHG reductions from 2007 levels by 2050 (Lepitzki and Axsen 2018).[7] Figure 5 depicts the incremental impacts of the LCFS on 2050 GHG reductions.
- An LCFS may have the largest additive impact in the freight sector, being responsible for about 20 per cent of GHG reductions in that sector in 2050 (Lepitzki and Axsen, 2018).[8]
- Canada-wide modelling shows that to meet national 2030 targets, a federal LCFS would need to require a 15 to 20 per cent reduction in fuel carbon intensity by 2030 (compared to 2015 levels). The LCFS would need to reduce carbon intensity by 80 per cent by 2050 to achieve GHG targets (Vass and Jaccard, 2017).

7 Peer-reviewed journal article, specific to British Columbia.

8 Peer-reviewed journal article, specific to British Columbia.

Figure 5: The additive impact of an LCFS in achieving 2050 GHG targets in British Columbia's transportation sector



Source: Lepitzki & Axsen, 2018

Additional research has demonstrated that LCFS policy can drive innovation into low-carbon fuels and technology, be politically acceptable to citizens and may have similar cost-effectiveness as carbon pricing. The specific evidence is as follows:

- In California, the LCFS program has been successful in driving innovation, where the average carbon intensity of the alternative fuels supplied in 2011–2015 decreased by 21 per cent, while the market share of alternative fuels has increased by 30 per cent (Yeh, Witcover et al., 2016).
- In British Columbia, from 2010 to 2017, the LCFS has helped the average carbon intensity of ethanol supplied to the province to decrease by 41 per cent; the average biodiesel carbon intensity to decrease by 57 per cent; and the average hydrogenation-derived renewable diesel (HDRD) carbon intensity to decrease by 58 per cent (Government of British Columbia, 2017).
- Survey data indicate that about 90 per cent of Canadians support LCFS, as indicated by a representative sample of 1,306 (Rhodes, Axsen et al., 2015).[9]
- There is some controversy as to whether an LCFS is less cost-effective than a carbon-pricing policy. One study suggests that at a high stringency, an LCFS and carbon-pricing may be similarly efficient (Vass and Jaccard, 2017).

9 Peer-reviewed journal article, specific to British Columbia and Canada.

4.2 Zero-emissions vehicles mandate for light-duty vehicles

PHOTO Richard Truesdell, CC BY-SA 4.0

Main finding 2: A stringent and well-designed ZEV mandate is a priority mitigation policy and can play a moderate to major role in 2030 GHG reduction goals, and a major role in 2050 GHG reduction goals. British Columbia's ZEV legislation for passenger vehicles is amongst the most stringent in the world.

In addition, ZEV mandates have driven innovation into low-carbon vehicle technology and can be cost-effective compared to other policy options.

For vehicles, we use the term zero-emissions vehicle, which refers to vehicles that can have zero tailpipe emissions, including plug-in hybrid vehicles (PHEVs), battery electric vehicles (BEVs) and hydrogen fuel-cell vehicles (HFCVs). From a well-to-wheels emissions perspective (looking at the full life cycle of fuels and electricity), the purchase and usage of ZEVs will reduce GHG emissions compared to conventional vehicles and hybrid vehicles in all Canadian regions now and into the future (Kamiya, Axsen et al., 2019).[10] First, we focus on the ZEV mandate, a policy that is recognized for its strong potential to induce the uptake of ZEVs and to reduce GHG emissions in the long term.[11] The next subsection describes several other ZEV-supportive policies.

The ZEV mandate was first implemented in California in 1990 to reduce air pollution from passenger vehicles. It required automakers to earn a minimum number of ZEV credits each

10 For more details on ZEV-supportive policy, the Sustainable Transportation Action Research Team (START) has released a number of documents to summarize the breadth of ZEV-supportive policies, including Canada's EV Policy Report Card as well as Canada's ZEV Policy Handbook.

11 For more information on the ZEV mandate, we recommend two recent summary pieces: i) a comprehensive analysis of the ZEV mandate by The International EV Policy Council (Hardman, Jenn et al. 2018), and ii) The David Suzuki Foundation's report specific to the proposal for a ZEV mandate in British Columbia (Axsen, Bruce et al. 2019).

year (based on the number of vehicles they sell in the state) or pay fines. In 2004, California expanded the role of the ZEV mandate to also address GHG reduction goals; i.e., to help cut emissions 80 per cent by 2050 (Collantes and Sperling, 2008). Several U.S. states joined California and adopted the ZEV mandate in 2013. Quebec adopted a ZEV mandate in 2016, called the ZEV Act. Most recently, the Province of British Columbia has announced a ZEV mandate, which would be the world's most stringent, requiring ZEV sales to make up 15 per cent of light-duty vehicle sales by 2025, 30 per cent by 2030 and 100 per cent by 2040. Notably, Canada has recently announced the same sales targets as British Columbia (leading to 100 per cent ZEVs by 2040) but has not announced a corresponding ZEV mandate.

We break down the research insights into several types of evidence: how ZEVs can play a large role in GHG mitigation, how a ZEV mandate can induce ZEV sales, and secondary considerations of a ZEV mandate. Regarding the importance of ZEVs in GHG mitigation:

- Modelling of the British Columbia transportation sector demonstrates that ZEVs can reduce transportation emissions (well-to-wheel) by 78 to 98 per cent in B.C. (Kamiya, Axsen et al., 2019).[12]
- In combination with other stringent standards (fuel economy and low-carbon fuels), the ZEV mandate could reduce British Columbia's transportation GHG emissions by about 20 per cent by 2050 (Sykes and Axsen, 2017).[13]
- Due to the slow turnover in vehicle stock, the GHG emissions impacts in 2030 would be lower, around six to 13 per cent relative to the BAU scenario (Axsen, Goldberg et al., 2017).
- To achieve 2050 GHG targets, ZEV legislation requires 30 per cent ZEV sales by 2030, and a more ambitious goal by 2040, depending on which other climate policies are in place (Sykes and Axsen, 2017).[14]
- Likewise, several modelling studies have demonstrated the importance of the ZEV mandate in achieving long-term transportation GHG reductions in the United States (Greene, Park et al., 2014; Greene, Park et al., 2014; Greenblatt, 2015).
- A ZEV mandate could be a particularly important driver of emissions reduction in the light-duty vehicle sector, potentially more powerful than a stringent low-carbon fuel standard (Lepitzki and Axsen, 2018).[15]

Further, a number of studies demonstrate the particular potential for a ZEV mandate to be effective in achieving the 2030 target. Evidence includes:

- Several studies based in British Columbia and Canada demonstrate that ZEV supply is limited relative to conventional vehicles, including limited model variety and availability in a given jurisdiction (Wolinetz and Axsen, 2017; Axsen and Wolinetz, 2018),[16] and limited inventory and knowledge at dealerships (Matthews, Lynes et al., 2017; Clean Energy Canada, 2018).

12 Peer-reviewed journal article, specific to British Columbia and Canada.

13 Peer-reviewed journal article, specific to British Columbia.

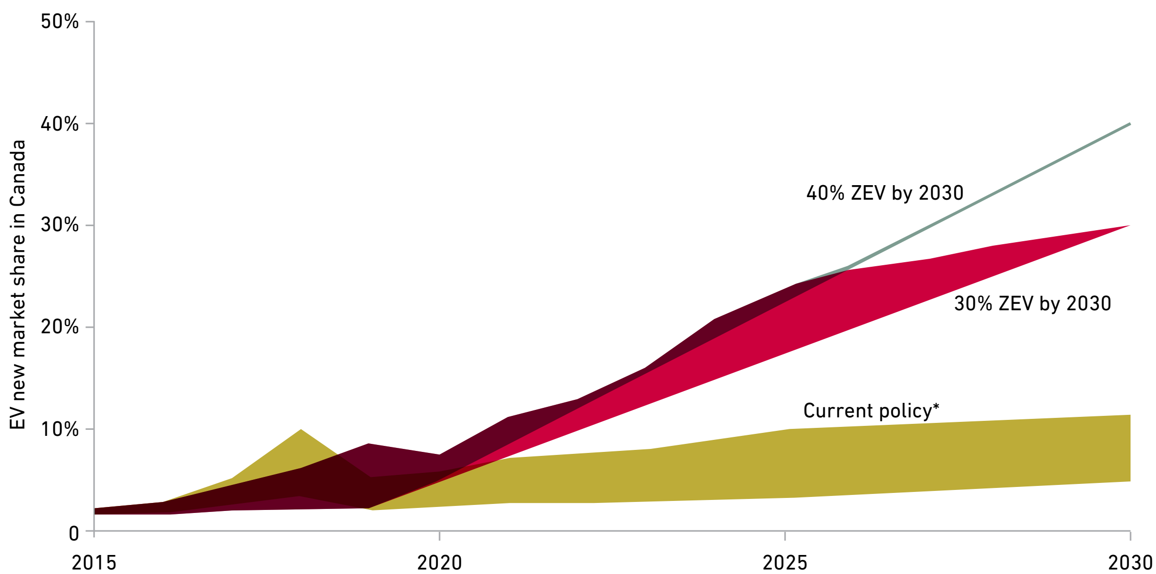
14 Peer-reviewed journal article, specific to British Columbia.

15 Peer-reviewed journal article, specific to British Columbia.

16 Peer-reviewed journal article, specific to British Columbia and Canada.

- Statistical analysis of 200 metropolitan areas in the U.S. finds that ZEV availability is an important driver of ZEV sales (Lutsey and Slowik, 2018).
- U.S. regions that are under the jurisdiction of the ZEV mandate have higher ZEV availability than other regions (Lutsey, Searle et al., 2015).
- B.C. and Canada-based modelling studies show that without increased ZEV supply, ZEV new market share by 2030 is not likely to exceed five to 10 per cent (Wolinetz and Axsen, 2017; Axsen and Wolinetz, 2018).[17]
- Another study shows that the Province of B.C. cannot effectively "free-ride" off of the innovation effects of a ZEV mandate enacted in other jurisdictions. Rather, a B.C.-based ZEV mandate is needed to drive sales to achieve long-term GHG reduction targets (Sykes and Axsen, 2017).[18]
- A Canada-based model, representing Canadian consumer preferences, demonstrates that even with pessimistic technology assumptions, automakers could comply with a 30 or 40 per cent ZEV mandate by 2030 (Axsen and Wolinetz, 2018). Figure 6 depicts this market share trajectory, under uncertainty in battery costs and oil prices, compared to a "current policy" scenario.[19]

Figure 6: Illustration of one possible scenario to achieve 2050 targets in the Metro Vancouver region



Source: Axsen & Wolinetz, 2018
* prior to B.C. ZEV mandate

17 Peer-reviewed journal article, specific to British Columbia and Canada.

18 Peer-reviewed journal article, specific to British Columbia.

19 Peer-reviewed journal article, specific to Canada.

Further, studies demonstrate that a ZEV mandate can successfully drive automaker innovation into low-carbon technology and can be relatively cost-effective compared to other policy options. Specific evidence is as follows:

- Several studies find that California's ZEV mandate has driven ZEV-related innovation activities, including increased patent activity (Vergis and Mehta, 2010), the development of vehicle prototypes (Melton, Axsen et al., 2016), private companies forming partnerships (Dyerson and Pilkington, 2005), and increased employment and investment in companies in California (Burke, Kurani et al., 2000).
- One modelling study shows that a ZEV mandate can be more cost-effective or efficient if designed to send a strong and clear signal to automakers; for example, by focusing on electric vehicles to drive more innovation into that technology type (Fox, Axsen et al., 2017).
- Considering only direct government expenditure costs, a recent study demonstrates that a ZEV mandate–based strategy would be a considerably lower-cost pathway to achieve the 30 per cent by 2030 sales goal compared to a strategy focused on long-term purchase incentives (Axsen and Wolinetz, 2018).[20]
- Elsewhere, we note that there may be a case for British Columbia to enact a simpler version of the ZEV mandate than that used in California, Quebec and elsewhere. We proposed that British Columbia have a "one-to-one" credit system where each ZEV sale earns one credit, which would result in greater and more certain policy effectiveness (Axsen, Bruce et al., 2019).

Another consideration is that increasing adoption of ZEVs would eventually erode fuel tax revenue, which is a large source of funding for roads and transportation infrastructure in many regions (Jenn, Azevedo et al., 2015), including funds for TransLink. The province will need to find ways to replace this revenue stream, perhaps through one of the road-pricing schemes noted in Section 6.1.

Finally, we note that is possible that ZEV-supportive policy may affect the perceived lifespan of current conventional vehicles (Choi and Koo, 2019); that is, causing consumers to keep their existing vehicles for longer or shorter periods. However, the magnitude and direction of this effect is unclear, as are the net GHG and environmental impacts.

20 Peer-reviewed journal article, specific to Canada.

4.3 Other ZEV-supportive policies

PHOTO Rostichep, Pixabay

Main finding 3: Other ZEV policies can be complementary, notably purchase incentives and home-charging building codes — though either is only expected to play a supporting to minor role in 2030 and 2050 GHG targets.

The Sustainable Transportation Action Research Team (START) has released a number of documents to summarize and evaluate the breadth of ZEV-supportive policies.[21] These different policies can be divided into two broad categories: demand-focused and supply-focused. Here we focus on demand-focused policies that encourage consumers to purchase ZEVs, including:

- Financial incentives, such as subsidies or rebates for purchase of ZEVs,
- HOV lane access for ZEV drivers (even if driving alone),
- Deployment of public charging infrastructure,
- Building codes requiring new residential buildings to install chargers or be electric vehicle friendly, and
- Taxation (of fossil fuels or conventional vehicles).

In contrast, supply-focused policies generally encourage or require auto manufacturers to sell ZEVs; for example, a ZEV mandate (summarized in Section 4.2) that specifies a minimum market share of vehicles sold that need to be ZEVs, or an LCFS (summarized in Section 4.1).

21 Specifically, see: Canada's EV Policy Report Card, as well as Canada's ZEV Policy Handbook.

This section focuses on available evidence for the major categories of demand-focused policies, where the largest impact on ZEV sales is likely to be from a purchase subsidy, followed by changes to building codes to support home charging. The remaining demand-focused policy options are found to have little impact. The specific evidence is as follows:

- A modelling study demonstrates that Canada could achieve the 30 per cent ZEV sales by 2030 target with a ZEV purchase subsidy of $6,000 in place until 2030. This subsidy scenario could cost over $25 billion in direct government expenditure with over a decade of subsidies, or over $9,000 per added ZEV that is sold compared to a no-subsidy scenario (Axsen and Wolinetz, 2018).[22] [23]
- The provision of ZEV purchase incentives (using taxpayer money) can also be seen as leading to negative equity effects, unfairly rewarding higher-income households (Sovacool, Kester et al., 2019).
- The next highest-impact (demand-focused) ZEV policy is changing building codes to require home charging for ZEVs, which could increase 2040 ZEV sales by four to 12 percentage points (Melton, Axsen et al., 2017).[24]
- Home charging is found to be more highly valued than work or public charging (Axsen, Bailey et al., 2015; Kormos, Axsen et al., 2019). Thus, increasing the availability of public charging alone is expected to have little impact on ZEV sales (Melton, Axsen et al., 2017), potentially increasing 2040 ZEV sales by as much as two to four percentage points (Melton, Axsen et al., 2017).[25]
- HOV lane access is expected to have a negligible impact on ZEV sales, potentially boosting 2040 sales by about 0.1 percentage points (Melton, Axsen et al., 2017).[26]
- Norway has demonstrated the effectiveness of heavy taxation on conventional vehicles and gasoline, with exemptions for ZEVs and electricity. This has resulted in ZEVs making up 30 to 50 per cent of new market share (Fridstrom, 2019). However, a 2013 survey of citizen acceptance of climate policy in Canada suggests that such a taxation approach would be politically difficult (Rhodes, Axsen et al., 2017).[27]

22 Peer-reviewed journal article, specific to Canada.

23 Note that the government expenditure per added ZEV sale is actually higher than the purchase subsidy. This result accounts for “free-ridership”, where a certain portion of ZEVs would have been sold even without the subsidy in place. For example, if 5 ZEVs are expected to be sold, and a $10,000 purchase subsidy increases that number to 10, the government expenditure ($100,000 total) per added vehicle sale (5 extra vehicles) is actually $20,000/vehicle.

24 Peer-reviewed journal article, specific to Canada.

25 Peer-reviewed journal articles, specific to British Columbia and Canada.

26 Peer-reviewed journal article, specific to Canada.

27 In Spring 2019, SFU-START conducted an updated survey of Canadian citizen acceptance of climate policy, which largely mirrors the findings from the 2013 study.

5. EVIDENCE FOR VEHICLE EFFICIENCY STANDARDS

PHOTO Rudy and Peter Skitterians, Pixabay

Main finding 4: The existing vehicle efficiency standard is a priority mitigation policy and can play a major role in meeting 2030 and 2050 GHG targets (if Canada holds to the 2025 requirements). Increased policy stringency beyond 2025 could further contribute to 2050 GHG mitigation (e.g., following the EU's 2030 standards).

In addition, vehicle efficiency standards have driven innovation into efficient vehicle technology and can be cost-effective if implemented with complementary policy (namely carbon pricing).

This section covers the second "leg of the stool" for GHG mitigation in the transportation sector: improved vehicle efficiency. Aside from switching to low-carbon fuels, GHG reductions can occur by improving the efficiency of vehicles using gasoline or diesel, all else held constant. The most relevant policy in this category is commonly known as CAFE, a regulation that requires improvement in vehicle efficiency and reductions in vehicle emissions.

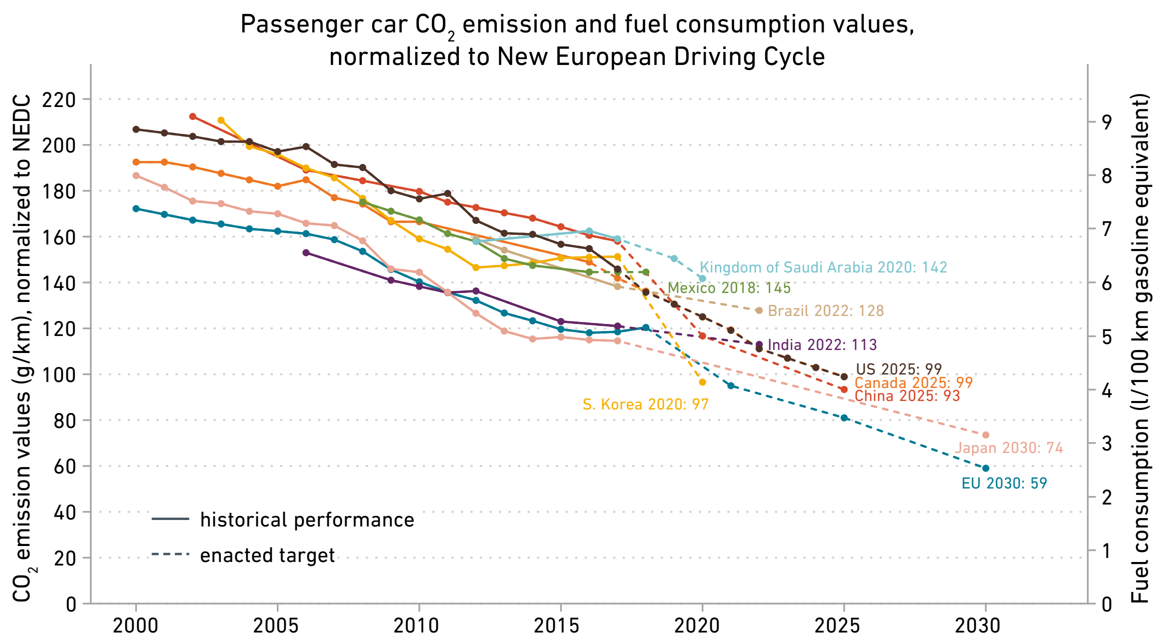
The United States started the Corporate Average Fuel Economy (CAFE) regulation in 1975 as a way to substantially improve the fuel economy of light-duty vehicles sold. The policy was effective in dramatically improving vehicle efficiency until 1985, though requirements (and fuel economy) then stagnated in the 1990s. After some initial leadership by the State of California, then-President Barack Obama changed CAFE to focus on GHG emissions (gCO2e/km), requiring reductions in new vehicles of about five per cent per year from 2017 to 2025.

Canada adopted the same standard as the U.S. in 2012. Though they are technically called the "Passenger Automobile and Light Truck Greenhouse Gas Emissions Regulations," the standard is commonly referred to as "CAFE" in that it is similar to the U.S. version. The policy requires a

40 per cent improvement in light-duty vehicle efficiency from 2011 to 2025 (Posada, Isenstadt et al., 2018). In Canada, there is evidence that the current CAFE standard is one of the most stringent and effective GHG mitigation policies in the transportation sector.

Many countries and regions have "CAFE-like" vehicle emissions standards, including the EU, Mexico, Brazil, Japan, China, South Korea, the U.S. and Canada (Lipman, 2018). See Figure 7 for a summary of the different requirements over time. Most policies now focus on the average gCO2e/km of the entire fleet sold in a given year. Although the average emissions of a 2007 model year vehicle range from 160 to 190 gCO2e/km, the required 2020 and 2021 emissions for several of these policies are as low as 97 gCO2e/km (the EU and South Korea). Before the U.S. opted to "freeze" its CAFE requirements at 2020 levels, both the U.S. and Canada required fleet averages to decline to 99 gCO2e/km by 2025 (Figure 7). The EU 2030 standard now leads the world with required emissions of to 67 gCO2e/km by 2025.

Figure 7: GHG emissions standard for passenger vehicles in several major countries

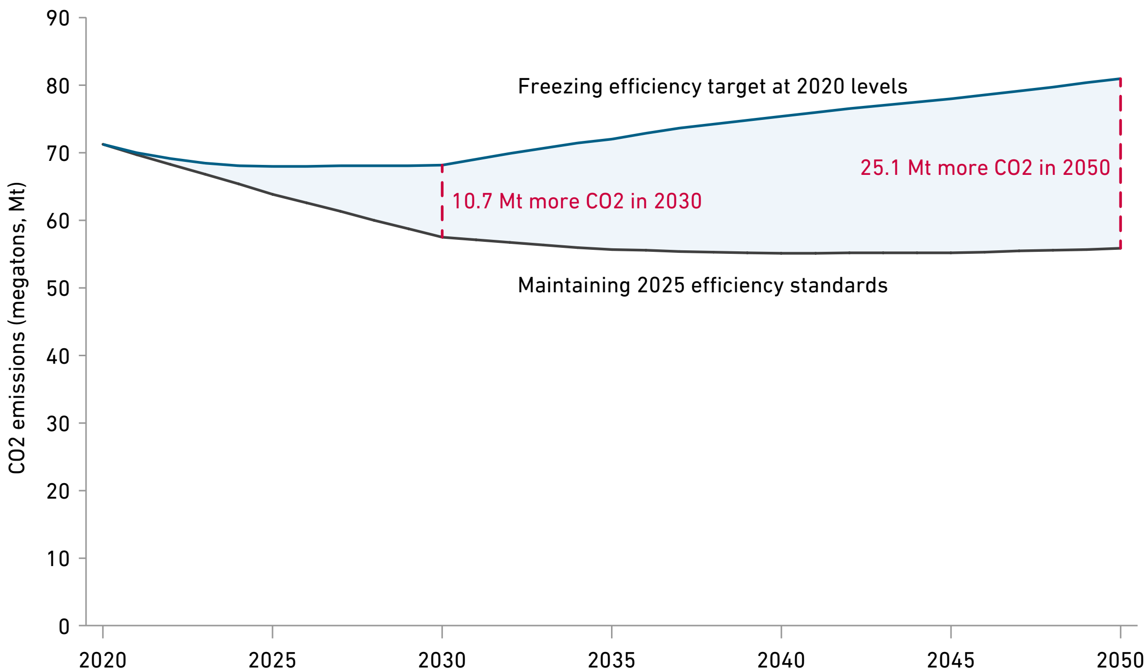


Source: International Council on Clean Transportation, https://theicct.org/chart-library-passenger-vehicle-fuel-economy, updated June2019

Because Canada's CAFE policy is based on reducing GHG emissions per kilometre, the GHG benefits are quite clear, where the current policy is already set to play a large role in 2030 GHG targets, and a strengthened version could also have a large role in 2050 targets. The evidence is as follows:

- Canada's current 2025 CAFE requirements can reduce 2030 GHG emissions from each light-duty vehicle (on average) by up to 35 per cent compared to 2015 (Sykes and Axsen, 2017).[28]
- A stronger CAFE requirement in Canada could reduce 2030 light-duty vehicle emissions by 50 per cent, and 2050 emissions by 60 per cent, relative to 2015 (Sykes and Axsen, 2017).[29]
- Rolling back Canada's 2025 CAFE requirements (like the U.S., freezing efficiency at 2020 levels), would increase 2030 light-duty vehicle emissions by about 18 per cent, and increase 2050 emissions by 45 per cent (Posada, Isenstadt et al., 2018) — depicted in Figure 8.

Figure 8: CO2 emissions from Canada's light-duty vehicle fleet with the 2025 efficiency standard, versus freezing the standard at 2020 levels



Source: Posada et al., 2018; used with authors' permission

28 Peer-reviewed journal article, specific to British Columbia.

29 Peer-reviewed journal article, specific to British Columbia.

As for secondary considerations, CAFE has been shown to successfully drive innovation and can be cost-effective while saving money for consumers, though the policy could be designed to be more effective. Specific evidence is as follows:

- Since the 1970s, the auto industry has continued to innovate and improve overall efficiency; however, this innovation has only translated to fuel economy improvements when guided by stringent CAFE standards (Lutsey and Sperling, 2005).
- Modelling of the U.S. CAFE finds that the policy can be relatively cost-effective from a broader social welfare perspective, if combined with a gasoline or carbon tax (Small, 2012).
- Canada's current 2025 CAFE requirements are expected to save money for consumers (Posada, Isenstadt et al., 2018).
- Existing technology and consumer preferences would have allowed compliance with the U.S. CAFE requirements, even before they were rolled back (Xie and Lin, 2017; Lipman, 2018).
- The current CAFE policy in Canada (and in the U.S. before the rollback) might allow too many loopholes; that is, automakers can comply with 2025 requirements without actually achieving the full reductions that are expected (Lipman, 2018). For example, special allowances are provided for ZEV sales, which lessens the combined GHG effects of CAFE and a ZEV mandate (Jenn, Azevedo et al., 2016).
- More could be done to help retire used, less-efficient vehicles (Keith, Houston et al., 2019), which would in turn increase the GHG impact of CAFE-like regulations.

6. EVIDENCE FOR TRAVEL (VKT) REDUCTION

PHOTO Roland Tanglao, Flickr CC BY 2.0.jpg

Main finding 5: In a region expecting significant population growth (like Metro Vancouver), a mix of well-designed VKT reduction initiatives could be an important mitigation strategy and play a minor role in 2030 and 2050 GHG mitigation targets. Of the individual strategies, road pricing can have the largest impact on VKT reduction.

In addition, VKT reduction can reduce traffic congestion while increased active travel and public transit service can help to achieve other desirable social goals, including improved health, accessibility and equity.

The third category (or "leg of the stool") for transportation GHG mitigation is travel demand reduction, commonly framed as reduction in vehicle kilometres travelled (VKT). Whereas the first two legs focus on technological solutions to vehicles (efficiency and low-carbon fuels), the third leg focuses on reduced vehicle use altogether, or on the reduced usage of private vehicles. We divide the various VKT reduction actions and policies into four categories: road pricing, the built environment (e.g., compact development and changes in land use), increased use of active travel (cycling and walking) and increased use of public transit. Results for such studies are often presented in terms of VKT reduction rather than GHG mitigation. The assumption is that, all else held constant, a reduction in VKT alone would translate to a proportional decrease in GHG emissions.

Related to VKT reduction is the goal of reduced car ownership. Intuitively, owning fewer (or zero) cars should translate to fewer VKT overall. However, there is less emphasis of research or policy focused on reduced car ownership. There is some potential for car-sharing programs to help reduce vehicle ownership (noted further in Section 7.1).

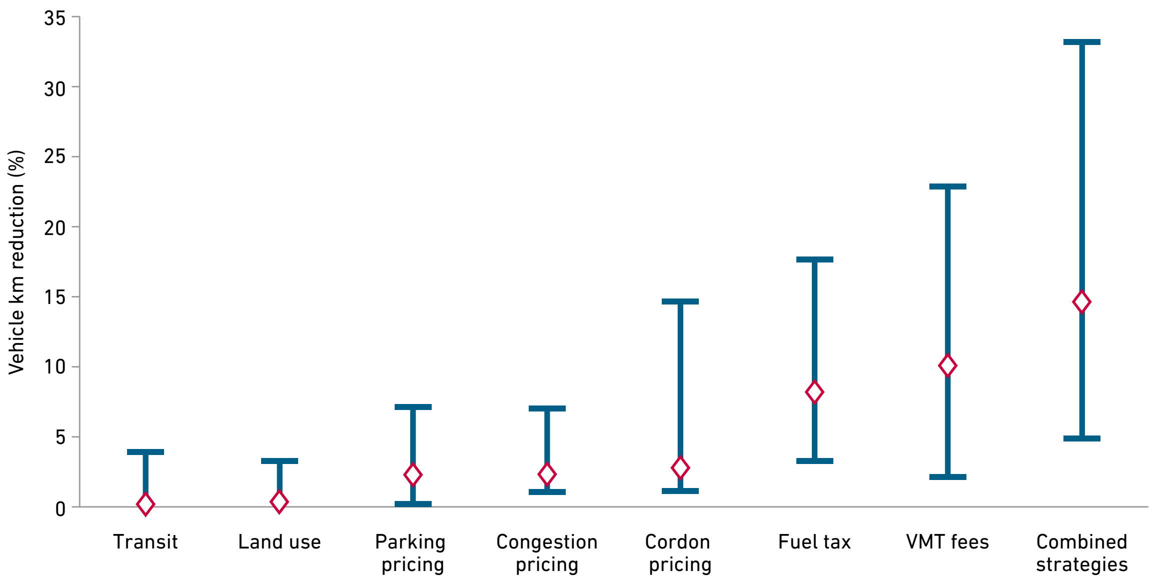
As noted in Section 2, the VKT for a region will be heavily impacted by population growth. In Metro Vancouver, the population is expected to increase by about 70 per cent during the study time frame, from 2.1 million in 2006 to 3.6 million in 2050. Without changes in travel patterns, total VKT in Metro Vancouver would grow by a comparable amount from 2007 to 2050. With that in mind, our evaluation indicates that VKT reduction measures are likely to play supporting to minor roles in GHG mitigation — helping to avoid a worsening GHG emissions scenario, and in some cases to help to combat the expected growth in VKT.

Some studies in the literature address VKT reduction in general (considering multiple types at once), while others zero in on a given category. This first summary considers VKT reduction strategies in aggregate, mainly studies that include some mix of increased road pricing, changes to the built environment, active travel and/or public transit. The following subsections provide more details on results for each category.

The general evidence for potential VKT reduction is as follows:

- A systematic review of modelling studies found that a "mixed" strategy of road pricing, improved transit and compact development could reduce VKT in a given year by seven to 23 per cent over 10 years of implementation, and 15 to 26 per cent over 30 years (Rodier, 2009). Comparing the impacts of individual measures, the highest impact was from road pricing, notably VKT-based pricing (five to 22 per cent VKT reductions over 30 years). Results are summarized for the 10-year timeline in Figure 8, where reductions do not address population growth.
- Others similarly argue that, in the past, VKT reduction strategies have at best slowed the growth of VKT, rather than reducing VKT (Poudenx, 2008).
- A modelling study of the City of Vancouver finds that investment in density, cycling, transit and road networks can hold VKT constant through to 2030, despite a growing population with increased transportation demand. In 2050, these measures can cut Vancouver's transportation GHGs by roughly 15 per cent relative to a scenario with no policy or action (Zuehlke, 2017).
- Modelling by the California Air Resources Board (CARB) expected VKT reduction strategies to account for eight per cent of transportation GHG emission reductions by 2020 — the rest being achieved through fuel economy standards (50 per cent), the LCFS (25 per cent) and GHG reductions in the freight sector (eight per cent). (Bedsworth, Hanak et al., 2011).

Figure 9: Summary of potential of different VKT reduction policies (Studies over 10-year time frame only, similar to 2030 targets for Metro Vancouver)



Source: Rodier's (2009) review of studies that model the effect of policies on VMT reduction.

A secondary consideration is that, due to the broad diversity of VKT reduction measures, it is important that they be well-coordinated and planned to be complementary, to assure that VKT reduction, GHG reduction and other social goals are met (Bedsworth, Hanak et al., 2011; Boston, 2017).

6.1 Road pricing

PHOTO Jason Tester, Flickr CC BY-ND 2.0

Main finding 6: Road pricing alone is an important mitigation policy and can play a minor role in meeting 2030 and 2050 GHG targets, if strong and implemented to directly discourage GHG emissions (not just congestion), ideally charged per kilometre driven or per unit of fossil fuel consumed.

Secondary considerations: road pricing can reduce congestion, support mode shift to active travel and associated health benefits, and generate funds to further support compact development, public transit and active travel. The impact of road pricing will likely be limited by political acceptability, though some research suggests that public opposition can be potentially overcome through careful design (to avoid inequity) and clear communication of acceptable goals.

Road pricing is a broad category of pricing mechanism that can serve to reduce VKT, congestion and/or GHG emissions. Some have argued that road pricing is the most important start for VKT reduction, such as Manville's (2017) summary:

"Governments give drivers free land; people as a result drive more than they otherwise would. That's it. The rest is commentary."

Road pricing is most commonly thought of as a way to fund road management, control congestion or reduce traffic in urban areas. However, it can also be a means to meet GHG reduction goals, and to support other VKT reduction strategies, such as increased use of transit and active travel. Road pricing can take a broad number of forms, including:

- A fuel tax or carbon tax, which increases the price of a unit of gasoline or diesel, and thus is charged for actual driving behaviour (VKT). It produces an incentive for reduced VKT and more fuel-efficient vehicle use.
- Cordon pricing applies a charge to drive into a particular area, such as a downtown core.
- Congestion-based pricing charges higher prices to use roads at peak times of day. The primary goal is to reduce peak congestion, not necessarily overall VKT.
- VKT (or distance-based) pricing is somehow charged based on the overall usage of the vehicle, such as a "pay as you go" insurance plan. Such systems may or may not account for the carbon intensity of travel (e.g., with or without reduced rates for ZEVs).
- Parking pricing includes charges meant to discourage driving vehicles to particular areas.

Although road pricing is found to be the most effective means of reducing VKT, no study has shown the potential for such VKT reductions to overcome the likely VKT increases that will come with the magnitude of population growth expected in the Metro Vancouver region. Instead, studies demonstrate the types of GHG reductions that can be expected in a future year (rather than compared to 2007). The evidence is as follows:

- A recent systematic review finds that road-pricing schemes can reduce GHG emissions in a given year, with effectiveness varying by type of program (Cavallaro, Giaretta et al., 2018):[30]
  - For pricing on cordon areas, fees ranging from one to 10 euros can reduce CO2 emissions by two to 10 per cent;
  - For distance-based fees, reductions average around 13 per cent, reaching as much as 36 per cent in the example of Cambridge, U.K.; and
  - For "pay-as-you-drive" insurance, emissions reductions are eight to 12 per cent.
- Another systematic review similarly finds that the effectiveness of road pricing at reducing VKT in a given year depends on the design, and how long the road pricing scheme is in place (Rodier 2009), where:[31]
  - Cordon pricing can reduce VKT by one to six per cent over 10 years (same over 30 years).
  - Parking pricing can reduce VKT by one to three per cent over 10 years (same over 30 years).
  - Congestion pricing can reduce VKT by two to seven per cent over 10 years, and three to eight per cent over 30 years.
  - VKT pricing can reduce VKT by four to 14 per cent over 10 years, and five to 22 per cent over 30 years.

30 Peer-reviewed journal article, systematic review.

31 Peer-reviewed journal article, systematic review.

    - Fuel taxation can reduce VKT by four to 17 per cent over 10 years, and four to 16 per cent over 30 years.

- A recent Metro Vancouver analysis found that a “decongestion price” can reduce VKT by four to six per cent and GHG emissions by two to four per cent in 2030, compared to a 2030 baseline (Mobility Pricing Independent Commission, 2018). Note that the suggested road price was relatively low due to anticipated political acceptability (not fully accounting for all the social costs of driving). A higher road price would have larger impacts.
- As will be noted in Section 7, road pricing might be especially important to guide development of future “new mobility” options (Hensher, 2018), notably to avoid rebound effects from the potential low travel costs offered by future vehicle electrification, automation (Wadud, MacKenzie et al., 2016) and ride-hailing (Coulombel, Boutueil et al., 2019).

As noted, road pricing can also offer a number of additional social benefits (Gouldson, Sudmant et al., 2018). The Metro Vancouver study noted above indicates that a “decongestion price” could result in travel time savings of 20 to 25 per cent in 2030, and improve travel reliability by 17 to 20 per cent (Mobility Pricing Independent Commission, 2018). The estimated net economic benefit of this plan would be from $220 to $290 million a year (Mobility Pricing Independent Commission, 2018).

The major drawbacks of congestion pricing are the potential for negative equity impacts and political opposition. Negative equity impacts mainly involve the potential for unfair hardship on lower-income drivers and households. However, several studies indicate that such equity impacts can be alleviated through better design of the road-pricing scheme (Eliasson and Mattsson, 2006; Levinson, 2010; Vandyck and Rutherford, 2018). Similarly, citizen or political opposition to road pricing can potentially be overcome with clear, positive framing about the program’s goals and potential benefits (Balbontin, Hensher et al., 2017; Nikitas, Avineri et al., 2018). Communicating how the road-pricing revenue will be used to achieve these goals and benefits is also important for acceptance (Balbontin, Hensher et al., 2017).

6.2 Built environment (and compact development)

PHOTO Glotman Simpson, Flickr CC BY-NC 2.0

Main finding 7: Actions to improve the built environment (including increased density, diversity and transit-oriented development) are complementary and can play a supporting role in mitigating transport GHGs. Failure to sustain existing density levels in the face of population growth could lead to a worsening of GHG impacts.

In addition, improvements to the built environment can offer a variety of other social benefits, including improved health (by supporting active travel), affordability and support for economic activity.

There are many terms for improvements to the built environment, including compact development, smart development and smart growth. The built environment inevitably shapes energy use and transportation patterns of those living in it. Such patterns can vary substantially across different types of neighbourhoods. Notably, what is called the “active core” has the highest proportion of active travel trips, yet makes up only 12 per cent of the Canadian population (Gordon and Shirokoff, 2014). In contrast, 70 per cent of the population lives in “auto suburbs” with negligible public transit or active travel, which is also where 80 per cent of population growth is occurring nationally (Gordon and Shirokoff, 2014). In the City of Vancouver, 96 per cent of population growth is in the active core and in areas with high access to transit, while in the rest of Metro Vancouver, 83 per cent of growth is in auto suburbs and rural (exurban) areas.[32]

32 Source: http://www.canadiansuburbs.ca/canadiancitygrowthchart.html

Clearly, trends in the built environment and population growth are associated with VKT trends. Importantly, more dense neighbourhoods (e.g., the active core) are associated with lower energy use and fewer VKT. However, it is difficult to tease out cause and effect. For example, do people drive less because they live in a dense neighbourhood, or do they choose to live in a dense neighbourhood because they prefer to drive less? A number of studies explore such "self-selection" effects, where individuals may have certain attitudes that lead them to choose to live in a more dense area and to drive relatively less — or, conversely, to want to live in a suburban or rural area, and to drive relatively more (Cao, Mokhtarian et al., 2009; van Wee, 2009). Some studies suggest that such attitudes can explain a large part of travel behaviour, rather than the built environment itself (Handy, Cao et al., 2005), including vehicle ownership (Van Acker, Mokhtarian et al., 2014). This complexity presents a large challenge to isolating the impact of the built environment on travel patterns (and GHG impacts).

For its part, the Province of British Columbia and most of its municipalities have agreed to a Climate Action Charter, where local governments will "develop strategies and take actions" to achieve a number of goals, including:[33]

> *"Creating complete, compact, more energy efficient rural and urban communities (e.g. foster a built environment that supports a reduction in car dependency and energy use, establish policies and processes that support fast tracking of green development projects, adopt zoning practices that encourage land use patterns that increase density and reduce sprawl)."*

Improving the built environment is not simply about household density. The relationship between built environment and VKT is commonly broken down into five principles, or the "Five Ds" of built environment (Ewing and Cervero, 2010):

1. "Density" is often the main focus, which can be measured as population density or household density;
2. "Diversity" measures the number of different land uses in a given area, which can be measured using jobs-to-population ratios (among other measures);
3. "Design" or connectivity relates to street network characteristics, ranging from highly connected urban grids (with lots of intersections and pedestrian crossings, smaller blocks) to sparse suburban networks (cul-de-sacs, long streets, few pedestrian sidewalks);
4. "Destination accessibility" tries to measure the ease of access to key attractions, such as distance to the central business district, or jobs reachable in a given travel time; and
5. "Distance to transit" measures the average distance between homes and bus or train station stops.

33 Source: https://www2.gov.bc.ca/assets/gov/british-columbians-our-governments/local-governments/planning-land-use/bc_climate_action_charter.pdf

The best evidence for the relationship between built environment and VKT reduction comes from several systematic reviews published over the past decade. Each of these reviews suggests that while improvements to the built environment can indeed reduce VKT, the impact tends to be quite low. The evidence is as follows:

- A systematic review of various built environment strategies (including increasing housing density and transit-oriented development) finds that such strategies can reduce VKT in a given year by 0.1 to two per cent over 10 years, and by 0.1 to six per cent over 30 years (Rodier, 2009).[34]
- Another systematic review finds that changes to the built environment have little impact on VKT, where any effects are small or inelastic (Ewing and Cervero, 2010). Following the "Five Ds", the VKT responses are very low for increases in density and diversity. The largest effects (which are still small) in VKT are from increased destination accessibility (lower distance to downtown, and improved job accessibility).[35]
- A more recent (or updated) systematic review echoes these same findings of only minor (inelastic) responses to changes in the "Five Ds"(Stevens, 2017).[36]
- A modelling study of four Canadian cities finds that urban densification can cut 2030 energy consumption by two to five per cent (compared to the baseline in that year) and 2050 GHG consumption by four to eight per cent, which in each case does not come close to offsetting expected growth in GHG emissions (Doluweera, Hosseini et al., 2019).[37]
- Similarly, others find that, at best (and if combined with road pricing), compact development in Metro Vancouver can help to partially offset the expected growth in annual VKT and GHG emissions by 2050 (Bataille, Goldberg et al., 2010).

As with other VKT reduction measures, improvements to the built environment can offer several secondary benefits. Compact development in Metro Vancouver can potentially lead to more substantial GHG reductions in the building sector and energy supply sector (Bataille, Goldberg et al., 2010). Also, compact development can occur while sustaining or even improving economic activity in the region (Bataille, Goldberg et al., 2010). Improvements to the built environment can improve walkability, with health benefits and decreased obesity (Ewing, Bartholomew et al., 2007), and compact development can increase housing supply and improve affordability (Boston, 2017).

34 Peer-reviewed journal article, systematic review.

35 Peer-reviewed journal article, systematic review.

36 Peer-reviewed journal article, systematic review.

37 Peer-reviewed journal article, Canada-focused.

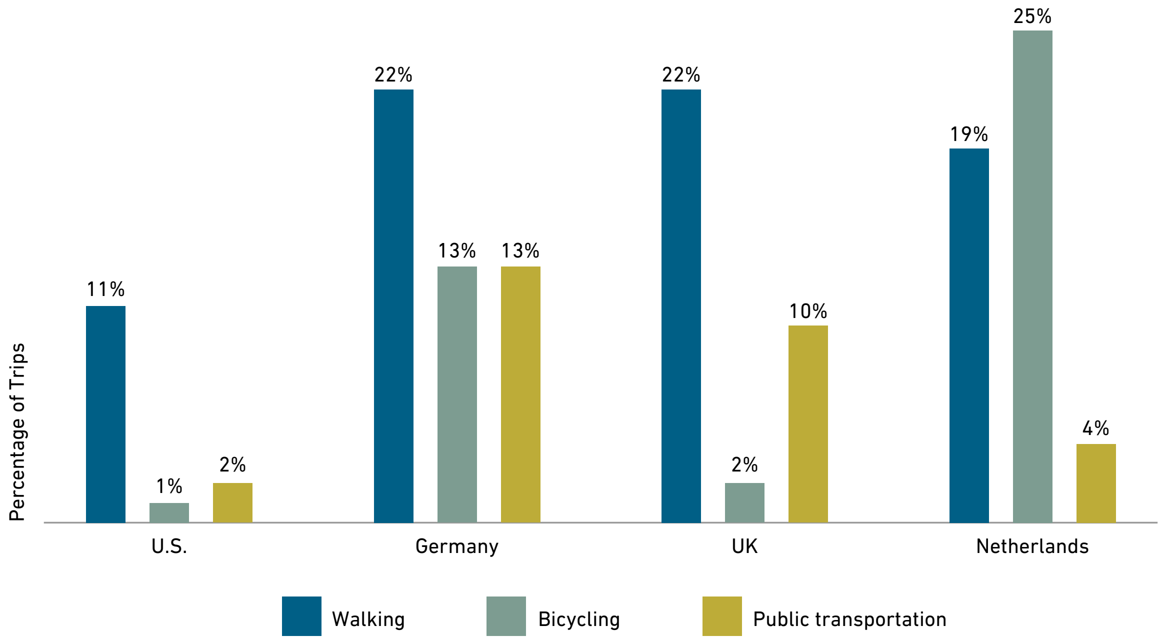
6.3 Active travel (cycling, walking, etc.)

Main finding 8: Initiatives to increase cycling and walking are complementary and can play a supporting to minor role in 2030 and 2050 GHG targets, though they can complement a larger strategy to reduce VKT and GHGs. Failure to sustain active travel infrastructure in the face of population growth could lead to a worsening of GHG impacts.

Secondary considerations: Increasing the share of active travel offers clear health and social benefits.

The term "active travel" mainly refers to walking or cycling for travel. Among developed countries, active travel can account for 12 per cent of trips (in the United States) to a high of 44 per cent (in the Netherlands), as depicted in Figure 9. Active travel tends to be promoted primarily for the resulting health benefits, where regular walking or cycling can help to reach the recommended 150 minutes of physical activity per week (Buehler, Gotschi et al., 2016). Of course, if the uptake of active travel is replacing vehicle use, then active travel can be a means of reducing VKT and GHG emissions from transportation.

Figure 10: Rates of active travel in different countries



Source: Buehler, Gotschi et al., 2016

In this section, we briefly summarize the evidence for how active travel may relate to VKT and GHG reductions, and then consider other social benefits, and recommendations for how to improve active travel rates. To start, the evidence suggests that active travel is likely to play a small role in 2030 and 2050 GHG targets, though there are few studies that focus on this research question. The existing evidence includes:

- As noted earlier in this section, a modelling study of the City of Vancouver finds that investment in density, cycling, transit and road networks can at best hold VKT constant through to 2030, despite a growing population with increased transportation demand (Zuehlke, 2017). The study did not tease out the specific effects of the active travel initiatives.
- A modelling study of California finds that an ambitious cycling-focused strategies could lead to an eight per cent reduction in 2040 car GHG emissions (compared to a no policy scenario), which would be equal to 2010 emissions in that region (Maizlish, Linesch et al., 2017).
- A Montreal-based model simulated that a further seven per cent increase in the cycling network could lead to a two per cent reduction in commuting GHG emissions in a given year (Zahabi, Chang et al., 2016), not accounting for population growth.

In contrast, there is clear and robust evidence for the significant health and social benefits of active travel, including the following studies:

- In the vast majority of contexts, the health benefits of active travel (physical activity) greatly outweigh any added health risks (injury or exposure to air pollution) (Mueller, Rojas-Rueda et al., 2015; Buehler, Gotschi et al., 2016).

- Studies indicate that just the health benefits of policies that increase active transport can make them cost-effective, regardless of GHG or congestion reduction (Winters, Buehler et al., 2017).[38]
- Among different strategies to support active travel, a modelling study of California finds that ambitious cycling-focused strategies lead to more long-term (2040) health benefits than walking- or transit-focused strategies (Maizlish, Linesch et al., 2017).
- Pedestrians and cyclist commuters tend to be happier than commuters who drive or use the subway or bus (St-Louis, Manaugh et al., 2014).

Further, a number of studies have reviewed evidence for how to increase the uptake of active travel:

- Policies that promote active transport are most effective when applied comprehensively with other VKT reduction (and smart growth) strategies (Winters, Buehler et al., 2017).[39]
- Improvements to the built environment, including mixed use and improved street connectivity, can increase cycling (Buehler, Gotschi et al., 2016; Winters, Buehler et al., 2017).[40] Such improvements can also increase walking, though the impacts are quite low (Ewing and Cervero, 2010).
- Improved access to cycling networks, bike parking and related facilities can increase cycling (Winters, Buehler et al., 2017).[41]
- Policies that make cars less attractive (road pricing, parking fees, lower speed limits) can increase active travel (Winters, Buehler et al., 2017).[42]
- Looking at Montreal commuting data from 1998 to 2008, researchers found that a 10 per cent increase in the cycling accessibility index is associated with a four per cent increase in ridership (Zahabi, Chang et al., 2016).
- If planned effectively, improved public transit can complement and encourage active travel (Winters, Buehler et al., 2017).[43] At the same time, there can be some competition between active travel and transit (Nielsen, Olafsson et al., 2013).
- Active travel is best promoted by improved convenience, safety and connectivity (Buehler, Gotschi et al., 2016).
- Some targeted behaviour-change programs can be effective in shifting behaviour (increasing active travel to account for up to five per cent of household trips), though it is not clear if larger-scale behaviour-change programs can be effective (Scheepers, Wendel-Vos et al., 2014; Buehler, Gotschi et al., 2016; Petrunoff, Rissel et al., 2016).
- Another review study finds that behaviour-change programs can decrease car mode share by five percentage points (Bamberg and Rees, 2017).
- Safety and perceived safety of active transport are crucial to increasing this mode share (Winters, Buehler et al., 2017). Actual and perceived safety are higher where more people participate in active travel.

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38 Peer-reviewed journal article, systematic review.

39 Peer-reviewed journal article, systematic review.

40 Peer-reviewed journal article, systematic review.

41 Peer-reviewed journal article, systematic review.

42 Peer-reviewed journal article, systematic review.

43 Peer-reviewed journal article, systematic review.

6.4 Public transit

PHOTO Pau Casals, Unsplash

Main finding 9: Improved public transit service is expected to play a supporting role in 2030 and 2050 GHG abatement. Failure to sustain public transit service and infrastructure in the face of population growth could lead to a worsening of GHG impacts.

Secondary considerations: a well-designed public transit system can provide equity and accessibility to the broader population, and complement a broader package of policies to reduce VKT.

Public transit includes buses, subways (or SkyTrain), light rail and commuter rail (like the West Coast Express). Transit development is motivated by a variety of goals, including alleviating traffic and parking congestion, providing mobility options and access or equity, reducing traffic accidents, and reducing energy use, air pollution and GHG emissions (Litman, 2019), while environmental goals tend to be of lower priority. That said, any investments or initiatives that replace vehicle trips with transit trips would serve to reduce VKT and GHG emissions in a region (all else held constant).

As in the active travel section, we briefly summarize the evidence for how improved public transit may relate to VKT and GHG reductions and then consider other social benefits and recommendations for how to improve active travel rates. The existing evidence suggests that the GHG impacts from public transit investment would be limited:

- A systematic review of various transit service improvement strategies finds that such strategies can reduce VKT in a given year by 0.1 to one per cent over 10 years, and by 0.2 to three per cent over 30 years (Rodier, 2009).[44]

44 Peer-reviewed journal article, systematic review.

- Investment in public transit tends to yield a small (inelastic) response in VKT reduction, with a one per cent increase in transit networks leading to 0.16 per cent reduction in VKT (McIntosh, Trubka et al., 2014).
- One study finds reduced transit fares do not translate into reductions in transportation energy use in the region (Liddle, 2013).

There is more evidence for the potential secondary benefits and impacts of transit development, including:

- There can be significant health, safety and economic benefits from improved transit use (Gouldson, Sudmant et al., 2018).
- While there is some concern that improving transit services may increase home costs (Kramer, 2018), transit-oriented development can result in lower transport costs that offset higher housing costs (Renne, Tolford et al., 2016).

Further, a number have studies have reviewed evidence for how to increase the uptake of public transit:

- A systematic review of the impacts of the built environment shows that the biggest increase in transit use comes from improved access to and from the transit system, with increased intersection density and reduced distance to the nearest transit stops (Ewing and Cervero, 2010).[45]
- A travel survey in Ontario found that big barriers to transit usage include unreliable service, cheap parking passes and the need to make transfers (Agarwal and Collins, 2016).The most common actions noted in the survey that would be expected to increase transit use are prohibitive parking costs, faster/more direct transit routes and subsidized employee transit rates.
- As further noted in the next section on "new mobility," transit market share can face particularly strong competition with the emergence of ride-hailing services (Clewlow and Mishra, 2017).
- On the positive side, an emerging area of research is exploring mobility-as-a-service (MaaS), where public transit could be seamlessly integrated with other modes to provide a complete transportation service with one payment; e.g., car-share, bike-share or ride-hailing (Lyons, Hammond et al., 2019). Research is only exploratory at this stage, though there is some evidence that such "bundling" of transportation options could be appealing to some consumers (Matyas and Kamargianni, 2018).

45 Peer-reviewed journal article, systematic review.

7. EVIDENCE FOR "NEW MOBILITY"

PHOTO Richard Eriksson, CC BY 2.0

Main finding 10: the emergence of car-sharing programs, ride-hailing, automated vehicles (AVs) and other forms of "new mobility" could have a range of positive and negative social impacts, notably for GHG mitigation. Important and priority mitigation policies are needed to increase the probability of positive social impacts, including GHG mitigation.

In recent years, transportation stakeholders have become increasingly interested in what some call "new mobility," a term that includes emerging forms of shared mobility and automation, among other innovations.[46] As we have already addressed vehicle electrification elsewhere, here we consider three particular modes: car-sharing, ride-hailing and automation.

There remains considerable uncertainty about the likelihood of widespread deployment, uptake and usage of these innovations, and the ultimate magnitude and direction of societal impacts (Axsen and Sovacool, 2019). Several modelling studies have shown the dramatic potential for positive impacts resulting from a fleet of shared, automated, electric vehicles, under idealized conditions. As examples:

- One study shows how, under ideal conditions, automated taxis could cut GHG emissions (per km) by 87 to 94 per cent compared to conventional vehicles, even with substantial increases in vehicle travel, average speed and vehicle size (Greenblatt and Saxena, 2015).
- Similarly, Viegas et al. (2016) use travel data from Lisbon, Portugal, to show that a fleet of shared taxis and vans could meet travellers' requirements with 97 per cent fewer vehicles, 95 per cent less parking space, 37 per cent fewer vehicle kilometres and much lower operating costs.

46 Other terms include the "Three Revolutions" (Sperling, 2018), as well as ACES (automated, connected, electric and shared mobility).

- Finally, Alonso-Mora et al. (2017) find that 98 per cent of New York taxi demand could be met with 15 to 20 per cent of the vehicles (if shared and automated) with no projected negative service impact.

While such visions and scenarios of "new mobility" are inspiring, they should be viewed as a type of boundary analyses — in these cases as attempts to anticipate the potential extreme positive outcomes of such technological transitions. However, there is no clear evidence that shared mobility or automation will necessarily lead to GHG or other societal benefits; GHG increases are also possible.

7.1 Car-sharing

Main finding 11: Car-share programs provide a useful travel option for some households, though the present and future impacts on vehicle ownership, VKT and GHG emissions are uncertain. GHG and social benefits could be improved if coordinated with VKT reduction measures, such as road pricing and improved transit.

We split the broad concept of shared mobility between vehicle sharing (e.g., car-sharing or bike-sharing) and ride sharing (e.g., ride-hailing or car-pooling). Car-sharing (or a "car club" in the U.K. and Europe) involves the adopter paying an hourly (and/or mileage-based) rate to pick up a vehicle, use it and return it somewhere (Cervero, Golub et al., 2007). Car-share programs vary in their requirements for parking (station-based or free-floating) and trip structure (one-way or two-way). An emerging version, peer-to-peer (P2P) car-sharing, allows individuals to rent out their personal vehicles.

Overall, car-share users are driven by a variety of motives. The most common reasons for using car-share in Vancouver are convenience and saving money, while more than half of users also mentioned environmental concern as a motivation (Vancity, 2018). The main barriers to car-share tend to be the required changes in time management and convenience, and learning to adapt to a new system (Kent and Dowling, 2013).

The net societal impacts of car-sharing programs are uncertain. It is considered by some as a potential pathway to reduce vehicle ownership and VKT (Firnkorn and Müller, 2011; Baptista, Melo et al., 2014). For example, a survey study suggested that car-share programs lead to reduction of vehicles owned, from an average of 0.47 vehicles per household to an average of 0.24, mostly due to some one-car households becoming carless (Martin, Shaheen et al., 2010). A Vancouver-based study warns, however, that when non-car users join car-share, they end up increasing travel (VKT), which can increase energy and GHG impacts (Namazu, MacKenzie et al., 2018). Taken together, it is not clear if the emergence of car-share programs will play a significant role in 2030 or 2050 GHG goals. However, it is advisable that transportation planners consider it as a travel mode that could possibly be supported to help achieve various social goals in the transportation system.

7.2 Ride-hailing

PHOTO Charles, Unsplash

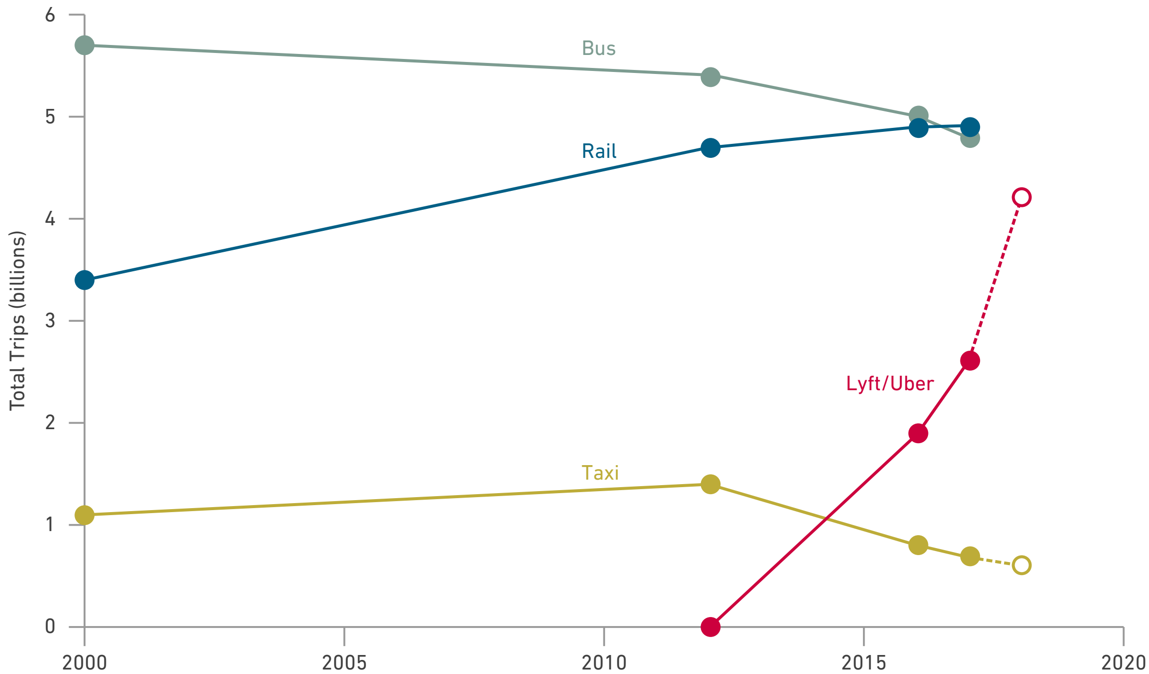
Main finding 12: Ride-hailing is providing a competitive transportation mode in many cities it enters, though its present and future impacts on VKT and GHG emissions are variable and uncertain. The presence of important and priority mitigation policies are likely needed to guide ride-hailing in a low-carbon direction, including the road pricing and regulations noted above.

In addition: careful policy design could aim to increase the use of "pooled" ride-hailing (multiple travellers per vehicle), and to better complement (rather than compete with) public transit and active travel.

Another broad category of shared mobility is ride-hailing, typically defined as an app-based platform that allows users to hail a ride from a professional or semi-professional driver — with Uber and Lyft being the most well-known service providers (Shaheen, 2018). It is common and arguably important to distinguish between i) individual-use ride-hailing, that is, alone or with friends/acquaintances, and ii) "pooled" ride-hailing where a trip is shared with one or more strangers (aside from the driver) and generally require multiple pickup and drop-off points.

As with car-sharing, the environmental impacts of ride-hailing are uncertain. There is some evidence that increased uptake has led to increases in vehicle travel (Schaller, 2017), and decreases in transit and taxi usage (Clewlow and Mishra, 2017; Shaheen, 2018). In a study of seven major U.S. cities, 21 per cent of respondents used ride-hailing, with top motivations including parking concerns and plans to drink alcohol (Clewlow and Mishra, 2017). The study also shows that ride-hailing seems to have reduced bus use in these cities (by about six per cent), and light rail use (by three per cent), while it may have helped to increase commuter rail usage (by three per cent) by helping to address the "last mile" problem. Figure 10 depicts these trends from a separate study. In total, ride-hailing can increase VKT, at least in the studied cities.

Figure 11: The impact of ride-hailing on mode share in U.S. cities



Source: Transit data from APTA, Taxi data from US Census, and projections from Schaller Consulting (2018)

Relatedly, a modelling study based in Paris, France, found that widespread uptake of ride-hailing might lead to "rebound effects," where time and cost savings lead to increased travel that can partially cancel out any social benefits (Coulombel, Boutueil et al., 2019). They found that such rebound effects could cancel out 52 to 73 per cent of aggregated social benefits (including congestion, air quality, CO2 emissions, noise), and 68 to 77 per cent of CO2 emission reductions. Among the listed rebound effects, the patterns include some people switching from public transit and active modes to the ride-hailing car, people travelling longer distances than they would otherwise, and people relocating their residence further from the urban centre than they would otherwise.

Due to the potential for ride-hailing to increase VKT, Sperling (2018) argues that widespread use of pooling (ride-hailing with multiple users per vehicle) is essential to ensure that ride-hailing helps to reduce overall VKT and thus contribute to GHG targets and other societal goals. Transportation stakeholders ought to consider these trends as ride-hailing services are deployed in Metro Vancouver.

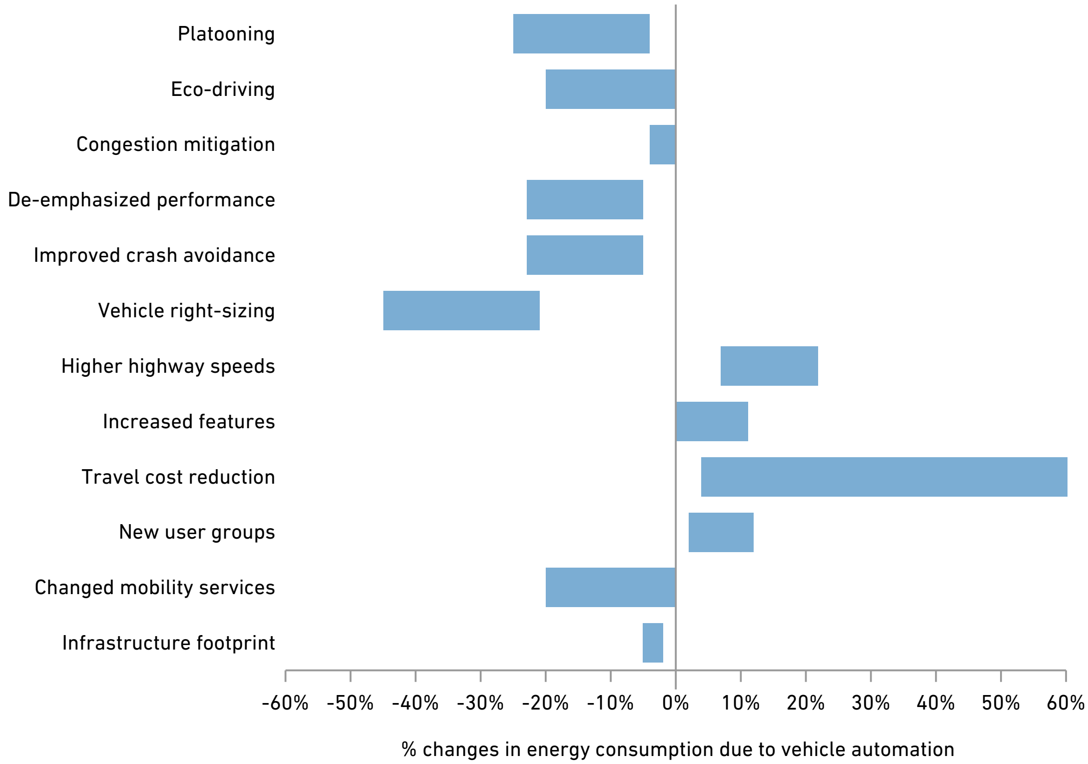
7.3 Automated vehicles (AVs)

Main finding 13: Automated vehicles present a wide range of potential benefits and threats to sustainable transportation goals, with scenarios demonstrating their potential to halve or double GHG emissions. Important and priority mitigation policies are needed to guide development in a low-carbon direction, particularly the regulations and pricing policies noted in previous findings.

We use the term automated vehicles, while acknowledging that the terms autonomous and self-driving vehicles are often used synonymously (Sperling, van der Meer et al., 2018). According to the five-level SAE system of automation (J3016), Levels 1 and 2 include automated features that are already available in the market (e.g., adaptive cruise control, self-parking and lane changes). Level 3 automation can fully drive itself, though the driver needs to be ready to take over on short notice (typically keeping hands on the steering wheel). Our definition of AV targets Levels 4 and 5, which require no driver attention. A Level 4 AV cannot drive in all possible conditions (e.g., extreme weather, traffic emergency), while a Level 5 AV can. Level 4 and 5 AVs are not currently available for sale, though many companies (automakers and others) have announced plans to introduce full AVs to the market in coming years (ranging from as early as 2020 to 2040 or beyond).

Widespread AV uptake could profoundly affect society with a wide range of positive and negative scenarios for GHG emissions and energy impacts. Wadud et al. (2016) provide a particularly useful analysis of boundary conditions for automated vehicles (including scenarios with sharing and electrification), finding that calculations of energy use and GHG emissions impacts could range from half to double present day emissions, depending on consumer uptake and technology usage. Figure 11 summarizes their results, where a number of impacts can reduce GHG emissions (e.g., if the AVs drive more efficiently and facilitate usage of smaller vehicles), and other impacts can increase GHG emission (e.g., if accessibility to new user groups and the reduced costs of travel leads to more VKT overall).

Figure 12: The impact of vehicle automation on energy use



Source: Wadud et al., 2016

Similarly, Milakis et al. (2017) provide a broader, three-order framework to organize qualitative thinking and estimates of AV impacts, broken down as i) day-to-day usage impacts (travel costs and choices), ii) impacts to long-term decisions (vehicle ownership, sharing, residence choice) and iii) overall societal impacts (energy, environment, equity and health). Sperling et al. (2018) simplify the possibilities into two extremes for future transportation systems. The "heaven" scenario improves safety, accessibility and equity among travellers, who forgo private ownership, and willingly subscribe to a system of shared, automated, electric vehicles that slash energy use and GHG emissions, saving road space that could be reallocated to other socially beneficial uses (e.g., green space). In stark contrast, the "hell" scenario exploits automation to further entrench private vehicle ownership and increased vehicle use (including "empty" miles or "deadheading", when the AV drives with no humans), exacerbating suburban sprawl and fossil fuel usage and further diminishing public transit and active travel modes.

In short, the range of potential AV futures is wide and uncertain, though most of the effective policies reviewed in this report so far could help to guide AV development toward the pathway of GHG reductions and other social benefits.

8. EVIDENCE FOR HEAVY-DUTY AND FREIGHT VEHICLES

PHOTO Dennis Schroeder, National Renewable Energy Lab (CC BY-NC-ND 2.0)

Main finding 14: The GHG emissions from heavy-duty vehicles (primarily involved in freight transportation) are just as significant as the emissions from passenger vehicles, yet policy is weaker in this sector. As with passenger vehicles, important and priority mitigation policies are needed to have major GHG reductions in this sector, notably a ZEV mandate, LCFS and vehicle efficiency standards.

The road transportation sector is often split between passenger travel and freight (or goods movement), or between light-duty vehicles and heavy-duty vehicles. Overall, less research and policy attention is devoted to climate policy relating to freight or heavy-duty vehicles. GHG emissions from on-road, heavy-duty trucks (HDVs) involved in freight transport account for about 12 per cent of British Columbia's GHG emissions, similar to the total amount from light-duty cars and trucks.[47] HDV emissions increased by eight per cent between 2007 and 2016, yet this sector was largely neglected in the recent B.C. climate plan (Government of British Columbia, 2018). HDVs account for about five per cent of GHG emissions in Metro Vancouver. Nationally, freight makes up about 11 per cent of Canada's GHG emissions, and is expected to exceed passenger vehicle emissions by 2030 (Plumptre, Angen et al., 2017) due to a combination of expected growth in freight activity and a lack of climate policy in the sector. Freight vehicles are also known to have particularly harmful health effects due to air pollution from diesel, especially in urban areas (Coulombel, Dablanc et al., 2018).

Current freight policies in Canada are weak, mainly being voluntary information provision programs (Plumptre, Angen et al., 2017). A model of Canada's freight sector finds that current and announced policies for freight (including efficiency standards, carbon pricing and LCFS)

47 https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

are not strong enough to decrease future GHG emissions (Hammond, 2019). Similar to light-duty vehicles, GHG emissions can be reduced for HDVs via efficiency improvements and switching to low-carbon fuels.

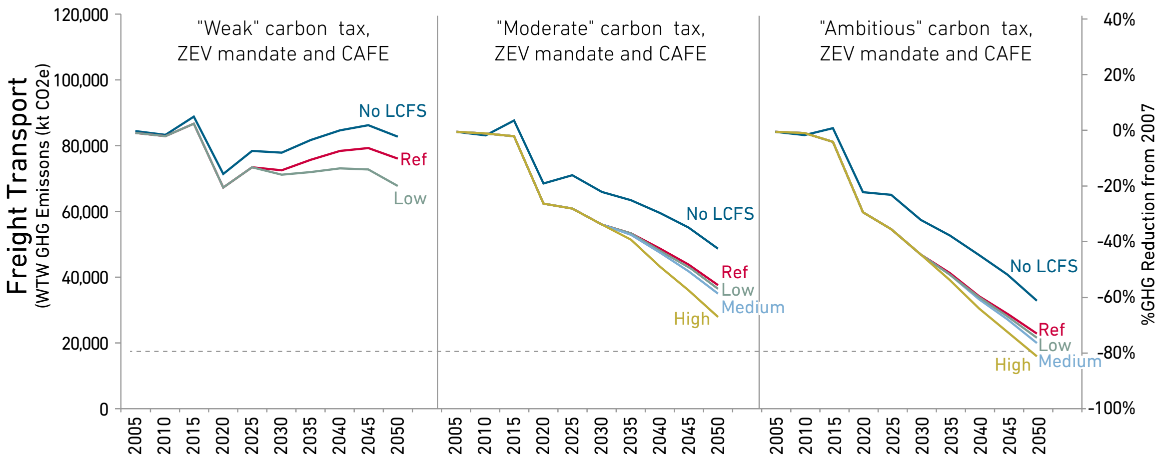
A U.S.-based study finds that many efficiency technologies are available and that the most advanced technology package reduces fuel consumption by 54 per cent, generating $226,000 to $552,000 worth of lifetime fuel savings (Meszler and Lutsey, 2015). The same study finds that for a range of efficiency packages, the median "payback period" is 1.5 years. In short, increased fuel efficiency standards for HDVs would save costs for the operators while also reducing energy use and GHG emissions. Some find, though, that even stringent efficiency policy is not strong enough to achieve 2050 targets in freight, where low-carbon fuels would also have to be used (Talebian, Herrera et al., 2018).

Although it was once thought that it would be difficult to commercialize alternative fuels in the HDV sector, in recent years hydrogen- and electric-powered HDV drivetrains have shown increasing promise. Work by the International Council on Clean Transportation compares the suitability of different options, finding that pure BEVs may be better for shorter-distance vehicles (delivery vans and trucks, refuse trucks); electric catenary vehicles might work better for medium- to heavy-duty trucks and drayage trucks; and hydrogen might be better for HDVs in long-haul operation (Moultak, Lutsey et al., 2017). Researchers at the University of California, Davis, have produced a similar analysis, favouring the potential for catenary electric trucks, which have lifetime costs not much higher than conventional diesel trucks (Zhao, Wang et al., 2018). Other studies suggest that hydrogen and BEVs provide promising low-carbon options (Moultak, Lutsey et al., 2017; Zhao, Wang et al., 2018), though natural gas drivetrains will only provide marginal GHG reductions of about 15 per cent (Lajevardi, Axsen et al., 2018). Several studies indicate that the suitability of different low-carbon fuels will differ by usage (Moultak, Lutsey et al., 2017; Liimatainen, van Vliet et al., 2019).

Modelling of British Columbia shows that a strong LCFS could play an important role in achieving 2050 targets in the freight sector, being responsible for about 20 per cent of GHG reductions out to 2050 (Lepitzki and Axsen, 2018). See Figure 12.[48] A Canada-based modelling study suggests that a stringent ZEV mandate and LCFS for the freight sector could make the largest contributions to 2050 GHG targets, followed by strong HDV-specific efficiency standards (Hammond, 2019).

48 Peer-reviewed journal article, British Columbia-based.

Figure 13: Impacts of an LCFS on GHG reductions in the freight sector



Source: Leptizki and Axsen, 2018

As one promising trajectory for heavy-duty vehicles, TransLink is proposing to replace most of its buses with electrified versions (e-buses), such that by 2040, its fleet would be entirely powered by electricity (aside from a few hundred buses powered by biofuels such as renewable natural gas or biomethane).[49] TransLink estimates that the life-cycle GHG emissions of e-buses will be at least 90 per cent lower than current diesel buses, and that the lifetime costs of e-buses will be cost competitive with conventional buses by 2025 or earlier. A recent report offers further support for bus electrification in Canada, due to reduced costs, GHG savings and the potential to support e-bus manufacturing in Canada (Clean Energy Canada, 2019). TransLink's plan would certainly decrease the GHG impacts of transit use, where buses represent about two per cent of transportation GHG emissions in the province.

49 Source is personal communication with Dom Repta of Translink.

9. SYNTHESIS OF BEST PRACTICES

PHOTO Mike Benna, Unsplash

This section provides some initial direction in synthesizing some key insights from this review. Table 1 provides a summary of the overall assessment for each policy category, including 2030 and 2050 GHG impacts and potential secondary benefits. We identify several priority mitigation policies, each with the potential to play a moderate to major role in 2030 and 2050 GHG targets. These policies include the low-carbon fuel standard, zero-emissions vehicle mandate and vehicle efficiency/emissions standards. This potential for large GHG impact applies to light-duty vehicles (e.g., for passengers) and heavy-duty vehicles (e.g., for freight). All three policies fit into the efficiency and low-carbon fuels “legs” of the stool.

Within the third “leg”, a comprehensive VKT reduction strategy is identified as an important mitigation policy, with the potential to play a minor role in achieving 2030 and 2050 targets. Of these measures, road-pricing mechanisms offer the highest potential for GHG impacts, notably a system with strong pricing applied per VKT or unit of fossil fuel. Initiatives focused on built environment, public transit and active travel are identified as complementary, and can play supporting to minor roles in GHG mitigation. These VKT reduction strategies can offer substantial secondary social benefits, including improved health and equity, and expanded travel options.

Table 1: Summary of GHG impacts and secondary benefits for the reviewed transportation policies and initiatives

		Potential role in GHG targets for...		
	Overall assessment	**...2030 targets (40% below 2007)**	**...2050 targets (80% below 2007)**	**Potential secondary benefits:**
Leg #1: Low-carbon fuels				
Low-carbon fuel standard	**Priority**	**Major**	**Major**	**Innovation, air quality**
Zero-emissions vehicle (ZEV) mandate	**Priority**	**Moderate to Major**	**Major**	**Innovation, air quality**
Other ZEV policy	Complementary	Supporting to Minor	Supporting to Minor	
Leg #2: Vehicle efficiency				
Vehicle emissions/ efficiency standards	**Priority**	**Major**	**Major**	**Innovation, air quality**
Leg #3: Travel (VKT) reduction				
Road pricing	**Important**	**Minor**	**Minor**	**De-congestion, health**
Built environment	Complementary	Supporting	Supporting	Health, travel options
Active travel (cycling, walking, etc.)	Complementary	Supporting to Minor	Supporting to Minor	Health, travel options
Public transit	Complementary	Supporting	Supporting	Health, equity, travel options
Heavy-duty vehicles and freight				
ZEV mandate	**Priority**	**Minor**	**Major**	**Innovation, air quality**
Low-carbon fuel standard	**Priority**	**Minor**	**Major**	**Innovation, air quality**
Vehicle emissions/ efficiency standards	**Priority**	**Minor**	**Moderate to Major**	**Innovation, air quality**

Drawing from this review, we can broadly identify a list of best practices for low-carbon transportation policies and initiatives. A starting point would be to emphasize the need for a coordinated mix of stringent policies to achieve 2030 and 2050 GH targets, while providing other societal benefits. Insights include:

1. For the efficiency and low-carbon fuel legs, there is clear evidence for the effectiveness of several market-oriented regulations, namely:

    - **Vehicle efficiency standards:** keeping to 2025 requirements for passenger vehicles (CAFE), and greatly increasing the stringency for freight vehicles.
    - **A ZEV mandate** for passenger vehicles (as recently announced for B.C.), but adding similar policies for medium-duty and heavy-duty vehicles used for freight transport and transit.
    - **A low-carbon fuel standard:** provincial and national policies will help to cut GHG emissions but will need to be strengthened to meet 2050 targets (or accompanied by very strong policies). Such a policy could also be particularly important for addressing the freight sector.

2. For the VKT reduction legs, road pricing appears to be the single strongest mechanism to reduce travel demand, though it would be more effective if VKT, GHG or fossil fuel–based, rather than simply a congestion price. Major challenges include political acceptability and designing a fair or equitable policy.
3. Other VKT reduction policies can play a supporting to minor role in GHG mitigation, including improving the built environment, transit and active travel. Although they're relatively negligible, all these policies are considered complementary, as they come with many secondary benefits; e.g.:

    - All three strategies can complement road pricing by providing more options for travellers to adapt.
    - Active travel has clear net health benefits, and users tend to be happier than those who use other modes.
    - Reducing congestion through such means can improve urban productivity.
    - Public transit is important to provide affordable mobility and accessibility to transport for low-income citizens.
    - Electrification of buses would further reduce the GHG impacts of transit use.

4. Shared mobility (ride-hailing and car-share) and automation present new opportunities and threats to GHG mitigation, where impacts could be positive, neutral or negative. The benefits could be improved through:

    - Road pricing (GHG or VKT based), to limit any rebound effects in vehicle travel.
    - Policies to encourage vehicle pooling, especially ride-hailing.
    - Electrification of automated and shared vehicles.
    - Integration of shared mobility with transit (e.g., MaaS) and active travel, if it serves to replace private vehicle usage and lower VKT.

10. RECOMMENDATIONS FOR BRITISH COLUMBIA AND METRO VANCOUVER

PHOTO Aditya Chinchure, Unsplash

As a final component to this report, we consider how the insights from this broad evidence base may suggest specific recommendations for British Columbia and Metro Vancouver in achieving 2030 and 2050 GHG mitigation goals. We split these recommendations based on policy jurisdiction: i) policies that are likely to be led at the provincial or national level, and ii) policies that are likely to be led at the municipal or metro level.

To be clear, we do not believe that one or two priority policies is enough. Rather, evidence suggests that a cohesive mix of policies is needed to induce a low-carbon transition, likely a combination of pricing mechanisms, subsidies, regulations and infrastructure implementation (Creutzig, McGlynn et al., 2011; Sperling and Eggert, 2014; Rogge, Kern et al., 2017). Therefore, we view our collection of priority and important policies as a sort of menu that policy-makers ought to prioritize for their region, as part of a broader, comprehensive policy mix. Likely, several priority and important policies will need to be implemented together, along with several complementary polices to support the low-carbon transition.

Most of the identified priority (major impact) mitigation policies for transportation concern the "low-carbon fuels" and "vehicle efficiency" legs of the transportation stool, where such policies are implemented at the provincial and federal level. With 2030 and 2050 GHG mitigation targets in mind for the transportation sector, Metro Vancouver should support such policies:

> **Recommendation 1:** Support British Columbia's recently announced ZEV mandate (with the 2030 requirement of 30 per cent ZEV sales by 2030, and 100 per cent by 2040). This stringency is already sufficient to play a moderate role in 2030 targets and a major role in 2050 climate targets for transportation.

Recommendation 2: Support the low-carbon fuel standard in British Columbia and the LCFS under development for Canada. However, both policies will need to become more stringent beyond 2030 to play a major role in 2050 climate targets.

Recommendation 3: Support Canada's vehicle emissions standard (CAFE) for light-duty vehicles, keeping with the 2025 requirements as they currently stand. Increasing stringency beyond 2025 would further improve the policy's contribution to 2050 mitigation goals.

Recommendation 4: Heavy-duty vehicles need strong regulations as well, which could include a stringent mix of vehicle emissions standard (like CAFE), ZEV mandate (like that in B.C. for light-duty vehicles) and LCFS.

Recommendation 5: The province should support Metro Vancouver and city and municipal governments in efforts to reduce VKT, especially implementation of road-pricing mechanisms and improvements to the built environment, infrastructure for active travel and improvements to public transit service.

City and Metro governments are more likely to have the capacity to lead the "VKT reduction" leg of the stool, as well as deployment of "new mobility" options. We offer the following recommendations to Metro Vancouver stakeholders, while noting that national and provincial support would greatly aid efforts to reduce VKT.

Recommendation 6: Seriously pursue road pricing as the lead mechanism to reduce VKT, ideally through a system that is based on VKT, gasoline and diesel use, or GHG emissions (not just congestion-focused). Road pricing can also be one of the most effective ways to responsibly guide the rollout of car-sharing, ride-hailing and vehicle automation, to ensure they lead to GHG reductions and avoid "rebound effects" from cheaper travel modes. Road pricing can also fund the other VKT reduction strategies noted below (active travel and public transit), which can boost political acceptability.

Recommendation 7: Support active travel, primarily for the health benefits that are consistently shown to lead to a net social benefit. Increase active travel infrastructure to at least match or exceed population growth, while providing more travel choices (complementing road pricing).

Recommendation 8: Support improved public transit, also primarily from a health and social equity perspective. Increase transit infrastructure and service to at least match or exceed population growth, while providing more travel choices (complementing road pricing). Also support TransLink's plans to fully electrify its bus fleet by 2040, to further contribute to GHG mitigation.

Recommendation 9: To avoid worsening impacts from population growth, maintain or improve quality of the built environment, including density, diversity and transit-oriented development. Improvements to the built environment can help support the uptake of active travel and public transit, and may help to achieve other secondary benefits, including health, equity in access and housing affordability.

Recommendation 10: Support shared mobility (including car-share and ride-hailing programs) to improve the variety of transport options. However, important and priority mitigation policies (regulation and pricing) will likely be needed for shared mobility modes to effectively contribute to GHG goals. Further, planning of these modes should be co-ordinated with other transport efforts (active travel, public transit, built environment) to sustain a robust ecosystem of travel modes, and to achieve a range of sustainability goals.

Recommendation 11: The emergence of automated vehicle presents a wide range of opportunities and threats to sustainable transportation goals. Metro Vancouver should carefully monitor progress in AV technology to consider and address its potential in policy-making and planning. Most of the important and priority mitigation policies summarized above will help support pro-societal AV scenarios, including low-carbon vehicle regulations and road pricing. With large-scale deployment of AVs, other policies may become even more important, such as maintaining or improving the built environment (e.g., to avoid scenarios where AVs lead to excessive suburban and rural sprawl). Additional policies will be needed to steer AV technology toward achievement of secondary sustainability goals, such as equity and health.

Recommendation 12: To achieve 2030 and 2050 GHG targets, governments must effectively plan for and co-ordinate all the various transportation and climate policies. This includes not only the various VKT reduction policies, but how they may interact with efficiency and low-carbon fuels regulations, as well as adaptation to “new mobility” options. The task will be challenging and needs regular review, consultation and updating over time.

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