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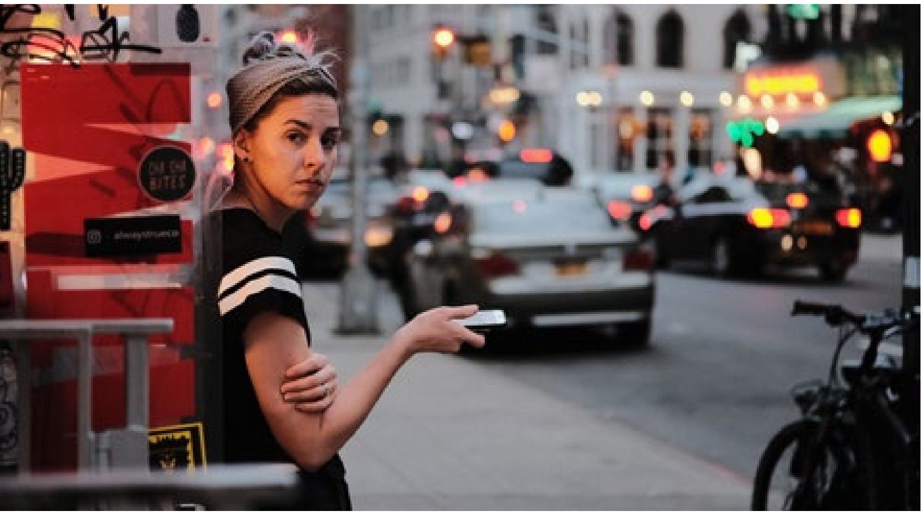
# New Mobility and Autonomous Vehicles

## Impacts on Greenhouse Gas Emissions in Metro Vancouver



March 2021

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New Mobility and Autonomous Vehicles: Impacts on Greenhouse Gas Emissions in Metro Vancouver

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ISBN print: 978-1-988424-66-8
ISBN digital: 978-1-988424-67-5

Canadian Cataloguing in Publication Data for this report is available through Library and Archives Canada.

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All materials contained within this report are developed by the Canadian Urban Transit Research and Innovation Consortium for the David Suzuki Foundation.

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ACKNOWLEDGEMENTS

The authors would like to thank the following reviewers: Curran Crawford and five anonymous reviewers. While the authors thank the peer reviewers for their contributions, the report's contents and recommendations remain the sole responsibility of the authors and the David Suzuki Foundation.

FUNDERS

Funding for this report was made possible through the generous support of the Real Estate Foundation of B.C., the Bullitt Foundation and the Claudine and Stephen Bronfman Family Foundation.

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SERIES

This is the third 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

# USHERING IN A NEW ERA OF MOBILITY: UTOPIA OR DYSTOPIA?

Self-driving, or autonomous, vehicles will be coming to a neighbourhood near you in the not-too-too-distant future. Many newer vehicles already include early iterations of key technologies such as collision-avoidance systems. But many questions remain about how they will be ushered into the Metro Vancouver region and whether they will provide climate and equity solutions or exacerbate negative environmental and social patterns.

Imagine the future. Scenario 1: riding around uncongested roads in shared and connected clean autonomous vehicles, the ride arranged moments earlier on a smartphone. Fewer private cars are on the road, more public space is freed up where there used to be parking and there's lots of infrastructure for biking, walking, scootering and public transit. Getting around is easy through connected services aligned to respond to the climate crisis. Cities are more compact and driving distances have plummeted.

Scenario 2: Single-occupant vehicles continue to dominate roads but they are self-driving and privately owned by those who can afford them. Streams of cars without passengers circle neighbourhoods and increase congestion. Urban sprawl increases and people travel longer distances, using the commuting time to work, sleep or read. Autonomous vehicles are not yet electric or hydrogen-powered.

We're at a crossroads and must plan for the future we want.

To have any hope of reaching its climate goals, Metro Vancouver must dramatically reduce carbon pollution from the region's transportation system, which produces about 45 per cent of emissions. Livability and health are also negatively affected by poor air quality from polluting fossil fuel–powered vehicles.

New mobility options like autonomous vehicles offer hope but also raise concerns. Autonomous vehicle introduction must favour climate-friendly, livable and dense cities that serve all with low-cost, connected transportation options. Regulations around AV use are now being shaped by a few large corporations that sell them or the services they provide, not by local residents and businesses that will be most affected by their introduction.

We must ensure that in our efforts to move to a fully decarbonized economy by 2050, we avoid scenarios where new mobility options lead to emissions increases, worsen an already congested traffic system or exacerbate accessibility challenges or underlying inequalities.

AVs may be self-driving, but policy-makers must steer them in the right direction. It's time for decision-makers to proactively chart the course that directs Metro Vancouver to the best environmental and social outcomes for AV rollout.

If AVs simply offer corporations the opportunity to add more polluting single-occupancy vehicles, a dystopian future becomes our reality. But we have the opportunity instead to reduce the emphasis on privately owned vehicles and increase access to mobility services integrated with public transit and active transportation infrastructure.

This paper offers insights for Metro Vancouver at a critical time. Priorities include integrated strategies for new mobility and AV technologies that enhance the value and usefulness of transit and active transportation infrastructure, maximize climate change mitigation and serve the region's mobility needs, accounting for equity, livability and well-being. Frameworks, pilot projects, partnerships, knowledge-sharing and advancing shared and clean mobility opportunities are discussed.

Understanding how AVs might reshape our cities is a challenging task given that the technologies are in their infancy, relatively few vehicles have been deployed and governments have yet to set the rules for deployment. Drawing on the literature and their knowledge of leading transportation trends, the authors have given their best assessment of key considerations. This is the beginning of a longer conversation. Further analyses and assessments will be needed as more is learned about these technologies and how cities can be shaped by them.

A diversity of voices must be brought into the discussion, from the region, cities, transit authorities, private businesses and residents. We hope this paper moves the conversation ahead and contributes valuable considerations to the region's vision for livability and climate resilience.

We must act now to rapidly move our region on the right climate trajectory through wise transportation choices. Scenario 1 for a utopian autonomous vehicle future is within reach, but only if we steer clear of Scenario 2's pitfalls.

Tom Green, Senior Climate Policy Advisor

PHOTO: CUTRIC

## CONTENTS

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# LIST OF ACRONYMS

| | |
|---|---|
| AV | autonomous vehicle |
| BEV | battery electric vehicle |
| CAV | connected and autonomous vehicle |
| CO2 | carbon dioxide |
| e-LSA | electric low-speed automated shuttles |
| ETS | Edmonton Transit Service |
| EV | electric vehicle |
| FKLK | first-kilometre/last-kilometre |
| FCEV | fuel cell electric vehicle |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GNSS | global navigation satellite systems |
| GPS | global positioning systems |
| HD | high-definition |
| ICEV | internal combustion engine vehicle |
| ITF | International Transport Forum |
| LCA | life cycle assessment |
| LIDAR | light detection and ranging |
| MaaS | mobility as a service |
| PAV | private autonomous vehicles |
| Radar | radio detection and ranging |
| RTD | Regional Transportation District |
| RTK | real-time kinetic |
| SAE | Society of Automotive Engineers |
| SAEV | shared automated electric vehicles |
| TNC | transportation network company |
| TTC | Toronto Transit Commission |
| VKT | vehicle kilometres travelled |
| V2I | vehicle-to-infrastructure |
| V2P | vehicle-to-pedestrian |
| V2V | vehicle-to-vehicle |
| V2X | vehicle-to-everything |
| ZEV | zero-emission vehicle |

# EXECUTIVE SUMMARY


PHOTO: CUTRIC

This report addresses how new mobility services and technologies could affect the transportation sector's greenhouse gas emissions in the Metro Vancouver region, as well as equity, well-being and livability. It reviews academic and industry literature to understand the positive and negative impacts of new mobility solutions. It focuses mainly on mobility as a service (MaaS) and connected and autonomous vehicles (CAVs)[i]. These technologies could encourage greenhouse gas emission reductions if deployed within frameworks that focus on public transit and shared mobility modes. In considering different scenarios and applications (e.g., shared mobility, on-demand solutions and autonomous mini-bus or smart shuttles for first kilometre/last kilometre transit applications), this report aims to support the Metro Vancouver region in its effort to achieve ambitious targets of reducing GHG emissions by 45 per cent by 2030 and achieving carbon neutrality by 2050. This study highlights strategies that could be deployed to ensure new mobility services help to decrease emissions in the Metro Vancouver region while also improving mobility offerings to residents and equity, livability and well-being outcomes throughout the region as a result.

This report addresses the question of how new mobility services and technologies will affect the overall environmental impact of the transportation sector in the Metro Vancouver region. Table E1 summarizes a range of plausible "heaven" and "hell" scenarios associated with new mobility, known as MaaS, and CAV technology deployment impacts.

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i Urban air mobility, such as flying vehicles, is out of the scope of this study.

**Table E1. Summary table of "heaven" and "hell" scenarios related to new mobility, known as MaaS and CAV technology deployment.**

| Themes | "Heaven" scenario | "Hell" scenario |
|---|---|---|
| **Vehicle kilometres travelled** | VKT decreases if MaaS and CAVs offer a modal shift from private car to other shared transport modes and transit agencies or municipalities within Metro Vancouver owned MaaS or CAVs as shared mobility options to improve existing transit systems[1, 2]. | VKT increases if MaaS and CAVs, which may induce longer commutes, are deployed primarily with economically wealthy users or if CAVs are owned and deployed privately[3]. Additionally, owners of private CAVs may cause substantial increases in VKT (and resulting emissions) if CAVs circle communities, rather than park, while awaiting owners or if CAVs are sent "home" to park and then return — repeating the journey and route — at the end of the day to collect owners. |
| **Built environment** | Shared MaaS and CAVs in combination with existing public transit results in population concentration in urban areas[4]. This outcome is more influential in municipalities with a well-established public transit system, such as the City of Vancouver. CAVs as a shared mobility option promote mass transit by providing first-kilometre/last-kilometre solutions, which encourages a more densified and diversified urban environment resulting in an increased quality of urban life[5]. | No specific improvement to the built environment in terms of density and diversity occurs. Private CAV owners are able to make longer trips more conveniently, resulting in the reshaping of cities in negative ways by exacerbating urban sprawl and increasing congestion. |
| **Active and public transportation** | MaaS and CAV technologies complement active transportation and public transit, both of which are prioritized in Metro Vancouver's 10-year vision[6]. | MaaS and CAVs compete with walking and cycling and thus reduce investment in high-capacity active and public transit systems and infrastructure.<br><br>Investments in private vehicle technology, or low-capacity shared vehicles instead of mass transit, result in more auto-oriented, less walkable, less bikeable, sprawling community development over time. |

| | | |
|---|---|---|
| **Parking** | Parking space demand decreases as shared MaaS and CAVs reduce the number of private cars on the road and parking space requirements. Parking spaces in highly desirable areas (e.g., central business districts or downtown areas) can be used for other purposes[7,8]. Metro Vancouver with its highly valued real estate specifically benefits from this result. | MaaS that serves the well-off primarily may not lead to any specific changes with regard to parking spaces[9], but privately owned CAVs may end up requiring additional parking space if owners park the vehicles as they would normal passenger cars rather than sending CAVs "home" to park. |
| **Energy usage** | Shared MaaS and CAVs that use electric powertrains contribute to GHG emission reductions per person, per vehicle and per VKT. | Conventionally fuelled cars deployed for MaaS platforms or conventionally fuelled CAVs in combination with being owned privately will increase GHG emissions per person and per VKT. |
| **Time efficiency** | Individuals benefit from socially owned or communally shared MaaS and CAV assets and use commute times to achieve other goals such as reading, eating, making calls, etc. rather than driving[10]. | Private MaaS and CAVs serve primarily the affluent — i.e., those who can afford private vehicles and specifically those who can afford high-end, technologically advanced vehicles — thereby improving time efficiency primarily among the rich. |

This report provides an overview of the Metro Vancouver landscape in terms of demographic context and regulatory frameworks affecting new mobility and CAVs. The report also reviews Metro Vancouver's policies related to new mobility modes, automated vehicle transportation goals, CAV deployment goals, new mobility technology ecosystem goals and manufacturing and innovation capacity, as well as climate change action plans that overlap with new mobility and transportation innovation in the region.

This study also highlights summary data collected from Metro Vancouver governmental organizations from a series of semi-structured interviews. These interviews were conducted to obtain current insights into new mobility goals and potential CAV impacts on GHG emissions as judged from the point of view of current policy-makers. These interviews were conducted in July and August 2020. Stakeholders highlight the need to establish a thoughtful regulatory system that requires all elements to work together to create more livable cities with affordable and accessible transportation solutions for all users while increasing the use of low-carbon energies within the transportation system.

The report concludes with a series of recommendations related to improvements in regulations, social planning, and policy development within the space of MaaS and CAV technology deployment in the Metro Vancouver region.


PHOTO: Elenabsl, Adobe Stock

British Columbia and Metro Vancouver have identified targeted goals (relative to 2010) to reduce GHG emissions by 45 per cent by 2030 and achieve carbon neutrality by 2050[11]. The transportation sector plays a major role in achieving this goal as 45 per cent of Metro Vancouver's emissions come from this sector[11]. Vancouver city council also adopted the Transportation 2040 plan and Climate Emergency Response[12]. The plan sets long-term targets and includes both high-level policies and specific actions to achieve a smart, efficient, affordable, safe and green transportation system in the city to ensure a healthy future for its citizens. The plan includes several goals, including that, by 2030, two-thirds of trips in Vancouver will be by active transportation and transit and 50 per cent of the kilometres driven on Vancouver's roads will be by zero-emissions vehicles. The plan envisions at least two-thirds of all trips in the city to be on foot, bike or transit and envisages zero traffic-related fatalities by 2040[12]. In 2019, the Province of British Columbia passed the Zero-Emission Vehicles Act. The ZEV Act requires automakers to meet specified annual targets in new light-duty ZEV sales and leases. This act mandates ZEVs to account for 10 per cent of light-duty vehicle sales by 2025, 30 per cent by 2030 and 100 per cent by 2040[13].

In this regard, the David Suzuki Foundation published a report in November 2019 using Metro Vancouver as a case study. "Shifting Gears: Climate Solutions for Transportation in Cities"[14] draws on available evidence to offer an overview of climate solutions for transportation in cities. The implications of new mobility and autonomous vehicles for GHG emissions are examined in Section 7 of that report. Based on the report's findings, the emergence of new mobility options and CAV deployment could have positive and negative impacts on GHG emissions and urban livability. Therefore, prioritized mitigation strategies and policies focusing on shared or mass mobility, rather than individual mobility modes, are required to increase the likelihood of positive social impacts, including GHG emissions reduction across the region.

By focusing on Metro Vancouver's responsiveness to new mobility modes and CAV deployments specifically, this report reviews academic and industry literature to understand the impacts of new mobility solutions. This report also considers outcomes emanating from the past four years of technical consultation sessions that CUTRIC has held nationwide on the issue of "smart mobility," understood as connected, autonomous, low-speed applications that support FKLK and transit gap mobility solutions.

Based on the data from these sources and a consideration of the differing scenarios that new mobility and CAV mobility can produce, the report identifies the potential opportunities and challenges associated with applying CAV technologies as a means of ensuring transportation-related GHG emission reductions across Metro Vancouver.

This study sheds light on strategies and policy frameworks that could be deployed to ensure new mobility services, devices and tools — including CAV technologies — are used to help decrease emissions in Metro Vancouver while improving equity, livability and well-being outcomes in the region.

Specifically, this report seeks to address the following questions:

- What is "new mobility"?
- What is "connected and autonomous vehicle" technology?
- What are the positive and negative potential impacts of new mobility modes and CAV technology deployments in the transportation sector? What are the impacts on GHG emissions from transportation?
- In what ways can new mobility and CAV-related policies and strategies support positive transportation outcomes in Metro Vancouver region?

# INTRODUCTION: NEW MOBILITY, MAAS AND CONNECTED AND AUTOMATED VEHICLE (CAV) TECHNOLOGIES

PHOTO: Okai Vehicles, Unsplash

“New mobility” refers to a wide set of emerging transportation and mobility services that are intended to be service-oriented and on-demand. New mobility usually refers to mobility services that can be rented swiftly, for a limited period of time and with no ownership obligations on the part of the user. These can include digital ride-hailing services (e.g., Uber or Lyft taxi services), broader car-sharing services (e.g., ZipCar) or bike-sharing services that are common across Vancouver, Toronto and Montreal today. Most 'new mobility” services have emerged within the past decade and all such services rely heavily on internet-based online platforms that connect users to services primarily via smartphones.

## NEW MOBILITY AND MAAS

“New mobility” is a general term that refers to a wide set of emerging public and private transportation services that are mostly available on demand, some of which include digital ride-hailing services, car-sharing services, bike-sharing services, and even e-bike and scooter sharing services[15, 16]. In recent years, 'new mobility” has become known as “mobility as a service,” or “MaaS”. According to the European MaaS Alliance, mobility as a service is defined as “the integration of various forms of transport services into a single mobility service accessible on demand”[17].

MaaS services have grown in popularity over the past decade. Connectivity via online platforms combined with growing smartphone capabilities have created new ways of getting around through “smart-enabled” mobility systems designed with travellers, riders and commuters in mind.

According to the European MaaS Alliance[17], new mobility services are intended to meet a customer's goals by having operators offer a "diverse menu" of mobility options — whether those are fixed-route transit bus services, ride-share services, bike-sharing or scooter usage — all available via one simplified online portal that users can utilize to order and pay for services and coordinate pickups, drop-offs and user requirements. Therefore, MaaS is heavily dependent on a user having access to internet services (usually via smartphone technologies) and digital payment mechanisms, such as credit cards or other digital currencies like cryptocurrencies.

From a public transit, municipal or regional standpoint, the overall goal associated with MaaS is to help users, riders and citizens get to where they need to go in the quickest, most economically efficient and environmentally sensitive manner. Optimized publicly oriented MaaS would aim to connect a user to local shared assets and help users get from point A to point B by avoiding the use of single passenger cars, wherever and whenever possible, in an efficient and cost-effective manner[18-20].

Examples of common new mobility services that readers may be familiar with include transport network companies (TNCs) like Uber and Lyft, which provide on-demand taxi services to users with smartphones and credit cards. These services can be procured for individual use — one passenger with one driver — or they can be shared and deployed to move multiple people in one vehicle trip (i.e., Uber Pool services). Examples of active mobility services that are on-demand, shared and service-oriented include Vancouver's bike share program, Mobi, which makes public bicycles available for use by individuals on a short-term basis. Users can unlock bicycles from one station and return them to any other station in the system to enable one-way trips with simplified pickups and drop-offs of bicycles[21].

Traditional transit systems are also looking to 'new mobility" and MaaS technologies to help overcome gaps in their fixed-route services, which cause potential users to avoid using the transit system altogether due to factors associated with inconvenience or time. Several studies have shown that traditional route-based transit services that rely on buses, streetcars, trains and subways that arrive and depart according to fixed transit schedules can move high numbers of people over great distances in energy-efficient and cost-effective ways[22-24]. However, transit agencies, including those in dense urban centres, also suffer from low-usage or low-performing routes, such as fixed-route services in low-density neighbourhoods. Low passenger loads may lead transit agencies to reduce services to specific routes or zones, which leads to a "death spiral" phenomenon of fewer and fewer riders over time due to lack of convenient service. However, a transit agency may still carry substantial costs associated with the full costs of operating even low-frequency buses on the route including driver labour and vehicle maintenance despite low ridership.

In addition, transit systems also suffer from first-kilometre/last-kilometre gaps, which refer to distances that users need to traverse but that are too short and too costly to allocate a fixed-route bus service to. These routes may, however, be too far to be accommodated by walking or other active mobility options, especially for people with disabilities, people with children or in inclement weather. Specifically, studies have shown people are less likely to use transit systems if there are no bus or train systems within a 20-minute walking radius of their origin or destination point[23, 25]. These FKLK gaps might also be short in distance but too dangerous to traverse on foot when there is no adequate sidewalk space or pedestrian infrastructure. These transit gaps have been highlighted by researchers as fertile ground for MaaS technology solutions[19, 20, 22].

Transportation network companies, such as Uber and Lyft in particular, have stepped into the gap in recent years by innovating their passenger mobility offerings to provide transit-like services in communities with insufficient transit services and/or substantial FKLK gaps. These TNCs have launched pilot programs aimed at integrating their shared mobility systems within existing transit systems to solve FKLK challenges[26, 27]. In 2020, Lyft launched a series of public transit route connections via its mobility application across the Greater Toronto Hamilton Area (GTHA) and Ottawa. In Toronto, for example, customers using Lyft could make FKLK connections with the Toronto Transit Commission or GO Transit by directing their mobility service to accept a pickup or drop-off transit location. Meanwhile, the company advertised its ability to help TTC riders overcome maintenance closures on subways or streetcars[28]. A recent report shows 56 per cent of Lyft riders in Toronto and 44 per cent in Ottawa have used a Lyft service to get to or from public transit services[29].

These types of private-sector led FKLK solutions with TNCs specifically have been delayed in the Vancouver region as TNCs were legally approved to operate in the region only as of January 2020. With the rise of the global COVID-19 pandemic, a drop in transit ridership overall affects the ability of the city or transit agency to assess the extent to which TNCs have supported or drained the mass transit system in the city. Therefore, results of the integration of TNC services by Lyft and Uber in particular are still pending and will require attention as transit ridership returns to normalcy post-pandemic[30]. It is valuable to note, however, that as of November 2020, Lyft has already launched a public transit integration option for users of its on-demand platform to address FKLK gaps in Metro Vancouver[31].

In tandem with TNCs offering FKLK gap solutions on a fee-for-service or fee-per-ride basis to individual customers, other "on-demand" MaaS pilot programs have also been deployed across Canada to determine whether flexible shared mobility options could help grow mass mobility services or replace them in communities where mass transit is financially unfeasible. A pilot program with Innisfil, Ontario, and Uber — in which the city subsidized Uber rides in lieu of building a mass transit system with fixed route service — showed an increase in communal and ridership in the city's transportation network. Innisfil Transit aimed to save on the capital costs associated with procuring buses and maintaining them by instead contracting with private ride-share providers to provide community ride services[32]. In 2018, a total of 85,943 trips were taken by "shared ride" commuters that had signed up to the program, thereby demonstrating that tens of thousands of residents without access to transit would embrace a subsidized, low-cost on-demand public mobility service[33]. Another program demonstrating MaaS technologies in Belleville, Ontario, with Pantonium Inc., a Canadian startup, showed successful implementation of on-demand bus services that resulted in a 300 per cent increase in ridership and a 30 per cent reduction in mileage for transit vehicles[34]. The project also saved on the costs of operating buses by reducing the number of empty buses driving on previously fixed routes[35].

More recently, the City of Calgary launched an on-demand program with more customized service models in areas with low ridership to make transit more accessible, more convenient and tailored to the needs of specific community users[36]. The newness of the program means data are still unavailable to demonstrate the cost of the program versus its benefits to riders. The intention of this program, however, is to provide full transit service for West Calgary communities with the same service hours as fixed transit routes. Instead of having access to buses driving along fixed routes through the community, however, a series of on-demand shuttles or buses will be deployed to households or locations where they are needed at given moments in time.

While these services may seem like highly subsidized taxi services, rather than cost-effective mass mobility, the intention of on-demand transit services is that artificially intelligent algorithms would pair and match clusters of demands for mobility within given (short) time frames in specific geographical areas thereby creating on-demand "routes" in real time. Based on CUTRIC's past four years of technical consultation work with manufacturers and transit agencies nationwide, stakeholders within the public mobility industry have identified the fact riders and commuters should ultimately share rides wherever possible. AI-enabled technologies based on real-time route creation and real-time clustered demand overlaid with clustered pickup and drop locations in targeted communities would furnish such solutions.

Within the Vancouver region, TransLink has taken a leadership role in testing on-demand pilot technologies over the past year. The primary objective of the Bowen Island Pilot Project is to explore the feasibility of a wider flexible, on-demand solution across TransLink's service areas. The project aims to provide Bowen residents with features such as custom pickup and drop-off locations (instead of fixed-route station stops), a means of reserving seats on buses or shuttles through a smartphone application or phone service, and a method for users to track the bus, although no service was available at the time of the pilot to see "Next Bus" information[37]. As of March 2020, the public transit agency had completed a cutting edge "transit on-demand" pilot on Bowen Island. More than 500 transit riders requested special pickup and drop-off locations over the course of the 1,200 trips delivered. About half the participants in the study said the service had stopped them from using a car[38].

Currently, BC Transit has identified "on-demand" services as part of a MaaS effort to innovate its transit services in its current five-year plan[39]. Specifically, the agency states its desire to improve "customer experience" by developing a "Mobility as a Service (MaaS) model that works for BC Transit, its partners and systems."

## CONNECTED AND AUTOMATED VEHICLE (CAV) TECHNOLOGIES

Within the universe of traditional transit and new mobility (i.e., MaaS) technologies, connected and automated vehicles have emerged as yet another technological offering that hypothetically promises a different level of flexible transit and mass mobility services while reducing operational costs and improving rider and pedestrian safety outcomes. These technologies are emerging as complementary tools that could support the growth of transit and the mass mobility sector, if deployed as shared shuttle services with public transit and shared mobility objectives in mind, as well as oppositional and competitive tools that could diminish public transit's value proposition to riders by providing potential riders with luxury, personalized driverless services when embedded into a single passenger car platform and sold as a personal mobility device.

CAVs are composed of both vehicle- and infrastructure-based technologies that could also reshape the urban landscape, given than driverless vehicles require infrastructure deployments on roads, traffic lights, buildings and in other vehicles to operate functionally. Given the level of safety required to navigate mixed traffic and left-hand turns in particular, CAVs may also force the redesign of city streets to ensure more dedicated laneways for shuttles and buses that rely on driverless and connected technologies to navigate their surroundings and integrate safely with riders and pedestrians alike.

Based on CUTRIC's four years of consultation sessions with industry and transit leaders in CAV mobility across Canada, the expectation among experts is that CAVs could provide driverless shuttle alternatives (or people-mover pods) similar to current mini-bus services today. Without a driver and with an electrified powertrain, these shuttles are expected to cost less to operate compared to driver-led buses, when deployed on dedicated laneways to avoid extraneous safety challenges or costly roadway accidents. If deployed "on demand," CAVs could also offer further cost savings by helping agencies eliminate redundant or inefficient fixed-route services, as other driver-led on-demand services are doing today (as noted above).

From a technical standpoint, CAVs combine two distinct but related groups of technologies: "connected" vehicle technology and "automated" vehicle technology.

### Connected vehicle technology

Connected vehicle technology enables a vehicle to communicate with other vehicles within the community or local network, as well as the surrounding environment. This communication allows a vehicle to be smart-enabled by allowing it to "speak" with its surroundings through a variety of signalling devices. According to some studies, connected vehicle technologies could help to improve safety and efficiency outcomes by supporting more informed decision-making by the vehicle's operating systems[40]. For example, a connected vehicle should, in theory, be able to identify another vehicle entering its pathway from a hidden corner, thus enabling the two vehicles to communicate with one another and slow down mutually to stop in time to avoid a collision.

Similarly, a connected vehicle should be able to communicate with a wider network of internet-and cellular-connected devices across roads and highways, allowing it to read traffic conditions in real time, to avoid congested roadways and high collision areas or automatically decelerate when entering zones in which children play or in which there are known pedestrian crossings where accidental deaths have occurred[41, 42].

"Smart" technologies that connect vehicles to one another and to their surroundings should, in theory, support smart decision-making across the transportation network. These smarter decisions could support lower death rates due to avoidable collisions by virtue of improving driver adherence to posted road speed limits (automated speed governors could be implemented as part of smart-controlled vehicles) and greater vehicle respect for non-separated bicycle lanes or other unprotected vehicle traffic that shares road space by virtue of lane alerts and automatic redirection of a given CAV when a nearby vehicle or cyclist is veering dangerously into the CAV's occupied lane[43-45].

"Smart" technologies also refer to all the internet- and cellular-connected applications and devices within the vehicle. Thus, a fully connected vehicle is one that has access to the internet on-board and within the passenger cabin, so passengers can connect to the worldwide web, as well as outside the vehicle, so the vehicle can connect to other devices via Wi-Fi, cellular or near-field communications platforms. This may include entertainment media, social media or telecoms connectivity. These access points essentially make CAVs moving internet and cellular network pods. While potentially beneficial to passengers in a vehicle, internet connectivity may lead to distracted driver behaviour, as drivers have access to email, social media and other sources of infotainment or news information in real time while driving in non-fully-automated vehicles. More concerning, this level of multilayered connectivity means that CAVs — both private — may become unsafe access points for malicious hackers who aim to enter a vehicle's control systems through its connected portals, thereby exposing riders, cyclists, pedestrians and other drivers on the road to dangerous roadway behaviour[46-49].

Depending on the source of real-time data that the vehicle connects to, a vehicle's "connectivity" can be categorized into several types. Vehicle-to-vehicle (V2V) connectivity involves wireless transmission and reception of data among and between vehicles in operation[50]. This type of connectivity is specifically applicable in collision warning and intersection and passing car warning systems[51]. The benefits of V2V increase over time as more vehicles become equipped with this type of connected technology[52].

Vehicle-to-infrastructure (V2I) connectivity supports the transmission of data between vehicles and surrounding infrastructure. V2I technology contributes to the safe and efficient operation of vehicles, especially at intersections, by transmitting information such as red and green light time-to-change signals and red light warnings to enable transit and emergency vehicle priority[15]. Through roadside infrastructure, V2I technology can also transmit useful information about speed limits, work zones, curve speeds and wrong-way warnings to vehicles.

Vehicle-to-pedestrian (V2P) technology provides another level of connectivity through smartphone devices where warnings can be received when a pedestrian crosses a pathway in which a vehicle is travelling[53]. This type of data connectivity allows a vehicle to "see" a pedestrian and potentially avoid a collision with that pedestrian. As the technology is still going through different levels of testing applications, some potential failure for CAVs to detect pedestrians in all circumstances exists[54]. These technological failures lead to serious social concerns about equity, racialization and discrimination within a region's mobility network. For example, current object-detection models for CAVs are mostly trained on light-skinned pedestrians, resulting in failure to detect dark-skinned pedestrians. In addition, CAVs may promote economic inequity as individuals with smart phones would be more likely to be detected than those without smart phones.

One of the benefits frequently associated with CAVs compared to conventional vehicles is their expected ability to reduce the number of fatal crashes[55]. Driverless vehicles such as CAVs use a combination of hardware (sensors, cameras and radar) and software that is supposed to help vehicles identify certain safety risks and reduce or eliminate fatal crashes. At the same time, human errors such as distracted driving, speeding, drunk driving, reckless driving, unsafe lane changes and other conditions such as rain, running red lights, running stop signs, design defects, inexperienced driving and night driving are currently the main reasons for traffic accidents and fatalities[56]. Enabling and programming a CAV to predict, react and safely avoid or respond to all of these scenarios is an engineering challenge. Thus, the degree to which CAVs will actually be able to help reduce unsafe driving outcomes and avoidable collisions is an open question. Nonetheless, combined with urban redesign, integration of dedicated laneways for shared shuttles, reduced speed limits and highly connected infrastructure systems with advanced cybersecurity systems in play, the possibility remains that CAVs — as shared public transit mobility devices — could reduce transit-related accidents and collisions. However, no long-term demonstration of automated or connected buses, shuttles or shared mobility vehicles exists to prove the possibility is true.

In addition, challenges persist with regard to how CAVs value human life in their algorithmic decision-making. This issue relates to the programming that determines whether a vehicle adopts one or another decision in diverting itself when an inevitable collision scenario arises. These programmed decisions are in fact moral decisions codified in computer code and integrated into vehicle and infrastructure decision-making systems. A typical ethical query posed about the philosophical morality of CAVs is the moral quandary a CAV faces when it is situated in a context of colliding with either a car carrying a child or a senior citizen who is crossing the street. Which life is more valuable? Given that CAVs in mixed traffic — including shared shuttles — will potentially face these contextual scenarios due to human error in driving or pedestrian behaviour, the decision as to how the vehicle should react is an unresolved one for manufacturers of cars and shared shuttles and buses with automated and connected vehicle devices[57].

Studies assessing regulatory options have found that regulations to dictate solutions for these dilemma scenarios facing CAVs could be counterproductive, as some moral algorithms for CAVs could create social dilemmas, such as deciding a priori whether a senior or a child's life is more valuable[57, 58]. It is not clear that regulators or municipal/regional decision-makers would want to bear the responsibility for such decisions. These considerations raise important ethical question for the manufacturers and programmers of CAV technology about how they value human life[59], but they also raise concerns for policy-makers in regions such as the Metro Vancouver Region, which will require political guidance and political decision-making on the matter of CAV deployment as local consumer demand for on-demand, low-cost mobility services rises with urban density. While some believe that CAVs would be better moral decision-makers than human beings because they are programmed with an accurate set of moral principles[60], ethical challenges associated with the guidelines that artificially intelligent systems in CAVs should follow remain as ongoing issues for scientists and researchers[61, 62].

In addition, if manufacturers offer different versions of moral algorithms, and a customer (such as a transit agency) chooses one of them, the question of whether the customer is to be blamed for the harmful consequences of the algorithm's decisions remains an open one with significant insurance consequences for the vehicle owner; i.e., the city or region that operates the transit system in public- or shared-fleet scenarios[63]. Such liability considerations will need to accompany ongoing municipal, regional, provincial and federal discussions of CAV regulations.

A future scenario in which vehicles, passengers and infrastructure are all connected and able to exchange real-time digital information between and among themselves is what technologists refer to as a vehicle-to-everything (V2X) connected system. Technologies associated with V2X are frequently described as tools that society can use to improve the safety and efficient navigation of connected vehicles using a multiplicity of data inputs in real time[64, 65]. According to these studies, V2X has the potential to solve some of the most challenging traffic problems inhibiting transportation systems in Canadian cities. Congestion, traffic delays and parking access challenges are examples of traffic problems that create pollution and unnecessary time wastage and vehicle kilometres for drivers[65, 66]. V2X technology provides vast amounts of live traffic data available to urban traffic management centres, other vehicles and infrastructures. Data could be used to improve traffic management, enable new services like smart parking applications and strengthen multimodal mobility services[66].

Based on a coherent integration of V2V, V2I and V2X technologies, available data suggest that actual crash rates for CAVs may, in fact, end up being lower than those of conventional vehicles if and when urban design considerations are taken into account, including roadway dedication for driverless and connected vehicles, and cybersecurity protocols for roadside infrastructure that communicates effectively with vehicles in real time[55, 67].

### Automated vehicle (AV) technologies

"Automated vehicle" (AV) technology refers to the hardware and software tools that support sensing, localizing and navigating a given environment to support the safe movement of a vehicle with little to no human guidance or decision-making.

As defined through the Society of Automotive Engineers' J3016 standard, a vehicle's degree of automation is divided into six levels of automation: level 0 indicates a vehicle is under the full control of a human driver and decision-maker while level 5 indicates the vehicle is fully automated without any human input[68]. Figure 1 demonstrates all levels of driving automation on a scale of 0 to 5.

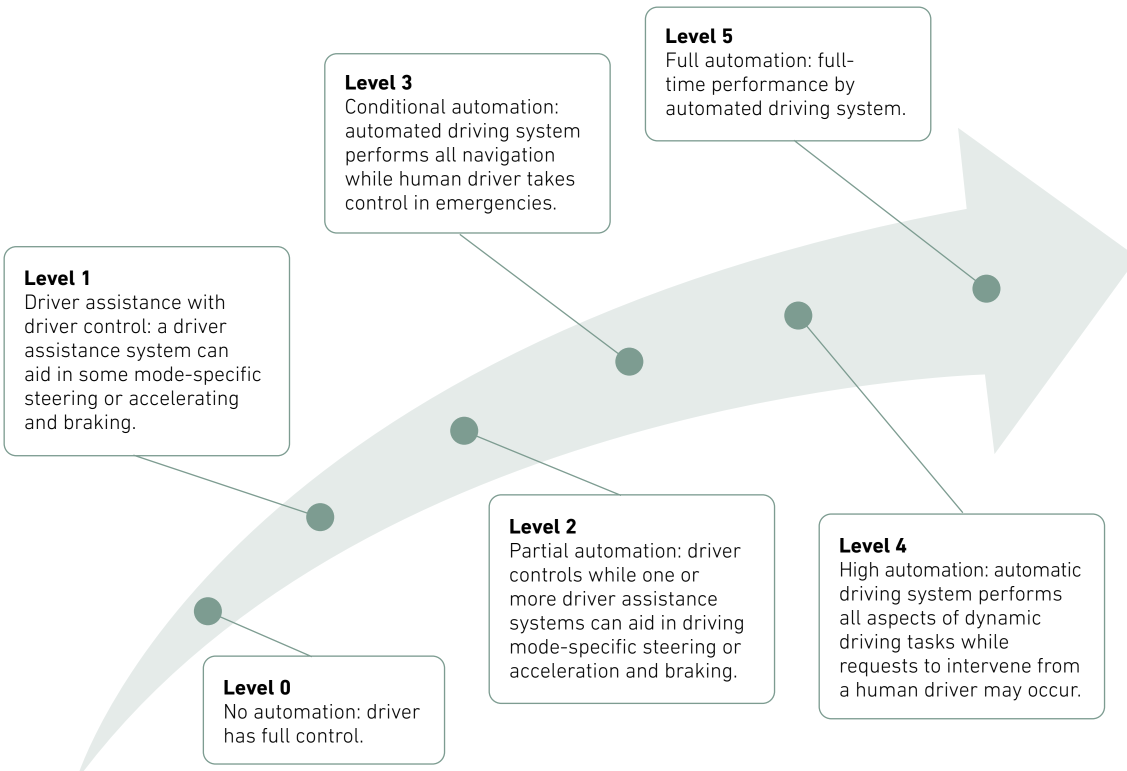


**Figure 1. Levels of driving automation**

Automated vehicles use a combination of sensing technologies to perceive their surroundings. These include light detection and ranging (LIDAR), radio detection and ranging (radar), cameras, and ultrasonic sensors, as well as inertial measurement units and infrared sensors [69]. A combination of these sensing technologies ensures a safe level of redundancy within the vehicle since a fully automated vehicle receives a wide range of real-time data inputs from servers[70]. A set of parallel systems also exists to guide an AV to locate itself and navigate through a road network or along an established laneway. Typical localization technology systems that are used by manufacturers include high-definition (HD) mapping, global positioning systems (GPS), global navigation satellite systems (GNSS), real-time kinetic (RTK) positioning, cameras and magnetic markers[70].

As automated technologies improve, AVs combined with MaaS platforms provided by TNCs or other on-demand software service providers could offer financially and geographically accessible solutions to FKLK problems nationwide. For example, autonomous shared shuttles could offer a low-cost, rapidly deployed and energy-efficient solution for transit riders and clients in low-density communities or areas with no current transit service[52]. Fully autonomous vehicles (SAE Level 5) are still not available in the marketplace, but Level 4 autonomous vehicles are. Such vehicles are already in operation, led by technology companies such as Waymo, whose self-driving taxis currently operate in Phoenix and San Francisco[6]. Honda has also announced that it expects to have an SAE Level 4 (personal) vehicle model available by 2025 with highly automated capabilities in most driving situations[71].

A number of factors are shaping the integration of AV technologies. These include road infrastructure (i.e., dedicated laneway) availability, charging station availability (as most shared AVs are also "EVs", or electric vehicles), roadside or 5G communications systems for V2X connectivity that supports autonomous driving, and traffic regulations that govern the operation and usage of AVs on city streets and highways[72]. Any local timeline predicting the widespread deployment of CAVs will depend on how cities and regions respond to these requirements.

At a microcosmic level, several transit agencies and cities across Canada have already experimented with CAVs in recent years or are preparing to do so in 2021. Several CAV pilot projects have been funded by Transport Canada's Program to Advance Connectivity and Automation in the Transportation System (ACATS)[73]. This program funded a series of multi-week demonstration projects in which a variety of CAV shuttles manufactured by differing shuttle makers, such as Easy Mile and Olli, were deployed to test both user and client perceptions, as well as vehicle performance, seasonal performance and other road-design factors that cities need to account for when attempting to deploy CAVs within a shared mobility setting.

In September 2018, the City of Calgary and Pacific Western Transportation pilot-tested a CAV shuttle capable of carrying 10 to 12 passengers between the Calgary Zoo LRT station and the Telus Spark Science Centre — one of the first public demonstrations of autonomous vehicle technology in Canada. The aim of the project was to understand how the CAV shuttle could be able to operate in Calgary. The pilot also aimed to increase public awareness of the technology and gather feedback to determine whether the technology could find a longer-term future within the transit system. And the pilot project sought to train public sector officials in the area of AV technology in general to ensure the city could prepare for future procurements based on technological maturity. The City of Calgary has reported that it achieved its project goals and that overall public perception of the technologies was largely positive[74]. However, the city has made no plans to proceed with CAV procurements or integration into Calgary Transit's operations either as fixed-route operations or an on-demand mobility service.

In February 2019, the City of Surrey pilot-tested a CAV shuttle. In this instance, the project deployed an automated shuttle to make loops in and around Surrey Civic Plaza over the span of more than two weeks. The intention was to provide Metro Vancouver residents with an opportunity to experience new mobility services and technologies in a temporary show-and-tell demonstration[75]. Surrey has not made any further plans to proceed with CAV procurements or integration into local community transit plans either as fixed-route operations or an on-demand mobility service connecting its communities to the wider TransLink network.

In 2021, the City of Toronto will deploy a CAV shuttle in the community of West Rouge. In a national first, the City of Toronto, the Toronto Transit Commission and Metrolinx are working toward launching a trial AV public transit service that connects local residents to and from Rouge Hill GO station. The objective is to demonstrate the future opportunity for FKLK transit-focused CAV deployments that would enable West Rouge residents another means of connecting with the local mass mobility network via TTC and/or Metrolinx rail drop points[76]. The outcomes of this project will be keenly observed by people interested in new mobility nationwide to see whether it establishes a ridership growth metric that can be translated into a business case for further CAV procurements as fixed-route or on-demand solutions in the community.

# THE IMPACTS OF MAAS AND CAVS ON GHG EMISSIONS

PHOTO: CUTRIC

This section of the report reviews outcomes associated with academic and industrial research exploring the potential positive and negative impacts of new mobility services — understood as a suite of MaaS technologies, including CAV technologies — on greenhouse gas emissions. This literature review investigates different scenarios and applications of MaaS technologies and CAVs to provide an understanding of the nature of future policies and regulations that will be needed to deploy these systems safely and effectively and with transit or shared-mobility goals in mind.

The emergence of MaaS and CAV technologies is expected to reshape city landscapes and transportation systems fundamentally. An important question to consider is whether these new mobility services and technologies will reduce or increase the overall environmental impact of a transportation and mobility network within a given region due to increases in travel demand, combined with considerations of congestion and pollution in local communities[1].

## THE IMPACTS OF MAAS ON GHG EMISSIONS

Advocates of MaaS technologies have posited that mobility services, especially on-demand services, could provide several positive benefits to local environments, specifically by supporting a mass modal shift away from private cars to public transportation networks. Advocates have also contended that the sharing services enabled by MaaS technologies allow citizens to avoid having to buy and maintain an asset, such as a car. As a result, MaaS allows for growth of a sharing economy that helps to reduce GHG emissions by supporting a general reduction in the consumption of vehicle assets per capita[77]. However, a major challenge to these dual promises of modal shift and consumption reduction comes from studies demonstrating that any gains from improvements in mobility obtained through modal shifts, and the use of on-demand, software-enabled mobility platforms, tends to be offset by increases in personal distance travelled and sometimes increases in vehicle kilometres travelled[2]. Consequently, the introduction of MaaS technologies will not on their own reduce emissions. Rather, comprehensive strategies must be implemented that aim to attain a notable reduction in GHG emissions from transportation based on the behaviour patterns of users of MaaS technologies at local and regional levels[78]. For example, driving behaviour patterns can be changed with congestion charges and fuel tax strategies, which may reduce single-occupancy vehicle travel during a congested period. A practical example is the electronic road-pricing system in Singapore, which charges based on vehicle type, location and time of day, which has resulted in distributed travel patterns to some extent.

As an example, the UbiGo MaaS trial in Sweden monitored users of mobility services over a period of six months to collect data associated with their travel behaviour, and to track any changes to their behaviour that resulted from access to new mobility services[79]. The pilot service offered citizens comprehensive, reliable, customized and multimodal mobility packages that reduce costs, increase flexibility and contribute to sustainable everyday travel. The experiment shows users becoming less positive about using their private cars and more positive about using alternative modes, such as car-sharing, buses, trams and bike-sharing. These findings indicate the need for a more holistic and flexible approach to the role that private MaaS services, like shared car services, can play on users' willingness to abandon their own car usage and to adopt, potentially, public or active modes over time. Were the results of the UbiGo MaaS trial to hold over the long term, it might be possible to track a reduction in GHGs from personal car usage. The trial did not, however, provide a GHG reduction calculation.

While mobility services such as car-sharing networks may create new products in the mobility market that move car owners away from their personal cars, the overall impact on the environmental remains to be determined and has been at times contradictory. On one hand, a recent study showed that car-sharing can reduce CO2 emissions from a transport system by up to 50 per cent by reducing single passenger car trips and vehicle kilometres[80]. On the other hand, a recent evaluation of the car2go system in Amsterdam showed that car-sharing mainly replaces trips formerly taken by public transport and therefore adds additional passenger car travel to the network and additional vehicle kilometres travelled[81].

A further study by Grischkat et al.[2] has enabled the quantification of GHG emission reductions based on behavioural changes that arise when individuals access new mobility services. This study explored the outcomes of a survey of German transit and car users, a representative sample of 43 per cent of the German population aged 18 to 80 (22.6 million habitants). Researchers found the average reduction potential for GHG emissions from transportation per person per year is about 78 kg CO2e, or 4.2 per cent, in an optimistic scenario of shifting from private vehicle to other modes of transport, and 25 kg CO2e, or 1.3 per cent, in a pessimistic scenario. The analysis indicates that a metropolitan population between 18 and 80 years of age may contribute between one and four per cent of transport-related GHG emissions reductions by shifting to environmentally friendly mobility services. Nevertheless, the reduction largely depends on the number of car owners choosing to reduce their vehicle-kilometres-travelled[80].

These studies show that the diffusion of MaaS technologies can contribute to a modal shift away from individual car usage, and they can support the growth of shared resources and assets, but they do not necessarily or in all cases reduce GHG emissions per person or across the transportation network overall.

The International Transport Forum runs an ongoing series of studies exploring shared mobility in different urban and metropolitan contexts[82]. Researchers examine different "what-if" scenarios. For example, what if all private cars in a city were replaced by shared vehicles? Researchers at the ITF developed highly detailed computer models using mobility data from real cities (e.g., Lisbon, Portugal, Helsinki, Finland and Auckland) to explore how deployment of shared mobility services could change mobility when replacing private car trips with shared vehicles. One of these studies evaluates different vehicle configurations, including shared EVs, six-seater shared taxis, and eight- and 16-seater taxi-buses. The outcomes of these varied shared mobility scenarios, as applied to the City of Lisbon, demonstrate that there would be a substantial reduction in the total size of the vehicle fleet required to deliver the same number of passenger trips if shared mobility mechanisms were utilized across the municipality. In addition, shared mobility platforms and vehicle deployments would lead to a substantial reduction in parking spaces, overall transportation emissions and vehicle congestion. Researchers conclude that shared mobility networks can move the same number of people, while improving equity of access to mobility, compared to single passenger cars and compared to the status quo (a traditional mixture of mobility modes). The simulation also demonstrates that the carbon dioxide emissions from the transportation sector would drop by one-third and on-street parking space would likely disappear as the need for parking spaces would dissipate[83]. The findings for a similar Auckland City simulation show that when a subset of private car users switch to shared mobility services, the reduction in VKT and CO2 emissions can reach up to 15 per cent[84]. The study also demonstrates that the use EVs as shared vehicles would further reduce CO2 emissions.

A similar study analyzing on-demand shared transport modes in the Helsinki Metropolitan Area in Finland points to a wide array of indicators measuring the performance of new modes of mobility with regard to service efficiency, quality of service and cost competitiveness[85]. The study assesses shared mobility impacts on accessibility, ridership, parking spaces, congestion and CO2 emissions. The study concludes that when all private car users switch to shared mobility services, traffic congestion and CO2 emissions are reduced by around 37 per cent and 34 per cent, respectively.


# SUMMARY OF MAJOR FINDINGS: THE GHG IMPACTS OF NEW MOBILITY SERVICES AND MAAS

PHOTO: AA+W, Adobe Stock

The European Commission has determined that MaaS technologies could offer travellers easy, flexible, reliable, price-worthy and environmentally sustainable everyday travel options[86]. These include everything from on-demand public transport services to car-sharing services. If combined with car-leasing programs and smart road-use programs (i.e., limiting specific roads at specific times to specific transportation applications, such as freight or delivery drop-offs or commuter traffic, transportation systems across regions would experience substantial drops in CO2 emissions while improving mobility options for citizens.

But as the literature review above has demonstrated, several potential positive environmental effects may only solve the problem of transportation emissions if new mobility services are integrated across an entire region, and users increasingly abandon their single passenger car ownership or usage. Establishing a strategic modal shift from private and single car usage to other transportation modes, such as new mobility services and MaaS, could reduce VKT but only if shared mobility modes are privileged primarily rather than "smart-enabled" individual mobility modes, such as single passenger car trips on demand. This means integrating new mobility services and MaaS with active mobility platforms, such as bike-sharing, and — perhaps most importantly — integrating those technologies with urban public transportation systems. Findings from the studies above show the need for a more holistic and flexible perspective of mobility technologies that can serve users' needs, but that require synergies between public and private actors to develop in the interests of the public.

Across the Metro Vancouver Region, local authorities will need to gain greater knowledge about the potential differing uses of new mobility and MaaS services and will need to set public transit and active mobility targets as part of the build-out of new mobility and MaaS technologies to ensure that inadvertent increases in inefficient VKT or single passenger trips do not arise as a result of the tools. But rather, that the tools support the greater clustering of MaaS users into existing public transit and active mobility networks. In so doing, new mobility services and MaaS hold out the greatest potential for CO2 reductions across the transportation network by minimizing car usage, maximizing shared rides and shared assets and reducing consumption of road space, including parking spaces, for vehicle assets.

## THE IMPACTS OF CAVS ON GHG EMISSIONS

It is true that CAVs, as forms of vehicles, do not necessitate shared modes. Indeed, CAVs may be deployed entirely for individual use or single passenger trips. If such a scenario were to arise, it is unlikely the transportation network would benefit from extensive CO2 reductions unless all such CAVs were also electrified. But, in this scenario, the electrification of CAVs themselves would not address other allied issues such as urban sprawl, parking space congestion and traffic congestion, all of which have negative implications for CO2 emissions across regions such as Metro Vancouver.

Problematically, a limited number of studies explore the comprehensive environmental impacts of CAVs specifically[1, 3, 87, 88]. However, integrating CAVs into new mobility services and MaaS opens potential avenues for convenient new services for users and riders of a public transit or shared mobility networks. These avenues may lead to new and additional opportunities for GHG reductions across the Metro Vancouver transportation network.

Currently, several studies show how the combination of targeted technology design along with an array of market and policy forces could result in outcomes ranging from significant reductions to drastic increases in GHG emissions from the transportation sector[1]. The main factors determining overall CAV energy consumption outcomes include the following variables[87]:

- eco-driving mechanisms for vehicles
- platooning options for AVs
- light-weighting of vehicles (to reduce energy consumed per kilometre)
- right-sizing of vehicles to accommodate passenger load expectations
- ride-sharing options
- congestion mitigation measures enabled through connected data sources
- reduced waste-kilometres driven to locate parking
- higher travel demands due to reduced travel costs per passenger
- increased travel by underserved populations
- faster highway speeds

Core considerations regional planners need to account for when planning for CAV deployments within a new mobility or MaaS framework include the following six key areas of concern:

1. Shared automated electric vehicles
2. Travel demand
3. Parking demand
4. Urban environment and livability
5. Fuels and energy
6. FKLK applications

## SHARED AND AUTOMATED ELECTRIC VEHICLES (SAEVS)

The convergence of electrification with two other emerging technologies, namely vehicle automation and smartphone technology, has enabled the growth of new mobility option known as "shared automated electric vehicles" (SAEVs)[89]. Platforms dedicated to this new mobility option have the potential to increase vehicle occupancy through ride-sharing, and they might be able to facilitate the development of flexible transit services that are on-demand and that offer right-sized vehicles for specific trips. They may even be able to promote a shift from private car ownership to transportation-as-a-service. In achieving these ambitious goals, this new mobility option would also accelerate the transition to an electrified transportation system and overcome the barriers of electric vehicle adoption, including technological uncertainty, slow charging, range anxiety and higher capital costs[90, 91].

In these scenarios, SAEVs can be deployed with a precise number of seats (i.e., "right-sizing" which ensures the vehicle deployed is of a size that responds to the demand) or a battery range appropriate for the required trip. Charging sessions could be split over many short periods between trips[92]. This type of shared mobility paradigm could enable fleets to utilize smaller cars with smaller battery capacities. The downsizing of battery capacity would support long-term environmental goals by minimizing battery consumption, and it would help to overcome barriers associated with slow charging speeds that low-powered car-charging systems deliver. Additionally, smaller batteries could result in lower vehicle costs for fleet operators and vehicle owners, cost savings that could be passed onto the consumer and/or rider through lower overall fares[92, 93].

An SAEV mobility paradigm may be able to promote the use of public transit overall by integrating passenger cars and public transportation options into one integrated network that seamlessly interconnects the rider from bus to on-demand electrified driverless shuttle that gets the person from point A to point B via publicly organized modes of delivery. SAEVs that offer on-demand transportation would support FKLK applications similar to services currently provided by private TNCs today, such as Lyft and Uber, but they could likely do so at a much lower cost and with less carbon intensity[92]. These opportunities could support GHG reductions by making mobility more accessible, affordable and energy-efficient.

In fact, a recent report by the Rocky Mountain Institute predicts the marginal cost of SAEVs may fall rapidly based on fleet adoption — below that of conventional private vehicles — to such an extent that SAEVs could dominate the mobility market by 2050[94]. The same report concludes SAEVs could reduce per-vehicle GHG emissions relative to privately owned vehicles, and spread the capital costs for vehicles across a greater number of operational kilometres, thereby optimizing the vehicle asset over its usable life cycle. Similarly, other studies have shown that SAEVs deployed by 2030 could reduce GHG emissions by more than 90 per cent per kilometre relative to privately owned conventional vehicles, while also increasing the cost effectiveness of each vehicle deployed within and across a fleet by extending passenger kilometres across the life cycle of the vehicle[95]. While it is possible that such cost savings would increase overall VKT as a result of increasing demand for mobility, researchers have predicted the efficiency gains earned would far outweigh any resulting potential increases in emissions emanating from more mobility services operating on roads overall[93].

## TRAVEL DEMAND

Recent studies have shown that an intense CAV adoption scenario could result in a wide range of possible outcomes, depending on usage patterns by riders and clients and on the types of vehicles used to deliver MaaS services[1]. A study by Stephens et al.[88] concludes that — depending on those factors — CAVs could vary in their effect on GHG emissions, causing anywhere from a 60 per cent decrease to a 200 per cent increase in pollution. Their analysis considers the effects of CAV technologies on VKT and fuel consumption. Another study by MacKenzie et al.[3] also estimates a wide range of potential VKT impacts, showing a VKT increase of four to 13 per cent with partial vehicle automation and 30 per cent to 160 per cent for full automation. The study assumes that changes in travel time, travel costs and lower energy costs per mile associated with AVs may have a significant impact on VKT.

The most significant factor to note, which may lead to an increase in the environmental impact of CAVs, is that they could make driving more comfortable and cheaper, leading to dramatic increases in travel demand and fuel consumption. New user groups that are currently unable to drive (e.g., elderly, disabled or unlicensed people) may find a newly accessible means of travel, subsequently increasing overall travel demand[1, 3, 87]. With regard to TNCs and digital ride hailing, the negative impacts associated with a potential increase in travel demand and modal shift of these new mobility options raise concerns. Based on the results of a stated preference survey by Oviedo et al., one third of public transit trips will be transferred to TNCs with an overall increase in VKT once TNCs are introduced as a travel choice[96]. This latter outcome does not bode well for transportation emissions reductions overall.

However, the potential increase in VKT does not necessarily lead to more emissions if CAV technology is utilized to facilitate adoption of more efficient vehicles that use low-emitting electric powertrains and to encourage shared mobility platforms (and thereby reduce car ownership). Technology could also be used to smooth out traffic flows and thus support better urban designs, creating communities that consume less energy while providing a higher quality of life overall[1]. Some studies have shown that energy consumption and GHG emissions could be drastically reduced without sacrificing personal mobility if the rate of privately owned vehicles and single occupancy trips is lessened as new mobility technologies, such as car sharing and on-demand mobility services, become more widespread[93, 97]. In sum, shared CAVs could lower total VKT per person, as well as total energy consumed and GHGs emitted per person, if designed to be deployed based on per trip passenger needs.

## PARKING DEMAND

If conventional cars were to be replaced by CAVs, an added benefit for cities would emerge in the form of more efficient spatial planning with fewer parking lots, improved living space and denser working environments. Studies show that the arrival of CAVs is expected to significantly reduce urban parking demand and correspondingly alter the urban parking landscape[7, 8]. A study by Chester et al.[98] shows that each parking space adds 1.3 to 25 grams of CO2 per passenger-kilometre travelled to the total life cycle GHG emissions of a car. The study also shows that parking spaces add 24 to 89 per cent more sulphur dioxide emissions and 10 micrometres of particulate matter emissions to local environments. A parking-reduction policy in urban planning could be enabled by CAVs, especially on-demand CAVs.

SAEVs and private autonomous vehicles (PAVs) play different roles in changing parking demand. Studies reveal that SAEVs can dramatically curb the demand for parking space by reducing vehicle ownership[99-101]. Compared to existing shared mobility services, SAEVs are expected to be more effective in reducing parking demand as they can be more affordable and efficient under centralized operation[101]. Parking areas in highly desirable lands can then be used for businesses and other useful purposes such as green spaces, parks and entertainment areas.

By contrast, a study by Zhang et al.[9] shows that PAVs are only able to reduce parking spaces marginally by a mere 10 per cent. In this scenario, PAVs would change the spatial layout of parking spaces in cities as these vehicles could automatically cruise to more affordable parking spaces after dropping off owners at certain trip destinations[7]. Given that most travellers would likely want their vehicles to be available within a few minutes of a command being issued, parking within a kilometre or two of a drop-off destination will be sought out by CAVs. This scenario may allow more off-site and shared parking areas, which may reduce but not eliminate urban parking demand[102]. Additionally, some vehicle owners may program their CAVs to return home after dropping off passengers, potentially causing another traffic problem by adding delays and uncertainty about when the passenger should or could be picked up[103].

## THE URBAN ENVIRONMENT AND LIVABILITY

Recent studies of new mobility, and CAVs in particular, have examined the long-term spatial effects of CAVs on the form of cities, specifically whether the adoption of CAVs leads to population concentration in urban areas or the reverse (i.e., urban sprawl). Gelauff et al. simulated the spatial effects of AVs in the Netherlands and found that in a car trip mode, AVs lead in population flight from cities while the public transit component results in a concentration of people in urban areas[4]. In a similar study, Kim et al. investigated users' "residential location" and "vehicle ownership" in Atlanta, Georgia, as two long-term variables in a "fully-AV era"[104]. Researchers asked whether autonomous vehicles would change a person's residential location and vehicle ownership goals. They found the majority of people would expect "no change" regarding these variables; however, younger people with lower incomes who are pro-suburban and pro-non-car-modes are more likely to make a change[104]. In general, however, studies predicting the deployment of CAVs, especially in the form of shared mobility, show they would result in increased safety for riders and pedestrians and better user experiences among shared mobility riders and clients[105, 106].

These studies predict that CAVs and new mobility services could improve the efficiency of existing infrastructure, operation and management while increasing productivity gains as people use in-vehicle times for activities other than driving (e.g., reading). CAVs as part of the new mobility paradigm could contribute to improved travel time and route planning, resulting in travel-time savings for individuals. CAVs may also offer an overall higher safety level for pedestrian-oriented neighbourhoods since they move at much slower speeds compared to typical passenger vehicles (e.g., many shared shuttle automated shuttles in the marketplace today are designed to operate at speeds between 20 and 25 km/hr). In studies exploring the interactions between pedestrians and AVs, researchers found that since these technologies are "risk-averse," they can facilitate the shift toward more pedestrian-oriented built environments given that the current inclination of the technology is to stop or stall upon object detection, leading to slower vehicular travel overall[107].

As previously mentioned, CAVs could promote mass transit by providing FKLK solutions and subsequently encouraging a more densified and diversified urban environment, resulting in enhanced livability and an increased quality of urban life, if they are deployed as transit-oriented or shared mobility solutions[5].

## FUELS AND ENERGY

The ability of CAVs to reduce GHG emissions is associated with multiple factors, as noted above. But a primary aspect of the promise of GHG reductions associated with CAVs is that shared CAVs in particular are likely to be electrified vehicles. Indeed, most shared CAVs available in the marketplace today (i.e., by manufacturers and operators such as EasyMile, Navya and 2GetThere, among others) are, in fact, electrified vehicles that reduce petroleum fuel consumption by virtue of their battery electric powertrains. Typically, such shuttles are designed to travel to a maximum speed of 25 km/hr, although recent models of larger AV shuttles produced by 2GetThere (Netherlands) have demonstrated an ability to go up to 60 km/hr. While no AV shuttles on the market today are hydrogen-powered, it is possible that future autonomous shuttles may be designed with electric powertrains that incorporate fuel cell technology, so that in lieu of recharging, they can be refuelled quickly at hydrogen fuelling stations.

Electrified and hydrogen-powered CAVs would also support improvements in air quality because these technologies would eliminate tailpipe emissions of nitrogen oxides, volatile organic compounds and particulate matter that can cause respiratory illnesses[93].

Additionally, recent studies predict CAVs could reduce energy use by up to 80 per cent through platooning (using AV technologies that allow vehicles to follow one another in a structured line, thereby reducing air friction and drag), improved efficiency of traffic flow (by virtue of connectivity with traffic lights to privilege movement of platoons of shared shuttles through intersections), light-weighting (which integrates advanced materials to remove weight from vehicle chasses and platforms so vehicles require less energy to move) and automated ride sharing, which ensures more passengers and riders are served effectively by one vehicle[108-110].

Different studies have explored the effects of CAV deployment on energy consumption levels, assuming a high market penetration of CAVs, concluding that changes in energy consumption due to CAV deployment vary dramatically depending on the energy intensity, travel demand effect and fuel mix change[111]. Greenblatt et al.[93] conclude that CAVs are likely to lead to a net decrease in energy consumption and GHG emissions, but another study by Liu et al.[112] argues conversely that CAVs could affect the total GHG emissions in multiple ways. While the overall impact of CAV deployments on GHG emissions is not expected to be significant in the near- to mid-term future, researchers propose a bottom-up method to calculate the GHG emissions of CAVs by using a sample passenger vehicle fleet as an example. This type of analysis reveals that increased shared CAV penetration combined with reduced vehicle ownership would support increased shared vehicle use overall, and help to decrease vehicle fuel-consumption rates in a given region, leading to a net reduction in GHG emissions over time.

One caveat is that AVs deployed for private business or marketing purposes are unlikely to demonstrate the same environmental benefits. CAVs that are deployed to support special pricing on the purchase of a meal, or for entertainment activities such as watching movies, may encourage more VKT with less passenger density leading to greater emissions even when vehicles are electrified (given that many electrical grid systems in North America do not use green power)[113]. These marketing and entertainment applications of CAVs may not support climate benefits to the same extent that shared mobility CAVs deployed for moving people in a public or transit setting would do. However, given the highly renewable nature of British Columbia's electrical grid system, even CAVs deployed for business or marketing purposes would potentially support GHG reductions if electrified, though not necessarily congestion reduction or other environmental goals associated with road-space consumption reduction.

### Life cycle assessment

A full assessment of the impact of CAVs on transportation emissions must incorporate a consideration the life cycle of the vehicle itself. Life cycle assessment methodology offers a systematic approach for evaluating the environmental consequences of CAVs by offering a complete picture of this emerging technology from inception to decommissioning. The LCA process explores resource extraction, energy use and GHG emissions of CAVs from "cradle to grave"[101].

LCA studies of CAVs point to predicted improvements in the life cycle energy consumption of these vehicle systems compared to conventional single-passenger cars. In brief, decreases in GHG emissions are expected as a result of shared mobility and optimized routing. While the increased demand for mobility may counterbalance some GHG savings over the life cycle of these vehicle systems, studies have not fully explored the extent of those effects. The development of a more comprehensive sustainability assessment of CAVs on the overall transportation system is needed, as current literature exploring CAV energy consumption focuses attention at the operational level rather than the full life cycle[3].

A recent study analyzes the outcomes of an LCA with SAE Level 4 automation capabilities[114]. The study assesses the integration of sensing and computing subsystems into an internal combustion engine vehicle (ICEV) and a BEV platform. The finding indicates that CAV subsystems could surge vehicle primary energy use and GHG emissions by three to 20 per cent because of increases in power consumption, weight, drag and data transmission. On the other hand, if eco-driving, platooning and intersection connectivity technologies are deployed, the net outcome of SAE Level 4 CAV deployments is a nine per cent decrease in energy consumption and GHG emissions in the base case.

## FKLK APPLICATIONS

Shared mobility services can allow for increased flexibility in terms of offering riders and clients a wider variety of mobility options, especially with regard to enhanced FKLK connectivity[115]. If CAVs become ubiquitous, then SAEVs could become a major public transportation mode, enabling accessibility among a wide range of socio-demographic groups, including those who cannot drive and those who live in low-demand service areas[93]. Due to smaller vehicle sizes, affordability and low GHG emissions, SAEVs can enhance FKLK connectivity to public transit. Results of a simulation-based study assessing SAEVs deployed in Austin, Texas, show that SAEVs have the potential to solve FKLK transit problems when fare benefits are provided to transit users[116].

Scheltes and Correia[10] use an agent-based simulation model to explore the use of SAEVs as a last-kilometre connection mode for train trips. Their findings show that in terms of operational speed, the current SAEVs are only able to compete with walking modes while other factors, such as a reduction in waiting time and travel time, should be considered as variables that make SAEVs competitive with other modes of mobility as well. Shen et al.[117] model FKLK trips to and from a heavy rail station in Singapore. This study identifies fleet sizes required to serve users. Their results indicate that SAEVs are best used in replacing transit lines that are scarcely used. From an energy perspective, Moorthy et al.[118] compute the benefits of using SAEVs for FKLK services to Ann Arbor airport and conclude that there is a savings of up to 37 per cent in energy. Considering the potential of ride sharing and transit use, Stiglic et al.[119] indicate that transit use can drastically increase, particularly when transit is more frequent and travellers have flexibility in utilizing other mobility services in tandem.

Alemi and Rodier[120] focus on larger regions and study FKLK using travel demand data in the San Francisco Bay Area, California. They detect that nearly 30 per cent of existing single-occupant work trips could be shifted to public transit by using a TNC as an access mode. Pinto et al.[121] investigate on-demand transit interaction and analyze SAEV as an FKLK option as well as a stand-alone enterprise that can be offered independent of public transit needs. The computational results of this study indicate that wait times for an average traveller could significantly improve by optimizing the joint design of transit networks and SAEV fleets. Another study, which develops a bilevel optimization model to identify demand for transit versus a SAEV fleet, found considerable changes in travellers' behaviour occur when they must choose between the two modes[122]. This study suggests that incorporating price elasticity and congestion into such a model can significantly impact travel patterns and encourage optimized ridership patterns.


# SUMMARY OF MAJOR FINDINGS: THE GHG IMPACTS OF CAV TECHNOLOGIES WITHIN NEW MOBILITY SERVICES AND MAAS

PHOTO: CUTRIC

The literature scan above provides an outline of core considerations within six key areas of concern vis-à-vis new mobility services as they relate to CAVs. The studies show that the emergence of new mobility services inclusive of CAVs could result in outcomes ranging from significant reductions in emissions to drastic increases in GHG emissions from the transportation sector, depending on the policy forces at play and the business model for deployment (i.e., private and personal single-passenger deployments or shared mobility and transit-oriented deployments).

The primary environmental benefits of CAVs are those that address pressing urban mobility challenges such as FKLK problems, VKT per person, fuel and energy usage, and traffic congestion. New mobility such as MaaS and CAVs both offer encouraging sustainable transport choices for the future if deployed within sustainably oriented municipal and regional policy frameworks[20].

However, the potential benefits of MaaS and CAVs are mostly theoretical at this time, and they have not been analyzed empirically based on multi-year, real-life deployments. As new mobility technologies, CAVs could support a shift in Metro Vancouver's transportation paradigm. However, limited research is available today exploring the impact of this new mobility technology on the travel behaviour of city dwellers or regional residents and transit users, such as those dispersed across the TransLink network and/or across Metro Vancouver more broadly.

Moreover, there is a scarcity of CAV service data available from pilots launched in Canada and the United States. This lack of data availability is deterring development of models that could evaluate and predict travel demands and CAV usage[44, 123]. Although CAV technologies within new mobility services possess great potential to offer convenient travel options that cost less than owning and maintaining a car, policy-makers need to invest in more predictive and data-driven empirical research, as well as multi-year demonstration trials that pilot CAV technologies, to support the growth of effective new mobility services in the Metro Vancouver region.

# METRO VANCOUVER'S LANDSCAPE IN CONTEXT

PHOTO: kalafoto, Adobe Stock

## DEMOGRAPHIC CONTEXT

In 2020, Metro Vancouver population was estimated to be 2.6 million[124]. The 2016 census population for the City of Vancouver counts 630,000 residents, making it the eighth largest city in Canada with a 1.16 per cent annual population growth[125]. Metro Vancouver is projected to grow steadily into the future with an increase of one million people from 2016 to 2050, a 38.4 per cent increase overall, leading to a population of nearly 3.6 million by 2050.

In 2019, total motor vehicle registrations increased in almost every province and territory in Canada compared to 2018. Lightweight vehicles represent the largest segment of that increase. Together, Ontario, Quebec, Alberta and British Columbia accounted for 86.5 per cent (30.9 million) of vehicles registered in Canada[126], the largest number of vehicle registrations ever recorded. In Metro Vancouver, private vehicles constitute the primary mode of mobility the majority of residents use for daily commuting and travel. Based on data from 2017, 55.3 per cent of automotive trips in Metro Vancouver were private vehicles[127]. Despite the lack of a significant shift in transportation modes over the past decade, as of 2016, 49 per cent of people living in the City of Vancouver commuting to a workplace use non-automobile modes to get to work[128]. Thus, alternative public transit modes of mobility may be ripe for fruition in the Metro Vancouver region given the area's strong use of transit modes for daily work commutes.

In addition, as of 2016, both the City of Vancouver and Metro Vancouver can count more seniors (people aged 65 and over) than children (people under 14 years old) within their general populations. From 1996 to 2016, the absolute number of seniors in the City of Vancouver increased by 46 per cent, double the growth rate in the overall population of both the City of Vancouver and Metro Vancouver, while the absolute number of children in the City of Vancouver declined by two per cent over the same period[128]. As a result, there is an increasing need in Metro Vancouver and the City of Vancouver for accessible, convenient and low-cost public transit and shared mobility solutions as seniors transition away from independent driving toward shared modes.

## CLIMATE ACTION PLANS

In Metro Vancouver, approximately 70 per cent of personal trips are made by private vehicles. In comparison, 13 per cent of personal trips are made by walking and cycling and 14 per cent by transit[129]. Hence, the region is facing the challenge of encouraging major shifts away from personal car-based travel to cleaner modes of transportation. This transition will require infrastructure investments and changes to land-use policies so that walking, biking and transit become more convenient ways of getting around for most trips[128]. The Climate 2050 strategic framework[129] indicates that without strong action to reduce GHG emissions, locally and globally, current trends will accelerate over the coming decades and it will become increasingly difficult and expensive to maintain a high quality of life for the region. In October 2012, Vancouver City Council adopted the Transportation 2040 plan and passed a Climate Emergency Response[12]. The plan sets long-term targets and includes both high-level policies and specific actions to achieve a city with a smart, efficient, affordable, safe and green transportation system to ensure a healthy future for its citizens and the planet. The plan includes several targets. By 2030, two-thirds of trips in Vancouver will be supported by active transportation options or transit services and 50 per cent of the kilometres driven on Vancouver's roads will be delivered by zero-emissions vehicles. The plan envisions at least two-thirds of all trips in the city will be on foot, on bike or by transit by 2040, supporting a wider move toward zero traffic-related fatalities[12].

In 2019, the Province of British Columbia also passed an aggressive Zero-Emission Vehicles Act. The ZEV Act requires automakers to meet an annual minimum percentage of new light-duty, zero-emissions vehicle sales and leases of 10 per cent of total light-duty sales by 2025, 30 per cent by 2030 and 100 per cent by 2040[13].

Metro Vancouver and municipal governments around the region have taken further critical action on climate change. The City of Vancouver is perhaps the furthest ahead regarding sustainable transportation and modal shifts. Pre-pandemic, the city committed to active investments in carpooling and ride-sharing programs[5]. In addition, based on its Transportation 2040 Plan[12], the City of Vancouver is investing in dense, walkable and complete communities that are well-served by transit through investments for "all ages and abilities," cycling facilities and shared mobility options.

## PROVINCIAL CLIMATE POLICIES

The Metro Vancouver region is situated within a supportive new mobility-oriented provincial context. The CleanBC Plan has committed the province to become a carbon-neutral region by 2050 with an interim target of a 45 per cent carbon reduction from 2010 levels by 2030[129]. According to the CleanBC Plan, Metro Vancouver has the ability to control the distribution of key federal funding sources in the form of the federal gas tax and allied Sustainability Innovation Funds. These funding sources enable the region to support GHG and climate adaptation projects across its corporate operations and throughout the region. For the transportation sector, the plan targets cleaner private vehicles (e.g., battery and plug-in hybrid personal vehicles) with the intention of helping to make those vehicles more affordable based on incentive programs that subsidize EV purchases. The plan also emphasizes the importance of active transportation (e.g., walking, cycling and scootering) as well as expanding public transit services to ensure public transportation is accessible for all people in the province.

While the CleanBC Plan makes no direct reference to new mobility services, investments in MaaS or specific CAV demonstrations, it does highlight the importance of making more compact and complete communities to reduce driving distances by having housing, workplaces, parks and other facilities built close to one other. The plan also emphasizes the need for better urban planning and design choices in cities to make them less emissions-intensive and more supportive of transit mobility modes. As part of this plan, the B.C. government states that it will support partnerships with local governments to achieve the emission reduction goal, which would be required for MaaS or CAV demonstrations and/or long-term deployments for evidence-based policy-making and procurements.

## REGULATORY FRAMEWORKS AFFECTING CONNECTED AND AUTOMATED VEHICLES

All three levels of government — federal, provincial and municipal — play an actual or potential regulatory role in governing CAV operations on public roads. In Canada, unlike the United States, most regulatory activities have been concentrated at the federal level[130].

Federally, Transport Canada is responsible for the Canada Motor Vehicle Safety Standards (CMVSS), which enforce compliance with safety and technical standards for all manufactured and imported vehicles. At the time of writing this report, no electric low-speed autonomous (e-LSA) shuttle manufacturers were present in Canada. Currently, if any entity were interested in importing an e-LSA for a pilot project in Canada, it must apply for a certificate to temporarily enable the import[131]. The Office of the Privacy Commissioner of Canada also plays a CAV regulatory role in protection of data and privacy through the Personal Information Protection and Electronic Documents Act (PIPEDA), which applies to the collection, use and disclosure of personal information by any private sector organization as part of a commercial activity[132].

Provincially, British Columbia, Alberta and Quebec have enacted private sector regulations similar to PIPEDA to which all manufacturers, technology companies and other organizations involved in autonomous vehicles are subject[130]. In addition, provincial governments in Canada are responsible for regulating vehicle types, registration requirements and insurance obligations for the safe operation of vehicles on public roads[130].

In B.C. specifically, the Ministry of Transportation and Infrastructure provides plans for transportation networks and infrastructure and develops related policies, acts and regulations. At the time of writing this report, B.C. did not have any CAV testing regulations in place nor did it have a robust plan in place for developing the CAV industry across the province. Currently, any CAV — whether deployed in pilot projects for private purposes or for MaaS trialling or commercial purposes — needs to be in compliance with CMVSS, and the company or operator must declare that they have addressed all safety concerns associated with CAVs[130].

In Vancouver specifically, there are currently no municipal regulations related to driverless vehicles on local roads. Recently, the B.C. Ministry of Transportation announced it will monitor improvements to autonomous vehicle technology in general and has established a working group to investigate insurance requirements, policy and regulatory implications and potential challenges related to AVs operating on public roads. It has also identified gaps that exist in B.C.'s infrastructure[133]. However, to the best of CUTRIC's knowledge, no Metro Vancouver authorities have issued any specific guidelines in this regard.

No regulatory bodies are set up federally or provincially to assess, monitor and potentially accommodate CAV deployments on a piloting basis. There appears to be no task force or dedicated and co-ordinated federal-provincial-regional regulatory framework for CAVs as new mobility, or as MaaS delivery modes. An integrated provincial-regional new mobility and CAV regulatory task force may need to be established to support development of a regulatory and compliance framework to ensure safe, cybersecure and effective CAV and MaaS-oriented CAB piloting, and demonstrating projects can be launched in the near term to assess the viability of these technologies within the Metro Vancouver region.

### Areas of CAV activities

In 2018, Vancouver and Surrey were shortlisted for a $50 million award through Infrastructure Canada's Smart City Challenge[64]. Their joint proposal featured Canada's first two collision-free, multi-modal transportation corridors that would link the two cities.

- The 3.4-kilometre Surrey corridor connects Surrey Memorial Hospital and other key services to a major transit hub.
- The two-kilometre Vancouver corridor extends from Granville Island to Science World.

The proposal included autonomous shuttles with sensors in traffic signals along the corridors, lighting and other roadway infrastructure to generate data for real-time traffic signal adjustment and communication with AV shuttles. It also contained advanced data analytics integrating data from disparate sources to support corridor and AV operations and enhance user experiences through shared mobility options and optimizing trip planning[134].

Although the joint bid was not successful in gaining federal funding as part of the national Smart Cities Challenge (the Smart Cities Challenge was ultimately awarded to the City of Montreal), Vancouver and Surrey's proposal for multi-modal collision-free corridors should be revived as a well-developed foundational starting point for future MaaS and CAV deployments and demonstrations[135].

It does not appear, however, that any version of the joint bid by Vancouver and Surrey is being revived at the Metro Vancouver level for execution in the near future using alternative federal or provincial funds.

### Vancouver's technology ecosystem and CAV manufacturers

In 2017, the City of Vancouver was ranked as Canada's top startup hub. The ranking identified the city's major assets in clean tech, blockchain resources, life sciences knowledge and gaming capacities. Startup Genome's report indicates there were approximately 250 clean tech companies (employing 7,700 employees in total) in Metro Vancouver in 2017. Canada's gaming studios contribute $3.7 billion to the country's gross domestic product, one-third of which is based in Vancouver.

According to a more recent Startup Genome report published in 2019, following the Toronto-Waterloo corridor, Vancouver now ranks second in Canada and 24th in the world among startup ecosystems. The report attributes Vancouver's decline in ranking to three factors: the debut of four other ecosystems, Vancouver's lack of a life sciences ecosystem and Vancouver's "static" state of funding[136].

The revival of the Vancouver-Surrey Smart Cities proposal combined with dedicated commitments by the Metro Vancouver region to piloting and ongoing demonstration of on-demand, new mobility through MaaS modes of service, as well as CAV deployments for FKLK challenges facing TransLink and regional end points, could serve as a means for reinvigorating Vancouver's startup technology sector. Meanwhile, the startup technology sector in the Metro Vancouver region should be leveraged as it exists to help develop the operational control systems, user applications and transit-oriented software solutions needed to deploy safe, cost-effective MaaS services and CAV mobility services.

# SUMMARY OF KEY CONSIDERATIONS: METRO VANCOUVER POLICY LANDSCAPE AS IT RELATES TO THE FUTURE OF MOBILITY

PHOTO: DedMityay, Adobe Stock

Achieving reductions in transport GHG emissions will be a significant challenge for cities throughout Canada. To enable a transportation network that ensures a highly accessible rate of personal mobility with few emissions requires several climate strategies be integrated across the Metro Vancouver region.

Importantly, the region has already established a long-term strategic vision of future mobility, embodied in its Transportation 2040 Plan and its Climate Emergency Response[12]. The plan sets out long-term targets and includes high-level policies and specific actions the city can achieve with a smart, efficient, affordable, safe and green transportation system aimed at Metro Vancouver residents.

The plan includes a number of goals that would support MaaS and CAV services as part of a new mobility paradigm. For example, it targets 2030 as the date by which two-thirds of trips in Vancouver will be by active transportation and transit, and 50 per cent of the kilometres driven on Vancouver's roads will be by zero-emissions vehicles. As the region is facing the challenge of encouraging major shifts away from personal car-based travel to cleaner modes of transportation to achieve these goals, this transition will require infrastructure investments and changes to land-use policies so that walking, biking and public transit — including new mobility modes, MaaS technologies and CAVs as people-mover technologies potentially deployed on demand — become more convenient ways of getting around for most trips across Vancouver.

Building on an already existent and widely support Transportation 2040 Plan, Metro Vancouver policy-makers could play an important role in advancing the deployment of new mobility modes, MaaS technologies and CAVs as emissions-reducing and mobility-improving tools in the fight against climate change, if funding for deployments and demonstration programs were tied to urban redesign efforts that allocate dedicated laneway and support on-road digital infrastructure build-outs that enable safe, shared mobility that is driverless, connected and on-demand.

# STAKEHOLDER INTERVIEWS

PHOTO: noppawan09, Adobe Stock

As part of this study, CUTRIC interviewed decision-makers at three critical governmental organizations and bodies in the Metro Vancouver region to obtain more insights into current and future new mobility and CAV impacts on GHG emissions. The names of these organizations are withheld in this report to comply with non-disclosure agreements.

In total, seven questions were formulated to obtain insights from government officials regarding new mobility and CAV deployments in the future. The semi-structured nature of the interview and associated questionnaire enabled qualitative inputs from interviewees as well. These questions are transcribed below along with a detailed amalgamation of answers.

## INTERVIEW QUESTIONNAIRE AND QUALITATIVE RESULTS

**1. Under what circumstances do you envision new mobility and CAVs helping to reduce greenhouse gas (GHG) emissions in Metro Vancouver?**

Participants interviewed in this study provided the following feedback:

- The B.C. government's CleanBC Plan outlines goals for cleaner transportation in the future. Municipalities in Metro Vancouver are working together on a transportation strategy for 2050 and the main focus of this plan is on EVs and new mobility services.
- CAVs should not be privately owned. If CAVs are privately owned, there would be more vehicles on the roads, resulting in increased GHG emissions.
- The B.C. government aims to address the environmental impacts of transportation by integrating more active transportation with new mobility services, such as the use of electric scooters and other shared electric forms of personal mobility or micro-mobility.
- It is necessary to scale down the VKT for new mobility services while using renewable energy. They noted that the way to reduce VKT could be road pricing and encouraging shared mobility.

**2. What attributes of new mobility and CAVs do you see as most problematic from a GHG emissions and urban livability perspective?**

Participants interviewed in this study provided the following feedback:

- There is a possibility that new mobility services and CAVs increase the amount of travel, including deadhead trips, which could have a dramatic negative impact on GHG emissions.

The regulations of new mobility and CAVs are challenging and the public must perceive these new forms of mobility to be safe.

- New mobility services and CAV technologies need to be considered within the context of a dense urban environment with unpredictable movement from different users.

Automated and connected technologies are not mature enough yet to be safely deployed and the transition period will be challenging.

**3. How well is the region prepared for the advent of new mobility and CAVs?**

Participants interviewed in this study provided the following feedback:

The region and the province are working together on issuing business licences, regulations and pricing based on the usage of distance travelled for ride sharing and on-demand services.

Metro Vancouver is well placed to benefit from new mobility services and especially shared mobility services. The municipalities in Metro Vancouver have valuable experience in compact transit-oriented growth management, which is a solid foundation on which to build any new mobility service.

- CAVs have the potential to contribute to a "utopian vision" of sustainability and equity for all, or the opposite. In a best-case scenario, or "utopian" ideal, CAVs would complement active transportation and mass transit, radically reduce the total number of cars on roads, increase safety and mobility options, and free up public space currently used for parking. In a 'nightmare" scenario, CAVs induce longer commutes and sprawling development, compete with walking and cycling and reduce investment in high-capacity mass transit. It is important to understand how exactly the technology needs to be leveraged in service of the kind of future British Columbians are seeking.

**4. What local and/or regional trends do you see as particularly influential in the uptake of new mobility and CAVs that should be considered in this study?**

Participants interviewed in this study provide the following feedback:

- The region is taking necessary climate action plans. Metro Vancouver adopted more aggressive targets for its climate strategy[58], so the region will become carbon-neutral by 2050, with a 45 per cent reduction by 2030.
- The regional strategy pursues three main threads in the Metro Vancouver Regional District 2050 plan: First, what trips can be substituted through digitization? Second, how to bring people closer together through improved land-use planning and high-quality compact communities. Third, how to design a sustainable transport system that focuses on new mobility, walking, cycling and extensive frequent transit for all users.

**5. What information related to emissions and livability aspects of new mobility and CAVs would be particularly relevant to your organization's planning and decision-making (or for regional planning and decision-making).**

Participants interviewed in this study provided the following feedback:

- The high cost of zero-emission forms of transportation impeded accessibility. Government officials in B.C. are interested in equitable access for everyone so that services can serve people of all income levels. Therefore, making cities more attractive and livable means less motor traffic on main corridors and prioritizing shared mobility.
- The regional transportation strategy does not allow high-speed CAVs to take over the cities' roads. The intention is to reduce VKT, which is the biggest driver of GHG emissions over the next decade.
- In the near future, cities may move towards shared CAVs. So, it is important to make sure city parking is adaptable and flexible, and that road space can be reallocated for other purposes, as shared mobility allows.

**6. To the extent you are aware of them, which regulations, government policies and strategies are regions and cities outside of B.C. using to support new mobility and CAVs that should be considered for the Metro Vancouver region?**

Participants interviewed in this study provided the following feedback:

B.C. transport officials are working with the Urban Mobility Task Force, Transport Canada and the Ontario, Saskatchewan and Quebec transport authorities to review AV technologies. More focus is on actual technologies around the implementation of CAVs, which guide the technical components. However, unlike other provinces such as Ontario, no laws or regulations govern CAVs in B.C., and these vehicles are not currently permitted on B.C. highways.

**7. In what ways are you aware of the COVID-19 pandemic influencing the future deployment of new mobility and CAVs? To what extent do you believe these effects will shape livability or GHG emissions?**

Participants interviewed in this study provided the following feedback:

- The most significant impact of the COVID-19 pandemic on the transport system is the decline of transit ridership. It is expected that the pandemic's impact will continue over the next couple of years and is likely to make structural changes on how people work and commute to work. As a result, many people will probably continue working from home in some way. In the near term, people will be choosing to drive alone, instead of carpooling or ride sharing.
- Given the negative impacts of COVID-19 on individual, local, regional, provincial and federal finances, smaller forms of new mobility services, either electric or non-motorized, could be more popular as they are more affordable.
- COVID-19 has resulted in specific transportation changes, such as increasing cycling and telecommuting, which can contribute to overall GHG emission reductions. It is important for cities to recognize these changes, learn from each other and re-evaluate the role of shared mobility and new mobility services within the context of these unprecedented times.

Many unknown parameters around the impact of this pandemic on mobility exist, which require more investigation.

## INTERVIEW ANALYSIS

Interview insights from stakeholders provide information on the perceived environmental impact of new mobility options, such MaaS technologies and CAVs as envisioned within the Metro Vancouver region specifically. Interview participants identify different attributes of new mobility and CAVs from both GHG emission and urban livability perspectives.

Participants indicate various alternatives related to the future of mobility, including driverless vehicles, connected technology and more shared mobility services such as transit, walking and cycling, need to be positioned at the forefront of government and city planning.

Participants highlight the importance of a smart, integrated and environmentally friendly transportation system with a focus on active transportation and transit. New mobility technologies, such as MaaS and CAVs, need to be brought within that planning framework.

Participants highlight the need to establish a thoughtful regulatory system that requires all transportation elements — public transit and private TNCs or mobility service providers — to work together to create more livable cities with affordable and accessible transportation solutions for all users, while increasing the use of renewable energies for the transport system.

Participants highlight the importance of reducing privately owned VKT as a key contributing factor in GHG reductions and the fight against climate change. This can be done through pricing incentives that encourage shared mobility platforms over individual cars.

Participants also focus on the needs for structural changes to how people work and commute in a post-pandemic world, which can possibly reduce people's interest in shared mobility options, including transit. Thus, transport authorities need to consider that various new mobility services may be efficient and affordable while accommodating health and safety concerns over COVID-19 and/or other airborne illnesses.

# RECOMMENDATIONS AND CONSIDERATIONS

PHOTO: AndSus, Adobe Stock

The research outcomes summarized above lead to several recommendations for consideration by policy-makers in the Metro Vancouver region regarding regulation, procurement, deployment and performance of new mobility technologies, such as MaaS and CAVs.

## RECOMMENDATIONS

### Regulations and demonstrations

New mobility options, such as MaaS technologies and CAVs, will be shaped in the future by a combination of overlapping federal, provincial and municipal regulations. These regulatory frameworks — many of which are yet to be developed — will need to cover new mobility technology piloting, safety and data management regulations and deployment guidelines. The findings show that any MaaS solution would require strong political willpower and commitment at the municipal, provincial and federal levels, combined with amenable safety frameworks and funding programs that proactively support demonstrations, pilots and evidence-gathering in the near future so that policy-makers can design appropriate regulatory structures that grow mobility rather than hinder it.

Regulations for new mobility and CAVs would be best developed based on the empirical evidence of pilot programs and demonstration deployments that last at least one year and that cover multiple differing jurisdictions within the Metro Vancouver region so that policy-makers can obtain substantial and real-life mobility behaviour data to inform their regulatory work.

This includes data about how users utilize MaaS and CAV technologies at different times of day, in different seasons and when integrated with differing (other) public and private options. These demonstrations would furnish data about whether such technologies lead to VKT reductions per person and whether new mobility can be designed to grow transit ridership rather than hinder it in the Metro Vancouver Region.

From a new mobility perspective, and specifically a MaaS perspective, Metro Vancouver should consider the following strategic and regulatory innovations:

- Develop a new mobility and MaaS framework that identifies users' needs at its core and that outlines specific synergies and partnerships between public actors, such as TransLink, and private actors, such as TNCs, that may support addressing FKLK challenges. This will require specifically highlighting forms of public-private partnerships to trial new mobility solutions within the region, given the late arrival of TNCs to the Metro Vancouver Region overall. Such a framework must identify targeted (a) car reductions to be achieved as a result of new mobility and CAV technologies (distinct from car reductions achieved through active mobility), (b) percentage of intended passengers and riders that will rely on the modes if successful, (c) quantity of dedicated road space likely to be dedicated to new mobility modes such as CAVs, and (c) a trialling time period and intended full in-service operational schedule for new mobility modes within TransLink's existing growth plans. This framework should build on and stay consistent with other Metro Vancouver and British Columbian strategies developed and published by governments that currently focus on people-friendly environments. To be an effective development tool, this framework must integrate with and encourage active transport solutions and protection of green spaces, watersheds, natural habitat and agricultural land, and aim to prevent sprawl.
    - » Within this framework, recognize that CAVs in Canada will be low-speed and deployed on dedicated or semi-dedicated laneways for the next five- to 10-year period, if not indefinitely, given the technologies are not able to safely and securely navigate complex levels of interactions with other road users, especially left-hand turns in uncontrolled environments or mixed-traffic scenarios.
- Encourage and fund the deployment of multi-seasonal MaaS and CAV pilot programs and demonstration projects that de-risk the cost of deploying new software platforms for on-demand MaaS tools, and that support dedicated laneway (SAE Level 4) trialling of CAVs as transit shuttles along fixed routes to start, followed by on-demand service delivery within defined geographies. This will require completion of detailed route-based and on-demand geo-fenced "service area" feasibility studies in advance of pilot deployment. These feasibility studies should model the physics and economics of client usage, vehicle movements, user clustering, service frequency and energy demand (for charging of electrified pods) that help agencies fully understand the operational needs and unique characteristics of MaaS combined with CAV deployments. Route-based performance analyses of CAVs especially will help to paint a picture in advance of the actual and likely performance (in terms of range, passenger load, average speeds) that CAVs can achieve on particular routes in Metro Vancouver today.

    - » This feasibility work should integrate short- and long-term economic and financial cost assessments using differing comparative models, such as the "asset ownership" model (wherein a city owns and operates MaaS tools and CAVs) versus a "service delivery" model (wherein a city pays a provider of MaaS tools and/or CAV services to deliver a specific number or frequency of CAV rides or passenger kilometres).
    - » This feasibility work should integrate detailed environmental predictions related to direct CO2 and smog/pollution effects associated with MaaS and CAV pilots and demonstrations, as well as direct ridership growth predictions and indirect health cost effects (through long-term smog reduction).

- Require private sector partners to share all vehicle and performance data associated with the pilot and demonstration programs so that policy-makers at Metro Vancouver and the Government of B.C., and decision-makers at TransLink, can help to formulate more broad-ranging shared mobility mode regulatory frameworks incorporating vehicle safety requirements, speed requirements, cybersecurity requirements, on-road infrastructure requirements and personal data (of users) specifications and requirements.
- Utilize trials and demonstrations to ensure ongoing training for high-quality personnel knowledgeable in new mobility, MaaS and CAVs at TransLink and in the public service so a fundamental skills gap in these new technologies does not hinder the growth of transit and mobility opportunities and so that unintended negative consequences associated with the deployments of these technologies are understood a priori as potential risks of deployment.

As noted throughout this report, CAVs specifically can be deployed on fixed routes or as on-demand mobility services. Given the technology's development, and the complexity of current street designs, CAVs are optimally applied to dedicated laneways such as bus rapid transit routes, dedicated streetcar or bus lanes, or other forms of newly dedicated space, such as mixed streets that have extended bicycle lanes in which low-speed small-shuttle CAVs carrying four to six people could operate at speeds no greater than 20 km/hr. As a form of new mobility, which could be deployed in structured or on-demand shared modes, CAVs carry the potential to support more dynamic transit services, especially for first-kilometre/last-kilometre challenges. Thus, to support the growth of these technologies in a form that fits local needs best, Metro Vancouver should consider the following innovations:

- Recognize within a new mobility and MaaS framework that CAVs can form a part of the transit fleet, whether owned or operated publicly or privately, or a mixture of the two business plans (i.e., private ownership of the assets with public management of vehicle deployment, or vice versa), and that these small electrified shuttles can be deployed to promote FKLK solutions in support of TransLink and public transit specifically.
- Ensure street-level urban design considerations account for the need for more dedicated laneway (such as expanded bicycle or scooter lanes) that would support low-speed SAE Level 4 CAV deployments for FKLK solutions and as supplementary on-demand transit

services. Ensure speed limits are designed for these services in advance to increase safety levels and ensure street-level design considerations also take into account a priori the roadside infrastructure needed to support CAVs specifically, such as roadside dedicated short-range communications (DSRC) units installed at traffic lights and corners, as well as the on-route charging stations the CAVs will need access to if they are intended to be operational in all-day service.

  » Ensure local connectivity devices that support CAVs in real time can help to enforce slow zones (e.g., near schools, parks, bike routes, construction zones).

- Launch pricing pilot programs with time-of-use pricing mechanisms that restrict private vehicles, including privately deployed CAV devices, and that privilege shared mobility mechanisms through MaaS platforms that connect users to transit networks and transit-led CAVs in their communities. Price signalling will help to ensure the ease of new mobility modes — such as on-demand taxis provided by Uber or Lyft and other TNCs, or privately owned CAVs — will not lead to greater congestion, greater emissions and worsening urban liveability.

The Metro Vancouver region is already an innovation zone, and strategic investments and regulatory frameworks that shape the safety, cybersecurity and intended ridership improvements associated with new mobility, MaaS and CAVs could help the ongoing growth of this jobs-rich economic zone in Canada.

### Transit agencies and cities

As with public transit and mass mobility in general, new mobility technologies such as MaaS and CAVs could help to overcome socioeconomic inequalities and support active mobility growth, existing public transit and other low-cost shared transportation modes if properly designed with the public interest at heart. If, instead, MaaS and CAVs are allowed to be deployed without a public mobility transit framework in mind, a complex web of overlapping, inefficient and competing private interests will emerge that may do little to reduce the price of mobility, improve equality or support the movement of people in an environmentally sustainable manner. Ensuring that new mobility tools, and CAVs especially, are designed and deployed so they offer cheaper, faster and more efficient modes of mobility than personal ownership of single-passenger vehicles will require leadership from TransLink. Beneficially for Metro Vancouver, the agency is already exceptionally well structured to support this type of innovative leadership.

From a new mobility perspective, and specifically MaaS and CAV perspectives, research studies indicate that Metro Vancouver's transit services — specifically TransLink — should consider the following opportunities:

- Deploy advanced piloting and demonstration projects with MaaS and CAVs in the worst performing areas of the TransLink network. Utilize these demonstration data to determine whether low-cost, smaller, electrified and on-demand shuttles can effectively replace or cheaply supplement more expensive driver-led 12-metre bus services and whether they can support the transition from car use to transit use in car-dependent communities. These deployments will require the redesign of some streets in those areas to ensure CAVs especially are not required to navigate left-hand turns in mixed traffic; therefore, early deployments need to establish dedicated, semi-dedicated or traffic-light controlled service delivery with CAVs so that SAE Level 4 technologies perform safely and effectively.

- Utilize real-time ridership surveys to determine whether on-demand platforms combined with on-demand or fixed-route CAVs support consumer and rider needs in those areas as intended, or whether they lead to unintended avoidance of transit services (possibly due to technological delays caused by the frequent stopping and starting of low-speed CAV shuttles that arises from object-detection software onboard the vehicles).
- Seek to leverage current TransLink payment mechanisms within MaaS platforms and onboard CAV vehicles. The primary intention of these technologies is to support low-cost publicly oriented mobility. Riders and users should not be inconvenienced or deterred by duplicate or competing payment systems. Integration of TransLink's digital Compass ticketing online or physically within the fare network will be critical to the success of new mobility platforms and CAVs as part of Metro Vancouver's transit network. The integration of existing digital fare systems with new mobility delivery modes will ensure buses and trains are fully accessible to new mobility users and, conversely, that buses and trains are not inadvertently excluded from the MaaS ecosystem due to fare inconvenience.

### Social

New mobility, like MaaS and CAV technologies, could help motivate transit agencies and cities to adapt to new mobility options and technologies and establish specific targets for shared CAV deployments and CO2 reductions as part of city-led climate action plans. From a new mobility perspective, and specifically MaaS and CAV perspectives, Metro Vancouver should consider the following opportunities:

- Support the development, by TransLink and allied service providers, of more digitally enabled planning tools that support public transit travel through digital interfaces, automated payment mechanisms and electronic applications. This requires effective integration of real time street-level information, transit telemetry data, and trip-planning, pre-booking and digitized ticketing tools to fully enable MaaS growth as a set of mechanisms that drive users toward public transit use in a seamless and unproblematic fashion.
- Ensure that any such new mobility frameworks, pilot programs or digitized ticketing solutions also dedicate capacity and space to achieving public transit and mobility accessibility and equity by offering the unbanked and less economically privileged citizens a means of using these services even if they have no smartphone, credit card or credit history. This may require the innovation of needs-based free passes for transit services for some segments of the population; otherwise, new mobility technologies may

exacerbate existing digital divides and consequent economic segregation among and between residents of Metro Vancouver.

- Promote the integration of new mobility options with feeder modes such as walking, cycling and any active and innovative transportation solution. This will require cities to furnish providers of MaaS technologies with high-resolution mapping data and active transportation data through open sourcing of those data sets in real time.

## TECHNOLOGY CONSIDERATIONS

New mobility technologies, such as MaaS and CAVs, could help motivate the wider national effort to transform mobility into active, shared and electric networks. From a new mobility perspective, Metro Vancouver should consider the following opportunities:

- Begin development of a big data analytics and machine-learning program within public transit services to ensure that public transit operations are future-proofed over the long term to manage customer needs more efficiently and to establish digital mechanisms for linking real-time customer needs to mobility devices (trains, buses, shuttles, pods, active transport infrastructure).
- Support development of a regional open technology architecture that private partners, such as TNCs and CAV manufacturers and operators, can integrate with to ensure their services and vehicles fit municipal requirements and specifications early on. This will help avoid the scenario of incompatible and competing vehicular and service tools that cannot integrate into one seamlessly available set of user-oriented, on-demand services or transit vehicles.

## PANDEMIC CONSIDERATIONS

Although the COVID-19 pandemic may have changed travellers' behaviours and frequency of service for mass transit, the focus should still be on increasing shared mobility and improving connectivity by making it easier and more convenient for users to connect to existing public transit[137, 138].

From a new mobility perspective, Metro Vancouver may consider the following opportunities:

- Continue prioritizing the health and safety of transit riders and mobility users in all shared mobility vehicles by supporting provision of hand sanitizers and safety information for passengers, including mask-wearing and social-distancing requirements.
- Support information-driven digital platform communications structures that can increase user awareness, and make them adaptable to fast-changing needs based on pandemic considerations. Existing and future MaaS platforms could support digitized communication with users in real time effectively.
- Ensure that MaaS is at the forefront of potential mass "return to transit" efforts so that opportunities such as load- and demand-shifting based on time-of-use price signals or

clustering ridership information conveyed to users via their smartphones and transit applications help users better decide when to ride and when to disperse or stay home.

- Build back trust and confidence through transparency of communications with public users of the transit and shared mobility system by leveraging the systems' smart-enabled communications platforms today (including social media platforms), and by building out better MaaS communications structures for future pandemic-communications needs.

## OTHER CONSIDERATIONS

Other more general recommendations supporting efficient and optimized new mobility services and CAV deployments in Metro Vancouver include the following:

- Maintain strong regulations to contain and prevent sprawl to ensure Metro Vancouver remains a thriving, liveable and dynamic region that attracts citizens because of its high liveability scores, and to ensure new mobility services and public transit services remain low-cost based on high ridership and demand.
- Discourage single-passenger or private vehicle transportation by prioritizing roadway allocation for active transport, mass transit and shared mobility modes and use new mobility and CAV regulatory frameworks and data-supported traffic-control systems (e.g., AI-enabled traffic light controls) to prioritize the movement of shared mobility assets on roads to reduce VKT and GHG emissions.
- Consider policies such as road-pricing and other travel-demand measures that involve penalizing privately owned vehicles and/or single passenger trips to support the integration of active transport, public transit and low-cost new mobility modes of people movement.
- Support the ongoing growth of a high quality of urban life in Metro Vancouver where dense and diversified built environments in combination with variety of shared mobility options are integrated and built into environment and land-use planning policies with new mobility, public transit and CAV deployments at the heart of design processes.

# CONCLUSIONS

PHOTO: Monopoly919, Adobe Stock

This report has reviewed a combination of academic and industry sources to explore the impact new mobility tools, such as MaaS and CAV technologies, may have on GHG emissions and overall access to mobility.

Based on a review of the literature and a synthesis of findings on possible environmental impacts associated with these technologies, this report provides insights into how to develop mobility services that support GHG emission reductions in Metro Vancouver. Primarily, the report concludes that a targeted framework for deployment of these tools and their integration with public transit is needed at the Metro Vancouver level, and that within this framework, funding for long-term (minimum 12 month) demonstration trials is needed to gather sufficient data to predict how users will alter their behaviour, potentially abandon their cars and move toward shared modes if these services and technologies were more widely available. Conversely, these demonstration projects may show unintended consequences or unpredicted user behaviour that worsen public transit access, drive up costs or lead to greater, not fewer, emissions. In brief, more data is needed to support a fully developed MaaS and CAV-enabled future in Metro Vancouver because global studies are still insufficient for the purpose.

What has been shown is that new mobility services and CAVs have the potential to reduce congestion and GHG emissions if proper policies exist that promote active transport, public transit, ride sharing and electrification while enacting carbon taxes and road-pricing mechanisms to control the threat of empty vehicles on roadways. Research studies indicate MaaS could help to enhance accessibility and equity through a shift from ownership-based to access-based transportation[17, 19, 20]. MaaS technologies could also offer a wide range of customized mobility solutions, which could improve societal value based on user preferences, increasing accessibility and the ability to utilize transportation modes for residents of low-density areas, while offering affordable solutions for low-income households. In this regard, MaaS could support a new transportation paradigm as it addresses many of society's grand challenges in mobility, promising thereby to support improvements in terms of environmental sustainability, reduced congestion and better accessibility.

This report also offers a summary table of a range of plausible "heaven" and "hell" scenarios with impact themes discussed throughout, including vehicle-kilometres travelled, the built environment, parking demands, energy usage, time efficiency and active and public mass transit — important variables that new mobility like as MaaS and CAV deployment could possibly influence in positive and negative ways. While some studies estimate an increase in VKT as a result of lower-occupancy vehicles within MaaS or switching from conventional vehicles to CAVs, which is most likely applicable for non-shared mobility solutions or private CAVs because of increased travel demand and modal shift from public transit[40, 80, 83, 105], other studies demonstrate that differing policies could ensure new mobility and CAVs contribute to reducing GHG emissions when deployed in shared mobility modes regulated by a region or municipality.

Regarding the Metro Vancouver region's readiness for new mobility such as MaaS and CAV deployments, new frameworks, rules and regulations could support the positive growth of these technologies. As CAVs and other innovative mobility technologies are already emerging and in operation in some parts of the world, the preparation and prioritization of their arrival by the regional government as well as the municipalities is paramount. Governmental considerations of critical regulatory developments and infrastructure requirements should focus on the desired societal benefits of future mobility within a transit framework.

It is evident that in a post-pandemic world, the Metro Vancouver region — as with other Canadian and global municipal regions — will be struggling to bring ridership back to shared modes and transit-focused mobility services. But these services are critical to environmental sustainability, and MaaS and CAV technologies could be leveraged to support a post-pandemic, return-to-transit scenario in which agencies attract riders back with faster, cheaper, more innovative and more convenient mobility options. Metro Vancouver can become a leader in MaaS and CAV technology deployments in Canada and lead the transition within large urban areas and to low-cost equitable new mobility modes. This will require vision-setting within a MaaS- and CAV-oriented strategic framework. If that is achieved, Metro Vancouver could lead the nation in planning and procuring new mobility modes and integrating them with other innovative climate action technologies, such zero-emissions bus technologies.

If governments and transport authorities plan to invest in new mobility and CAV deployment, it is essential to establish thoughtful regulations, policies and targeted strategies that ensure MaaS and CAVs are deployed as shared mobility options that improve safety, reduce congestion, increase shared mobility and reduce GHG emissions overall. While the key positive or negative potential future outcomes related to new mobility and CAV deployment are identified throughout this report, they largely depend on the Metro Vancouver region's drive to address climate action through a transit-privileged, shared-mobility investment action plan.

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