Sustainable Mobility

An economic overview of shared, automated and Electric vehicles in **Metro Vancouver**

Shabnam Khalaj, UBC Sustainability, 2019

Eve Hou, Project Manager, New Mobility, TransLink

August 2019

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organisations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of TransLink and Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of TransLink and Metro Vancouver or the University of British Columbia.

CONTENTS

EXECUTIVE SUMMARY

In the new era of sustainable mobility, the focus is mostly on the environmental impacts of electric, autonomous and shared vehicles, yet they will also have other meaningful impact on regional economies. Not warranting enough attention to the economic aspect would not give us a complete picture of the impacts of these new modes of transportation.

Identifying the contribution of these new modes of transportation to the regional economy is challenging as this sector does not have a well-identified sectoral code. Due to the unavailability of regional data, In this study, we instead analyzed the size of the clean transportation sector in BC and found that the clean transportation sector contributed CAD $1.87 billion to the provincial GDP and 24,175 people were employed in this sector in 2018. For the purpose of this study, clean transportation is defined as "public transit, clean transportation vehicles, rail and low-carbon marine transport, improvements to the transportation system through technology".[1]

The diffusion of these new modes of transportation will have important implications for the labour market. Penetration of electric vehicles (EVs) will disrupt jobs in several sectors such as the oil and gas industry, manufacturing of ICEs (conventional vehicles) body and parts, repair and maintenance.

An increase in deployment of electric vehicles would push car manufacturers who have not adapted their production to the new trends out of business, which results in job losses. On the other hand, electric vehicles have fewer moving parts, therefore their assembly is less labor intensive, which can negatively affect jobs in the manufacturing sector. The cost effectiveness of electric vehicles will decrease the oil demand by passenger vehicles, potentially affecting the jobs in this sector.

Electric vehicles need less maintenance in comparison to Internal combustion engine (ICE) vehicles. This will decrease the demand for jobs in the repair and maintenance industry even if given the upskilling of workers. Nevertheless, penetration of EVs will have positive effects on the electricity generation and distribution sector, manufacturing of car-related electronics, battery technology and recharging equipment. Despite the proven positive environmental impacts of EVs, the overall impact of electric vehicles on the economy is ambiguous.

Autonomous vehicles (AVs) bring new disruptions to the labour market. Driving-related jobs, for example taxi driving, will be eliminated as well as other related jobs to driving like traffic police officers. However, with adoption of the AVs, people who are physically impaired but have the qualifications for certain jobs or older people will have more job opportunities.[2] The size of the effect will depend on the rate of deployment, combination of technologies used and also the upskilling of workers in the disrupted sectors.

---

[1] Globe Advisors. (2012). British Columbia Clean Transportation Sector

[2] Public and Private Benefits of Autonomous Vehicles W. David Montgomery, PhD, June 2018

Although the size of the effect on the labor market is unpredictable, we presented the current statistics on the labor market where public data was available.

Taxi driving is expected to be the sector with most negative outcomes. In 2018, 6,080 people were employed in the taxi driving sector with the expected annual average employment growth of 1.5% until **2028** in the Lower Mainland and Southwestern BC.

In total, 68,600 people were employed in the sectors that will be positively affected by electric vehicles and 115,500 people are working in sectors with possible negative effects in 2018 in B.C. These results should be used with caution as they are based on the NAICS codes which span a broader range of sectors than those identified in above.

The channels through which autonomous vehicles can provide benefits for the economy through cost savings have been identified by screening of the literature and quantified specifically for the Metro Vancouver region. **The benefits of AVs will come from fuel saving, collision reduction, time value and congestion reduction and have been estimated to be around CAD $8 billion**. This number is highly sensitive to the assumptions made in the paper and should not be taken without attention to the detailed assumptions. [13]

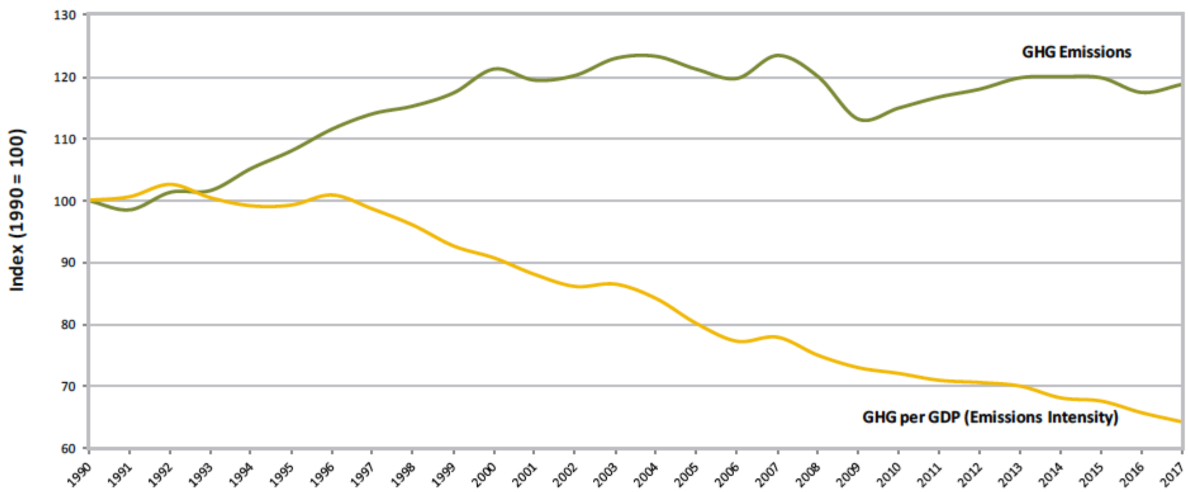
The final part of this research project identifies the cost per kilometer travelled for these new modes of transportation and their combination. Although it is difficult to predict the rate of deployment of these new modes of transportation, comparing costs provides a framework for the probable reaction of consumers to new mobility options. This report concludes that, on average, the cost of an autonomous vehicle is higher than a human-driven vehicle, which only justifies their penetration if they are offered in the form of shared vehicles. Since autonomous shared electric vehicles have a lower cost per kilometer travelled in comparison to the autonomous shared internal combustion engine (ICE) vehicles, they will become the dominant technology at least in the shared vehicle fleets.

3 The Conference Board of Canada. (2015). vehicles; the coming of the next generation

INTRODUCTION

Canada's greenhouse gas (GHG) emissions have increased steadily over time but have stagnated since around 2013 (Figure 1). GHG emissions were 716 megatons of carbon dioxide equivalent in 2017. However, looking at the GHG emissions levels will not give us a complete picture. Canada's economy has also expanded over the years. The GHG emissions per GDP has a persistent downward trend meaning that the emissions intensity has decreased relative to the size of the economy. The level of GHG per GDP in 2017 was almost 40% lower than its 1990 levels.

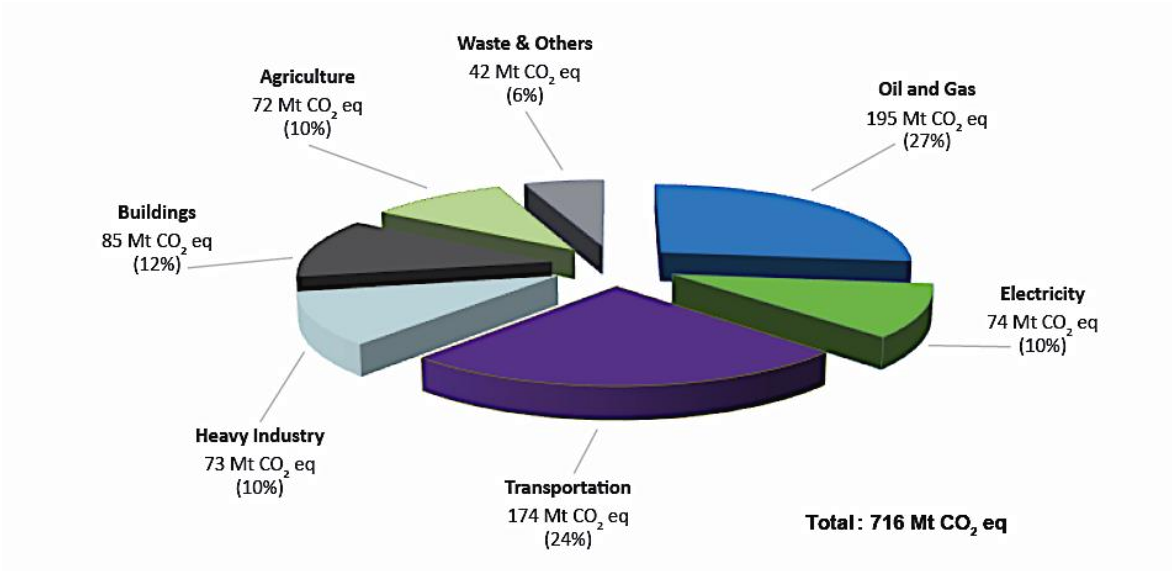
Figure 1. Indexed Trend in GHG Emissions and GHG Emissions Intensity (1990–2017)



Source: Canada—National Inventory Report 1990–2017—Part 1 (2019)

The majority of the emissions in Canada in 2017 came from the Oil and Gas, and the Transportation sectors with 27% and 24% from each sector, respectively. According to the National Inventory report of Canada (2019), the majority of emissions come from road transportation, both from personal and heavy-duty vehicles. A closer look into the sector shows that although the vehicle kilometres travelled (VKT) per vehicle has decreased, the overall increase in the number of vehicles on the road has increased the has increased the overall vehicle kilometres travelled.

Figure 3: The Emission Breakdown by Economic Sector (2017)



Source: Canada—National Inventory Report 1990–2017—Part 1 (2019)

Greenhouse Gas Emissions in the Metro Vancouver Region

As the scope of this study is specific to the Metro Vancouver region, we focus mostly on regional emissions. The 2015 emissions inventory finds the main contributors to GHG emissions in the Lower Fraser Valley to be “cars and light trucks, the petroleum products sector (mainly refineries), the non-metallic mineral sector (mainly cement plants), heating (e.g., buildings), non-road engines and heavy trucks and buses.”[4]

In the Metro Vancouver region, transportation is the largest source of greenhouse gas emissions, accounting for approximately 45% of the regional total. Cars and light trucks make up the majority of these emissions.

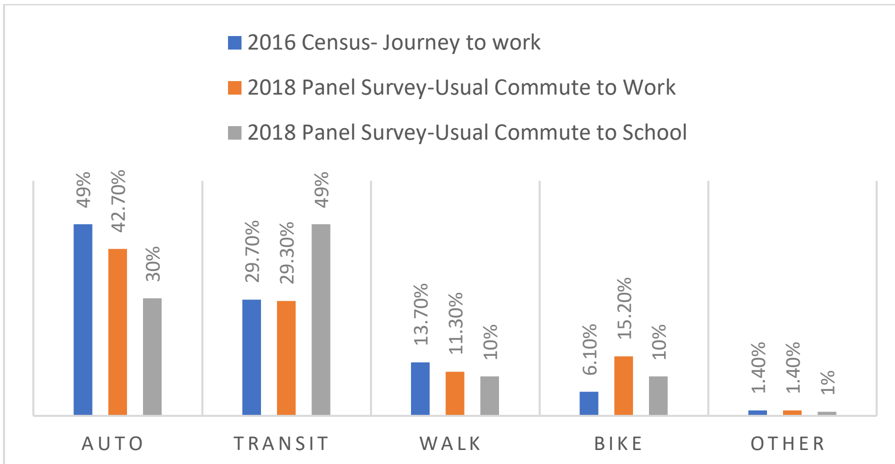
The Metro Vancouver Regional District is targeting a reduction in GHG emissions of 45% below 2010 levels by 2030. As mentioned, a substantial amount of greenhouse gas emissions come from the transportation sector, which is why the uptake of clean energy vehicles is central to decreasing GHG emissions both at the national, provincial and regional levels. In the following sections, shared, automated and electric vehicle transportation modes are analyzed in more depth.

[4] 2015 Lower Fraser Valley Air Emissions Inventory and Forecast, March 2018

Mobility Patterns in the City of Vancouver

The Vancouverites' mobility pattern was assessed in the City of Vancouver's sixth annual Transportation Panel Survey conducted in 2018.[5] This panel survey is based on one-day personal travel diaries submitted by the respondents. Information on the transportation mode, the purpose of the trip along with the demographic characteristics were gathered. In 2018, 2,600 Vancouverites responded to this survey.

Figure 10: Usual Mode of Transport in Vancouver



Source: Retrieved from 2018 Vancouver Panel Survey Summary Report- April 2019

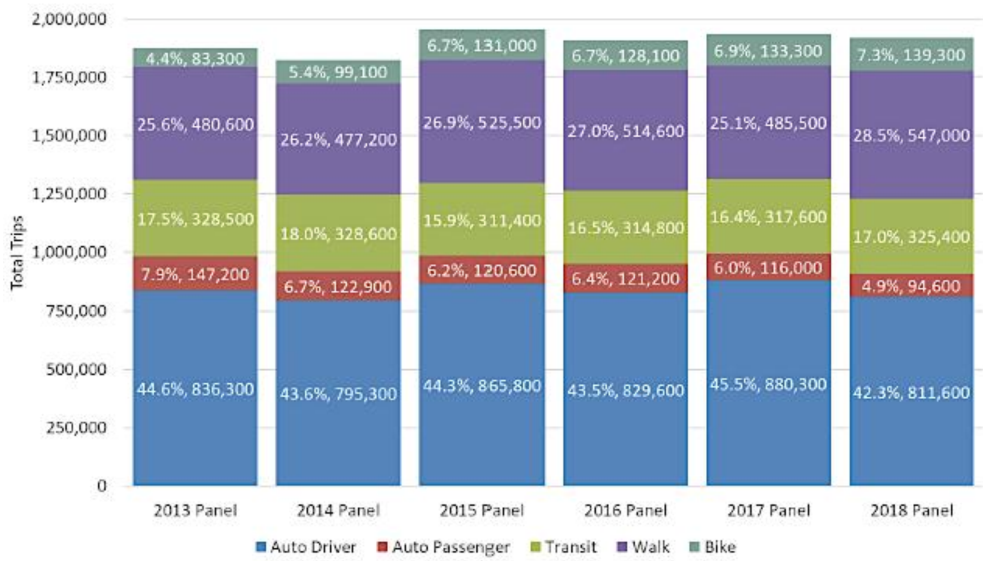
According to this survey, in 2018, automobile was the main mode of transportation for work commute with 43% of respondents reporting auto as their primary mode of transportation to work. However, the main mode of transportation to school was transit. Only 30% of the respondents reported that they used transit as their main mode of transport to work. The results of this study are then compared with the journey to work data collected by census in 2016 as a robustness check, since the census is compulsory and does not include a bias in terms of respondents.

[5] City of Vancouver, April 2019, 2018 Vancouver Panel Survey Summary Report, Retrieved from https://vancouver.ca/files/cov/2018-transportation-panel-survey.pdf

Distribution by Mode

Although driving is the dominant mode of transportation, it has a downward trend throughout the sample period. The share of auto drivers decreased by 3 percentage points from 2017-2018. A greater share of trips was made walking, using transit and biking in comparison with their 2017 shares.

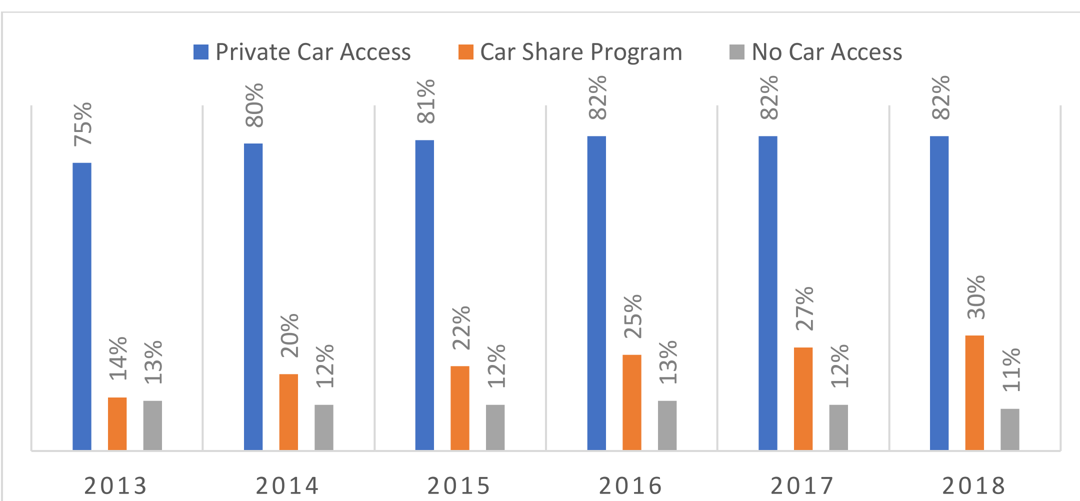
Figure 11: Total Trips by Mode and Mode Share (2013-2018 Survey)



Source: 2018 Vancouver Panel Survey Summary Report- April 2019

According to this report, both access to private vehicles and car share membership has increased over the past six years. Access to the shared cars has increased steadily over the years by 2018. In 2018, 30% of respondents had access to car share programs.

Figure 12: Access to Motor Vehicles (2013-2018)



Source: 2018 Vancouver Panel Survey Summary Report- April 2019

ELECTRIC VEHICLES (EV)

Regional Market Overview

Sales in 2018 reached their all-time high with 44,175 EVs sold in Canada. There were 93,091 electric vehicles (EV) on the road in Canada. EV sales in **British Columbia** (+154%), Québec (+128%) and Ontario (+109%) more than doubled over the year. For B.C. and Québec, this is an impressive increase since the growth rates in these provinces were 56% and 58%, respectively, between 2016 and 2017.[6] This can be attributable to different federal and provincial incentives that exist in Canada. For example, the Government of B.C. distributes up to CAD $3,000 dollars in incentives for the purchase or lease of an eligible electric vehicle, with currently over CAD $72 million dollars in funds disbursed through this program.[7] Zero Emission Vehicles now make up over one per cent of all passenger vehicles in **Metro Vancouver**.[8] *National Observer* estimates that approximately 15,000 of the roughly 1.5 million passenger vehicles in Metro Vancouver are now Zero Emission Vehicles (ZEVs) based on data from ICBC, the Province of B.C., and the CEV for BC rebate program.

Canadian fuel cell industry created 207 million of revenue, of which 150 million was through product sales and 47 million of revenue from research and development contracts in 2018. 1,630 jobs were created within Canada with 60% of this employment growth being attributable to the Province of British Columbia (978 employees). The majority of the activities and facilities were located in British Columbia (51%). The focus of 19% percent of the fuel cell producers was research while 13% of the players are fuel cell manufacturers or developers. [9] [10]

---

6 Retrieved from https://emc-mec.ca

7 Clean Energy Vehicle Program, retrieved from https://www.cevforbc.ca/clean-energy-vehicle-program

8 Retrieved from https://www.nationalobserver.com , Electric cars now over 1% of Vancouver vehicles, May 28th 2019

9 MNP (2018), Canadian Hydrogen and Fuel Cell Sector Profile

10 survey of 74 organizations associated with hydrogen and fuel cell in Canada.

Figure 4: B.C Fuel Cell Industry

As far as electric vehicles are concerned, a range of different technologies exist (Table 1).

Table 1: Type of Electric Vehicles

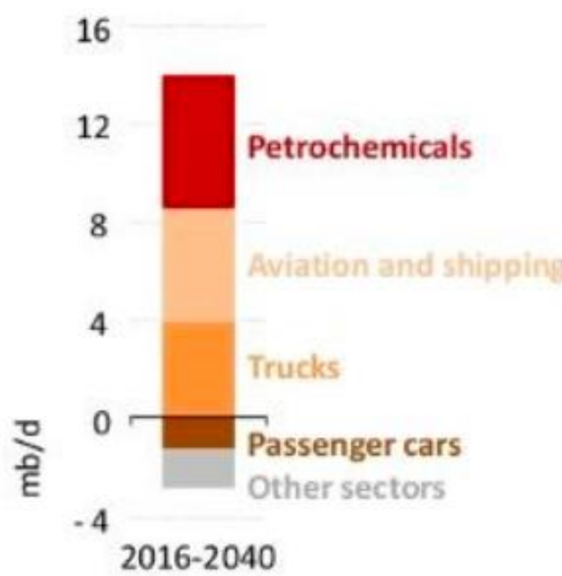
Power Train Type	Abbreviation	Definition
Hybrid Electric Vehicle	HEV	HEVs are powered by both gasoline and electricity. The electric energy is generated by the car's own braking system to recharge the battery
Plug in Hybrid Electric Vehicle	PHEV	PHEVs have a large battery and an internal combustion engine. The battery of the vehicle can be charged by being plugged into a grid
Battery Electric Vehicle	BEV	BEVs are fully-electric vehicles with rechargeable batteries and no gasoline engine
Fuel Cell Electric Vehicle	FCEV	FCEVs are hydrogen fuelled vehicles, which include a fuel cell and a battery-powered electric motor

The Effect of EVs on the Labour Market

Oil and Gas Sector

Annual net sale of gasoline in British Columbia is more than 5 billion liters.[11] 75% of this consumption is used by passenger transportation for motor vehicles.[12] This will account for 3.75 billion liters of gasoline.[13] . First, EVs decrease the overall demand for oil. Reduction in the oil demand would have a negative effect both on the GDP and employment in this sector. The extent of this effect depends largely on the rate of the adoption of EVs. The International Energy Agency reports that although the demand for oil by passenger vehicles is decreasing, the growth in demand by trucks, aviation, shipping and petrochemicals will drive the oil demand to 105-million-barrel day by 2040.[14] This result highlights the importance of electrification of the trucking industry.

Figure 5: Change in Global Oil Demand (2018)



International Energy Agency[15]

[11] Statistics Canada, CANSIM table 405-0002.
[12] NRCan, Comprehensive Energy Use Database.
[13] This calculation is based on gasoline price of CAD $1.45 and provincial plus federal taxes of 25 cents per liter
[14] How will electric cars affect the oil industry (2018), retrieved from https://www.nanalyze.com/2018/12/electric-cars-impact-oil-industry/

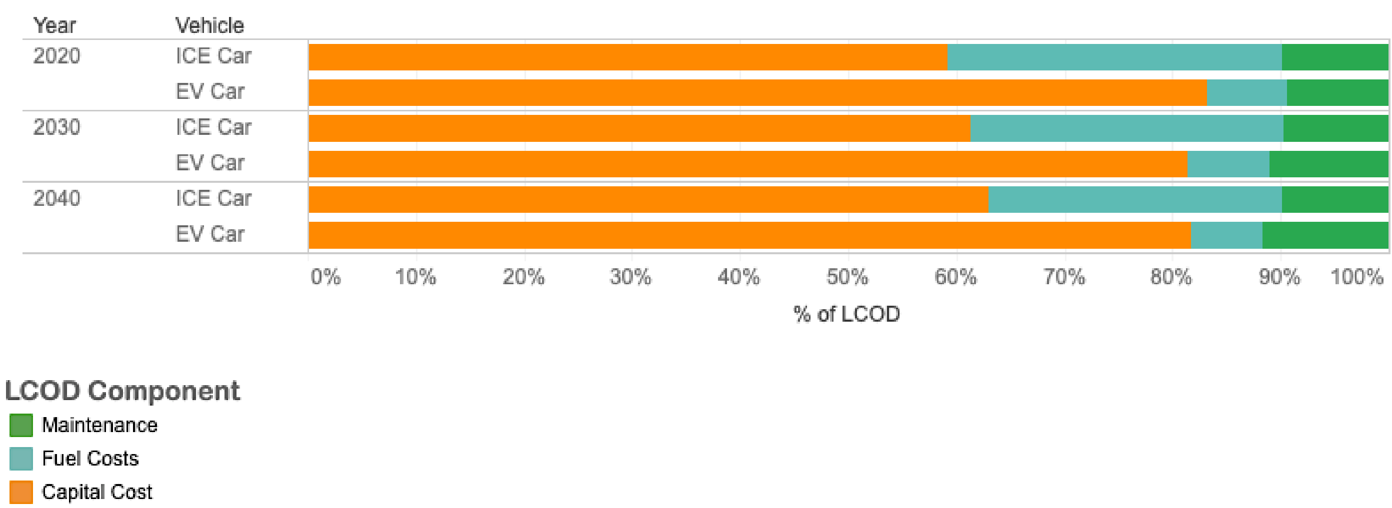
Vehicle Production

The production process and technology of the electric vehicles are very different from the conventional vehicles, or ICEs (internal combustion engine). Electric vehicles are simpler and have fewer parts than the ICEs, which makes the production process less labour intensive. For example, because EVs have fewer moving parts, less assembly labour would be needed.[42] The intensity of the effect also depends on the production share of the battery-electric vehicles versus hybrid electric vehicles.

Vehicle Maintenance Services

The secondary impact of this technology would be on the providers of maintenance services, motor vehicle parts distributors, motor vehicle and parts dealers. The main contributory factor to the lower average per kilometer cost is the fuel cost with the maintenance costs slightly lower than the ICE vehicles, however this difference increases overtime (Figure 6). The maintenance cost for EVs will be 0.03 cents per kilometer while it costs an extra cent to maintain an ICE car by 2020.[15]

Figure 6: Levelized Cost of Driving



Source: Natural Energy Board, 2019

15 National Energy Board Canada, Market Snapshot: Levelized costs of driving EVs and conventional vehicles

Certain maintenance services would not be required in EVs, such as changing oil and brake pads. However, electric vehicles still need some maintenance similar to ICEs, for instance, changing tires and repairing the body of the vehicle. The maintenance of the electric vehicles also would require some upskilling of the technicians' knowledge, which would enable them to operate diagnostic tests and screenings of the equipment to solve the problems associated with the electric vehicles.[16] The intensity of the effect on the labour market also depends on whether the battery electric vehicles will be more common than hydrogen-based vehicles, which are more labour intensive in maintenance. Despite the negative effects, penetration of EVs can at the same time increase the demand in certain sectors like software engineering.

Electrical Services

Penetration of electric vehicles will increase the demand for electricity, car-related electronics, battery technology and recharging equipment. This increase in demand will expand the related businesses and create new jobs. However, there is concern that penetration of electric vehicles will substantially increase the demand for electricity and disrupts the electricity distribution system, if new electricity-generation capacity is not built.

A study by McKinsey suggests that e-mobility will not put substantial pressure on the electrical-grid power demand through 2030, however will change the load curve. [17] The peak load will happen in the evening when people usually come home from daily errands and plugin their electric vehicles, however this problem can easily be addressed by using smart charging, overnight charging for wind-dominant countries to avoid the peaks and daytime workplace charging for Photovoltaics countries. Vehicle to grid (V2G) can also provide electricity to the local power network when needed.

It is worth noting that In B.C. most of electricity is generated through hydroelectric sources (90%) with natural gas contributing 6% and biomass 2% to the production. Only 1% of electricity is produced from wind power[18].

---

[16] Holley, P.(2017).Will electric vehicles doom your neighborhood, retrieved from https://www.washingtonpost.com/news/innovations/wp/2017/12/11/people-are-freaking-out-why-electric-vehicles-might-doom-your-neighborhood-auto-mechanic/?noredirect=on&utm_term=.db414e483a1a

[17] McKinsey & Company. (2018). The potential impact of electric vehicles on the global energy systems

18 National Energy Board Canada. (2017). Provincial and Territorial Energy Profiles-British Columbia

Summary

The following table summarizes the industries that will be affected by the EVs in BC sector and demonstrates the current employment in this sector.

Table 2: Positively Affected Sectors by EV

Industry	Employment 2018 (thousands of persons)[19]
Computer and Electronic Product Manufacturing	8.4
Electrical Equipment, Appliance and Component Manufacturing	5.0
Computer System Design Services	55.2
Total	**68.6**

Table 3: Negatively Affected Sectors by EVs

Industry	Employment 2018 (thousands of persons)
Motor Vehicle, Body, Trailer & Parts Manufacturing	4.7
Other Transportation Equipment Manufacturing	6.6
Motor Vehicle and Parts Wholesaler-Distributors	4.8
Machinery, Equipment and Supplies Wholesaler-Distributors	21.3
Motor Vehicle and Parts Dealers	33.9
Gasoline Stations	6.6
Repair and Maintenance	37.6
Total	**115.5**

[19]BC Stats, BC Employment by Detailed Industry

AUTONOMOUS VEHICLES (AVS)

A self-driving or autonomous vehicle is a vehicle capable of sensing its environment and moving safely with little or no human input.[20] Automation will happen at different phases.

- Level 0 (No Automation): Automated system sends some warnings, but can't intervene in the control
- Level 1 (Driver Assistance): The driver and the automated system share control of the vehicle like park assistance services
- Level 2 (Partial Driving Automation): The automated system takes full control of the vehicle; however, the driver should still be aware of his environment. In this mode, the vehicle cannot be used with the hands off
- Level 3 (Conditional Driving Automation): The driver can divert its attention from the wheel and no connection between the hand and the wheel is required; however, the driver is required to intervene in emergency situations. As converging the attention back to the wheel might be difficult, some manufacturers have announced that they would not produce level 3 autonomous vehicles.
- Level 4 (High Driving Automation): There is no need for human intervention in most circumstances, so people can even sleep in the car. However, legislation might allow their use only in certain areas, so human drivers might have to drive a specific part of the trip and the rest can be done via the automated system
- Level 5 (Full Driving Automation): No human intervention is required. [21]

Deployment of AVs

Predicting the penetration of AVs is a complicated task as there is a lot of uncertainty involved in it: technical capability to operate safely, government legislation enabling the use of AVs and consumer acceptance of the new technology.

KPMG publishes a study of autonomous vehicles readiness index yearly. In their most recent report, good quality of labour force and strong government leadership were identified as Canada's main strengths, however it ranks low in the 4G coverage and the accessibility of EV charging stations, which are both important factors in the case that AVs become electric. [22]

---

[20] Taeihagh, Araz; Lim, Hazel Si Min (2 January 2019). "Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks". *Transport Reviews*. **39** (1): 103–128
[21] Wikipedia, self-driving cars
[22] KMPG, 2019 Autonomous Vehicles Readiness Index

Blackberry and the Government of Canada are investing 350 million combined into autonomous vehicle technology with the Federal Government spending 40 million dollars from its innovation fund to help develop the central neural system for autonomous vehicles.[23] Canada ranked first in government-funded AV pilots in the KPMG ranking. In 2016, Ontario launched a pilot program to allow the testing of the automated vehicles on Ontario roads. The program is a collaboration between researchers from the University of Waterloo, BlackBerry and The Erwin Hymer Group (an international auto manufacturer). This program was updated in January 2019 allowing automated vehicles equipped with SAE Level 3 technology, that are available for public purchase in Canada, to be driven on Ontario roads, and this is no longer restricted to the registered pilot participants.

Canadian Perception towards Autonomous Vehicles

Consumer acceptance and trust in the new technology are important factors when it comes to the penetration of the new technology. Other than cost, the perception of consumers about the safety of the vehicle and the brand trust play a role in the adaptation of this technology.

Several studies have looked at consumers perception towards autonomous vehicles. In 2017, only 20 to 25% percent of consumers believed in the safety of autonomous vehicles. [24][25] A follow up study by Deloitte in 2018 shows that Canadian's opinion towards safety of autonomous vehicles is increasing with 56% reporting that they think autonomous vehicles are safe. The main concerns among Canadians are the accountability in the event of an accident and privacy concerns like hacking of private information. 81% of Canadian believe that there is a need for clear, enforced rules to protect the privacy of personal information[29].

Brand trust is another important factor for the adoption of the new technology. 43% of the Canadian respondents trusted the traditional car manufacturers to bring fully autonomous vehicles, while 33% trusted the new AV companies and 24% believed in the existing tech companies. [28]

---

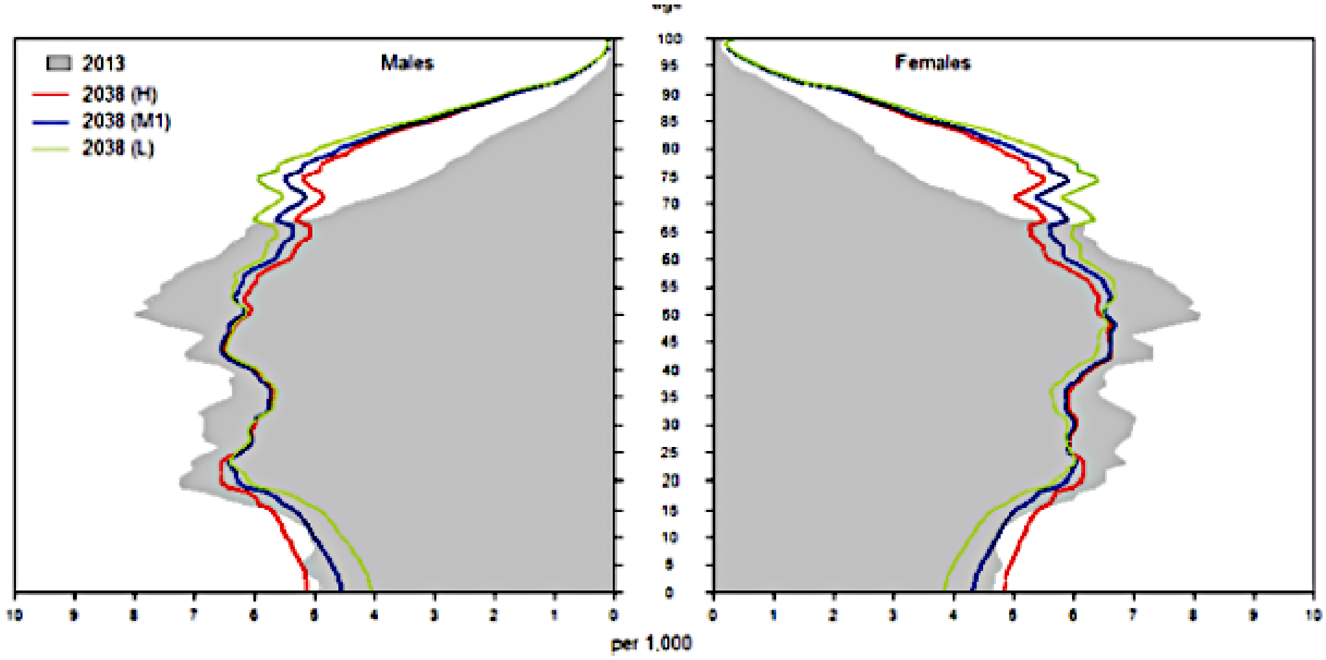
[23] Feb 15, 2019, BlackBerry, federal government pour CAD $350M into autonomous cars, retrieved from https://www.cbc.ca/news/canada/ottawa/blackberry-funding-government-autonomous-vehicles-1.5020137

24 Giffi, Graig, Evaluating the big bets being made on autonomous and electric vehicles, A reality check on advanced vehicle technologies, 2018

25 CAA, Special Study on the Regulatory and Technical Issues Related to the Deployment of Connected and Automated Vehicles, May9, 2017

Autonomous Vehicles and an Aging Population

Figure 14: Population (in relative value), Observed (2013) and Projected (2038) according to Selected Scenarios by Statistics Canada



Source: population projections for Canada (2013-2063)

Automation would expand equitable access to mobility options. People who cannot move themselves due to physical, mental or financial barriers would benefit from car sharing and automation. [26]This is an important factor as the population of British Columbia is aging (Figure 14). The proportion of the population aged 65 and over is projected to reach between 23.9% and 27.0% in 2038.[27] This share was 16.4% in 2013. It is worth noting that the proportion of the population of British Columbians aged 65 and over will be above the national average in Canada in 2038, which will be between 23.2% and 25.4%. Even if there are no self-driving vehicles, the lower cost of car-sharing services will make a substantial difference to the mobility ability of the impaired.

The Effect of Automation on the Vehicle Kilometers Travelled

It is anticipated that the vehicle kilometre travelled (VKT) would increase as a result of automation. Autonomous vehicles would reduce transportation costs, which might increase the average vehicle kilometre travelled. The extent highly depends on the demand elasticity of VKT. The elasticity of demand refers to the responsiveness of the vehicle kilometre travelled to increase of the vehicle costs. There exists a vast literature on the demand elasticity of VMT with respect to price of fuel, which commonly identifies

[26]Public and Private Benefits of Autonomous Vehicles W. David Montgomery, PhD, June 2018

[27] Population Projections for Canada (2013 to 2063), Provinces and Territories (2013 to 2038), Catalogue no. 91-520-X, Statistics Canada

the demand for VKT to be inelastic, however there are few studies on the effect of vehicle costs on the VKT demand. Litman (2019) finds the elasticity of demand to be -1.2 with respect to the total cost of vehicle which is relatively inelastic. [28] Regardless of the size of the elasticity, even if due to the rebound effect, the reduction in travel cost will lead to higher vehicle usage, congestion will grow and this growth will increase the travel cost disincentivizing driving more.

It should also be considered that autonomous vehicles will also create new road demand, for example through the expansion of package delivery services and a higher utilization of the shared mobility services, with the combination of the autonomous vehicles with shared mobility potentially affecting the vehicle kilometre travelled differentially. Although the utilization of shared vehicles will increase VKT, shared mobility may reduce the vehicle kilometre travelled by privately owned vehicles. As mentioned before, shared mobility would also increase the demand for this service by those who couldn't drive themselves, making the impact on total VKT ambiguous. From an economic perspective, an increase in demand for vehicle kilometre travelled through shared mobility will expand related businesses and employment. However, from an environmental perspective, if automation would not be combined with electrification, alternative policy solutions should be considered, for instance, road pricing[29].

Benefits from Cost Savings of Autonomous Vehicles

The benefits of autonomous vehicles through the cost saving channel have been identified by the Conference Board of Canada for Canada. We closely follow the methodology used in this paper to identify the effects for B.C. and, when data allows, for the Metro Vancouver Region.[30]

Benefits from Collision Reduction

The number of fatalities per 100,000 of the population is 5.7 in BC compared to 5 in Canada. The number of injuries is 437.4 compared to the Canadian average of 421.9 per billion vehicle kilometres. This ratio is 6.9 to 4.8 for fatalities and 523.5 to 404.9 for injuries.[31] Autonomous vehicles can decrease the number of collisions caused by human error and misbehaviour, specifically accidents that are caused by speeding, impaired and distracted driving. According to the ICBC report, these three factors caused 80 percent of all crashes in 2017.[32]

---

[28] Litman, Understanding Transport Demands and Elasticities: How Prices and Other Factors Affect Travel Behavior, March 2019
[29]Public and Private Benefits of Autonomous Vehicles W. David Montgomery, PhD, June 2018
30 The Conference Board of Canada, Automated vehicles; the coming of the next generation, 2015
31 Statistics Canada. (2017). Canadian Motor Vehicle Traffic Collision Statistics
[32] ICBC. (2018) Quick Statistics

To calculate the cost of traffic accidents, we need to assign different values to fatal and non-fatal accidents. For fatal accidents, we consider the value of a statistical life (VSL). We follow the same methodology used by the Conference Board of Canada.[33] The Ontario Ministry of Transportation and Transport Canada estimated the average value of a statistical life to be $13.6 million in 2004 Canadian dollars. VSL in current Canadian dollars would be $17.64 million.[34] Using the 5-year average of fatality rate reported by CIBC for the Lower Mainland area (94), we get an estimate of $1.65 billion.

The cost of non-fatal injuries depends on the estimate of the activity and workdays lost due to injury. Ontario Ministry of Transportation and Transport Canada estimated the average cost of $82,000 in 2004 Canadian dollars. This amounts to $106,342.53 in 2019 Canadian dollars. Applying this estimate to the 5-year average of non-fatal accidents in Lower Mainland (65,000) results in a total cost of $6.91 billion.

From the analysis described above, the total cost of fatal and non-fatal accidents would add up to CAD $8.56 billion. Assuming that AVs would be able to decrease at least accidents that are related to the human error (almost 80% of accidents), the **cost saving from collision avoidance would be CAD $6.84 billion per year.**

Although autonomous vehicles can potentially decrease the human error aspect of collisions, getting a complete picture would not be possible without considering the following factors:

1) At the level 3 of automation where the driving tasks are transferable to the driver, the collisions based on human misbehaviour will not be reduced. This has become the central argument around focusing on level 4 of automation by companies like Ford and Google.
2) If automation increases the kilometres travelled, longer travelling might result in an increase of the total number of accidents.
3) Automation might encourage risk-taking behavior both by passengers and other road users as they might feel safer. [35]
4) Hardware and software failures might increase the chance of collisions.

---

33 The Conference Board of Canada. (2015). vehicles; the coming of the next generation
34 Inflation Calculator, Bank of Canada
35 Evan Ackerman. (2017). Spectrum, International Institute of Electrical Engineer: Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy

Benefits from Value of Time

Canadians spend a lot of time in their vehicles. According to the 2016 census of population, commuters in Vancouver spend on average 30 minutes to travel to their work and 11 % of commuters spend more than 60 minutes travelling to work.[36] AVs would allow individuals to focus on other activities increasing their productivity and leisure time in the vehicle[37], potentially reducing the opportunity cost of commuting time.

AVs need a strong Wi-Fi infrastructure, which will additionally provide a high-speed internet access for the passengers. Having access to the high-speed internet can boost passengers' productivity.[38] The time freed from driving tasks can be used to work, such as answering emails, participating in business meetings from the vehicle, etc. This increase in productivity might contribute to GDP, however quantifying this impact is not possible due to the uncertainty about the extent to which automation will increase productivity.

Instead, we focus on the contribution of the automation to the personal welfare. In 2018, annual VKT for the Metro Vancouver region was 2.51 billion or 3,690 in per capita terms.[39] We assume that AVs would decrease congestion and vehicles would be able to operate at the free-flow speed (90 kph on highways and 40 kph on local and arterial roads with an average speed of 65 kph). Considering the average speed, Vancouverites spent **38.6 millions** of hours in their cars.

Although the increase in productivity and its contribution to GDP cannot be quantified at the moment, the value of time spent driving can be calculated. The value of travel time refers to the cost of time spent on transport. Empirically observed results show that the value of travel time is 30% of the hourly wage.[40] To take a more conservative approach, we take this value to be one-fourth of the hourly wage. The hourly wage in Canada is approximately $26.13 meaning that the value per hour unlocked is $6.5. Assuming that only two-thirds of this time is spent differently due to automation, then the estimated benefit from the time freed in the vehicle and not engaged in the work activity is 166 million.

These results are highly sensitive to the assumptions made on the value of travel time and proportion of time spent on leisure as a result of automation.

[36] Statistics Canada, results from the 2016 Census: Long commutes to work by car
[37] The Conference Board of Canada, Automated vehicles; the coming of the next generation, 2015
[38] Public and Private Benefits of Autonomous Vehicles W. David Montgomery, PhD, June 2018
[39] City of Vancouver, April 2019, 2018 Vancouver Panel Survey Summary Report, Retrieved from https://vancouver.ca/files/cov/2018-transportation-panel-survey.pdf
[40] Victoria Transport Policy Institute. (2019). Transportation Cost and Benefit Analysis II – Travel Time Costs

Fuel Saving

The effect of automation on energy consumption is ambiguous. "Automation per se is unlikely to significantly affect energy consumption, but is expected to facilitate myriad other changes in the road transportation system that may significantly alter energy consumption and GHG emissions."[41] Brown et al. (2014) estimated the range of -91% to 173% for the fuel demand change due to automation.[42] Chen et al. (2017) projected an increase in fuel consumption by 30% in their pessimistic scenario and a reduction of 45% in fuel consumption in their optimistic scenario.[43] As previously mentioned, the overall effect of automation on the fuel consumption depends largely on VKT change. However, automation will reduce fuel consumption through two channels regardless of the effect on VKT: safety enhancement and improving the fuel efficiency of cars. Automation will increase the safety of cars. This will enable the production of lighter vehicles, which will improve the fuel economy. Various features of the autonomous vehicles like platooning, enhanced vehicle performance, improved crash avoidance and eco driving would impact the fuel economy of the vehicle. [44]

We want to disentangle the effect on fuel efficiency due to automation from the general improvement in the fuel efficiency that would happen even in the absence of automation to meet international and national standards. Following the Conference Board of Canada paper, we take a very conservative estimate of fuel efficiency improvement of 10%. Applying this estimate to annual fuel costs in B.C. ($4.5 billion dollars[45]) yields the fuel savings of $450 million.

Congestion

In 2018, Vancouverites spent on average 102 hours in traffic.[46] As discussed before, the effect of automation on the vehicle kilometres travelled and congestion is ambiguous. However, in the scenario that automation will reduce congestion, it is informative to quantify the benefits of the congestion reduction. Congestion negatively affects the economy through reducing productivity, lowering the access to the labour market, increasing vehicle costs and generating adverse environmental impacts. HDR reported that the cost of congestion in 2006 was $3.3 billion to commuters and $2.7 billion to the economy for the Great Toronto and Hamilton Area. This report forecasts that cost of congestion in these two areas will increase

---

[41] Wadud, Z., MacKenzie, D., Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly autonomous vehicles. Transport. Res. Part A: Pol. Pract. 86, 1–18.
[42] Brown, A., Gonder, J., Repac, B., 2014. An analysis of possible energy impacts of autonomous vehicles, road vehicle automation. In: Meyer, Gereon, Beiker, Sven (Eds.), Lecture Notes in Mobility. Springer International Publishing, pp. 137–153.
[43] Chen, Y., Transportation Research Part A (2017), http://dx.doi.org/10.1016/j.tra.2017.10.012
[44] Gereon M., Sven, B. (2014) An Analysis of Possible Energy Impacts of Automated Vehicles," pp. 137-153 in *Road Vehicle Automation*.. Springer International Publishing. 2014
45 Assuming the price of fuel net of taxes to be $1.20 and 3.75 billions of litre of gasoline used by passenger vehicles
46 2018 INIRX traffic scoreboard, retrieved from http://inrix.com/scorecard/

to $7.8 and $7.2 billion by 2031. [47] According to the mayor's transportation plan, the cost of congestion for the Metro Vancouver region was $1 billion a year in 2015 and will increase to $2.8 billion a year by 2045 if no policy intervention happens.[48] The CD Howe Institute estimated an extra cost of congestion between $500 million to $1 billion for the region in 2015 dollars. [49]

In addition to these costs, congestion limits the benefits that cities have to offer like labour market pooling and human capital spillovers. For example, congestion disincentives people to apply for jobs that would take them a long time to commute to. This will have negative effects on the GDP through two channels. First, this means that firms can not necessarily get access to the best pool of labour which will decrease their output and reduction in the output affect GDP negatively. Second, households' income would be lower than their potential income in the absence of congestion as high travel costs limit their career options.

Assuming a growth rate of 3.5 % per year for congestion [50] taking the lower bound both for the direct and hidden costs of congestion ($500 million) and conservative assumption that AVs will decrease congestion to half of its current levels, AVs will decrease the cost of congestion by around $573 million.

The **total potential benefit from AVs** sums up to **around $8 billion** expressed in 2019 Canadian dollars. Note that the results of this section would only be accurate under the stated assumptions.

Table 4: Potential Cost Savings of AVs

AV benefits	Dollar Amount
Benefits from Collision Avoidance	$6.84 billion
Benefits from the Time Value	$166 million
Benefits from the Fuel Saving	$450 million
Benefits from Congestion Reduction	$573 million
Total Benefits	**$8.02 billion**

[47] HDR, Costs of Road Congestion in the Great Toronto and Hamilton Area, Impact and Cost Benefit Analysis of the Metrolinx Draft Regional Transportation Plan, December 2008
[48] The case for Yes, Mayor's transportation plan, 2015
[49] Dachis, Economic Growth and Population, Tackling Traffic: The Economic Cost of Congestion in Metro Vancouver
[50] Compound annual growth rate based on 2015 congestion estimates and 2045 projections

Labour Market Outcomes from Automation

Automation will change the dynamics of the labour market. Grushen et al. (2018) in a comprehensive research study identify the effects of autonomous vehicle deployment in the U.S.[51] We summarize the key trends and results of this study in this section.

Automation can affect the labor market through three channels: growth in overall transportation, new labor input for the AV sector, and an increase in the purchase of goods and services by consumers who are now spending less on transportation portion of delivery.

The effect of autonomous vehicles can be summarized in the following graph (Figure 15). With increasing AV adoption, some jobs will be fully or partially eliminated (e.g. truck drivers. Still, the adoption of the AVs will increase firms' productivity, which will enable them to invest in training workers for new jobs. On the other hand, adaptation of the AVs will reduce transportation costs. Reduction in the transportation costs will increase demand for this service. This will lead to the expansion of transportation companies and creation of more jobs that can potentially attract the displaced workers. The interconnection between the transportation industry and other industries will indirectly create new jobs in other sectors. Finally, the money saved by households from transportation costs will enable them to spend this money elsewhere, inducing more job growth even in industries unrelated to AVs.

Although the displaced workers will eventually find new job opportunities, the pace of the adjustment depends largely on the three factors: geography, skills, workers voice and investment.

Geography: Displaced workers might need to relocate to seek new job opportunities, which may slow down the AV adoption process.

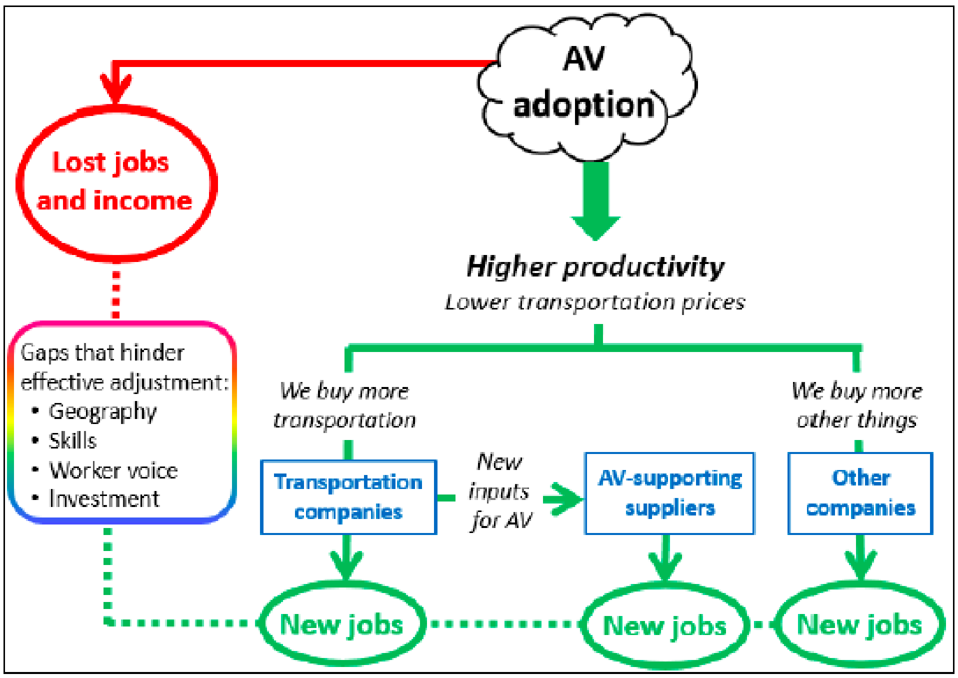
Skills: The new jobs might require a new set of skills, so absorption of the displaced workers into newly created positions will happen with a gap as short or long-time training prior to entering the market would be required depending on the type of job.

Workers' Voice: The effect of automation would be felt more intensely in the short run by those who will be directly affected by automation, so if the benefits of automation are to be distributed more equitably, an effective dialogue between unions and associations with regulators is necessarily and would determine the pace of adjustment.

[51] Erica L. Groshen et al, Preparing US workers and employers for the autonomous future, June 2018

Investment: Access to capital and firms' incentives in investing in creating new jobs and training workers for those positions greatly impact the adjustment of workers with the new trends in the labour market. If already trained workers can be attracted from the international labour market, there would be fewer incentives to train the local workers. In addition, the state of the national and local economy at the time of this transition plays an important role in this narrative. If a country is experiencing recessionary trends, they will be fewer incentives to invest in the market expansion and recruitment in general by firms increasing the adaptation period of the labour market to the new trends.

Figure 15: Effect of the AV Adaptation



Source: Groshen et al (2018)

Occupations can be divided into 6 categories in terms of the effect of AVs on the labor market. [52]

1. Occupations whose primarily responsibility is driving like bus and taxi drivers.
2. Occupations in which the main responsibility is not driving, however might be eliminated because of AVs like traffic and highway police officers.
3. Occupations that need retraining or upskilling to be able to provide the related AV services like maintenance and repair jobs."[57]
4. Occupations that will experience higher demand because of AVs like software engineers.

52 These categories are based on following research studies:

1) Erica L. Groshen et al, Preparing US workers and employers for the autonomous future, June 2018
2) Cutean, A. (2017), Autonomous Vehicles and the Future of Work in Canada, Information and Communications Technology Council (ICTC), Ottawa, Canada

5. Occupations in which duties will change because of AVs. These are occupations in which the main responsibility is not driving, however driving is necessary to get to reach to clients like visiting nurses, vehicle insurance workers and regional supervisors.
6. Those whose occupational responsibilities will not change as the results of AVs like teachers.

Unlike the first two categories of jobs that are going to be negatively affected, new opportunities can open up in the occupations where the main responsibility is not driving, yet driving skills are a prerequisite to get the job. With adoption of the AVs, people who are physically impaired but have the qualifications for certain jobs or older people will have more job opportunities.

Current Trends in the AV Related Occupations

ICTC (Information and Communications Technology Council) (2017) looked at the first four categorization mentioned above in the Canadian context[53]. The unemployment rate in the ICT (Information and Communications Technology) and auto-related occupations like car mechanics was low in 2019 (2.9% and 2.2% relative to the national average which was 6.3% in this year). The unemployment rate among the drivers is relatively high at 5%.

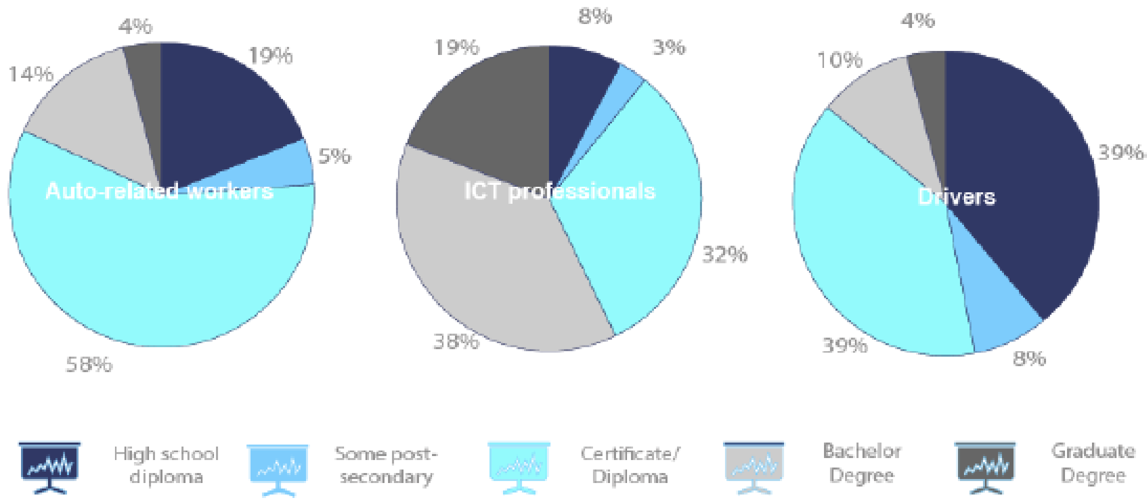
The level of education in each occupation is also important especially among workers who would be displaced as it affects the pace of transition of the workers into new jobs or retraining to adopt to the new duties in each occupation. In 2017, 39% of the drivers in Canada reported that their highest level of education was high school, 39% held a college diploma and 10% with bachelor degree. In the auto-related services, 58% held a college diploma and 14% with a bachelor's degree. The workforce in the ICT sector is highly educated with 39% holding a bachelor degree and 19% holding a graduate degree.

While we expect the occupations in which driving is the primarily responsibility to be negatively affected and the roles in the ICT sector to be affected positively, the effect on the auto-related occupations is not straight forward and depends on whether they can adapt to the new occupational responsibilities that will be required from this sector that are induced by the adoption of AV. If auto related industries are able to train their workforce to meet the new demand, the employment might even increase in this sector as with the introduction of AVs, we expect the demand for transportation to increase. ICTC predicts average growth rate of 3% for the clean (CAV) sector. This will increase the number of jobs in the CAV sector of 34, 700 by 2021.

---

[53] Cutean, A. (2017), Autonomous Vehicles and the Future of Work in Canada, Information and Communications Technology Council (ICTC), Ottawa, Canada

Figure 16: Education Level by Occupation



Source: ICTC,2017[54]

According to Grushen et al. (2018) the effect of AVs on the labor market depends on the following factors:

1) **Speed of adoption**
2) **Type of technology adopted**: Level 2 and 3 of automation will still depend on a human driver for certain tasks, whereas level 4 which completely eliminate a human driver. If level 4 AVs will become the dominant technology, the effect on unemployment will be higher through occupations which the primarily responsibility is driving like taxi driving or related jobs like traffic police.
3) **Phase of business cycle:** If this adaptation would happen at the same time as when the economy is experiencing a recessionary period, the transition of the displaced workers into new occupations would take longer
4) **Rate of occupational turn over:** The occupational turnover rate is the rate at which jobs in an occupation would decline if no workers are replaced. This might be because of the increase in the average age of labour force, injuries, adaptability of skills in that occupation to other occupations, etc.

   If the rate of occupational turnover is not considered, then we will be overestimating the effect of AVs on the labour market. For example, if drivers are already leaving the occupation to find jobs in other occupations, less people will be laid off by adopting the AVs.

[54] Cutean, A. (2017), Autonomous Vehicles and the Future of Work in Canada, Information and Communications Technology Council (ICTC), Ottawa, Canada

5) **Combination of AVs and EVs:** If AVs are electrified, adoption of AVs will change the dynamics of the labour market in a wider variety of the industries. As mentioned in the analysis of the EV labour market, EVs will affect variety of industries like oil industry, electricity production and distribution, manufacturing of vehicle parts. EVs have fewer moving parts in comparison to EVs and are easier to make and this will decrease the need for assembly labour.

A closer Look into the Taxi Driving Industry

Taxi driving is one of the occupations that is expected to be affected most by the new trends in mobility, so it is important to be informed about the size of this industry in the region and the socio-economic background of the people who will be affected. In the Metro Vancouver region, there are 30 taxi companies with the overall fleet of 2,081 as of June 6, 2018.[55] According to the Stat Canada job bank wage data, the annual median salary of taxi drivers, limousine drivers and chauffeurs is CAD $32,077.[56] According to the BC labor market outlook, there were 6,080 people employed in this sector in 2018 with the expected annual average employment growth of 1.5% until **2028** in the Lower Mainland and in the Southwest. [57]

A detailed analysis of the 2006 census shows that in Canada, taxi driving was an occupation with a high concentration of immigrant workers. In Toronto and Vancouver specifically, more than 80% of taxi drivers were immigrants in 2006. Taxi driving is identified as a skill level C in the National Occupational Classification and requires secondary school and/or occupation-specific training. About 35% of Canadian-born taxi drivers and 53% of immigrant taxi drivers had at least some postsecondary education and may be overqualified for their job. Over-education occurs both among Canadian-born and immigrant taxi drivers, but the rate was higher among immigrants. Although the data from this study is a bit outdated and cannot be used as an exact road map for policy formulation, it is useful for understanding the possible differential effects of reduction in demand for taxis across social groups and possible ways to accelerate their career transition.[58]

---

[55] BC taxi companies by regional district,June 6th,2018, retrieved from https://www.ptboard.bc.ca/documents/SA-licensees-by-rd-taxis.pdf
[56] Stat Canada job bank, Retrieved from https://www.jobbank.gc.ca/marketreport/wages-occupation/10557/BC
[57] BC labour market outlook, 2018 edition, retrieved from https://www.workbc.ca/Labour-Market-Industry/Labour-Market-Outlook.aspx
[58] Li Xu, March 2012, who drives a taxi in Canada? Retrieved from https://www.canada.ca/content/dam/ircc/migration/ircc/english/pdf/research-stats/taxi.pdf

MACROECONOMIC IMPACT ASSESSMENT

In this section, we identify the contribution of the clean transportation sector to the provincial economy. For the purpose of this study, clean transportation is defined as "public transit, clean transportation vehicles, rail and low-carbon marine transport, improvements to the transportation system through technology".[59] Two good indicators of contribution of a sector to an economy are employment and sectoral GDP. In 2018, 2,493,600 people were employed in B.C., and the Gross Domestic Product (GDP) was $234.133 billion dollars in this province. In this section, we aim to determine the contribution of the clean transportation to provincial GDP and employment.

Determining the sectoral contribution of electric and autonomous vehicles requires first defining these technologies, and then determining their contribution to each sector of the economy.

The most common method to calculate the regional sectoral contribution is **input-output models.** Input-output models are based on statistical information about the flow of goods and services among various industries and contain three main tables. First, a table showing the cost of input goods and services, labor and capital consumed by each industry in the production processes. This is called the input, or use, matrix. Second, a table showing which goods and services are produced by each industry. This is called the output, or make, matrix. Third, a table showing which goods and services are available for consumption by final users. This is called the final demand matrix. The final demand matrix includes goods and services that are locally produced, as well as those that are imported from other regions. Combined with the complementary information such as tax rates, this model can give information on the additional production created by a change in the product demand, or output of another industry.[60]

The only complication with the input-output models for this specific sector is that in the North American Industry Classification, no code is allocated to the clean energy vehicles, and therefore data from various sources like regional business screenings, survey data, key informant interviews combined with the public available data need to be combined to map this sector to already identified sectors under the NAICS coding system.

[59] Globe Advisors. (2012). British Columbia Clean Transportation Sector
[60] BC Stats (Septemeber,2010). B.C Input-Output model

Past Studies on Economic Impact of Clean Transportation Sector

Several studies have used this methodology to identify the contribution of this sector to the local economy. Economic impacts of EV adoption were estimated by this model in Ontario. The study finds that under the assumption that by 2050, 5% of the light duty vehicles are EVs, the EV sector would create 34,334 more full-time jobs, compared to manufacturing light duty gasoline vehicles. This accounts for 12,363 direct jobs and 21,971 indirect and induced jobs. This will create $ 1.8 billion dollars of value added for the economy.[61]

A study by MNP has identified the economic impact of the clean energy vehicles in BC using a similar methodology and estimated the total GDP of this sector to be 1.15 billion in 2016. This includes the direct GDP (373 million), indirect GDP (144 million) created through the increase in the demand for inputs from other sectors and induced GDP (150 million) which is the result of households spending the income they earned in the CEV sector on other goods and services. CEV sector employed 3,850 people directly and 1,472 indirectly. The induced positive impact on employment was estimated to be 6,670 new jobs.[62]

Although the MNP report is the closest geographical study to this research paper, extrapolating the results of this paper to the sectoral employment and GDP figures faces one main challenge. The proportion of the CEV related activities in each NAICS industry might not be applicable to current trends in this sector and applying the same shares as this study wouldn't produce a new insight.

Following the input-output methodology in our context requires obtaining micro-level information about businesses in the Metro Vancouver region by conducting key informant interviews or surveys, which is beyond the scope of this research project. However, in order to get a robust estimate for the purpose our analysis, we expand the analysis of GDP and employment to the Clean Transportation instead. The size of the Clean Transportation sector in BC was estimated to be worth 1.3 billion dollars in direct GDP and employed 16,730 full-time (and equivalent) workers in 2011 by Global Advisors.[63] A recent report by Navius research group has estimated an average annual growth rate of 5.4% for Canada's clean transportation sector[64]. Applying this sectoral growth rate to the employment and GDP estimates of the **clean transportation sector** in 2011, we estimate that the clean transportation sector contributed **1.87 billion** to the **provincial GDP** and **24,175 people were employed** in this sector in 2018**.**

---

[61] Wind Fall Centre. (2014). The Economic Impact of Electric Vehicle Adoption in Ontario
[62] MNP. (2016). Clean Energy Vehicle Economic Opportunities Assessment
[63] Global Advisors. (2012). British Columbia Clean Transportation Sector
[64] Navius research. (2019). Quantifying Canada's Clean Energy Economy

Cost Comparison

So far, we have demonstrated the potential impacts of electric and autonomous vehicles on the economy, however the extent of illustrated impacts is highly sensitive to the rate of penetration of electric and autonomous vehicles. Two important factors that will determine the future market share of EVs and AVs are (1) demand of consumers and (2) supply from the manufacturers and fleet owners. Due to uncertainty in the rate of technological advancement in this sector, predicting the supply side of this market is very difficult. Instead, we concern ourselves with the potential demand from consumers, which primarily depends on the cost of these vehicles. For example, a study by SFU shows that PEVs market penetration will be 10% by 2030 if there are no incentive programs that compensate consumers partially for the purchasing costs. This rate will increase to 30% with access to additional incentives and needed infrastructure.[65]

In the following section, we compare the cost of different types of vehicles to further understand the extent of the potential impacts identified throughout the paper.

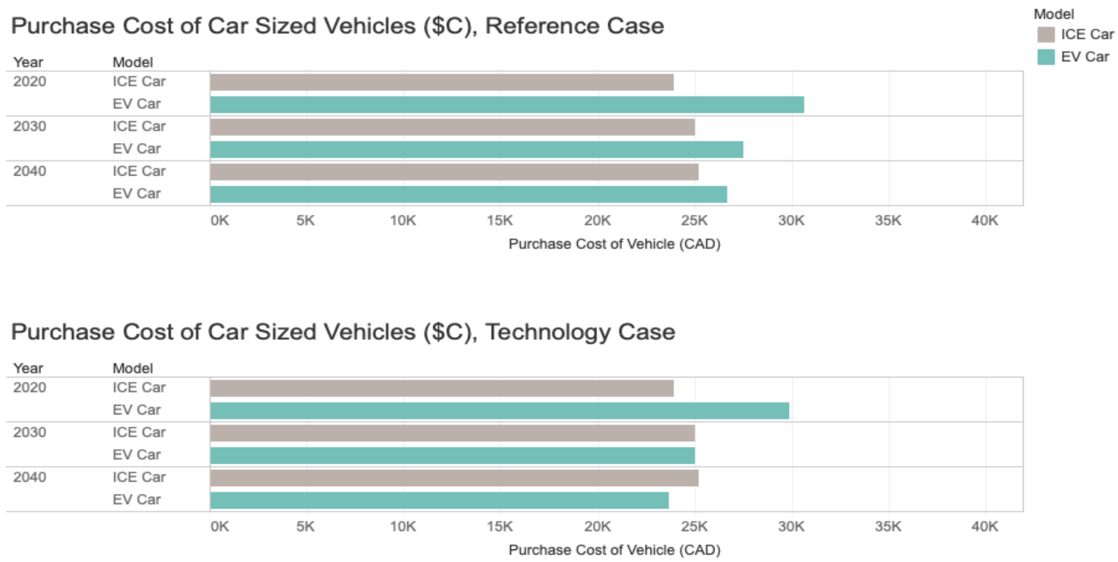
EVs and ICEs

A study by the Energy Board of Canada estimates the cost of EV and ICE cars in the future under two scenarios: Reference Scenario and Technology Scenario. The Reference Scenario is based on a current economic outlook, a moderate view of energy prices and improving technology, and announced and sufficiently detailed climate and energy policies in 2018 and the Technology Scenario forecasts Canadian energy supply and demand based on assumptions about stronger long-term carbon policy, faster uptake of technology such as electric vehicles, and lower costs of renewables. The deployment of electric vehicles is 60% by 2040 under the technology analysis in this case.

Under the reference scenario, ICEs would be cheaper to purchase even by 2040. An EV would cost CAD $27,000 CAD whereas an ICE would cost around $25,000. Under the technology scenario, electric vehicles could be purchased at the same price as ICE by 2030 (CAD $25,000). In 2040, an ICE would be $1,000 dollars cheaper than an EV. It is worth noting that while the purchase price of EV follows a downward trend, the price of ICEs increases incrementally.

[65] Wolinetz & Axsen, (2016). how policy can build the plug-in electric vehicle market: Insights from the Respondent-based Preference and Constraints (REPAC) model

Figure 17: Purchase Cost of Car Sized Vehicles under Reference and Technology Case

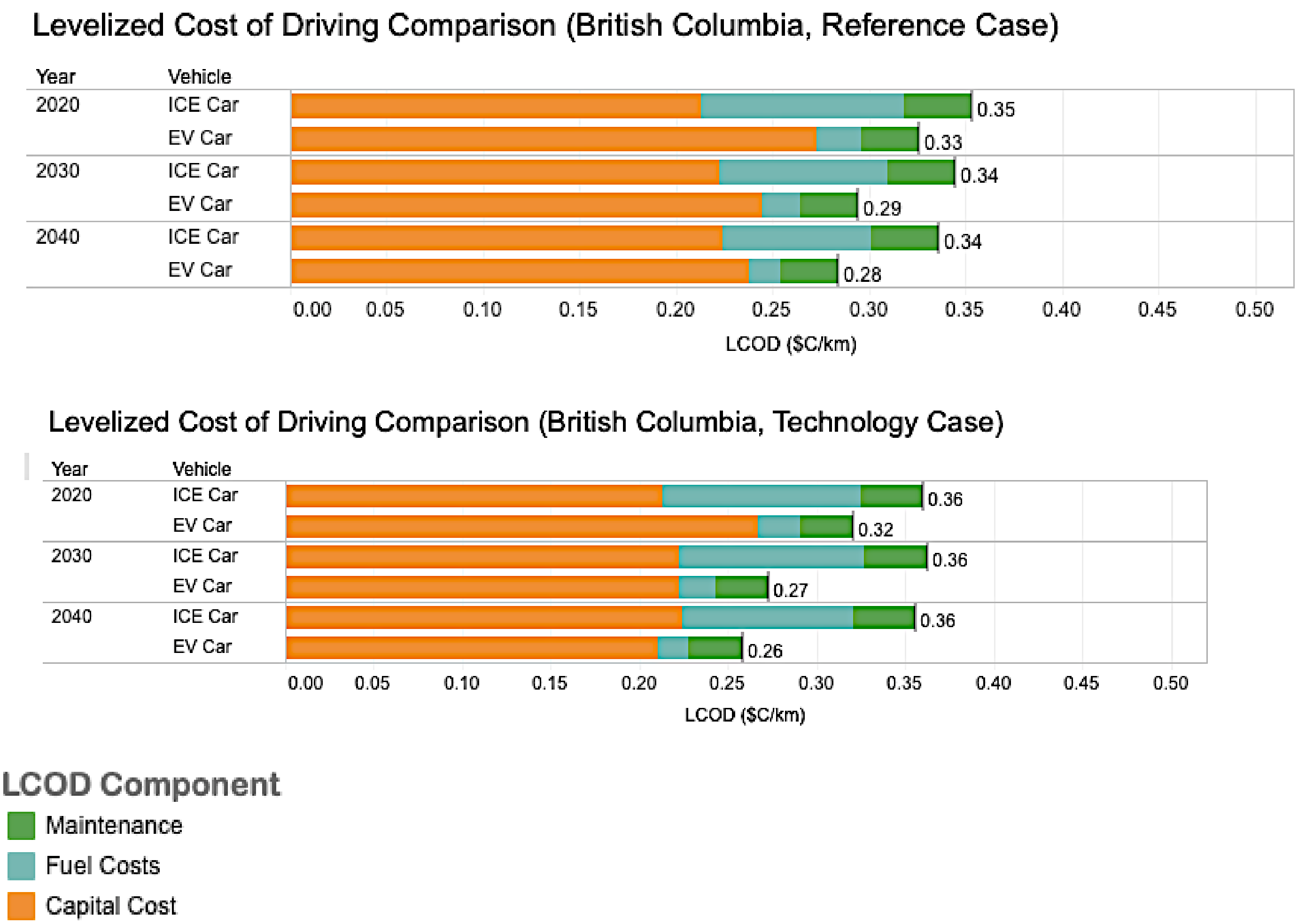


Source: Natural Energy Board, 2019[66]

However, the upfront cost of the vehicle is not the deterministic factor in the decision of a household purchasing a vehicle. The Levelized cost of driving, which is the cost to drive a vehicle per kilometre over the vehicle's life, drives this decision. In both scenarios, per kilometre cost of an electric vehicle is less than an ICE in 2020, 2030 and 2040. The main cost component of the EVs is their purchase or capital price, however the lower fuel costs per kilometre travelled make them a more affordable option which justifies the upward trend in their deployment by households.

66 NATIONAL ENERGY BOARD CANADA, MARKET SNAPSHOT: LEVELIZED COSTS OF DRIVING EVS AND CONVENTIONAL VEHICLES

Figure 19: Comparison of the Levelized Cost of Driving, ICE and EV under Reference and Technology Case



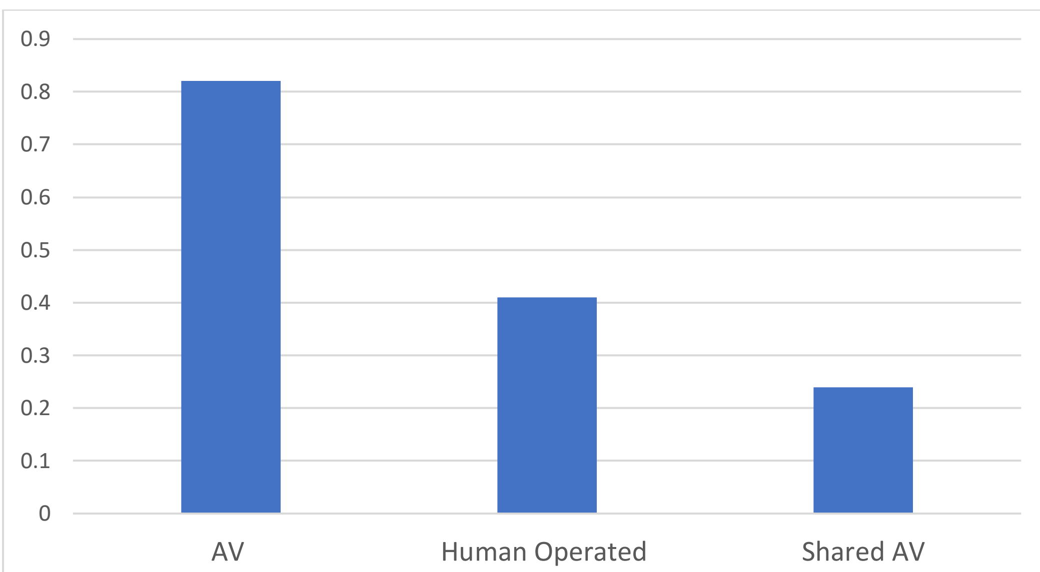
Source: Natural Energy Board, 2019[66]

Comparison of Human-Operated vs. AV

A study by Litman (2019)[67] provides insight into the relative costs of human operated vehicles (individually owned) and AVs. The new technological components added to the autonomous vehicles adds thousands of dollars to their prices. Although average cost per kilometre travelled decreases in the fuel and insurance component, this would not be nearly enough to compensate for the increase in the capital cost. Additional costs would be added to the operating costs of AVs like the road user fees in the near future. A review of the literature by Litman shows that autonomous vehicle costs will probably average around 0.8—1.2 US dollars per mile, which will eventually be dropped to the 0.6-1.00 per mile. The average human - operated vehicle. costs 0.4-0.6 cents per mile. [68] Shared autonomous vehicles will cost 0.2-0.4 cents per mile for each passenger.

The following graph demonstrates the cost comparison between AV, Autonomous Shared Vehicles and human operated vehicles in Canadian dollar per kilometre travelled and the midpoint of the mentioned ranges is presented in the graphs. AVs have higher cost per kilometre travelled compared to the human operated vehicles and this will make them a better candidate for shared mobility, than individual ownership.

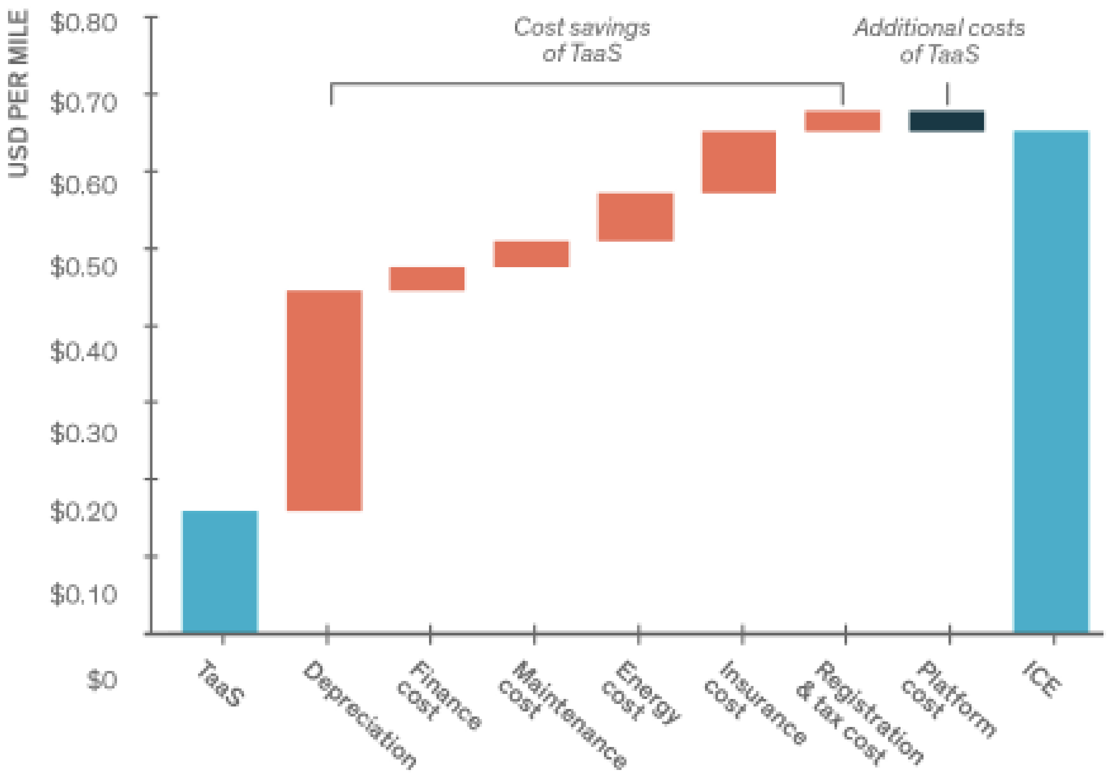
Figure 20: Per Kilometre Cost Comparison



[67] Litman.Todd (2019, 18 March), Autonomous Vehicle Implementation Predictions Implications for Transport Planning
[68] Kara M. Kockelman and Stephen D. Boyles (2018), Smart Transport for Cities & Nations: The Rise of Self-Driving & Connected Vehicles, The University of Texas at Austin (www.caee.utexas.edu); at www.caee.utexas.edu/prof/kockelman/public_html/CAV_Book2018.pdf.

Another interesting aspect to look into is identifying the savings gap between shared autonomous vehicles and human driven vehicles ICE vehicles. A study by Arbib and Seba (2017)[69] finds that the main difference in cost between personally-owned ICEs and shared autonomous vehicles (which are referred to as TaaS - Transportation as a Service) operated by the fleet managers is depreciation. It is expected that the shared autonomous vehicles will be utilized 10 times more than the individually owned vehicles. The higher utilization of this vehicles will simply decrease the per kilometre depreciation which is the biggest cost component. The lower maintenance and insurance costs are the next contributory factors to the per kilometre cost reduction. The platform costs will be added to the costs of shared autonomous vehicle; however, it is a small component of the per kilometre cost.

Figure 21: ICE Individual Owned Vehicles Vs TaaS Costs



Source: Arbib and Seba (2017)

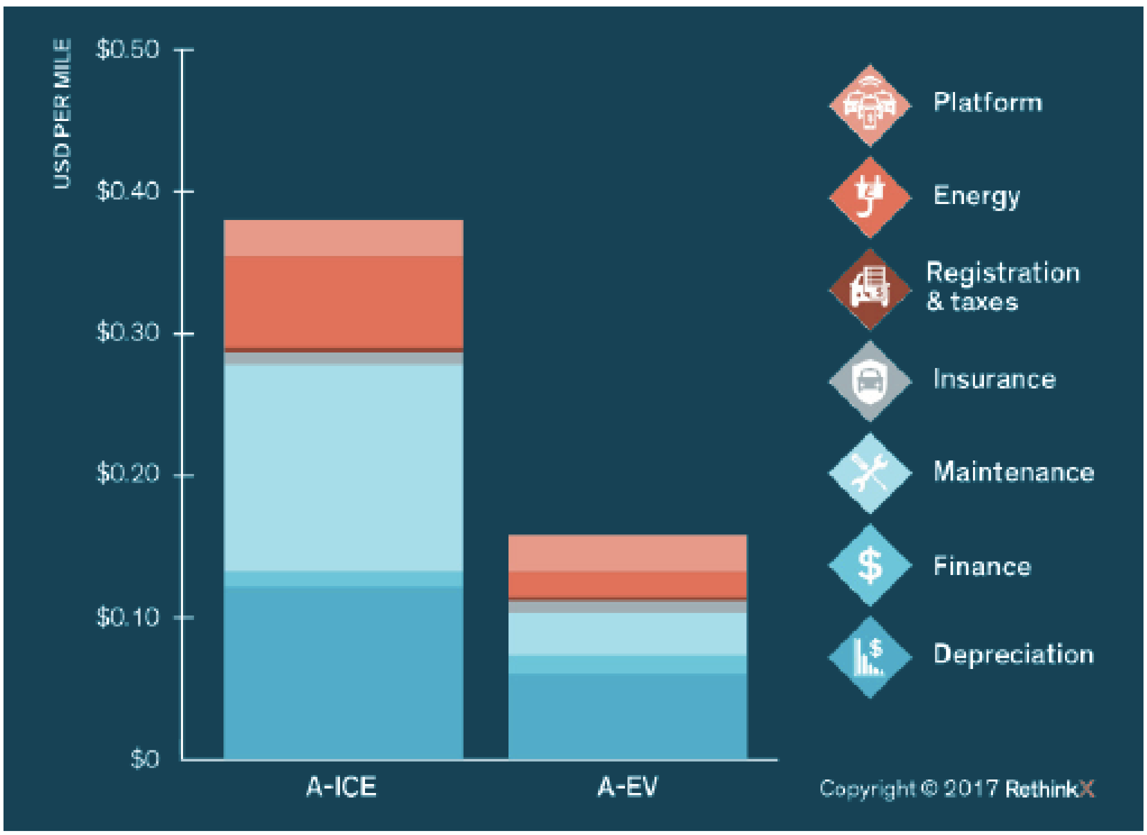
[69] Arbib, J. & Seba. T (2017), Rethinking Transportation 2020, The Disruption of Transportation and the Collapse of Internal-Combustion Vehicle and Oil Industry

Cost Comparison between the A-EVs and A-ICEs

Shared autonomous vehicles have the lowest per kilometre cost among the new modes of transportation. We cannot get a complete understanding of the future of mobility without addressing the type of autonomous vehicles that will be used in the fleets.

As it was mentioned in the comparison of the ICE and EVs, EVs have lower cost per kilometre. This will follow through when these two technologies are combined by automation. The operating costs of the A-EVs will be significantly lower than the A-ICEs. Main cost saving components of A-EVs is depreciation, maintenance and energy costs. The lower operating costs of A-EVs make them a more attractive option for the fleet managers.[65]

Figure 21: AV-ICE VS AV-EV as Fleet Base Choice



Source: Arbib & Seba (2017)

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

We estimated that in 2018 GDP from the clean transportation sector was CAD $1.87 billion and 24,175 people were employed in this sector. We further studied the potential effects of the new modes of transportation on the labour market. The oil and gas industry, manufacturing of ICEs (conventional vehicles) body and parts, repair and maintenance were identified as industries that will be negatively affected by electric vehicles whereas the electricity generation and distribution sector, manufacturing of car-related electronics, battery technology and recharging equipment were identified as the sectors that will experience positive impact. The ambiguity in the relative size of the positive and negative effects restricted us in making a definite conclusion about the overall effect of EVs on the economy.

By scanning the existing literature in the U.S. and Canada, we evaluated the potential impact of autonomous vehicles on the labour market in 6 job categories and concluded that many driving-related jobs, such as taxi driving, will be eliminated, as well as other related jobs to driving like traffic police officers. However, with the adoption of AVs, people who are physically impaired but have the qualifications for certain jobs or older people will have more job opportunities[70] . Quantifying the net effect of AVs on the labour market warrants more research as there is still a lot of uncertainty about the pace of technological advancement in autonomous vehicles along with the consumer acceptance.

The benefits of autonomous vehicle from the cost saving channel have been quantified by making assumptions based on the existing literature. **T**he **benefits of AVs** will come from **fuel saving, collision reduction, time value and congestion reduction** and have been estimated to be around **CAD $8 billion**.

We eventually identified the costs attributable to different modes of transportation and their combination and concluded that the cost of an autonomous vehicle is higher than a human-driven vehicle, which only justifies their penetration if they are offered as shared vehicles. Since autonomous shared electric vehicles have a lower cost per kilometer travelled in comparison to the autonomous shared internal combustion engine (ICE) vehicles, they will become the dominant technology at least in the shared vehicle fleets.

Given the regional focus of this study, there is a need to conduct local market research to identify specific businesses and players that will be affected by the changes to the transportation system. In order to derive more precise estimates of the effect of specific transportation scenarios. it would be recommended to conduct surveys and interviews with local businesses and other stakeholders to have a more detailed understanding of the local market and how particular agents will be affected.

[70] Public and Private Benefits of Autonomous Vehicles W. David Montgomery, PhD, June 2018

Furthermore, since previous surveys have revealed a lack of understanding of what autonomous vehicles are, building public awareness is another area where action could be taken. This would be important to inform consumers and stakeholders, as well as enable the public to make informed choices during elections and referenda regarding transportation-related projects. Given the size of investments and high impact of major transportation changes on local residents, a better understanding of the options and potential projects would improve the decision- and policy making.

Finally, policy makers might be interested in working together with the representatives of industries that will be negatively impacted by the expansion in the market of electric, autonomous, and/or shared vehicles. Earlier collaboration would then enable them to develop programs promoting the upskilling of the current workforce to adjust to and be prepared for the changing demand for skills in the labor market in the related industries.