

Harnessing Electric Tractors for Sustainable Farming in Ontario

By

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ABSTRACT

In the last few decades, there have been growing concerns about climate change and its effects on humans, plants, and animals. The climate emergency impacts the health and economies of all countries and people around the globe; however, it is impacting people in low-income brackets at a much greater rate (ironically, low-income people have contributed the least to create and sustain the problem). Anthropocentric greenhouse (GHG) emissions in general and carbon emissions (CO₂) are primarily responsible for climate change. Therefore, the immediate reduction of all those emissions is vital to solving the climate crisis. One of the most effective strategies for reducing emissions is shifting to cleaner energy sources and decarbonizing energy use in the agricultural sector (which currently is one of the big users of fossil fuels).

Therefore, a key goal of this major research report is to explore the advantages and barriers associated with using electric tractors to improve rural life while tackling pollution and reducing carbon emissions in rural areas. This research adopts a case study methodology to critically analyse the viability of introducing electric tractors powered with renewable energy, such as solar photovoltaics, which can help address the climate crisis while creating tangible benefits for Ontario farmers. Data was collected from electric tractor manufacturers in agricultural sectors across Europe and North America to understand market structure and environmental benefits of transitioning to electric mobility solutions powered by renewable energy sources in the agricultural sector of Ontario.

FOREWORD

During the first year of my MES program, I crafted a Plan of Study to organize my graduate research, which focuses on electric mobility solutions powered by renewable energy in the agricultural sector. My first intention was to study the roles of electric vehicles in decarbonizing transportation energy use in Toronto. Although this was an important research area, during the second stage of my Plan of Study I found my interest evolved into focusing my graduate work on the decarbonization of the agricultural system (since agriculture is a primary source of food supply for the world's increasing population). The electric sector caught my attention because I find it intriguing that Canada's demand for electric mobility remains relatively low; despite the great potential of electric mobility solutions for reducing greenhouse (GHG) emissions and air pollution. Agriculture is an integral part of the Canadian economy, and it is responsible for about 8% of Canada's annual GHG emissions (Environment and Climate Change Canada, 2021). That figure implies that the practices and technologies used in food production need to be upgraded to reduce GHG emissions and to develop sustainable farming practices for farmers and consumers. Therefore, energy management and sustainability in this area are worth researching and that is why I focused on analysing them in my MES research.

Additionally, understanding the diversity of governmental roles, for example in terms of policies that support energy divestment, is very important for achieving Canada's climate goals. Also, it can be argued that incentivizing key agricultural industries can help to promote behavioural change in the deployment and acceptance of electric mobility in rural Canada. Therefore, in my area of concentration, "Energy sustainability in the agricultural sector" I proposed to study the decarbonization of the agriculture sector using electric tractors for sustainable farming in Ontario. My original intention was to learn about energy management, planning and transition strategies in Ontario's energy system with a specific project. A practical opportunity to achieve my research goals was presented thanks to funding that was provided

to my MES supervisor, Dr. Jose Etcheverry, through a federal grant from Co-operative Education Work-Integrated Learning (CEWIL) Canada.

That grant provided funding to develop a project titled UN SDG Precision Agriculture, Renewable Energies & Sustainable Enterprise Training. I was fortunate to become part of that grant through one of the grant's key partners, Wheelbarrow farms. Through this partnership, I was able to be part of a team that developed a prototype of a new containerized solar photovoltaic system where electric tractors can be stored and charged with backup batteries. This research report provides the findings of that Renewable Energy Mobility (REM) project and provides contextual connections to broader energy planning challenges and energy transitioning strategies faced in Ontario's agricultural communities.

In recent years, climate scientists, concerned citizens and environmentalists have been demanding that society diversifies away from fossil fuel-based energy to renewable energy sources. In addition, the transportation industry has begun to transition from combustion engines to electric vehicles to reduce GHG emissions. Meanwhile, the agricultural sector is slowly accepting the replacement of combustion engines with electric motors. However, aggressive measures are needed to break the reign of fossil fuels and to increase the development and adoption of sustainable solutions in farming. Since agriculture directly causes close to 10% of Canada's annual GHG emissions (Environment and Climate Change Canada, 2015). Adopting cleaner technologies, such as electric tractors in the agricultural sector, is a crucial strategy for improving the performance of one of our nation's most important economic sectors

Although electric tractors may be considered a small solution to the climate crisis, their development and widespread adoption represents a highly iconographic strategy that can also include many other cleaner alternatives that need to be adopted in rural and in urban areas. That realization inspires me to provide in this report a strong case for deploying electric tractors

powered by renewable energy systems. Wheelbarrow farm in Uxbridge, Ontario, provided me with the opportunity for conducting this research. The farm is a profitable business that focuses on community-sustained agriculture, permaculture, and other sustainability strategies such as renewable energy in the form of photovoltaic systems and already has one of Canada's first electric tractors. Their solar systems offset the total energy used at the farm and their electric tractor symbolizes what rural ingenuity can achieve today when farmers are inspired by sustainability approaches.

ACKNOWLEDGEMENTS

The work done on this paper is the outcome of my years of learning at York University's Faculty of Environmental and Urban Change. Firstly, I want to thank God Almighty for giving me grace and strength to write this research project.

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I want to thank my husband, my mom and my three beautiful children for constantly pushing, supporting, and encouraging me to reach for the stars. Also, my special thanks to my fellow master's colleague, Apeksha Malik who had offered me her house to use for studying and helped me brainstorm creative ideas about this research. Lastly, the support from the faculty of EUC has helped me achieve this milestone and this research paper that I fondly enjoyed writing.

Alice

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LIST OF ABBREVIATIONS

CC	Climate Change
CEWIL	Co-operative Education Work-Integrated Learning
EV	Electric Vehicles
FARMER	Funding Agricultural Replacement Measures for Emission Reductions
GHGs	Greenhouse gases
HEVs	Hybrid electric Vehicles
HP	Horsepower
ICE	Internal Combustion engines
IEA	International Energy Agency
IZEV	Incentives for Zero Emission Vehicle
MHDVs	Medium and Heavy-Duty Vehicles
NRCAN	Natural Resources Canada
PHEVS	Plug-in hybrid electric vehicles
PV	Photovoltaics
R&D	Research and Development
RE	Renewable Energy
TTC	Toronto Transit Commission
WD	Wheel Drive
ZEVs	Zero Emission Vehicles

Section 1

Introduction

This report analyses the design and application of electric tractors powered by solar systems on Wheelbarrow Farm, a permaculture farm in Ontario. The main goal of Wheelbarrow Farm is to produce good quality vegetables sustainably with negligible environmental impacts and using strategies that address the climate emergency. The owners of Wheelbarrow Farm know that Climate change (CC) is real, and that we are presently at a historical stage where meaningful climate solutions are needed to address the climate emergency.

Many of the effects of CC have already occurred and are impacting many lives and, more specifically, the less privileged people around the globe. As a direct consequence of a system that is fuelled by fossil fuels, greed and consumerism, worldwide precipitation changes may detrimentally impact agriculture and pose risks to the planet's food security (Wael et al., 2020).

Agriculture has played a significant role in all of Canada's history and there are few items more symbolic than having a tractor in a farm. Furthermore, data from 2019 suggests that the agricultural sector accounts for about 8.1% of GHG emissions in Canada (Environment and Climate Change Canada, 2021). This research focuses on the deployment of electric tractors powered by solar photovoltaics (PV) as they can help offset the emission of greenhouse gases from farming operations that rely on fossil fuels (such as diesel). Most importantly the widespread deployment of sustainable farming solutions such as electric tractors powered by

renewable energy can become a beacon of iconographic inspiration in rural and urban areas.

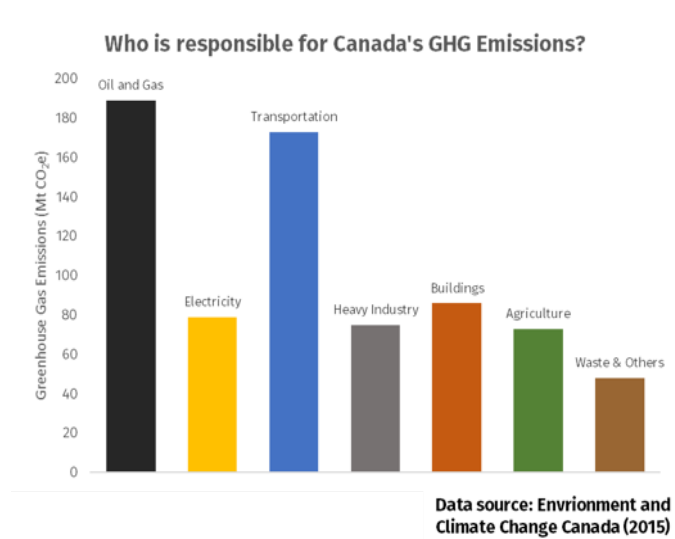


Figure 1: Canada Greenhouse Gas Emission per sector

Source: Government of Environment and Climate Change Canada, 2015.

Figure 1 above illustrates annual GHG emissions per sector in Canada, where oil and gas accounted for 191 mega tonnes of carbon dioxide equivalent (Mt CO₂ eq) (26% of total emissions), followed by the transportation sector, which also accounted for 186 Mt CO₂ eq (25% of total emissions).

	2005	2014	2015	2016	2017	2018	2019
	Mt CO ₂ equivalent						
National GHG Total	739	723	723	707	716	728	730
Oil and gas	160	190	190	181	183	191	191
Electricity	118	76	79	74	72	62	61
Transport	160	171	172	174	179	184	186
Heavy Industry ^a	87	79	77	76	75	77	77
Buildings	84	85	83	81	86	90	91
Agriculture ^b	72	71	71	72	71	73	73
Waste and Others ^c	57	50	50	50	50	51	51

Table 1. Source: Canada Historical Emission from Industry (2005-2019), Government of Environment and Climate Change Canada, 2022

Year	Oil and gas (megatonnes of carbon dioxide equivalent)	Transport (megatonnes of carbon dioxide equivalent)	Buildings (megatonnes of carbon dioxide equivalent)	Electricity (megatonnes of carbon dioxide equivalent)	Heavy industry (megatonnes of carbon dioxide equivalent)	Agriculture (megatonnes of carbon dioxide equivalent)	Waste and others (megatonnes of carbon dioxide equivalent)
1990	102.2	120.5	71.3	94.7	97.2	57.5	58.2
1991	102.0	114.3	70.6	96.1	97.1	57.7	58.0
1992	111.2	115.2	72.4	102.5	94.5	60.0	57.7
1993	118.0	116.7	76.0	93.1	94.0	62.0	57.0
1994	121.9	121.3	76.3	95.1	99.6	64.8	58.9
1995	128.2	122.1	77.0	98.2	100.3	68.0	62.5
1996	136.0	125.7	83.3	98.2	103.1	69.5	62.8
1997	136.6	131.5	80.8	109.4	102.6	69.9	60.4
1998	141.0	137.3	72.4	122.1	97.5	69.6	57.0
1999	149.2	143.0	76.4	119.2	94.7	69.5	57.6
2000	152.9	144.9	83.0	129.0	94.1	70.1	59.4
2001	153.4	146.6	79.7	129.3	88.4	67.9	57.6
2002	156.2	147.7	84.1	123.6	89.2	67.5	58.2
2003	159.3	151.7	89.5	127.4	88.4	70.2	58.3
2004	159.2	156.1	88.1	119.1	92.4	71.8	59.3
2005	159.9	160.0	84.3	117.6	87.4	72.2	57.4
2006	165.3	161.0	79.2	111.7	87.3	70.2	55.4
2007	171.0	164.7	85.0	117.8	86.3	70.7	56.2
2008	167.3	164.7	84.7	108.9	84.8	70.6	54.8
2009	164.8	161.3	83.1	93.8	71.6	67.9	50.9
2010	166.0	167.2	79.8	95.0	74.7	67.8	52.2
2011	171.8	168.3	85.1	87.0	80.7	68.5	52.7
2012	178.4	170.5	83.3	83.4	80.1	70.0	51.5
2013	184.4	173.8	84.2	79.9	78.4	72.6	52.1
2014	190.4	171.5	84.7	75.9	79.2	71.0	50.0
2015	189.9	172.2	83.1	79.1	77.4	71.2	50.1
2016	180.8	173.6	81.5	73.6	75.9	71.9	49.8
2017	182.7	178.8	85.9	72.0	75.0	71.2	50.4
2018	191.2	184.3	89.6	61.9	77.1	73.1	51.3
2019	191.4	185.8	90.7	61.1	77.1	72.7	51.5

Table 2: Greenhouse gas emissions by economic sector, Canada, 1990 to 2019
Source: Government of Environment and Climate Change Canada,2021.

For Canada to meet its targets and commitments on greenhouse gas emissions reductions we need to reduce or stop emissions from oil and gas production, the country's leading source of greenhouse gas emissions. Canada has taken a leadership role in key international negotiations aimed at slowing down the effects of greenhouse gas emissions. However, proactive energy policies and incentive measures are needed at the federal, provincial, and territorial levels. In short, Canada needs to reduce its addiction to fossil fuels because GHG

emissions are dangerous for humans and all ecosystems. This paradigm shift requires technologies that can capture the imagination of people and a key example is provided by the rapid deployment of electric cars in the last five years (which is fueled by bans on combustion engines and incentives to purchase electric vehicles).

Electric vehicles in general and farm tractors in particular have the potential to provide iconographic examples to limit greenhouse gas emissions from the atmosphere (Axsen et al., 2016). The widespread deployment of electric transportation solutions can also help achieve many additional benefits related to sustainable development. A good example would be an all-electric battery-powered farm tractor that uses no gasoline or diesel resulting in zero pollution particularly if such an essential farm tool is powered by renewable energy sources.

In short, an electric tractor manufactured with sustainable design and powered by renewable energy is a good option for producing our food without pollution or fuel related GHGs. Integrating electric tractors and agriculture equipment in farm operations can also help achieve increased energy efficiency and better operational conditions for farmers (Caban et al., 2018).

Research Objectives

The main objectives of this major research paper are to summarize the current evolution of the electric car sector in Canada and to apply that synthesis into suggestions that can help increase the use of electric tractors in Canadian agriculture.

Scope of the Study

This research project analyses Canada's electric vehicle sector to apply lessons from that sector to increase the electrification of the agricultural sector in Ontario. The role of renewable energy

in combating climate change was emphasized, especially in the agricultural sector for a reduction in global greenhouse gas emissions.

This paper also explores the barriers and advantages associated with mainstreaming the adoption of electric tractors in Ontario. By examining the policies and implementation of the electric car industry policy and its growth in Canada and in Ontario, my study highlights some of the major barriers and lack of financial incentives that currently inhibit the exponential growth of electric tractors in Canada.

Unsurprisingly, Canada remains one of the least advanced countries in renewable energy and mobile electrification technologies (particularly when compared to many European countries such as Germany and Norway). The validity of that statement is evidenced by a downward trend in EV adoption, and a lack of support for electric mobility solutions (such as electric tractors and electric farm equipment), especially in Ontario.

In addition, this study particularly showcases the case of an electric tractor (currently used in Wheelbarrow Farm in Ontario), with additional analysis of a 10-KW solar PV installation implemented to lower the fossil fuel bill and ecological footprint of the farm. That part of my research was conducted to fulfil the requirements for my graduate diploma in business sustainability (a concurrent program jointly managed by Schulich business and the Faculty of Environmental and Urban Change).

As part of that diploma, I am part of a York U development team that is designing and building an innovative solution that we call the “solar box”, which is based on using shipping containers designed to be powered by solar PV and battery systems (all made locally in Ontario). This project is being collaboratively developed by a group of students, professors, local private

sector firms, and NGOs that are working together to develop new climate solutions. The ‘solar box’ project is being developed as a versatile station for multiple purposes (such as off-grid applications with backup batteries for storing electricity generated by the PV systems to be used anytime to power solutions such as electric tractors and other energy needs in farms) as the solar box can also be a movable ‘tool shed’ for storing electric tractors and farm equipment. In addition, the inspiration I got from my business and sustainability classes (where I learned that business and environment can thrive sustainably without compromising the environment) prompted me to create and incorporate my own sustainable battery recycling company which will allow me to harness and profit from the entrepreneurship skills and insider knowledge that I have acquired while at York University.

Limitations of the Study

Due to COVID restrictions and resource constraints this study does not include empirical testing of electric tractors. Furthermore, due to the current limited deployment of electric tractors worldwide, performance data is not yet widely available in the public realm so this study cannot provide prescriptive or normative conclusions supported by empirical data.

To address the above limitations of this study it is recommended that future researchers interested in electric tractors powered by renewable energy conduct new independent empirical field testing to better ascertain performance parameters. It is also suggested here that such future researchers release their results publicly to help policymakers and decision-makers understand better the limits and potential of these novel and iconographic agricultural technologies.

SECTION 2

Literature Review

Climate Context

A rapid transition to cleaner technologies is essential to reduce GHG concentrations and help our planet stay well below a 2 (°C) increase. Our collective lack of action on addressing the climate emergency is already having devastating consequences. For example, we are now at the point where the melting of the West Antarctic ice sheet has reached an irreversible end. The sea ice off West Antarctic is melting aggressively, and as a result, species that depend on that ecosystem will either die or will have to adapt very fast (Welch, 2018).

In addition, Weller et al. demonstrated through their research that the western and central Arctic has also experienced general warming over the past 30–50 years of approximately 2–3 °C, which is more evident in winter months (Weller et al., 2005). Limiting global warming and the effects of climate change requires a planetary transition in terms of energy use, development of land, infrastructure, transport systems and buildings. That shift requires active investment in sustainable uses of energy in building and adaptation strategies, especially amongst Indigenous communities, who are impacted the most by climate change.

Since the Industrial Revolution, human activities have significantly contributed to climate change. Greenhouse gas emissions from extraction and burning of fossil fuels have been increasing at an alarming rate, thus causing today's increases in global average temperature (Government of Canada, 2019). Several factors influence the levels of greenhouse gas emissions in Canada. Burning fossil fuels from coal, oil, and gas for industrial activities have contributed to climate change and global warming (Environment Canada, 2019). The House of Commons in Canada declared a climate emergency in June 2019, an effort by the Federal

government to alert all Canadians and motivate them to achieve our international commitments under the Paris accord to reduce our nation's GHG emissions.

Canada ratified the Paris accord on December 12, 2015. Canada and 194 other countries reached the Paris Agreement, a voluntary agreement to fight climate change. That international agreement is essential to limit the global average temperature rise below 2°C and ideally to limit temperature increases to below 1.5°C (Environment Canada, 2019).

To solve climate change and avoid the worst consequences of this widespread problem, we must become a carbon-free society. Becoming carbon-free is not just about monitoring greenhouse gas emissions to meet a numerical data goal. It is, however, a public health, economic, and social equity endeavour. At present, our earth's climate is changing aggressively and differently.

The burning of fossil fuels also causes significant health issues such as cardiovascular diseases and cancer (Environment Canada, 2019; International Institute for Sustainable Development, 2019). Fossil fuels also create direct and indirect detrimental health effects such as respiratory diseases, and many more social problems such as poor air quality and losses of overall well-being (Canada Public Health, 2018; Wael et al.,2020).

Carbon Dioxide (CO₂) remains in the atmosphere for much longer than many other GHGs, and, therefore, even if we completely stop emitting CO₂ today, it will take many years for its levels to return to pre-industrial levels (McGrath, 2018). Marginalized communities and Indigenous peoples are more vulnerable because of the remoteness of their geographical locations, disproportionately high poverty levels, and lack of access to urban services.

Extreme temperatures, dilapidated infrastructure, and dependence on diesel for electricity generation, and space heating combine to create limited local ability to cope with climate change in Indigenous communities (NEB, 2017). In addition, climate change has augmented the loss of biodiversity in most parts of Canada's regions. As such, carnivores such as polar bears face risks of being in extinction or endangered due to habitat loss and climate change (Stirling and Parkinson 2006; Thiemann et al., 2011).

Therefore, to avoid widespread planetary damages it is imperative to implement climate change solutions that significantly reduce greenhouse gas emissions and pollution, and which also would provide opportunities to tackle long-term disadvantages and create positive outcomes for as many people as possible. Canada must continue to commit to deep GHG emission reductions, which can only be made possible by replacing fossil fuels with renewable energy sources and by shifting to sustainable technologies such as electric mobility vehicles.

Most modern electric vehicle technology has the potential of reducing automobile dependence on fossil fuels and is a particularly powerful climate solution if combined with the widespread development of renewable energy sources. The reality of the climate emergency is forcing politicians and decision-makers to address the potential impacts, risks, vulnerabilities, by focusing on the multiple opportunities that renewable energy sources can provide. The development of adaptation and mitigation measures and other pragmatic actions to address the climate emergency requires decision-makers to increase funding levels and to continue actively engaging stakeholders from across sectors.

A very effective way to engage people in climate solutions is by making technological innovations widely visible and available at commercially competitive prices. However, the implementation of the policies and incentive systems that make climate solutions commercially

competitive require increasing public awareness and translating that awareness into political support. Electric car manufacturers in North America have developed highly iconographic products and are investing heavily in increasing public awareness and growing political support for incentive systems that make their products more commercially competitive. In the agricultural sector, such efforts are lagging and yet a few manufacturers are focusing on electrifying one of the most iconographic rural tools: tractors.

Adoption of Electric Automobiles in North America, Europe, and Asia

In 2019, electric vehicle global sales increased to approximately 20 million compared to the previous year with a market share of 2.6% from 2.4% in 2018 (IEA,2020). The Chinese have become the top country driving the growth of electric vehicles sales followed by the Europeans, United States, and the Netherlands. China has recorded more than a million electric cars sold in 2019, the European five hundred and sixty and the United States over three hundred thousand sales was also reported (IEA,2020). These three countries combined have accounted for 90% sales of electric vehicles globally, thus progressing clean technology that specifically targets CO₂ emission reduction (IEA,2020).

Despite the Covid-19 pandemic, there has been a major increase in the number of EVs on the road, especially in dominating countries like China, Europe, and North America.

About three million electric cars were sold globally in 2020, compared to the sharp decrease in the sales for internal combustion engines (ICEs) which dropped to about 16%(IEA,2021). The increase in sales of EVs accounted for 40% of new registration leading to about 4.6% of market share (IEA,2021). Much of EVs success was accredited to some proactive measures put in place by the governments. There were supportive regulatory frameworks such as CO₂ emission standard and zero emission in vehicles aimed at rapid deployment of EVs.

In addition, there were subsidies and incentives that were provided by the European countries that helped augment the sales of EVs (IEA,2021). Also, the cost of batteries was much less as technologies improved, even in the face of pandemic (IEA,2021).

Strong policies have been proven to be effective in the development and growth of EVs, if we have well-meaning people from both the private sector and the government who are determined to place the health of the environment above personal gains.

With advancement in technology, EVs have low maintenance costs compared to internal combustion engines (ICEs). EVs could save drivers up to \$10,000 over the end life of the vehicle compared to gas powered vehicles (Noblet, 2021). The usage of electric vehicles on a large scale would significantly reduce GHG emissions. Although PHEVs run on internal combustion engines, they still generate fewer emissions than conventional combustion engines due to the high efficiency of their electric systems.

ADOPTION OF ELECTRIC VEHICLES IN CANADA

Electric Cars are Gaining Momentum in Canada

An electric car is a vehicle that uses one or more electric motors to propel the vehicle and stores electricity using chemical batteries (and/or other energy-storage devices). Electric automobiles did not gain traction in the last decades of the last century, mainly due to the lower cost of gasoline vehicles and the huge lobbying power of the fossil fuel industry.

However, it is worth noting that in the early twentieth century, electric cars were very popular (Wolfgang et al.,2008). Today (2022), due to the many detrimental problems that combustion engines create to users and to society (e.g., high gasoline prices, air pollution, and emissions of greenhouse gases), most automobile manufacturing companies are currently ramping-up manufacturing and deployment of electric vehicles.

Car manufacturers are also being forced to switch to electric vehicles due to legislation to ban combustion engines in entire cities, regions, and countries. The target date for combustion-engine vehicles to be banned have increasingly put pressure on automakers to modify their product lineups (Wapplehorst,2020).

In Europe and other parts of the world, the automotive industry is reacting to national banned targets that will take effect in about 20 years' time. Over the next ten years, Volkswagen Group, PSA Group, Renault Group, Hyundai Motor Group, BMW Group, Daimler, Ford, Fiat Chrysler Automobiles Group, Toyota Group, and Volvo Car Group have announced plans to increase sales of electric vehicles or shift their strategy away from combustion-engine vehicles (Wapplehorst,2020).

See table 3 below for the list of countries with their pledges on Net-zero emissions targets and ban on internal combustion engines.

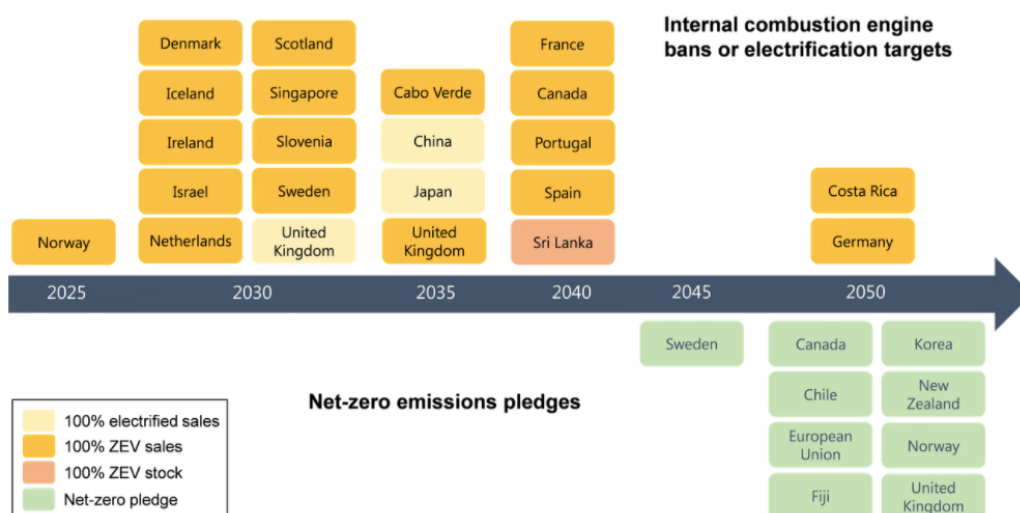


Table 3 Source: Internal Combustion Engine bans or Electrification Targets, IEA,2021

Electric drives will become more essential for use in mobile working equipment as handling characteristics improve and fuel consumption concerns grow due to rapidly increasing fossil fuel prices (created by Russia's war and European efforts to curtail fossil fuel supplies and

use). In the recent past electric mobility has gained momentum due to the growing demand for global emission reduction targets set for 2035, due to international efforts to address the climate emergency.

Electric mobility is one of the leading sectoral approaches that can limit GHG emissions. The fact is that in addition of not requiring fossil fuels, EVs are much more energy efficient than conventional gasoline engines (for example, most electric cars use regenerative braking to charge their batteries). EVs are also simpler to design and maintain because there is no need for complex engines and motor cooling systems, and exhaust systems. (Erickson et. al, 2017).

Globally today there is a rapid shift in the transition away from internal combustion engines (ICEs) to electric mobility and substantial progress has been made in the last two years.

Although the Covid19 pandemic has greatly affected the development and production of electric vehicles in most countries. However, car manufacturers are planning to introduce about 100 pure models of electric automobiles into their fleets by 2024 (Consumer's report. Org).

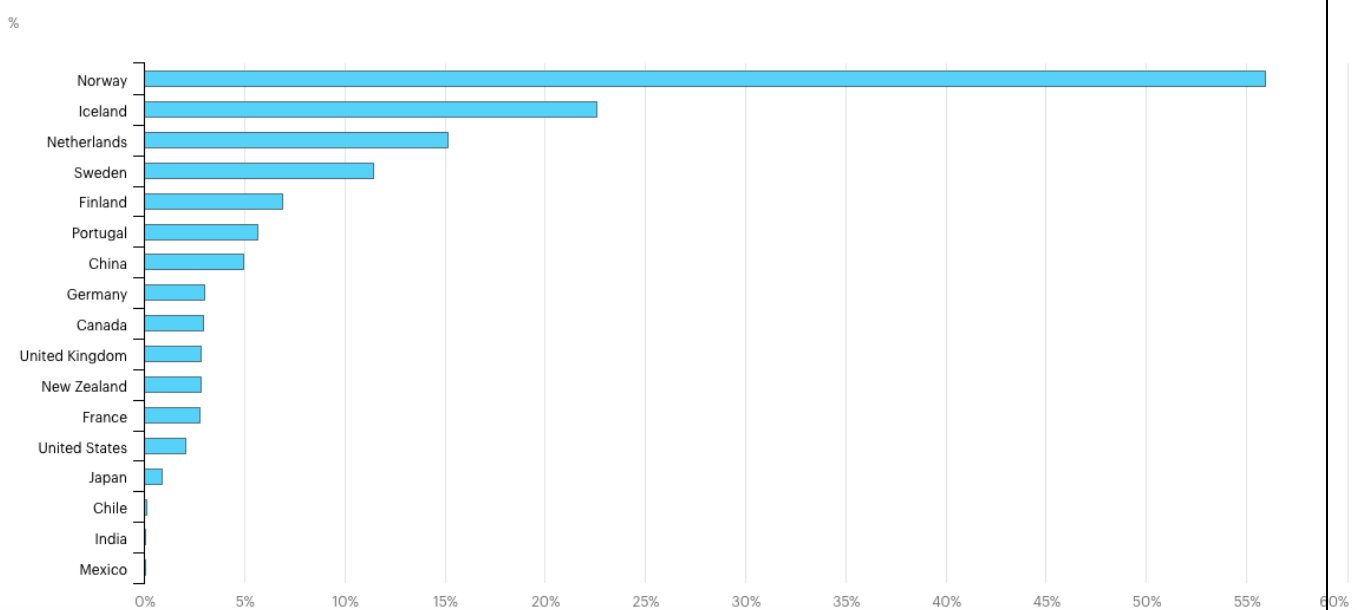


Fig 2 Source: Electric car market share in selected countries, 2019. IEA, 2019



Fig 3: Zero Emission Vehicle. Source: Canada Transportation, 2020

Tesla’s involvement in electric mobility production paved the way for the gradual acceptance of electric vehicles in the automobile industry. Elon Musk, the CEO of Tesla, was poised to hasten the transitioning of the automotive industry to a more sustainable system. One of his main goals was to scale up the fleet of electric vehicles and bring them to the marketplace as soon as possible (Zuchhi,2019).

Below is a graph showing the growth of Tesla sales and production worldwide in 2021.

About 500,000 models were added to its fleet all around the world and almost 400,000 in sales production.

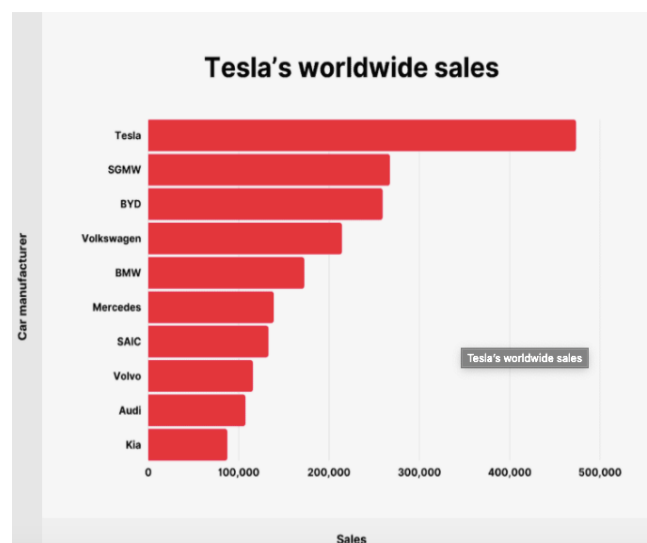


Fig 4 Source: Tesla Vehicle Global sales and production <https://backlinko.com/tesla-stats#key-tesla-stats>

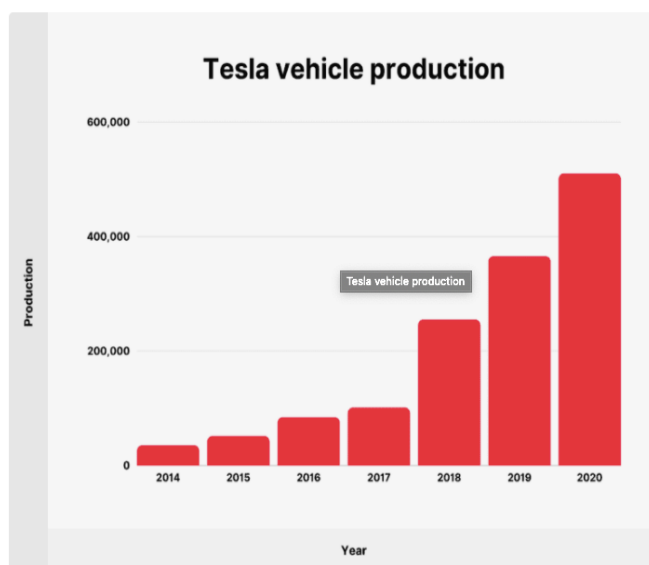


Fig 5 Source: Tesla Vehicle Global sales and Production; <https://backlinko.com/tesla-stats#key-tesla-stats>

Year	Production
2014	35,000
2015	51,095
2016	83,922
2017	100,757
2018	254,530
2019	365,232
2020	509,737
2021 (Q1+Q2)	386,759

Fig 6 Source: Tesla Yearly Vehicle Global Production; <https://backlinko.com/tesla-stats#key-tesla-stats>

This rapid growth dream is becoming a reality as society begins to witness more and more models of electric vehicles from Tesla. As nations begin to grapple with the adoption of

electric mobility due to environmental restrictions and regulations, more companies are coming up with different models of electric vehicles to compete with Tesla.

For example, Volkswagen is forming an alliance with Ford to provide a modular electric toolkit (MEB) platform supplier for electric vehicles in addition to its core business.

This modular electric toolkit platform will provide solutions for companies who are interested in fleet electrification. The platform, which can be used by a variety of brands and manufacturers, already serves as the technological foundation for ten electric vehicles from

Years	Battery electric	Hybrid electric	Plug-in hybrid electric	Other fuel types
2011	215	10,106	303	0
2012	646	20,938	1,343	13
2013	1,602	20,695	1,548	4
2014	2,839	19,791	2,533	8
2015	4,151	17,309	2,737	19
2016	4,990	21,722	7,019	6
2017	9,079	24,121	10,617	5
2018	22,570	25,837	21,713	257
2019	35,523	38,390	20,642	230
2020	39,036	41,453	15,317	58

five different manufacturers (Grob, 2021). In 2021, this platform is one of the main electric platforms in the world, with an estimated 300,000 units built (Grob,2021).

In 2020, about 43,000 zero emission vehicles were sold in Canada (StatsCan ,2022). There has been a major development in the automotive industry since 2015. During the same period, battery electric vehicles (BEVs) accounted for 71.8 percent of all new ZEVs registered in Canada (Statcan,2022). Table 3 below depicts a rapid change in the adoption of electric vehicles from 2011 to 2020 in Canada.

While Fig 8 shows that British Columbia, had the highest EV sales at about 8.4%. Similarly, Quebec, were at 6.8% slightly below BC with the highest number of EV's sold across Canada. Proven policy solutions are evident in Québec and British Columbia where they both have zero

emission standards. These provinces required automakers to have larger proportion of EV sales in their inventory. This illustration indicates that policy solution for Zero emission vehicle is working, and Canada needs to set a national standard across the province to ensure all Canadians have access to EV irrespective of their geographical locations.

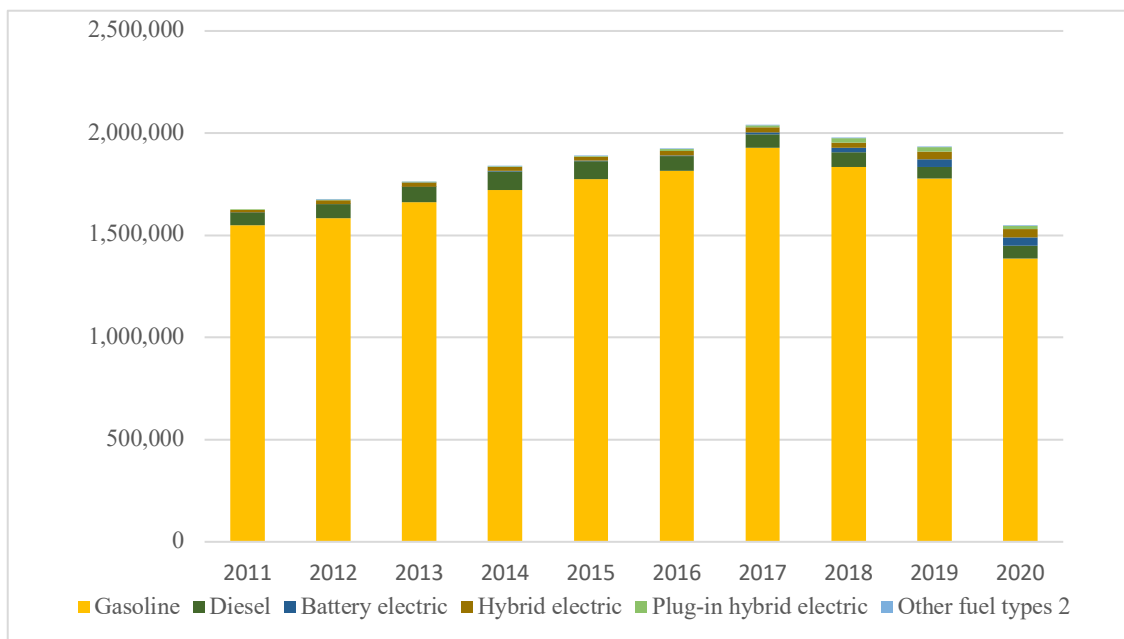


Fig 7. Source: StatsCan, 2022. Bar chart Representation of Canada’s Vehicles in Canada

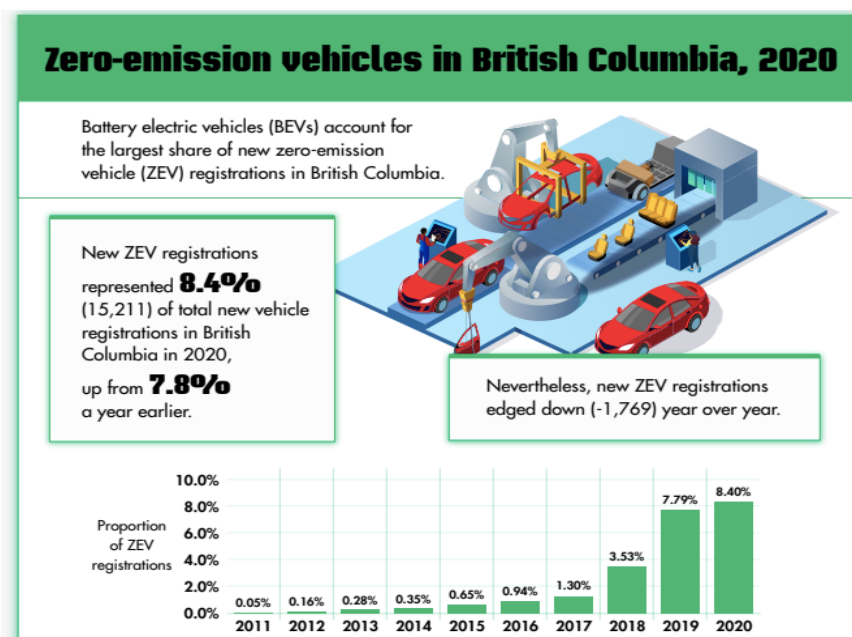


Fig 8. BC EV Registration. Source: Statcan,2022

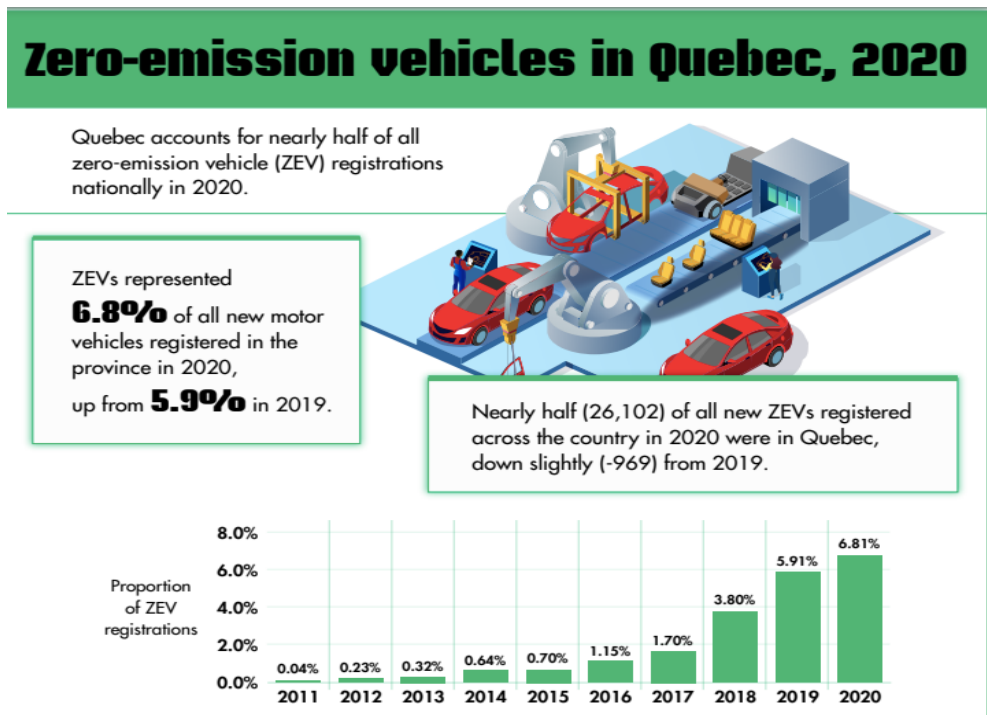


Fig 9. Source: StatsCan,2022 Quebec EV Registration.

Although Hybrid electric vehicles (HEVs) accounted for most of the total electric vehicle growth 6.21 percent in 2021 against 3.82 percent in 2020 (Haycock, 2022). The battery electric vehicle (BEV) registrations grew by a remarkable 51% year over year, reaching 20,197 electric models. BEVs accounted for 3.79 percent of all new vehicles registered in 2021, up from 2.68 percent in 2020 and nearly double the 1.96 percent in 2019 (Haycock, 2022).

The numbers above illustrate that Canadians have the potential to be a world leader in transformative, innovative technologies. Moreover, the current spike in electric vehicle sales in 2021 was partly driven by the federal government's strong incentive program for new buyers. For example, the Zero Emission Vehicle Infrastructure Program (ZEVIP) is a 5-year \$280 million initiative that is funded by Budgets 2019 and 2020 Fall Economic Statement to support the uptake of electric vehicle transition in Canada (Government of Canada, 2022).

With the rapid net growth in electric vehicles, it is imperative to increase the number of charging stations to accommodate the increase in demand and supply for EVs. Also, the management of the charging station should be effectively coordinated to avoid power overloads of one charging station over the other. Governmental policy is crucial for addressing the lack of charging stations in Canada, which is one of the most significant barriers to widespread Zero EV adoption.

Paralleling Canadian efforts, European countries, and Asian countries like; France, Japan, South Korea, and Sweden all are achieving rapidly growing electric markets ranging from 29,000-53,000 new EVs per year (Sharpe & Lutsey, 2020). Due to ongoing technical breakthroughs in electric vehicles, national and regional EV adoption numbers continue to grow at an unusually rapid rate.

A key aim of this paper is to analyse, using a comparative analysis approach focused on the regulatory policy framework currently in place for the uptake of electric vehicles in Canada. This paper also compares the policy structure in Ontario, Quebec, and British Columbia to understand the preparedness of each province in transitioning towards large electric vehicle numbers. In addition, the research focuses on these three provinces to determine whether each of them has favourable rules and guidelines, or existing policies at provincial level that can a smooth transitioning away from internal combustion engine (ICE) and towards electric vehicles (EV).

At the federal level, the focus of analysis here is on measures that are already in place for zero emission vehicles and other regulatory frameworks favourable for green technology adoption and development of sustainability innovations. The research also aims at

highlighting possible weaknesses in policy structures and existing drawbacks in technological advancement.

Incentives for Electric Cars in BC, Quebec, and Ontario

EV Policy in Quebec

Electric mobility is going to be a critical component in meeting provincial and national emission targets. With Canada's current electrical grid mix, electric vehicles may lower pollution by 45% to 98% compared to internal combustion vehicle (Axsen et al, 2016).

In response to the climate emergency, federal and provincial governments have implemented a variety of measures, involving financial incentives for EV purchases and private chargers' adoption, unrestricted access to high occupancy vehicle (HOV) lanes, public charging installations, carbon taxation and cap-and-trade laws (Axsen et al, 2016 & Government du Quebec, 2015).

The provinces of Ontario, Quebec, and British Columbia all offer different incentives for buying or leasing new electric vehicles. By 2030, the government of Quebec hopes to have 1.5 million electric automobiles on the highways of that province. The government of Quebec will sustain purchase incentives to close the price gap between electric vehicles purchased or leased.

As the market develops, these incentives will be modified. The goal is to speed up electrification processes, as part of a longer-term strategy that goes beyond 2030. By 2035, the government of Quebec intends for electric and other zero-emission vehicles to account for 100% of all vehicle sales thereby eradicating the sale of gas-powered vehicles (Government of Quebec,2020).

Quebec also plans to tighten their zero-emission vehicle standard, (ZEV standard), which pushes manufacturers to sell those vehicles, to ensure that a sufficient quantity and diversity of electric vehicles are available locally. Likewise, efforts are being made to install charging stations in both rural and urban locations.

Also, other projects will focus on taxis, with the goal of electrifying 40% of taxis by 2030. Efforts to electrify light cars will also extend to businesses with electrified fleets. Technological advancements have made it feasible to purchase 100% electric trucks built in Québec.

While the technology is still available but expensive, the government's assistance will include help with EV fleet acquisition costs. Simultaneously, the government will promote the electric truck manufacturing industry in Québec. The government will assist innovation and demonstration in areas where technology is new or non-existent to actively engage in the development of Québec-made electrification products that are appropriate for heavy transport.

Likewise, government's assistance will be extended to the industry's adoption of these innovative technologies. Quebec policy makers understood that the most valuable component of all electric vehicles is the battery, the more reason a lot of interest is vested in furthering the expansion of the battery industry in Quebec.

The government plans to be a key player in the manufacturing process. The policy will include, for example, essential mineral extraction and processing from mining and battery manufacturing.

The goal is to build and strengthen a complete, efficient supply chain of Quebecers. If Quebec's battery industry is to reach its full potential by 2030, significant investments and the recruitment of global companies will be required (Government of Quebec, 2020). The government may also fund projects to produce and export essential battery components such as anodes and cathodes.

The Quebec government has made a huge progress in becoming a climate solutions world leader. Quebec will contribute to the global fight against climate change by leveraging its abundance of natural resources and public benefits. Quebec believes in contributing to the worldwide effort to solve the climate emergency as contributing to that communal undertaking gives one a sense of accomplishment (Government of Quebec, 2020).

The Quebec government is dedicated to leading by example to encourage residents, municipalities, and enterprises to participate in the climate change transition. To that purpose, the government will lead by example by exceeding the targets established for the entire province of Québec by 2030. It will take firm steps to cut its own greenhouse gas output. When it comes to electrification and climate change, the government will also set an example in the acquisition of Quebec's products and services.

That focus will serve as a showcase for supporting local products and services while also promoting the growth of the companies that provide them.

The government's commitment to being a role model is also reflected in its climate change adaptation initiatives, which will include considering future climate when placing, developing, and maintaining public infrastructure.

Overview of EV Policy in British Columbia

The Zero emission (ZEV) policy serves as a significant economic instrument, ensuring that cleaner vehicles are widely available and reasonably priced. This policy will help boost B.C.'s clean energy vehicle (CEV) sector, which now employs 3,850 people and has 198 companies (Clean BC, 2019). The government is also assisting electricians in upgrading their skills to support ZEV infrastructure development.

The CEV sector generates over \$700 million in direct economic activity for the province each year (Clean BC, 2019).

This figure will continue to climb as the government and the private sector strengthens the policies that promote ZEV programs. It has been more than 10 years now since; the province first offered incentives to support the adoption of clean vehicles and technological innovation for the residents of British Columbia. This goes to show that if given the best support for subsidies, citizens would be encouraged to make an easy switch from the ICE to electric drives.

Qualifying British Columbians can save up to \$6,000 on a new clean energy vehicle under the CEV for BC programme (Clean BC, 2019). Since the start of the initiative, the program has provided funding for more than twelve thousand residents and companies. Likewise, workplaces can qualify for up to \$2,000 incentives per charger, when they buy and install level 2 networked EV chargers for employee use, totalling up to \$14,000 in rebate (PlugNDrive, 2022).

Clean BC will maintain the momentum by expanding and restructuring the programme to include new incentives for automobiles, infrastructure such as charging stations, commercial fleets, and public education.

In addition, expanding its current programs would help B.C.'s ZEV infrastructure and the larger CEV sector flourish, producing jobs and economic possibilities for businesses and organisations involved in all elements of the supply chain, from raw materials to final consumer products connected to electric vehicles (Clean BC, 2019).

EV Policy Overview in Ontario

Prior to the 2018 provincial election, the Ontario government provided EV incentives up to \$14000, depending on battery sizes, EV costs and number of seats in vehicles (Thorne & Hughes, 2019, pg. 520). That's program was cancelled in 2018, and currently, the Ontario government do not have any policy to support the uptake of electric vehicles. The current Ontario government is only promoting the adoption of electric vehicle by giving owners preferential access to High Occupancy Vehicle (HOV) lanes at no cost and limited access to reserved parking for EV charging spaces.

As good as those gestures may look, they do not amount to any tangible solutions for achieving the emission reduction targets from light duty car and passenger trucks for 2035 set by the Canadian government. Ontario must move quickly to build on the strength of its car industry and shift to a significantly higher rate of electric vehicle adoption (EVs). Currently, Ontario's EV market share is low, and charging infrastructure is inadequate; in the province there is around one public charger for every 25 EVs on the road (Pembina institute, 2021).

Globally, however, there is around one charger for every eight electric vehicles on the roads worldwide (Pembina institute, 2021). EVs account for 3.5% of the Canadian automobile market. While Ontario EV market share is only 1.75%, which is lower than the 8.4% and 6.8% market shares of British Columbia and Quebec, respectively. There is huge

potential for EV adoption at a larger scale if good policy measures are put in place to promote paid EV uptake.

Policy Drawbacks and Weaknesses

Zero Emission Vehicle Infrastructure (ZEVI) programs were created to encourage a societal switch from internal combustion engines to electric drive by providing incentives or subsidies for qualified drivers. Policy programs also are there to address lack of access to charging stations, one of the barriers to the adoption of EVs. However, one of the weaknesses in that policy is the lack of clarity on the source of energy used in powering the EV drives. It is very possible for electric vehicles to contribute to greenhouse gas emissions if the source of electricity that powers the electric vehicle is from fossil fuel.

Canada's goal of emission reduction by 2035 from light duty cars passenger trucks would be more realistic if policy that specifically targets emissions, like cap-and-trade system and carbon pricing were explored. However, the goal of providing subsidies is to promote the uptake of electric vehicles and this seems to be effective in the provinces of Quebec and British Columbia that are given subsidies to offset the cost of EVs.

There has been a rapid growth in the sales of EVs in these two provinces compared with Ontario with decrease in the sales of electric vehicle since 2018. Another drawback is the lack of uniformity in public policy at the provincial level.

Additional Electric Mobility Considerations and Solutions: Electric Buses

The previous sections illustrate that, thanks to the growth of regulatory measures and incentive systems since 2018, there has been a major increase in the sales of electric cars. In

addition to electric cars, many transit systems around the world are adding electric buses to their fleets. In Ontario, the Toronto Transit Commission has launched a new line of hybrid electric buses. More than 200 hybrid electric buses and 60 electric buses are currently running (Toronto Transit Commission, 2021). The Toronto Transit Commission (TTC) has agreed to buy 300 more electric buses.

There are many different types of electric vehicles. The HEVs, PHEVs, BEVs are the most widely used in the market. Firstly, Hybrid electric vehicles (HEVs) use the combination of electric motor and gasoline or diesel internal combustion engines with recharged batteries but cannot be charged by the grid (BC hydro; Ergon energy, Nd). Secondly, plug-in hybrid electric vehicles (PHEVs) are very similar to HEVs, also run by batteries and internal combustion engines, and can be charged or recharged by electrical outlets (BC hydro; Ergon energy, Nd). Lastly, BEVs, popularly known as EVs, is purely charged by batteries, and does not use fuels, but would have to be plugged into a charger (BC hydro; Ergon energy, Nd).

Although the hybrid electric bus still uses gasoline, it uses less than 29% than conventional buses (Draaisma, 2018). The new electric buses that the TTC is acquiring will be in service between 2023 and 2025, complementing the transport authority's existing fleet of 60 electric buses (Hampel, 2021).

The TTC has implemented a goal of being 50 percent carbon-free by 2028 to 2032 and 100 percent carbon-free by 2040 (TTC, 2021). This is just one example of how the TTC is providing a safe, dependable service to their customers through adoption of innovative technologies that can also mitigate the climate crisis.

As it is the case for electric cars, electric buses are also becoming more popular due to regulatory systems that aim at banning combustions engines, which are in parallel supported

by government incentives that make fleet and individual purchases of electric cars, electric buses and charging stations commercially possible.

That combination of regulation and incentives currently does not exist in Canada for electric tractors. Furthermore, the fact is that today (2022) in Canada, there are no manufacturing of electric tractors and there are no incentive systems to commercialize them locally (as there are for electric cars, e-buses and charging stations). The next section explores the history of tractor development and the policies that are supporting the development of electric tractors in the USA.

A Brief History of Tractors

Technological diffusion is often regarded as the primary cause favouring growth in the agricultural sector. Farm tractors brought about an industrial revolution to the agricultural sector (Leffingwell, 1998). Most of the work that was done by draft animals for thousands of years is currently done by tractors.



Fig 9. Draft animal used for farm operations

Source: <https://www.britannica.com/animal/draft-animal>

Historically, farm mechanization with the use of tractors began in the 1920s (Meyer,2013).

This era marked the beginning of the adoption and diffusion of gasoline-powered tractors for farm mechanization in North America (Lew & Bruce, 2018).

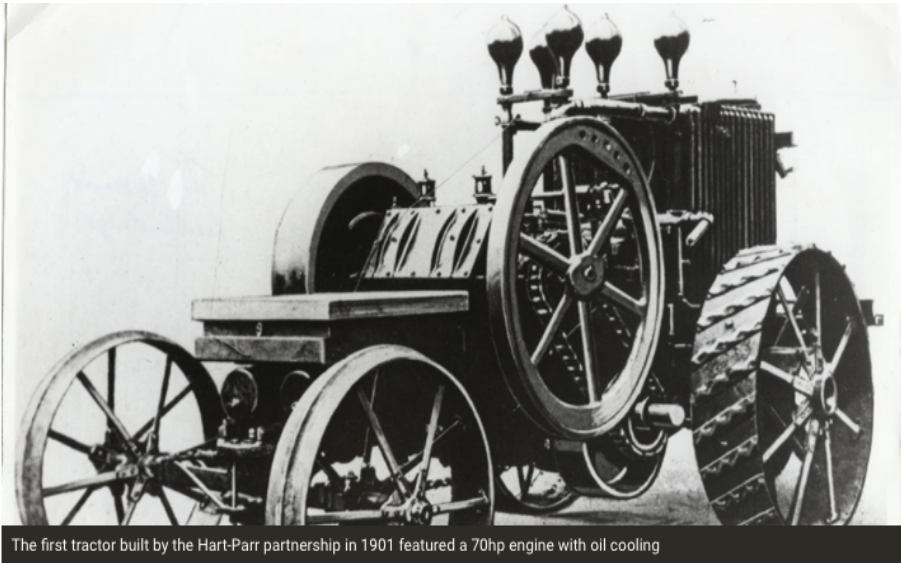


Fig 10. One of the First Tractor Built in 1900s by Hart-Parr Company

Source: <https://www.fwi.co.uk/machinery/tractors/machinery-milestones-the-worlds-first-tractors>

Long before the adoption of tractors, draft animals were commonly used on the farm, and they were a familiar force in agriculture. Technological advancement has helped shape farming operations around the globe.

Tractors are valuable tools in agricultural production. Tractors have also helped farmers to reduce the hard labour of feeding mass populations. The invention of the tractor has helped save the long and arduous hours of daily work that for thousands of years were invested by farmers in ploughing and harvesting crop yields.

Agricultural mechanization has provided an exponential increase in acreage, providing practical opportunities for farmers to feed more people. Historically, farm mechanization with the use of tractors gained momentum in the 1920s.

During the early 1900s, the Charles brothers owned a business in Iowa, United States, where they sold a two-cylinder gasoline engine they invented (Liebhold, 2018). Three years later, their company built fifteen self-propelled traction engines, and the company's sales manager coined the word "Tractor" to advertise the new product (Liebhold, 2018).

Scholars have acknowledged that farmers' ability and curiosity to learn more about the internal combustion (ICEs) engines have contributed significantly to the inception of Henry Ford's Model T invented in 1908. By the mid-1920s, automobiles and farm gas engines were familiar with few options available for tractors (Meyer, 2013).

However, in 1925, The Holt Manufacturing Company joined with the C.L. Best Tractor Company, which was launched by Daniel Best's son. During this period, the Caterpillar Tractor Corporation was launched, and the company's headquarters were relocated to Peoria (Britannica, 2021). Moreover, during the Great Depression, the company was able to stay in business in part by supplying tractors and combines to the Soviet Union to help the country implement its first Five-Year Plan 1929–1933 (Britannica, 2021).

Caterpillar invented a tractor powered by a diesel engine instead of a gasoline engine in 1931, and diesel engines subsequently became the industry standard for all heavy-duty vehicles. Caterpillar built the diesel engines that powered the Sherman (M4) tank during WWII (Britannica, 2020). After World War II, the company's tractor and truck revenue grew as these vehicles were needed for rehabilitation projects and the construction of roads and dams in countries all over the world (Britannica, 2020).

During this time, the term Caterpillar became comparable with bulldozer. In the 1950s, the introduction of the three-point hitch, with innovative redesign allowed for side-entry to the driver's seat. The change in design swept across models from numerous manufacturers during this time. Meanwhile, the Allis-Chalmers WD45, was the first farm vehicle with power steering, which is a highly regarded machine from the 1950s.

This powerful small row-crop tractor, the classic Allis-Chalmers piece of machinery was developed from 1953 to 1957 (Bellis, 2021). Nonetheless, the Allis-Chalmers WD45, the company's first vehicle with power steering, is a highly regarded machine from the 1950s.

This powerful small row-crop tractor, manufactured from 1953 to 1957, is a classic piece of machinery.

It is important to note that diffusion of technology takes much longer time to be fully implemented, for example, the first diesel engine was built in 1924 in the United States, but the technology did not become widely available until the 1940s and 1950s (Manuelli & Seshadri, 2014).

The main factors fostering growth and technological adoption appear to be a significant increase in quality, better fuel efficiency relative to the competition, and, perhaps more importantly, reduced labour demands (Manuelli & Seshadri, 2014). Studies have shown that technological advances reduce the cost of operating new technology relative to the old or exiting technology.

The birth of a new Technology: A summary of the development of the first commercial electric Tractor in North America (Solectrac)

Solectrac is an American electric tractor company first owned by Steve Heckerroth. The company was established more than a decade ago as a call to action for providing alternatives to fossil fuels, especially from combustion engines.

Heckerroth believes that the weight and heaviness of the batteries in electric cars can be used to gain tractions and stability in tractors. As a result, Heckerroth incorporated a company in 2012, tailored towards providing 100 percent solar powered tractors. The Compact Electric Tractor and the e-Utility were the first commercially available tractors in the United States.



Fig 11. eUtility Electric Tractor Source: Solectrac.com

Compact Electric Tractor (CET)	
<p>The 30 HP diesel-equivalent CET is a versatile, 4WD utility vehicle, great for vineyards, golf courses, sport fields and municipalities.</p> 	<p>QUICK LOOK</p> <ul style="list-style-type: none"> • 30HP (22kW) • 22HP (16kW) PTO • 3-6 Hours Runtime • 4 Wheel Drive • 3 Point Hitch • 4 Hour Charge • Front Loader* • Hydraulics <p>*Optional Accessory</p>
	

Fig 12. Compact Electric Tractor Source: Solectrac.com



Fig 13. Can Electric Tractors Override Diesel?

Source: <https://modernfarmer.com/2020/03/going-green-can-electric-tractors-override-diesel>

Technical Specifications of Compact Electric Tractors and eUtility Electric Tractors and Options for Charging

The Compact Electric Tractors

CET tractor is equivalent to the 30HP of diesel tractor. It is a 4-wheeler drive. The Compact Electric Tractor is a 22kWh battery power packed with efficient capacity, which can operate for about 3-6 hrs depending on load of work. This battery *could* be charged under four hours from a 220VAC, 30-amp outlet from a 110VAC, 15-amp outlet (Solectrac.com)

eUtility Electric Tractors

The utility electric tractor is the equivalent of a 40HP diesel tractor. This model is powerful and can be used for small to medium-size farm operations. The runtime time is between 4-8 hours (Solectrac.com). This model is the e-tractor used in Wheelbarrow Farm, which is located at Uxbridge Ontario.

The electricity needs for the Wheelbarrow Farm e-tractor is offset by a 10-kW solar PV system.



Fig 14. The First Solar Powered Electric Tractor in Canada, Wheelbarrow farm; Source: Toronto Star, 2018 <https://www.thestar.com/news/gta/2018/12/28/this-uxbridge-farmer-is-ditching-diesel-for-a-solar-powered-tractor.html>

BENEFITS OF ELECTRIC TRACTORS

ELECTRIC TRACTOR	DIESEL TRACTOR
95% Efficient	30% Efficient
Quiet operation, fewer moving components	Loud operations, many moving components, ~300 moving parts, causing discomfort to drivers.
Reduced Noise: 65 dB (avg. conversation)	95-105 dB (unsafe after 4 minutes)
Can be charged by renewable sources like solar Can also be charged by electrical grid with zero emissions, reduced operating cost	Dependence on fossil fuels and infrastructure. Diesel powered, produces GHG emissions. High maintenance leading to high operating cost
Battery weight is good for traction	Dead weight adds to additional fuel consumption

Table 5. Benefits of Electric Tractors. Source: Solectrac.com

Operating costs of Diesel Vs Electric Tractors

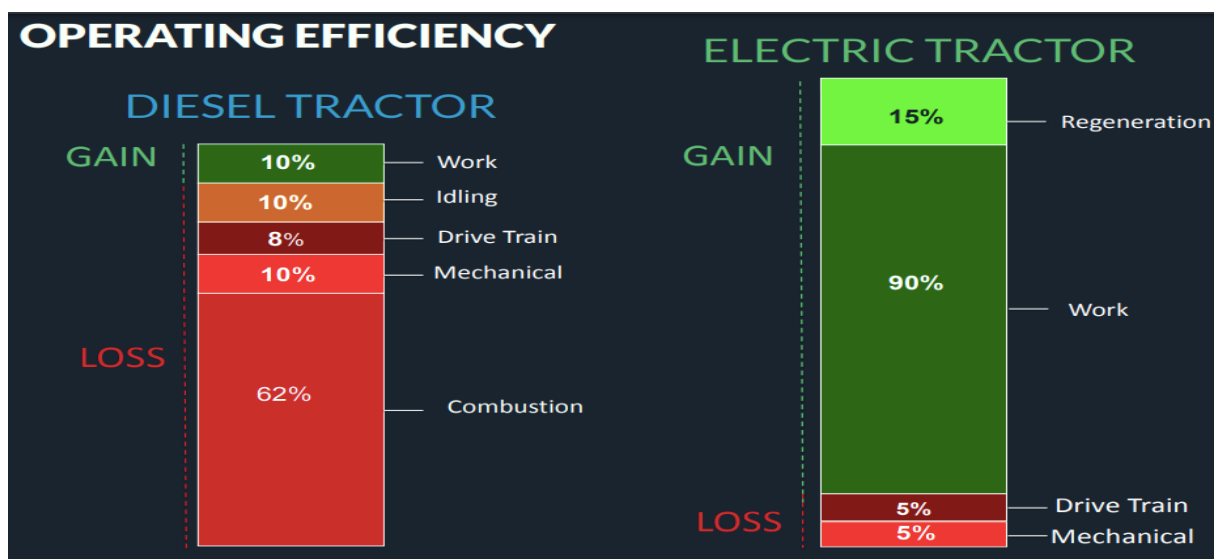


Fig 15. Operating Costs of Diesel verses Electric Tractor Source: Solectrac.com

“Total cost of ownership of a solar-powered electric tractor is 1/3 the cost of a diesel tractor” (Solectrac.com).

The advantages of Electric Tractors

The inclusion of electric tractors in the agricultural fleets of farm equipment provides benefits for energy efficiency, thus promoting long-term farm machinery functionality (Caban et al., 2018). According to Yu et al., the electrification of the transportation sector with cleaner energy sources is poised to combat air pollution and strengthen energy security (Yu et al., 2016).

Electric tractors produce less to no emissions while in use. The existing technology from the automotive industry has the potential of being repeated in agricultural applications. For example, hybrid tractors use internal combustion engines and electric motors; also, pure electric drives with backup batteries (Caban et al., 2018).

Although, there are concerns and barriers for the uptake of electric tractors, of which high cost of battery operating system is a dominant factor. Even though, there is justification for the high cost of electric tractors due to the sophisticated technology used in making them and their multiple health benefits.

Doolan and Boyden has argued that advancement and growth in battery technology for achieving cost reductions has led to a decrease in mining materials like cobalt and copper (Doolan & Boyden,2016). Using science and further research in technology and scalability, the cost of production of e-tractors will decrease.

Market for Agricultural Tractors

In general terms, the farm tractor market is naturally segmented into many brands, mutual alliance partners and joint ventures representing more than three hundred companies

globally (Credence research.com). In most cases, major manufacturers have been contending to hold their spot in the farm tractor business. These manufacturers have partnered with local tractor manufacturers to maintain their competitiveness, especially in North America and Europe (Credence research.com). Also, investment in Research and Development(R&D) has been one of the strategies used for staying competitive by most of these manufacturers.

Where Two Wheel Drive (2WD) farm tractors are projected to be the overall leading market from 2018-2026 (Credence market.com). As a result of low costs and savings, 2WD tractors have been popularly adopted, especially in Asian, Middle East, Latin America, and African countries.

Also, these tractors are commonly used by small to medium farms due to their energy saving cost and fuel efficiency. However, there has been a growing demand for 4WD with its ability to move heavy, large farm equipment with more power and torque (Credence research.com).

Fig16 below shows the main division of tractor power output excluding the type of drive source. Also, the diagram showcases an interesting area of the market which is autonomous tractors. This segment is very crucial, although the drive source is heterogenous, the electric tractor drive is very important for maintaining vehicle control.

Furthermore, fig16 illustrates the trend in countries that are dominating the farm tractors, where Asian countries ranked the first with more than 150 HP tractor engine followed by Europe with a little over 100HP. That said, there is a potential for electric tractors to gain momentum in a similar trajectory.

Studies have shown that Asian countries, specifically China are the world leaders in the EV markets and are well positioned for breaking the niche for electric tractors and farm equipment.

Similarly, in North America, Solectrac is poised to be a leading voice in the electric mobility industry especially in farm operations.

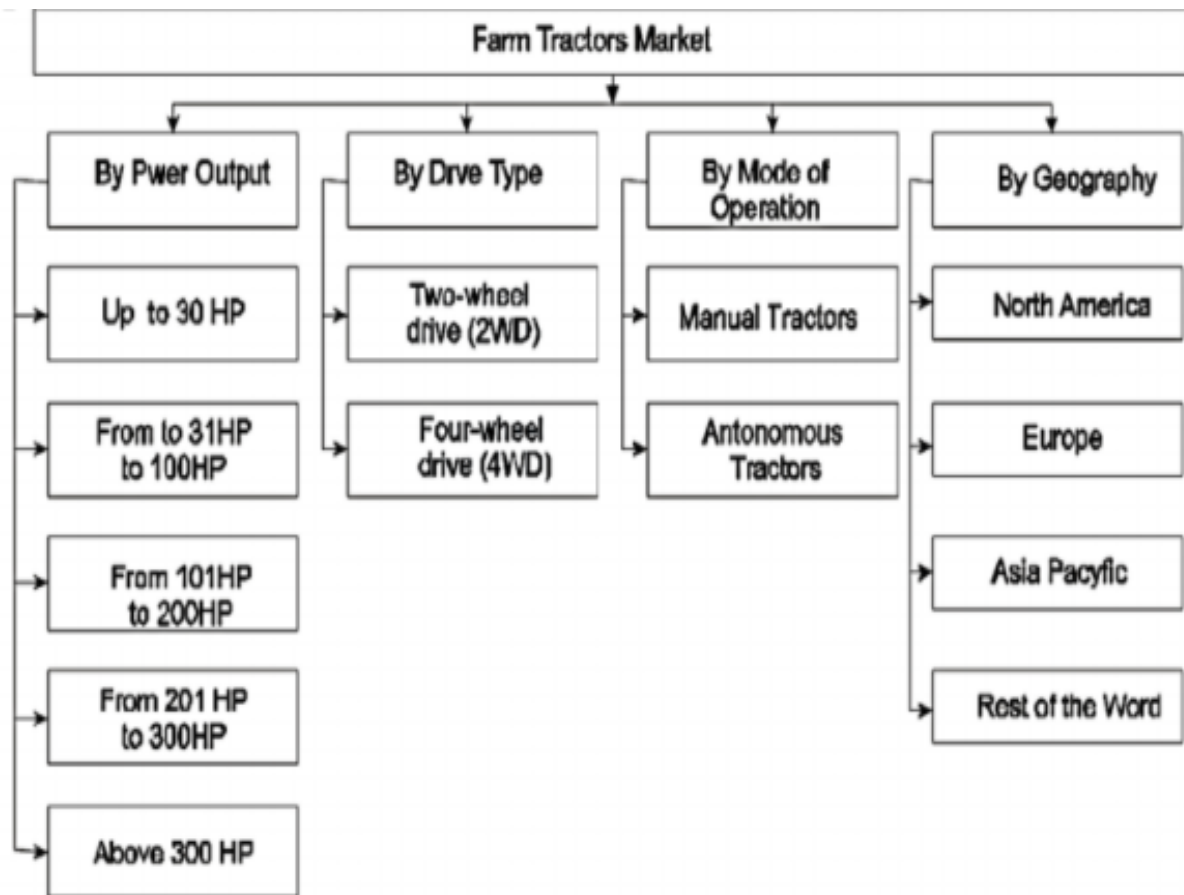


Fig16. World Agricultural Tractors Markets. Source:(CredenceResearch.com,2018)
<https://www.credenceresearch.com/report/farm-tractors-market>

Policies supporting electric tractors

Except for Solectrac (which manufactures in California), there are no other commercial models of electric tractors available in North America. The USA began the commercial production of e-tractors in late 2020 (Americafem.com,2020) and there are a few incentive systems available in that country. California’s local county air resources board offers two incentives programs to assist farmers offset the cost of farm equipment. The Carl Moyer program and the FARMER program (California Air Resources Board,2022).

The Carl Moyer Program is a collaboration between the California Air Resources Board and the state's 35 local air districts to provide opportunities for emission reductions with Net zero technologies. They also partnered with other stakeholders to formulate guidelines and ensure that the program decreases pollution and provides cleaner air for California residents.

About \$1 billion USD incentive funds have been awarded to equipment owners, and the Program continues to give over \$60 million in grant assistance each year to help California clean up ageing polluting engines (California Air Resources Board,2022).

Also, the Funding Agricultural Replacement Measures for Emission Reductions (FARMER) offers incentives through local air districts for agricultural pump engines and other farm equipment for operations. This program provides a scrap and replace subsidy/ incentives to farmers which can cover the cost of an electric tractor by up to 80% (California Air Resources Board,2022). Canada can replicate this type of incentive programs in their agricultural sector to aid the adoption of e-tractor technology.

Therefore, Canadian governments are encouraged here to implement a supportive new policy framework that promotes a rapidly growing market share for electric tractors and other electric farm equipment to encourage the adoption of these iconographic technologies.

It is important to note that the electrification of the farm tractor is not a new concept in the Agric-business industry.

Diesel-electric systems, such as the Farmall 450, IH Electrical model, were manufactured in the 1950s (Onnen,2011). The preceding sections provide a brief overview of the historical development of tractors. It is important to note that Canadians are becoming used to electric machines for landscaping (e.g., electric lawn mowers have become commercially competitive and are readily available in hardware stores).

The implementation of electric tractors in agricultural production offers opportunities to reduce dependence on fossil fuels. The electric mobility industry is currently growing faster than ever. Yet, there is a lot of uncertainty around the viability of this new technology, particularly when it comes to agricultural applications. Therefore, further research is needed to address some of the lingering environmental and social concerns attached to electric mobility in Canada and worldwide.

SECTION 3- KEY LESSONS FROM THE DEVELOPMENT OF ELECTRIC CARS WORLDWIDE.

MANAGEMENT OF BATTERY INFRASTRUCTURE OF ELECTRIC VEHICLES, ENVIRONMENTAL CONCERNS AND CHALLENGES

Lithium ion- batteries have become a very crucial technology in electric vehicles for achieving NetZero emission targets and improved air quality for urban dwellers. This technology is commonly used in Hybrid and electric drives due to their high efficiency (Farag et al, 2016). Expanding the electric battery infrastructure, the main crucial component for electric mobility, could result in more than 1000% increase in demands and mining of mineral resources (Sembiring, 2020). The extraction of aluminium, cobalt, iron, lead, lithium, manganese, and nickel poses a severe danger to the environment and the economy.

The rise in market demand for Cobalt, an important material for battery production has increasingly posed environmental and social concerns in Africa and other places around the world. The Democratic Republic of Congo produces more than 50% of the world's cobalt (Engineering and Mining Journal, 2018.pg. 50). In that country, cobalt extraction is known for causing political instability and social tension within the region.

Futhermore, mining has a poor track record of environmental management across several places of the world. Chile, after Australia, is the world's second-largest producer of lithium, which comes from salt brines in the Atacama Desert (McDonald, 2021). Community members in these areas often express concern about the mining operations, which utilise a lot of water and energy for extraction, impacting the delicate ecosystems of one of the driest deserts on the planet. Also, there have been reported cases of child labour and human rights violations and abuses in connection with mining operations in those areas. Resources management and

sustainability initiatives from environmental, social, and economic are fundamental policies that could be implemented to avoid excessive extraction of natural resources.

Many industries, however, are striving to find cost-effective solutions to recycle the lower-value components of used batteries. Using new material is frequently the most cost-effective option, but the detrimental consequences of excessive extraction places a huge burden on humans and the environment. Environmental pollution from battery mining has been a primary environmental concern. However, recycling a lithium-ion battery, a component found in a battery used for energy storage, offers a solution to the intensive mining of raw materials

There has been a significant shift in technology deployment for recycling lithium-ion batteries (Howes, 2012 & Harper et al, 2019). These authors argue that the success of lithium-ion battery recycling would depend on the ability to scale up. Battery recycling could help alleviate excessive pressure on mining, where most of the earth metals are recycled to be used for multiple purposes. Some metals, such as aluminium and cobalt, are already established in recycling, while only 1% of lithium in the global supply chain comes from recycled sources; reuse and recycling could aid the diversion of battery wastes from landfill (Harper et al ,2019 & Mc Donald, 2021).

The cost of extracting new material might make economic sense now, but not for the future. The cost of environmental burdens placed on people and the environment from mining operations are irreversible and are difficult to quantify. Hence, the fast developments in battery recycling technology provide for a great approach to manage well a finite resource. Battery recycling technology provides viable solutions to excessive extraction of mineral resources from the earth. Lithium-ion battery technologies are rapidly improving, and solid-state batteries are providing higher energy density, which means longer range and lifespan. The demand for

stricter emission reduction policies would naturally drive the market for electric tractors; thus, *combustible* engines might not be profitable.

The need for Proactive Development of Charging Infrastructure

Availability with an accessible charging infrastructure of EVs is paramount to the acceptance of this novel electric technology. Yu et al. argued that EVs adoption into the EVs market depends on the availability of charging stations (Yu et al.,2016). In general terms, social acceptance for new technologies is challenging and have become nearly impossible to implement. EV charging stations are on the rise as EV technologies demand are gaining momentum due to environmental concerns.

The integration of solar energy within the charging infrastructure will proffer action-based solutions to emission reductions and the global fight against climate change. Since, charging station technology is already available for small-medium size vehicles, similar technology can be adopted in agricultural settings for charging electric tractors. The adoption of electric tractor technology can reduce diesel dependence on fossil fuels in rural areas that rely on combustion engines for their energy use. Understanding the role of all-electric battery-powered farm tractors plays a significant role in increasing local resilience and fossil-fuel independence. Electric tractors can generate power with locally made renewable energy sources eliminating the need for gasoline or diesel.

The Need for Smart Regulation and Incentives to Foster Growth of Electric Tractors

According to Canada's plan for emission reductions for 2030, the Canadian government promised to contribute about \$1.7 billion to prolong the Incentives for Zero-Emission Vehicles (iZEV) programme, making new electric light-duty vehicles more affordable and accessible to Canadians (Government of Climate Change Canada, 2022).

The government will also enact a sales mandate requiring zero-emission vehicles to account for at least 20% of new light-duty vehicle sales by 2026, 60% by 2030, and 100% by 2035. To cut emissions from medium- and heavy-duty vehicles (MHDVs), the Canadian government wants ZEVs to account for 35 percent of all MHDV sales by 2030. In addition, the government will design an MHDV ZEV law that will demand 100 percent ZEV sales for a subset of vehicles by 2040 (Climate Change and Environment Canada, 2022).

Electric mobility technology is an emerging industry that requires research, new incentive policies and new regulations. Incentives and subsidies that promotes EV adoption would be more effective if all provinces are on board with the program. If Canada wants to be successful in meeting its emission targets by the set dates, EV incentives program must cut across all provinces.

Rebates have been in place in Quebec and British Columbia for several years, and the two provinces account for three out of every four electric vehicles sold in Canada. Quebec and BC are the only two provinces with sales quotas that punish automakers who do not sell a certain percentage of electric vehicles (Rabson,2021).

Although agriculture is not a direct source of emission pollution, electrification of this sector, could provide potential reduction in emission pollution especially from livestock. The Ontario provincial government provided an incentive program for electric automobiles so interested parties could receive incentives based on the types of models and make of their vehicles (Ministry of Transportation, 2018).

The incentive program was squashed by the Progressive Conservatives under the leadership of Doug Ford when they came into power in July 2018 (Ontario Ministry of Transportation, 2018). However, in May 2019, the federal government provided incentives for consumers who buy or lease eligible zero-emission vehicles (Transportation Canada, 2020).

Even though federal incentives remain in place for electric automobiles, there are no incentives at the federal, provincial, or municipal level for the electrification of farm equipment in general or electric tractors. Climate change mitigation on Canadian farms will require meaningful and easy to use support and reward schemes.

These support initiatives are crucial not just because they make it easier for farmers to transition to sustainable farming practises, but they also convey a strong message that sustainable farming and farmers are important contributors to climate crisis solutions. Intuitively, lower prices in charging infrastructure with attractive incentives for investors from governments would open new market opportunities for charging stations and ultimately drive EV market same as for electric tractor and farm equipment (Yu et al.,2016).

Government is encouraged to set an achievable EV goal that matches with the incentive program they are promoting. It must be clearly done in a way that it promotes easy adoption of cleaner energy sources for the end users. More so, joint adoption of e-tractor and solar energy should be one of the objectives of energy planning and policy formulation for stronger incentives to support farmers.

To illustrate, energy and EV policy must be drafted in such a way that it provides accommodation for incentives, especially for start-up farmers, who are starting new and eager to embrace green technology in their farm operations. EV technology and rural renewable power generation should be seen as a policy framework for rural economic growth and groundwork for Ontario's farms. Canada needs to do more in providing adequate funding for farmers especially for projects under the Agricultural Clean Technology Program. This program aims to further develop and promote the adoption of modern clean technologies for the reduction of greenhouse gases in agricultural sector.

Section 4- Case Study

Wheelbarrow Farm

Wheelbarrow Farm was established by Tony Neale in 2008, on a 10-acre of land, northeast of Toronto, Ontario. This farm is known for precision agriculture and permaculture with negligible environmental impacts. The modest wheelbarrow was selected as a symbolic name for the farm that aims at emphasising creativity based on innovative agricultural practises, without the use of herbicides or pesticides. This farm focuses on varieties of fruits, nut trees, six greenhouses, about 40 vegetable crops, and solar panels (Wheelbarrofarm.com).

As a conscientious farmer, Tony is concerned about doing the right thing especially when it comes to environmental impacts and what he can do to prevent harm. Having said that, Wheelbarrow farm is one of the first in Canada to implement electric drive in their farm operations. Since 2018, Tony Neale, has been using his quiet, carbon-emission free electric tractor to plant and harvest vegetable crops.

However, in 2020 a massive windstorm with a speed of 141km/h was reported in the Greater Toronto Area which has led to the destruction of many properties including Wheelbarrow's farm (The weather network.com). The wind speed was responsible for the destruction of the solar system on the Wheelbarrow farms.

The initial idea was to redesign and restore the solar system, with fellow MES students, Apeksha Malik, and Daniel Romero to be supervised by Professor Etcheverry and Kinetic Solar. For the most part, my role in this project was to assess the interrelationship between powering the electric tractor with solar energy.

It was during the time, Covid-19 struck, and due to Covid-19 lock down alongside provincial restrictions, we were unable to proceed with the project. Then opportunity has allowed to design a portable container powered with solar system, Wheelbarrow farm provided an ideal setting, where this project, solar on the container can be used as a toolkit for storing the existing electric tractor on wheelbarrow's farm, also as a backup battery pack powering the electric tractor.

Although, the electric tractor on wheelbarrow's farm is powered by existing solar panels installed on the farm. The electricity provided by these solar panels will be put to better use when stored in a battery pack using the Solar on the container as a storage. Please see Appendix A for a summary of the work done on the container and recommendations provided aimed at replicating this project on small-medium sized farm such as Wheelbarrow farm.

Section 5: Conclusion and Policy Recommendations

The development and widespread adoption of electric transportation solutions is becoming a key strategy to address the climate emergency. Governmental policies such as combustion engine bans, incentive systems to purchase electric vehicles and subsidies for installing charging stations are all becoming crucial components to accelerate a transition away from internal combustion engines and towards electric transportation solutions. Regulatory policies and financial incentives are helping ensure that electric cars and electric buses become a popular choice for families and transportation fleets.

Similar efforts are needed to increase sustainability and to lower the ecological footprint of the Canadian agricultural sector. Furthermore, in this paper it is argued that electric tractors can become an iconographic solution that can be harnessed to capture public imagination, which is a crucial component to ensure much needed political support for the development and adoption of new policies and incentive systems that favour rural areas and local people. All electric mobility solutions require to be powered by renewable energy sources such as those that have been implemented in Wheelbarrow Farm.

By using local renewable energy sources, all electric mobility solutions can become effective components to address the climate emergency. Further research is needed to ensure that all the materials that are used in renewable energy and electric mobility can be sourced using socially and environmentally responsible strategies and that once their useful lives end, they can be re-purposed, re-used and recycled properly.

Although much work remains to be done, the practical experience of Wheelbarrow Farm clearly illustrates that local farmers with a purpose can bring about very innovative solutions that hold great potential to inspire urban and rural people to work together in bringing about a more sustainable society. In addition, our own practical experiences (summarized in Appendix

1) developing a solar box that can be used for a multiplicity of productive solutions (and even as a portable charging station for electric tractors) shows that innovation can be fostered and nurtured by bringing students, professors, NGOs and local companies together to advance solutions.

Based on the analysis conducted for this research the following recommendations are provided so policymakers and decision makers can implement ambitious programs to advance the development and widespread adoptions of novel technologies such as electric tractors. To finance the recommendations provided below, it is recommended that revenues from the existing Canadian Carbon Pricing System be harnessed to provide tax and financial incentives so Ontario farmers can reap the benefits of EVs and renewable energy technologies. Based on the research conducted for this paper it is also recommended that:

- Canadian farmers should be encouraged to set ambitious goals for GHG emission reductions at the farm level and be given new financial incentives to purchase new farm technologies such as electric tractors that can protect their investments and the environment
- The prototype solar on the box project should be scaled-up (please see Appendix 1)
- New incentive systems need to be implemented in Ontario to support renewable energy development in farms and rural areas
- Local training programs should be provided to support farmers who want to transition to innovative technologies like e-tractors (Electric tractors) and renewable energy systems
- All Governments should stop giving subsidies to oil and gas and such subsidies should be re-directed to finance local manufacturing of renewable energy systems and electric mobility solutions

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Appendix: Developing a Solar Box for Electric Tractors

Developing the prototype of a Solar in the box project involved multidisciplinary teams of experts. Kinetic solar and SILFAB companies are key partners in this project. Kinetic solar, is a racking system manufacturer who uses innovative technology for snap-in cable management with multiple L brackets sizes for height modifications. Their innovative designs allow them to mount two panels on one rail, like the idea that was designed for this project (solar on the container).

Also, SILFAB is an Ontario based company who specialises in manufacturing PV(Photovoltaic)modules design that specifically targets North America markets. It uses precision engineering and automation to provide reliable and high-performance photovoltaic modules. The power market that offers minimal risks and rewarding opportunities for the solar market was provided through innovative partnerships with SILFAB solar and Kinetic solar. A prototype solar on a container project was done in collaboration with master's students including myself and undergraduate students.

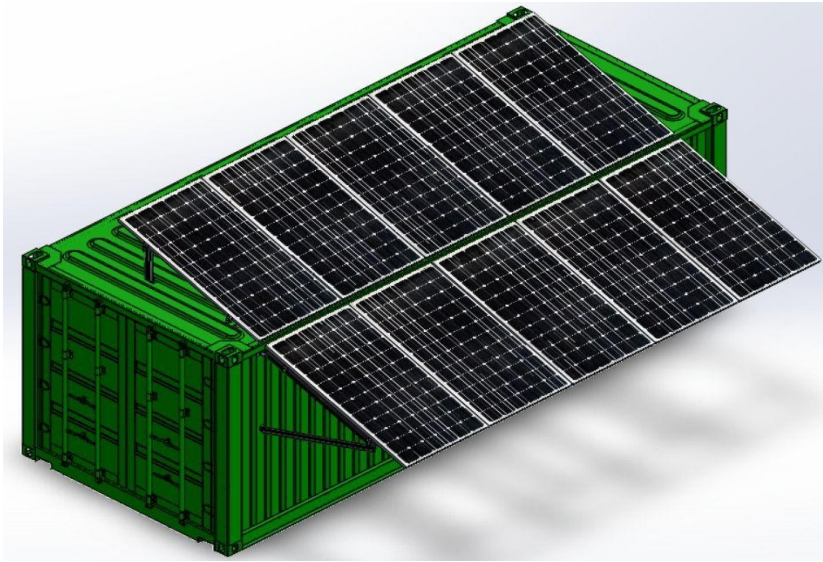
The used container was donated to York university by a private citizen. The 8 by 10-foot container was hauled from a long beach area in Ontario to a space near York university, where the container was groomed and made ready for solar PV to be installed. For accuracy in data collection, email was sent to Solectrac, an electric tractor manufacturer in California, United States, to obtain up to date data on electric tractor efficiency and market viability.

Solectrac was founded in 1990 in the United States in quest of finding solutions to pollution from GHG emissions from the agricultural sector. Their main objective is to find a sustainable replacement for fossil fuel powered tractors with low-cost maintenance and zero free emission e-tractors for agricultural purposes. They were also the manufacturers of the first electric tractor in Canada that was imported to the Wheelbarrow Farm in Ontario.

Pilot Project Design

The solar PV system was designed such that it relies on backup batteries and or electrical grid during prolonged times of reduced electricity (irradiation intensity). The prototype of the solar in the container was intended to use about 8KWh.

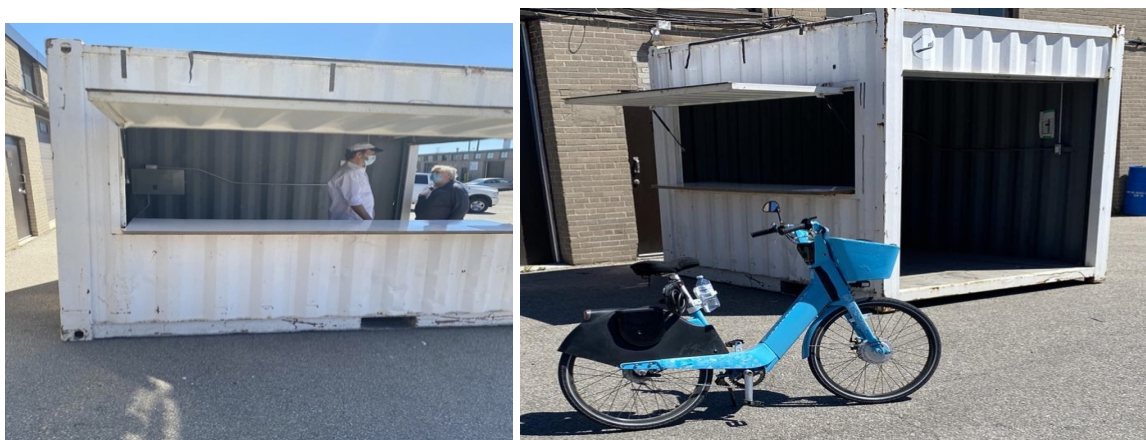
The 3D design of the solar in a box in fig7 below.



Appendix 1: 3D Design of the Shipping Container

The used Container before Grooming

Appendix 2 below shows the image of the preliminary work done in the first phase of priming and making the container ready.





Appendix 3 The Interior of the Container before grooming.

The Grooming of the Container

The used container needed a lot of preparation work before any work could be done on it. Firstly, the container was swept, and all wiring connections were disconnected. Screws and nuts were unscrewed, labelled accordingly, and stored safely for future use. About 2-3 methods of washing were explored, but power washing was the safest method that was used. Pre-washing was done followed by sandblasting to remove toxic resins from previous paintings from the container. Power washing was finally done to the container to remove sticky dirt and toxic substances during sandblasting. Below are some of the pictures showing some of the work done on and to the container.



Appendix 4 above shows the initial preparation of the container: removing electric wiring, washing, priming, painting.

The Measurements of the Container

Measuring the container from side to side, from top to bottom, making sure that solar PV is accurately and safely installed. The table and fig below show the exact measurements done with the interior and exterior of the container. Measurements were taken with door opening and without door opening.

Dimensions – outside (inches)		
	Full	One-side
Length	144	122.5
Width	95.75	94.5
Height	101.75	96
Dimensions – inside (inches)		
	Open container	Edges
Length	34.5	13.75
Width	94	12.75
Height	42	19.5

Appendix 5 Measurement of Container



Appendix 6. Measurements of Interior and Exterior of the Container

Budgeting of the Used Container

The cost of the container was not included in the budgeting because it was donated to the university by private citizen through Dr. Etchevery. The table below represents the estimated costs of fixing the container. By using new containers, the costs of fixing the used container would have been eliminated. Although, it is more expensive to buy a new container, the upfront costs would have been paid off over the years of use. A new container can last for many years before a new one is installed.

Cost Categories	Cost/unit	No. of units
Photovoltaic Systems Budget		
Lightweight Solar Panels	\$ 289.00	8
Solar Charge Management Panel	\$ 430.00	1
Inverter	\$ 717.60	1
Battery	\$ 415.10	2
Battery Enclosure	\$ 685.69	2
Sub-total	\$	5,661.18
Fixtures Budget		
Racking Systems	70.00	8
Wiring Costs	25.00	8
LED Strip Light	46.98	2
Solar Pest Repellent	44.98	4
Squirrel Guards	2.00	64
Waterproofing	79.98	2
Wood Cladding	\$	
Sub-total	\$	1,321.84
Miscellaneous Costs		
Gas	\$ 0.45	660
Assorted Materials	\$ 677.09	1
Sub-total	\$	974.09
Professional Costs		
Interior Designer/Artist	\$ 18.00	50
Painting	\$ 67.00	3
Pressure Washing	\$ 55.00	2
Sub-total	\$	1,211.00
Grand Total	\$	9,168.11

Appendix 7: Budgeting of the used shipping containers

The Installation of Solar PV on the Container

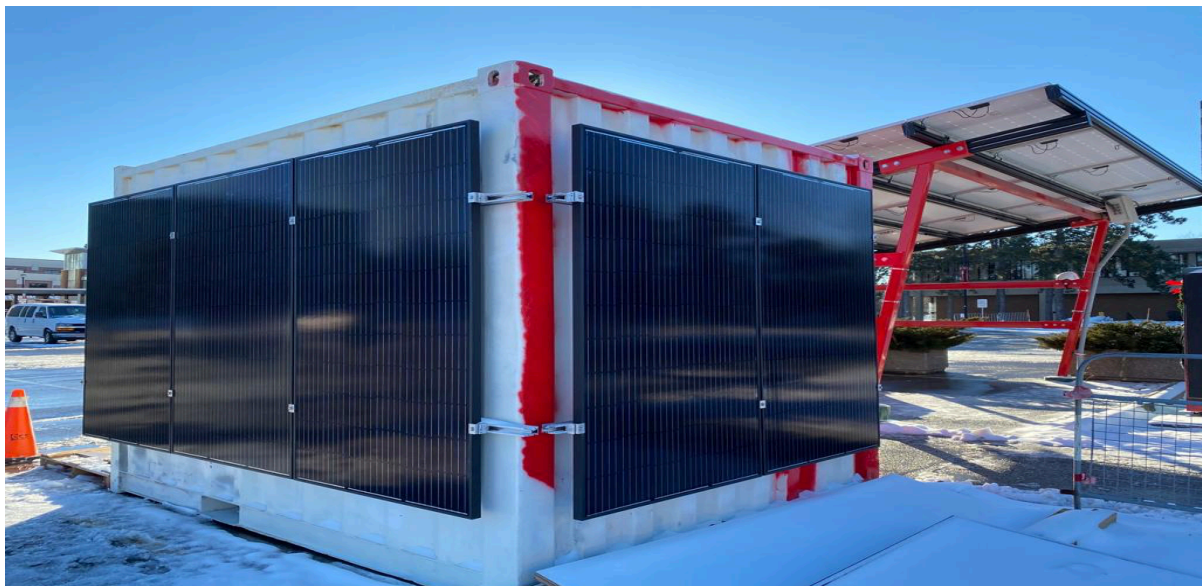
After all the preliminary work of fixing and grooming of the container, solar PVs donated by SILFAB were installed on the two sides of the container. Measurements were done for the racking rails where the PV is going to be placed. The maximum amount of energy produced by each PV is estimated at 360W.

Possible Number of Panels on the Box:

- 8 Panels at the side
- Possible 3-4 panels at the top

Total possible installed Capacity (STC):

- Side: 2.88 kW (8 * 360 W)
- Side and Top: 4.32 kW (12 * 360 W)



Appendix 8 After Installation

The key findings of this project include:

- The prototype project could be replicated in any remote location around the globe.
- The racking system was designed to withstand any form of corrosion or oxidation.
- The solar container could be used for multiple purposes
- A used container could be recycled reuse and repurposed, it is environmentally friendly
- The project is socially inclusive.
- Solar energy intermittency and ability to produce power is dependent on the sun
- The container is movable with tilted PV, there would be less shading and energy intermittency, therefore more energy is stored in the PV cells
- In the face of climate emergency, innovative technology like solar on the container could reduce dependency on fossil fuels
- Implementation of strong green technologies policies to drive the growth of RE in remote areas in Canada.

This project is beneficial to humans with less pressure on resource extraction, the benefit outweighs the costs