Transition to electric vehicles: the importance of macro and micro influences on spatial and temporal patterns

by

Yixin Chen

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Doctor of Philosophy
in
Geography

Waterloo, Ontario, Canada, 2025

Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

External Examiner	Dr. Jamie Baxter Professor, Western University Department of Geography and Environment
Supervisor	Dr. Jean Andrey Professor, University of Waterloo Department of Geography and Environmental Management
Internal Member	Dr. Sarah Burch Professor, University of Waterloo Department of Geography and Environmental Management
Internal-external Member	Dr. Clarence Woudsma Associate Professor, University of Waterloo School of Planning
Other Member	Dr. Ian Rowlands Professor, University of Waterloo School of Environment, Resources and Sustainability

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The climate crisis is widely recognized as being caused by unsustainable consumption and production patterns across various social domains, which motivates the demand for an acceleration of transformative changes with the goal of sustainability. Socio-technical transitions, offers a path forward. That said, a core impediment is an incomplete understanding of how multiple elements co-evolve in different contexts. Various lenses, theories, and approaches have been used to analyse and explain technology adoption and diffusion in societies; these can be characterised as macro-level ('structure') or micro-level ('agency'), but to date the linkages between them in understanding transition processes have been under-explored. This gap provides a research opportunity for the thesis to question in what ways can macro-level and micro-level lenses explain the spatial and temporal patterns of the transition process to electric vehicles (EVs), an example of a transition for the decarbonization of mobility.

With specific reference to Canada, the thesis aims to illuminate the multi-dimensionality and complexity of how the transition to EVs is unfolding, using a quantitative approach including indicator development and statistical modelling. The thesis adopts two complementary components. One aims to describe and explain the spatial and temporal patterns of transition to EVs at a national level between 2017 and 2022 by drawing upon the 'geography of transitions' literature and modelling secondary data of new EV registration by seven provinces in Canada by quarter. The other component seeks to understand and assess changes of consumers' likelihood and perceptions to purchase EVs in one municipality, Waterloo Region, between 2020 and 2023, framed by 'diffusion of innovation' concepts and based on primary data from two public surveys. In both analyses, robust models highlighted the importance of various factors in leading to EV adoption and diffusion.

These macro-level and micro-level analyses both depict the transition to EVs in Canada as proceeding at a slow pace, with variations across space and time and society. The micro-level analysis further suggests that the transition is hampered by the resistance of nearly half of the population in the local context. Longitudinal dynamics of individual consumers' perceptions of EVs and differences and changes at the landscape level mutually reinforce each other. For example, consumers' recognition of EVs' environmental benefits have the most substantial influence on people's interest in EVs, which also echoes the significant role of societal environmentalism, as one of the representations of informal localized institutions at a provincial level, in driving the EV transition. The importance of EVs' economic perspectives in individuals' likelihood to adopt EVs increased

between 2020 and 2023, which is aligned with the considerable influence of rising gasoline prices on the increase of new EV registrations in Canada.

The findings of the two analyses raise concerns about whether Canada can achieve its commitment of 100% zero-emissions vehicle sales by 2035 and whether EVs can fully penetrate the Canadian market. The Canadian transition process of EVs is a co-evolutionary process with multiple elements interacting with one another. Therefore, no single policy or action can singly accelerate the process. The heterogeneity across consumers highlights the importance of tailored strategies for different consumer segments and the importance of longitudinal dynamics in investigations. In conclusion, macro-level and micro-level lenses are both important in understanding socio-technical transitions due to their integration, synergy, and complementarity.

Acknowledgements

My PhD journey has its ups and downs, with joy, tears, thrill, struggles, and confusion. Nonetheless, this experience has been both rewarding and memorable, transforming a new version of me and steering me towards a research path. Although this thesis is my work, it is not a solo project, and I would like to humbly acknowledge all those people who are along with me during the journey.

First and foremost, I would like to express my deepest appreciation and gratitude to my supervisor, Dr. Jean Andrey, for all of your support, encouragement, trust, patience, and supervision during the process. You are always available to engage with me in research, guide me the right direction whenever I start spinning my wheels, inspire me with different ways of thinking, and challenge me to further improve my work. Your professionalism, broad vision, and generosity of spirit inspire me to follow your example both personally and academically. Thanks to Dr. Ian Rowlands for your guidance from the perspective of energy, continuous engagement in my research process, and kind and generous financial and academic support. Jean and Ian, I treasure the experiences of working with you both and I also look forward to our ongoing journey of knowledge exploration.

I would also like to thank other committee members, and your feedback shapes my research and professional development. Dr. Sarah Burch, thank you for your guidance from the lens of sustainability transition and climate governance. These perspectives enrich my research insights both theoretically and practically, which motivates me to further explore the transitions scholarship. Dr. Clarence Woudsma, thanks for your enthusiasm of my research and your guidance from the perspectives of planning and transport and new mobility regimes.

I am extremely grateful that I have many friends and colleagues surrounding me in my doctoral education, who directly and indirectly help me with life, inspire my thinking, give me inner strengths, and make me laugh. Thanks to my undergraduate friends, Qi, Jiayi, and Dr. Kun, for caring about my research and accompanying with me. Thanks to Ming and JJ from our Transportation cluster for always being by my side. Thanks to all my peers from our Environment community and peers from other programs for the wonderful time we spent together within and outside campus. I cherish our friendship and you all add more meaning and excitement to my doctoral life.

Extra thanks to the staff and professors in the Environment and staff from the library, the Centre for Career Development, the Student Success Office, the Centre for Teaching Excellence, the Writing and Communication Centre. You all helped me grow as a well-rounded instructor, researcher, and scholar. I also acknowledge that I used Generative AI at times to find alternative vocabulary and expressions during my writing process.

Dedication

To my parents, Xiaoying Wang and Shien Chen, for your endless love and care, continuous encouragement, and unwavering support. You always believe in me and the decisions I make and motivate me to pursue and follow my passion. Thanks for reminding me of the significance of education and learning in life. I am on my way and will always be moving forward without fearing uncertainty and challenges ahead.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AIC—Akaike Information Criterion

BEV—Battery electric vehicle

CMA—Census Metropolitan Area

DOI—Diffusion of innovations

EVAFIDI—Electric Vehicle and Alternative Fuel Deployment Initiative

EV—Electric vehicle

GLM—Generalized linear model

GHG—Greenhouse gas

HOV—High Occupancy Vehicle

HEV—Hybrid electric vehicle

IPCC—Intergovernmental Panel on Climate Change

ICEV—Internal-combustion-engine vehicle

KWh—Kilowatt-hour

MaaS—Mobility-as-a-Service

MLP—Multi-level perspective

NDCs—Nationally Determined Contributions

PV—Photovoltaic

PHEV—Plug-in hybrid vehicle

R&D—Research and development

SUV—Sport utility vehicle

SNM—Strategic niche management

SDG—Sustainable Development Goal

TIS—Technology innovation system

TM—Transition management

VIF—Variance inflation factor

ZEVIP—Zero Emission Vehicle Infrastructure Program

ZEV—Zero-emission vehicle

Chapter 1 Introduction

1.1 Chapter Outline

This chapter introduces the thesis, which delineates the ongoing transition process of electric vehicles (EVs) with an emphasis on its spatial and temporal patterns, specifically in a Canadian context. It begins with the research context and rationale of this thesis and the theoretical framework with general approaches. The following section also highlights the research question and objectives with an overview of the thesis structure.

1.2 Research Context and Problem Rationale

The First Industrial Revolution that occurred beginning in the eighteenth century was the catalyst for transformational change in global socio-economic systems with complex consequences for natural systems. More specifically, the mechanization of production and consumption enabled by the harnessing of power from the burning of fossil fuels and the introduction of new technologies increased productivity, and in many ways improved living standards. Rapid industrialization is further associated with other issues including faster extraction, production, and use of materials, urbanization, and increased energy demand. These processes have resulted in widespread, long-term, and detrimental environmental issues, such as environmental pollution, biodiversity loss, the exploitation of natural resources, land-use changes, and greenhouse gas (GHG) emissions (National Academy of Sciences, 2020).

Environmental issues have thus raised political and public concern over the past decades. By the late 1980s, the environmental movement had an international presence with numerous environmentally focused nongovernmental or intergovernmental organizations or networks established, e.g., Greenpeace (1971), World Wildlife Fund (1961), and the Intergovernmental Panel on Climate Change (IPCC, 1988). The movement sometimes presented (at least partial) solutions to environmental issues such as the mitigation of air pollution by coal smoke, the protection of endangered species, and the conservation of natural resources. More recently, many of the programs, initiatives, and campaigns focus on GHG emissions and concentrations that leads to climate change, an issue that has been described as the greatest threat of the current century (Poushter et al., 2022; United Nations, 2021). The IPCC First Assessment Report (1990) predicted that annual CO_2 emissions would rise from roughly 7 giga tonnes to 12-15 giga tonnes by 2025, contributing to an estimated 4°C of global mean temperature increases above the pre-industrial era by 2100. Climate change is accelerating and has a wide range of impacts on both natural systems (e.g., increases in weather and climate extremes, reductions in sea ice and snow cover, and deep ocean acidification) and human systems (e.g., increasing risks of food production, the occurrence of human diseases, and economic losses) locally, regionally, and globally (IPCC, 2022a; Mora et al., 2022; Romanello et al., 2022).

The increasing GHG emissions and global warming are widely attributed to human activities (G. Hansen & Stone, 2015; Oreskes, 2004). Different scholars have argued that societal challenges are associated with unsustainable consumption and production patterns in mobility, energy, land-use, and other social domains. Transitions literature (Köhler et al., 2019) makes this claim explicitly. Urban and planning studies (Dodman, 2009; Handy, 2005; Rode et al., 2017), which give weight to the impacts of urban form or land development patterns on consumption patterns, especially those of transport and energy consumption, have come to a similar conclusion. The field of Geography (Jorgenson et al., 2018; Tartaruga et al., 2024) tends to focus on unsustainable consumptive and productive economic activities and power imbalances from a geographical perspective by underscoring the notions of sector, city, region, nation, and globe. Additionally, social practice scholarship (Barr & Prillwitz, 2014; Shove, 2010), which frames individuals' behaviours and habits as the shaping of socio-economic contexts such as social value and social consumption patterns, also consistently argues this position.

Despite international recognition of the threat of climate change and climate-related commitments and policies that have been put in place, more ambitious actions and stronger implementations are urgently needed in achieving climate targets and reducing climate impacts. The 2015 Paris Agreement, an international climate change treaty, for the first time, united 196 countries to collectively improve global responses to climate change in the context of sustainable development and poverty reduction; each country is requested to prepare, outline, and communicate their climate actions and measures through Nationally Determined Contributions (NDCs) (United Nations Framework Convention on Climate Change, 2015). The Agreement aims to keep a global average temperature rise "well below 2°C above pre-industrial levels" and "pursue efforts to limit the increase to 1.5°C" by 2100 (United Nations Framework Convention on Climate Change, 2015, p. 2). Even with the full implementation of NDCs, there would remain a significant risk of that global warming will exceed these thresholds (United Nations Environment Programme, 2023). Countries establish their own emission reduction targets in NDCs and develop specific measures and policies for climate change mitigation and adaptation, aligning these efforts with their development priorities, e.g., economic recovery after the COVID-19 pandemic. They also provide the information on the finance and investment, technology deployment, and capacity building that are needed for those measures. Scientific evidence has further shown that the failure of achieving the target of 1.5°C could cross critical climate tipping points and thus cause more severe impacts globally, let alone 2°C (IPCC, 2018a; McKay et al., 2022). Therefore, increased global modelled pathways have focused on how to achieve the target of limiting warming to 1.5°C with a higher likelihood.

A large portion of the crisis can be regarded as an energy issue; the rise of GHG emissions are significantly attributed to fossil fuel combustion—something that was reduced only temporarily during the global COVID-19 pandemics. Global energy-related GHG emissions grew by roughly 1% in 2022 compared to 2021, reaching a highest record of over 36.9 giga tonnes CO_2e across sectors; despite a reduction of emission in industry and building sectors, GHG emissions from the power and transport sectors experienced growth (International Energy Agency, 2023a). Total direct emissions arise from fuel consumption, especially oil and natural gas, through different activities (e.g., tailpipe exhausts from gasoline vehicles and cement production), while the indirect emissions are mainly associated with electricity and heat production. According to the sectoral breakdown of GHG emissions (International Energy Agency, 2023a; Z. Liu et al., 2023), electricity and heat generation produced approximately 40% of the global GHG emissions in 2022, which was largely attributed to electricity and heat generated from coal (the largest source) and natural gas (the second largest source).

Diverse strategies for addressing climate change have been proposed; however, rapid movement away from fossil fuel sources and widespread electrification are vital among those solutions (Van Vuuren et al., 2018; Williams et al., 2012). Energy demand is expected to increase more slowly than previously or reduce slightly, decoupled from economic growth, whereas electricity demand is expected to rise much quicker than in the past, up to the year 2040 at least, across global future energy scenarios and trajectories (International Energy Agency, 2022; IPCC, 2018a). The soar of electricity demand is due to wide electrification in energy end uses—transport (e.g., electric vehicles), residential (e.g., electric heat pumps), and industrial sectors (e.g., electric boilers), increasing energy efficiency, and the reduction of fossil fuel consumption. Predominantly renewable energy integration from an electricity supply will be necessary to respond to rising electricity demand for electricity decarbonization and (zero-)low-carbon energy systems. It is predicted that renewable sources, including solar and wind, could meet over 85% of power demand by 2050 (International Energy Agency, 2022; International Renewable Energy Agency, 2019).

Limiting global warming to 1.5°C requires net zero GHG emissions, which is largely determined by both rapid and deep reduction in gross GHG emissions. Based on the IPCC's latest analysis (IPCC, 2022b), global GHG emissions in 2030 are predicted to reduce by 43% from 2019 emission levels for keeping the warming to no more than 1.5°C. However, the speed and scope of progress are significantly hindered by gaps in the implementation of climate actions, the ambition of these actions, and the setting of long-term targets (van de Ven et al., 2023). Rather than exclusively relying on specific sectors, innovations and technologies, spatial contexts, and policy instruments, the acceleration of transformative, systemic changes in different social domains is an urgent need (IPCC, 2018b).

1.2.1 Socio-technical Transitions

Transformative change is generally employed to describe radical, non-linear, and structural changes in complex systems; here it refers to socio-technical transition as conceptualized in the sustainability transitions research communities. Its framing is evolving and has become clearer in recent years. The concept of (socio-technical) transition is commonly referred to "changes in societal subsystems (e.g., energy and mobility) from one societal regime to another with foci on social, technological, and institutional interactions". This is different from the notion of transformation, which is generally applied to "large-scale societal changes involving socio-ecological interactions" (Hölscher et al., 2018, p. 2). Socio-technical transition has been captured and emphasized in many contemporary missions/initiatives (e.g., Sustainable Development Goals—SDGs) with emphasis on using science and technology policy for meeting social needs and achieving sustainable and inclusive societies from a fundamental perspective (Schot & Steinmueller, 2018).

Transformative change can be approached from multiple angles, not only technological and ecological, but also economic, cultural, and institutional. Diverse perspectives allow for various subcategories of societal change to be explored. Socio-technical change, one such perspective, explains how the nature and dynamics of technologies and social contexts interact so that socio-technical systems can be conceptualized. Such systems were the initial focus of transitions literature with technologies as the subject of transitions; later socio-ecological, with subject of ecology, and socio-institutional systems, with foci on institutional dynamics, also become research foci (Loorbach et al., 2017). The focus of the scholarship has been from a primary exploration of socio-technical transitions to a general examination of transitions with the goal of sustainability. Delineating and interpreting transformative change lays a foundation for further accelerating desirable societal change.

Among different socio-technical changes, the mobility revolution is of particular relevance to this thesis. This revolution, initially argued as being imminent (Arbib & Seba, 2017; Neckermann, 2015; Sperling, 2018; Sprei, 2018), has recently faced growing skepticism from experts regarding its progress and future prospects. It would involve not merely technological shifts but rather processes of multiple dimensions' alignment, thus accelerating the transition to sustainability and deep decarbonization (Geels et al., 2017).

1.2.2 Mobility Revolution

Mobility, as one of social domains, is generally used to describe movement and access across space to achieve certain activities and services and can be applied to people, freight, and information. Different transportation options thus occur for the fulfilment of a demand for mobility. The historical mobility transition from horses to cars (Geels, 2018; Kanger et al., 2019) due to technological advancements has locked in the existing land-based personal mobility systems that are generally dependent on individually owned, human-operated, internal-combustion-engine vehicles (ICEVs). The lock-in mechanisms lie in not only carbon-intensive physical infrastructure, including highways and gas stations, but also travel behaviours, patterns, and lifestyles, and institutional and political frameworks (Klitkou et al., 2015). The dependency is particularly evident in North America, where personal automobile is the dominant travel mode (Deloitte, 2022), where urban form and land development patterns are mainly influenced by the use of the automobile (Handy, 2005; Rode et al., 2017), and where private vehicles account for nearly 90% of urban passenger GHG emissions (International Transport Forum, 2021). The transportation sector accounted for roughly 21% of total energy-related GHG emissions globally in 2022 with road transport responsible for nearly 45% of global oil demand; passenger light-duty vehicles, including sport utility vehicles (SUVs) and vans, contributed 38% of total transport emissions (International Energy Agency, 2023e). It also contributes to social issues, including human health risks and traffic congestion. Therefore, a transition to sustainability in personal mobility is highly desirable.

The goal of the Paris Agreement to work toward limiting global warming to 1.5°C by the end of this century requires the achievement of net zero emissions around 2050 with the reduction of CO_2e emissions in transportation sector by almost 95% in 2050 relative to 2022 (International Energy Agency, 2023e). Transport is also an explicit or implicit contributor to most of the United Nations SDGs, such as affordable and clean energy (SDG7) and sustainable cities and communities (SDG11). Various mitigation solutions, including technological solutions (e.g., more efficient vehicle technologies operating on lower-carbon fuels) and social solutions (e.g., a shift of transport modes to walking and cycling), have incrementally led to more sustainable mobility systems. However, there are still many challenges in the pathways to achieve the ambitious goal:

- It is estimated that passenger travel demand will increase by 65% by 2050 compared to 2019 despite a drop during the lockdown of COVID-19 crisis (International Transport Forum, 2023),
- private vehicles remain dominant in meeting urban travel demand compared to public transport and active mobility and micromobility, especially in North America, Australia, and New Zealand (International Transport Forum, 2023),

- vehicle ownership and the number of vehicles per household are not found to reduce significantly amongst new generations (Knittel & Murphy, 2019), and
- current mobility decarbonization policies and actions are seen to be insufficient to drive passenger mobility onto a sustainable path (Cornet et al., 2021; Winkler et al., 2023)

An increasing number of scholars and industry experts have thus argued that the world is in need of a fundamental systemic transformation, conceptualized as a mobility revolution for accelerating the transition to sustainability and deep decarbonization (Babiker et al., 2018; Geels et al., 2017; McKinsey & Company, 2016).

The mobility revolution has mainly been characterized as having three parts involving large-scale shifts to shared mobility, electrification, and automation (Sperling, 2018; Sprei, 2018). Shared mobility is used to describe transportation services that are shared among users, which is mainly intended to optimize single-occupancy vehicle use and challenge dominant private vehicle ownership. Examples include Mobility-on-Demand and Mobility-as-a-Service (MaaS) networks, which provide travelers mobility provided as services based on their travel demand through an integrated multi-modal network on digital platforms. Electrification in transport mainly refers to new powertrain systems with electric motors and batteries in vehicles, thereby increasing energy efficiency and reducing tailpipe emissions. Automation here mainly represents autonomous vehicles' different levels in sensing environment independently and navigating and controlling own movement without human input, thus avoiding human errors and increasing road safety.

Despite robust forecasts of their rapid developments and their natural synergies to foster sustainable development (Chen et al., 2016; Weiss et al., 2017), and notwithstanding the optimistic tone of selected authors and reports, changes in the transportation sector are occurring more slowly and more piecemeal than what normally would characterize 'a revolution' (International Energy Agency, 2023d). Given the economic crisis and political turbulence, global investment put in the three segments all reduced significantly in 2022, which slowed down their processes to reach commercial scales (Oliver Wyman, 2023). Some shared mobility services (e.g., carpooling) have faced social challenges of trust concern among passengers since the outbreak of COVID-19 (Shokouhyar et al., 2021) and existing spatial infrastructure cannot support shared mobility users regarding their demand of using mixed forms in daily travels (Mock & Wankat, 2024). The electric vehicle (EV) market has also faced uncertainties as consumers grow more concerned about the affordability of EVs (S&P Global, 2023), and automotive executives become less confident in the industry's potential for profitable growth (KPMG, 2024). In terms of autonomous vehicles, some automotive companies have implemented specific automation features in vehicles (e.g., automated parking), whereas full-automation vehicles are only available in limited community areas, in specific hours a day, and mostly for taxis due to technological immature and regulatory constraints (Cascetta & Henke, 2023).

Transportation systems can be characterized as socio-technical systems which operate to serve the societal function of mobility (Köhler et al., 2019). They are also intrinsically linked with other systems, especially energy systems (as among the energy services). In this regard, the mobility revolution involves not merely technological shifts but rather interactions of technologies and social contexts, including consumer practices, markets, infrastructure, business models, and policies and governance. The way in which the transition is unfolding seems to be challenged by the limited understanding of (and effective intervention in) processes related to how the multiple dimensions align with one another and co-evolve. Understanding these processes is essential for further accelerating progress towards sustainability.

1.2.3 The Transition to Electric Vehicles (EVs)

Electrification, as one of the three elements of this revolution, has the potential to contribute to urban and infrastructure decarbonized transitions and is an indispensable mitigation action and technological enabler among different pathways relevant for achieving climate targets. Electric vehicles (EVs) that are partially or entirely powered by electricity and plug in to recharge are regarded as one of critical energy technologies for global clean energy transitions. Among EVs, those that run only on a battery and an electric drivetrain and plug into an external source of electricity to recharge are battery electric vehicles (BEVs), and others that also use an internal combustion engine should the battery run low and plug into an external source of electricity to recharge are plug-in hybrid electric vehicles (PHEVs).

There have been debates over EVs’ sustainability, especially around their negative impacts to environment and the embedded ‘incentive’ to continuing using private vehicles rather than transit or non-motorized modes. For one, EVs are criticized for their higher carbon footprints associated with battery manufacturing and end-of-life compared to ICEVs (Henderson, 2020). However, EVs generally produce fewer GHG emissions over their lifecycle—including manufacturing, operation, and end-of-life processes—compared to ICEVs (IPCC, 2022a; Z. Yang et al., 2022). As the electricity grid becomes greener, this difference is expected to grow even larger. On the other hand, it is possible that EVs’ lower operational costs and emissions may lead to more frequent and farther travels. The effects of EVs on travel behaviours, transportation infrastructure and systems are still uncertain as the transition to EVs is in its early stages (Babiker et al., 2018). This thesis acknowledges that mitigation actions can have both synergies and trade-offs with other dimensions of sustainable development, which further requires deeper understanding of the transition process and appropriate planning and policy strategies and different stakeholders' support.

While EVs cannot address all of the negative externalities of private vehicles (e.g., congestion and parking requirements) and would not necessarily alter automobile dependency, the transition to widespread EVs can be key to emission reduction and decarbonization with increasing electricity generation from renewables (International Energy Agency, 2023d; Wolfram et al., 2021). They have also received prioritised political attention during the United Nations Climate Change Conference and also in numerous national and regional initiatives; governments implement different policies and measures to support EV deployment and cooperates with other stakeholders, e.g., car manufactures and financial institutions to set EV sale targets (International Energy Agency, 2024b).

The birth of EVs can be traced back to the 1800s, but their adoption has never been widespread—until very recently. After the first crude EV was invented, EVs experienced improved battery performance and gained increasing urban popularity due to its quietness and benefits for reduced air pollution. They gradually diffused on the roads of some big cities such as New York and London. However, their adoption into the 'mainstream' market stagnated after 1910 due to slower technological advancements and less commercial viability compared to ICEVs. Nearly one hundred years later, California's Zero Emission Vehicle mandate passed by the California Air Resources Board in 1990 created a mini-boom in EVs (Sperling, 2018). Significant shifts occurred in the automotive industry in terms of production changes, battery range improvements, and cost reduction; different models was lunched—General Motors' EV1 in 1996, Toyota's Prius in 1997, Tesla's Roadster in 2008, and Nissan's Leaf in 2010 etc. After long-time failure in massive adoption, EVs' diffusion has accelerated dramatically in the last decade and a half (International Energy Agency, 2024a).

Despite rapid advancement in automotive and battery technologies, progressive regulatory and policy support, and increasing voluntary announcements of production and sales target among automotive companies, the transition to widespread EVs is still in an early stage with uncertainties; further it is geographically variable. Globally the EV percentage of new passenger vehicle registrations including both BEVs and PHEVs, was roughly 18% in 2023, which rose from 14% in 2022 but was still far away from the milestone in pathways and scenarios for keeping the temperature of 1.5°C and the goal in various countries of 100% zero-emission passenger vehicle sales by the time between 2030 and 2050 (Bloomberg New Energy Finance, 2024; International Energy Agency, 2023c, 2024a). The slowness of uptake is linked the ways in which EV registrations are embedded within dynamic societal contexts, such as global investment restraint during the COVID-19 pandemic, supply chain disruption, geopolitical tensions, and changes in international trade policies. Furthermore, over 85% of those new EV registrations in 2023 were in China (60%) or Europe (25%), while these regions accounted for approximately 60% of total new passenger vehicle registrations globally (International Energy Agency, 2024a; International Organization of Motor Vehicle Manufacturers, 2023). Market penetration has also occurred in the United States, United Kingdom, Canada, and South Korea; but to a lesser extent. Indeed, EV registrations are more geographically uneven than the registrations of conventional vehicles with EVs in some regions entering mass markets and those in others still in early stages.

There is thus an urgent need to understand the forces involved in shaping the transition to EVs, with implications for how to govern and guide such a process through policy practices and efforts. EVs, as radical technical innovations, are key enablers in creating new transportation systems through the construction of multiple and interlinked elements. More importantly, the transition to EVs strengthens the interactions and dynamics between both transport and energy systems and is enabled by both mobility revolution and energy revolution as well, which further underscores the complexity of how the transition of EVs is unfolding.

1.3 Theoretical Framework

The transition to EVs can be generally conceptualized as the adoption and diffusion of technological innovations in societies. A vest terrain of studies helps to inform a greater understanding of this focus; ‘adoption-diffusion’ theories can be broadly grouped into two families (micro-level analysis vs. macro-level analysis).

The first group of theories, on the one hand, including the Theory of Planned Behaviour and the Diffusion of Innovations Theory (DOI, which will be explicitly introduced in section 2.3), is mainly through the lens of individual (or collective individual) behaviours and decisions with an emphasis on rational choices or norms/values/attitudes. The theories have been widely used in comprehending how and why discrete technologies diffuse through a specific group of people and people’s behaviour change. They focus on the agency of people (e.g., individuals, households, and stakeholders) or the processes of interpersonal effect on people’s decision making (Sovacool & Hess, 2017). Some theories use economic perspectives to investigate how socio-economic characteristics or the calculations and assessments of costs and benefits affect people’s rational decision-making in adopting new technologies. Other theories, which mainly originated from the disciplines of behavioural science and innovation studies, utilize socio-psychological perspectives to explore how people’s psychological constructs (e.g., cognitive, emotional, and beliefs), the non-economic determinants, influence their behaviours or decisions. However, as made clear in the long-standing debates of ‘agency and structure’ in social science, people’s choices are not only based on their own desires or wills (agency), but also influenced by broader social contexts (e.g., social institutions) that are considered in the following.

Another set of theories (e.g., the Social Practice Theory and the Social Construction of Technology), are concerned with the diffusion of new technologies via social interactions, alignments, and struggles (Sovacool & Hess, 2017). Unlike the previous theories’ roots in the perspectives of human agency, they underscore that technological innovations are actively constructed with environments or contexts (e.g., cultures, business environments, and social practices) and the societal embedding processes are also involved into established environments or contexts. Therefore, they focus on diffusion of ‘systems’ within broader systems, i.e., ‘systems of systems’ (Geels et al., 2018). Among these theories, the socio-technical transition theory, which will be explicitly introduced in section 2.4, have received increasing attention since the early 2000’s with emphasis on a transition of broader levels or large social phenomena in which technologies situate and function. As an interdisciplinary system innovation framework, it serves as a valuable foundation for investigating how radical shifts can occur such that different components within the society can be aligned.

Despite rich insights provided by the two lenses, they rarely bridge with each other and enrich insights from each other theoretically and empirically. Much work has been called for seeking the resolution of the tension between macro- and micro-level analyses of transitions; how structural contexts condition or influence individuals’ decisions and how individuals behave or position in processes of social-technical changes (Huttunen et al., 2021; Köhler et al., 2019; Ruhrort & Allert, 2021). A more thorough consideration of theoretical applications is needed to better understand the technology adoption and transition in societies. This research thus enhances the understanding of transition to EVs with the consideration of the interrelations between macro (societal transition to EVs—Chapter 4) and micro levels (consumers’ perceptions and decisions of EV purchase—Chapter 5) in change processes. The two empirical components are grounded in different theoretically informed frameworks. The conceptual dilemma in the level of analysis are also reflected by the challenges in uncovering spatial and temporal dimensions and dynamics of transition processes, which is not well-studied among the literature and is also an area of discussion that can be contributed by geographers. This research investigates both spatial and temporal dimensions of transition processes to EVs embedded in the field of geography.

Since transformative change is regarded as being systemically complex with co-evolutionary elements and issues of lock-in and inertia, most previous studies have adopted in-depth single case studies with qualitative analysis for delineating the processes and articulating the complexity, through detailed narratives. Such a research design, however, may limit generic insights. In this regard, various modelling approaches and appropriate indicator development have become a new methodological emphasis in transition research (Köhler et al., 2019). They could provide a structured view and systematic representation of the complexity of transitions by identifying significant factors with different degrees of abstraction. Therefore, this research mainly adopts deductive and quantitative approaches while integrating insights from different research methods (e.g., surveys and secondary data analysis) with different datasets.

1.4 Research Question and Objectives

This research aims, broadly, to contribute to a more structured, systematic, and comprehensive understanding of the ongoing transition related to the adoption of EVs. The research addresses the complexity of how multiple dimensions align with one another and co-evolve, focusing on Canadian contexts at both national and local scales, and over time. The figures of EV registrations suggest that Canada is not a leading country in this transition, that its adoption of EVs is geographically uneven over space, and further that Canada is at the beginning of an acceleration stage. This thesis is intended to bring new insights into the processes of transition in this context. Details on the transition to EVs in Canada are provided in sub-section 4.3.5.

The thesis specifically asks to what extent, can macro-level and micro-level lenses explain the EV transition process, with specific reference to Canada. Its aim is to illuminate how socio-technical forces (e.g., social acceptance, multi-level governance strategies, and technological advancements) interact in the unfolding of the transition to EVs through two complementary research designs with emphasis on both societal levels (structure) and individual levels (agency) in the changing processes. It addresses the following objectives

- To describe and explain the spatial and temporal patterns of transition to EVs at national level between 2017 and 2022. The component is based on a unique national EV registrations data that is acquired from seven provinces in Canada between 2017 and 2022 and an approach that draws upon the geography of transitions literature and existing empirical studies on EV diffusion with a consideration of geographical aspects.
- To understand and assess changes of consumers' likelihood and perceptions to purchase EVs in a Canadian municipality, Waterloo Region, between 2020 and 2023. This part of research is based on local consumer surveys between 2020 and 2023 and is informed by Diffusion of Innovations (DOI) and existing empirical studies on EV adoption with emphasis on attitudes and perceptions.

1.5 Thesis Outline

The thesis has six chapters, including this chapter of Introduction. The following chapter (Chapter 2) reviews theories related to the adoption and diffusion of technological innovations in societies and elaborates on three groups of theories that form the basis of the thesis, especially how the three groups have been applied in geographical research. It also critically points out how they can help understand the ongoing transition to EVs from various perspectives.

Chapter 3 provides an overview of the research design and methodological framework that underpin the thesis. It discusses how the two research components complement with each other regarding research levels, geographical scales, and time frames in helping understand EV transition. It then highlights the value of using quantitative approach in this thesis and also acknowledges its potential limitations. Next, it specifically describes how secondary data and primary data provide integrated insights into understanding the EV phenomena in Canada, including a review of relevant existing datasets. Finally, a high-level overview of the key methodological decisions made in the thesis is provided.

Chapter 4 focuses on the first research component of the thesis which aims to understand the research question from a macro level. It begins by elaborating and justifying the conceptual framework, “geographical transition framework”, for exploring EV transition over space and time. It then synthesizes relevant empirical studies and overviews the Canadian EV market for contextualizing the five influential geography-of-transition constructs within the framework. A set of independent variables are thus defined and further used in modelling spatial and temporal patterns of EV registrations in Canada. This chapter concludes that ongoing transition to EVs in Canada has been progressive, but with variations across space and time. The effectiveness of models and results from important variables are further highlighted and interpreted, with insights into policy options for promoting and governing the transition to EVs.

Chapter 5 focuses on the second component which seeks to understand the research question from a micro level. It articulates how Diffusion of Innovations can help frame longitudinal dynamics of consumers’ likelihood and perceptions to purchase EVs through categorizing consumers into five groups. It then introduces the research method, two public questionnaire surveys in 2020 and 2023, and research context, Waterloo Region, in this study. It identifies the changes of consumers’ likelihood to adopt EVs and compares how consumers’ perceptions towards EVs, including perceived benefits, risks, and influential government initiatives, changed over time and across different consumer segments. Variables related to perceptions are further used to model and explain how they contribute differently to the changes of consumers’ general interests in EV adoption over time. Results suggest that EV adoption in this local municipal context has been increasing, but the transition is not likely to be complete. The heterogeneity across consumers provides practical implications for policy and communication strategies.

Chapter 6 describes the significance of specific research findings from the two research components, with similarities and variations, and practical implications for policy and communication strategies. It concludes the thesis and highlights the significance of both macro-level and micro-level lenses in understanding socio-technical transitions.

Chapter 2 Literature Review

2.1 Introduction

As mentioned in section 1.3, there are many theories in helping understand the adoption and diffusion of technological innovations in societies. After reviewing those theories, this chapter elaborates on three groups of theories that are chosen to specifically underpin the thesis. It outlines clean disruption theory and diffusion of innovations (DOI), both of which consider change through the lens of a micro-level perspective; as well as socio-technical transition theory, which is more from a structural and macro perspective. Both are of potential relevance to anticipating and understanding the EV phenomenon. Clean disruption theory largely focuses on novel technologies' characteristics and their effects on existing markets from product and business levels, while DOI mainly emphasizes diffusion of innovations through social networks. Unlike the two theories' roots in discrete technologies, socio-technical transition theory is concerned with diffusion of 'systems' in which technologies play important roles (Geels et al., 2018; Loorbach et al., 2017). Examples of environmental innovations in energy and transport sectors are also given to help understand how each theory can be applied. Given that the thesis is in the field of geography, how the above three groups of theories have been incorporated or applied in geographical research is emphasized.

2.2 Clean Disruption Theory

Clean disruption theory was introduced by Airbib and Seba (2017) as an integrated framework combining four models of disruptions: disruption from below, disruption from above, big bang disruption, and architectural disruption. This thread of scholarship is concerned with how technological disruption happens or the way new products or services with embedded technologies disrupt established markets. Across these four categories, disruptive innovation is commonly defined to happen "when new products and services create a new market and, in the process, significantly weaken, transform, or destroy existing product categories, markets, or industries" (Arbib & Seba, 2017, p. 12). The rest of this section will outline each model within this framework.

2.2.1 Disruption from Below

Christensen (1997) proposed the concept of disruption from below, noting that products with disruptive technology take place from the lower end of the market or unserved part of the market with worse performance but typically cheaper prices. Existing mainstream products often exceed customers' needs, with avoidable high prices and complex functions. Disruptive technology is thus attractive to price-sensitive or relatively poor people. With the increasingly better performance of disruptive technology, products then enter mainstream markets from niche markets competing with incumbent products and taking over their positions. Moreover, products have the potential to meet consumers' needs in the future. Their partial dimensions of performance are likely to distinguish and bring new value propositions that are inconsistent with the performance metrics that mainstream customers most value (Danneels, 2004).

North America's mobility markets are typical examples that overserve trip-makers with dominant private-vehicle ownership; trip-makers spend a large portion of their household expenditure on vehicle ownership although actual car-use rates are relatively low (McDowall, 2018). Thus, shared mobility, which provides customers with travel services without large initial costs, is regarded as a disruptive service catering to low-end and unserved markets (McDowall, 2018; Sprei, 2018).

2.2.2 Disruption from Above

Seba (2014), however, counter-argued that disruptive products or services can come from the higher end of the market where commodities have superior performance and are more expensive compared to mainstream products. With different embedded technologies developing over time at divergent rates and experiencing cost reduction, technology convergence results in lower prices of these products and further makes them more price-competitive in mainstream markets. The occurrence of smart phones can be well explained under this model; their prices are higher than older cell phones, but they provide more functions beyond phone calls, including giving GPS directions, online browsing, and numerous applications. The emergence of solar photovoltaic (PV) systems can be seen as disruptive innovations to fossil fuel-based energy industry; they have better performance in terms of cleaner and sustainable energy source but higher "levelized costs of electricity", a metrics quantifying costs of a technology's power generation over its lifetime (International Renewable Energy Agency, 2023).

2.2.3 Big Bang Disruption

Big bang disruption, the third model of clean disruption theory, describes that products may not only provide higher performance but also have lower prices (Downes & Nunes, 2014). These characteristics indicate that disruptive innovations may have more dramatic impacts on mainstream products and enter markets at a higher speed, often because they are commonly accompanied by new information and communications technologies with the involvement of early users' tests in an open atmosphere and related iterative design changes (Downes & Nunes, 2014).

The Google Map generally embedded in smart phones is a typical example, with free access and significant convenience for consumers compared to Garmin and TomTom, which both require stand-alone devices (Downes & Nunes, 2014). The model is also useful to explain the emergence of MaaS, which is not only with good services through convenient payment and booking in smart phones and short transfer times via real-time data, but also with low costs via monthly, quarterly, or yearly subscriptions (Hensher, 2017; Utriainen & Pöllänen, 2018). The success of the Finnish MaaS app, Whim, shows how quick a big bang disruption can enter a market.

2.2.4 Architectural Disruption

The model of architectural disruption is to investigate how new products or services shift the way "existing products and services are produced, managed, delivered, and sold" (Seba, 2014, p. 12). The model does not emphasize whether technological disruptions come from low-end or high-end markets and their performance; instead, it centers on their impacts on the structure of established products' supply chains. For instance, the emergence of off-grid PV and battery storage systems enable shifts in both grid infrastructure, from centralized electricity systems to distributed configurations, and actors in electricity markets, characterized as the changes of consumers to 'prosumers' (a term that describes customers can both consume and generate electricity) and utilities' existing business models.

There is limited geographical research incorporating this theory (Brackin et al., 2019). As Corsi and Di Minin (2014) noted, the results of disruptive innovations can happen not only in established markets but also in markets that are geographically varied from existing markets. For instance, some innovations, particularly health equipment, originating in developing countries, first diffuse in local environments but are later exported into markets in developed countries. This situation thus calls for the consideration of interrelations and interactions among and within geographical regions into this theory. Brackin et al. (2019) advocated a big-data approach to illustrate these links; they recorded Apple store openings and Uber services over spaces and time and indicated that their geographical and temporal relationships are distinct: Apple opened its stores several years before Uber started operating in the same city or country.

The clean disruption theory with the above four models paves the way for understanding the characteristics of EVs and how they, as low-carbon technological innovations, appear in markets and societies. Despite no EV studies explicitly using the clean disruption theory as a whole, its definition of disruptive innovations generates debate about how to consider the disruptive role of EVs. Most of scholars have supported EVs' disruptive role (Bergek et al., 2013; Dijk et al., 2016; Hajebrahimi et al., 2018; Kane & Whitehead, 2017; Seba, 2014), and some emphasize EVs' bi-direction to the grid with both charging and discharging capabilities (i.e., giving electricity back to the grid—vehicle-to-grid), the most disruptive characteristics (Sprei, 2018; Wilson, 2018). In contrast, some researchers regarded EVs as possible disruptive innovations or sustaining innovations that improve the dimensions of established products' performance for consumers' existing value proposition (Christensen, 1997; Christensen et al., 2015). Kanger et al. (2019) claimed that whether EVs are disruptive depends on the formation and essence of their societal embedding processes, which is closely associated with how EVs are expected to co-develop with shared mobility and automation. The theory further underlines the importance of uncovering the diffusion process of EVs among consumers, especially its geographical dimensions, which can be complemented by the following theories in section 2.3.

2.3 Diffusion of Innovations

DOI, initially put forward by Rogers (2003), provides a useful basis for understanding how, why, and at what rate an idea or a product diffuses through a specific group of people or a social system. From this perspective, the theory underscores an innovation as an idea, practice, or object that is perceived by people as new, indicating that innovations are not objectively new and merely confined to novel technologies, but rather perceived to be new and involved with new practices, insights, and policies. Additionally, DOI is not a single theory, but a set of interconnected sub-theories combining both the adoption theory, which sheds light on individual choices in accepting or rejecting an innovation, and the diffusion theory, which emphasizes innovations' spread in a broader level (Straub, 2009). Figure 2.1 explicitly delineates the relations between the two aspects. The reminder of this section will discuss their individual emphasis.

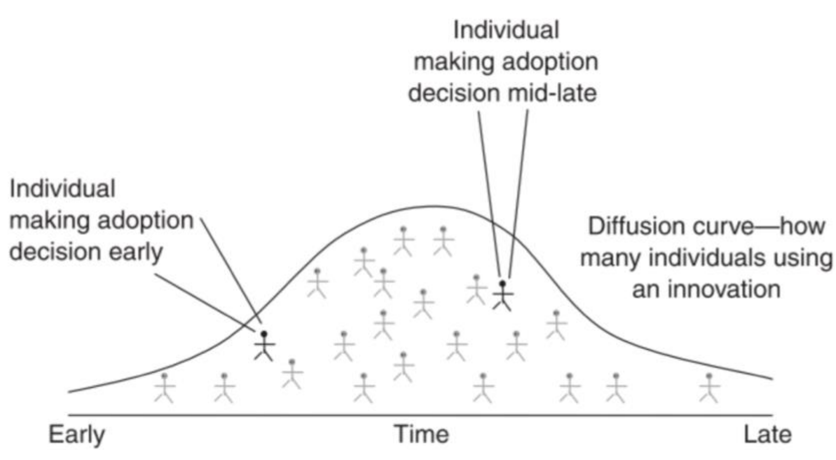


Figure 2.1 The relationships between individual adoption and social diffusion
Reproduced from Straub (2009, p. 627)

2.3.1 The Micro-level Perspective of Adoption

The micro-level perspective of individual behaviour change, which sets the foundation for understanding broader and macro-level social change, focuses on how “a decision maker passes from first knowledge of an innovation, to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision” (Rogers, 2003, p. 490). This approach takes socio-psychological perspectives, in contrast to the perspectives of neoclassical economics, within innovation diffusion studies. It suggests that the propensity for the adoption of innovation depends on individual socio-psychological constructs (Ferguson et al., 2018; Geels et al., 2018; Liao et al., 2017), stressing the significance of innovations’ perceived attributes and adopters’ characteristics.

Five perceived attributes of an innovation—relative advantage, compatibility, complexity, trialability, and observability—pave the way for assessing individual acceptability to an innovation and identifying related drivers and barriers of adoption. They have led to varied empirical studies of individual behaviour change under project introduction and practice promotion. Two sustainability examples illustrate how these attributes feature and interact. First, Nehme et al. (2016) measured employees’ perceived compatibility with commuter cycling in downtown Austin and concluded that higher compatibility is connected with being well-educated, young, and male. However, Synek and Koenigstorfer (2018) considered not only on employees’ perceptions of cycling but also on the organizational level. They incorporated the extra attribute of key stakeholders’ involvement and found that collaborations with ‘work councils’ and other stakeholders are likely to increase participation in company-bicycle leasing programs at both employee and employer level. A second example is from Strömberg et al. (2016), who examined the value of trials in enabling people to change to sustainable travel behaviours via the comparative analysis of two cases (transport-oriented bicycles and MaaS). The results indicated that trials can be useful strategic tools with careful considerations of duration, type of support, and people involved.

Furthermore, perceived attributes of an innovation may differ between different individuals, which explains the introduction of adopter categorization, which may be graphed as a bell-shaped (frequency) curve, as shown in Figure 2.2. The curve represents a normal frequency distribution of adopters over different adoption times because of their own characteristics. For example, innovators are the first group of people to adopt an innovation, accounting for a small percentage of total adopters (2.5% if the distribution is assumed to be perfectly normal), since they are eager and have the ability to take risks and deal with uncertainties (Rogers, 2003). The other tail of the distribution represents the ‘laggards’. In between are adopters who come on board at different times. Some scholars utilize the idea of adopter classification to understand the mechanism and dynamics of different adopters in the face of innovations and further formulate specific policies or regulations based on their characteristics. For example, a study was conducted in Canada to identify who might lead participation in a public bike-sharing scheme. Identified leaders were likely to be existing cyclists, public transit users, pedestrians, and participants of car-sharing services, all of whom will be the predominant targets of the future program (Therrien et al., 2014). The concept of adopter classification will be specifically utilized in the micro-level analysis of the transition to EVs in this thesis, which is presented in Chapter 5.

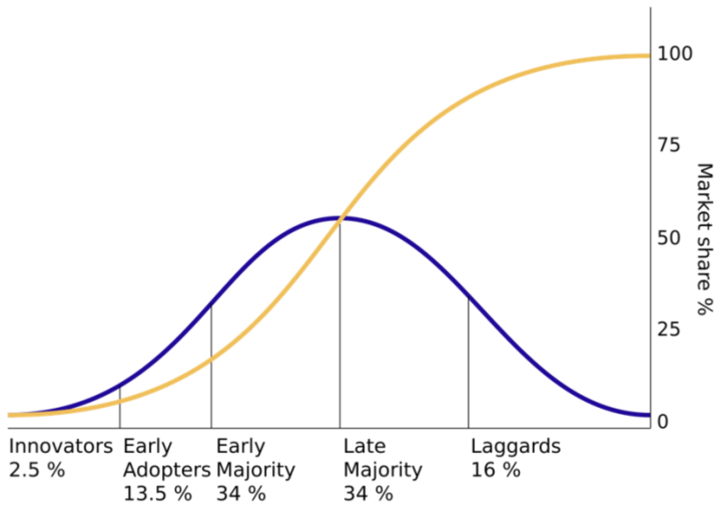


Figure 2.2 The bell-shaped (frequency) curve and S-shaped (cumulative) curve of adopter categorization and diffusion stages

Reproduced from Rogers (2003, p. 772)

2.3.2 The Macro-level Perspective of Diffusion

The macro-level perspective, which defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2003, p. 77), focuses on the process by which an innovation is introduced into social practice and leads to social change instead of just behaviour change. As Rogers (2003) argued, "diffusion of innovations was a kind of universal process of social change" (p. 49). Due to geographic traditions underpinning this perspective, it is more utilized in geographical studies than is the micro-level perspective when seeking to comprehend the impacts of social influence on innovation diffusion by physical proximity and different diffusion stages in varied places.

The definition of diffusion within DOI centers on the importance of 'neighbour effect' from spatial perspectives in geography, which underscores the effect of interpersonal aspects on innovation diffusion.

Coming up with an innovation itself is just the initial element; communication channels, time, and a social system also contribute to diffusion according to the definition above. Diffusion is a procedure mainly involving communication and information exchange, and a social system with a set of interrelated units confines its boundaries. Hägerstrand (1966), the first geographer studying diffusion, put forward his interpretation of how spatial distances affect diffusion. He initially introduced the term 'neighbourhood effect', which helps to explain that an innovation is more likely to be spread out in the vicinity of existing adopters instead of a far way place. The importance of this concept suggests that the linkage between individuals with their friends, relatives, co-workers, and neighbours, normally within a social system, will substantively affect the direction and consequences of information delivery. This dynamic, in turn, has great impacts on diffusion (Jansson et al., 2017). Specifically, a positive loop may exist in which innovations' utilities or values will be higher as they become more normalized due to interpersonal impacts. In fact, normalization results in the reduction of perceived risk.

Different growth stages of an innovation in markets shed light on the nature, current situation, and potential future trends of diffusion, and the general process allows for comparison in different spatial contexts. The process can be graphed as an S-shaped curve (cumulative distribution) as in Figure 2.2, linked to different growth stages in markets, including predevelopment, take-off, breakthrough, and stabilization (Rogers, 2003). Each stage corresponds with particular adopter categories, indicating that the innovation growth in a market will increase as adoption rates surge. These two curves describe similar phenomena, but differently. Parkes et al. (2013) provided an example of this perspective's application, examining how public bike-sharing systems diffuse in Europe and North America.

The DOI can provide rich insights into the way in which EVs diffuse through a social system by bridging individual decision-making processes of EV adoption and EVs' spread in a group of people. The two aspects are linked through adopter categorization; specifically, the notion emphasizes different individuals vary in their willingness to embrace new innovations and have different adoption times. This time dimension is well suited to help scrutinize the temporal dimensions and dynamics of EVs' transition processes in this thesis and its quantifiable representation of different growth stages in markets can also help interpret the current trend, process, or pathway of EVs and allow for comparison over time or spaces. The specific conceptualization and operationalization of the DOI in the context of this thesis will be illustrated in Chapter 5. Despite DOI's emphasis on innovation diffusion from 'adoption' and 'diffusion', it is still an agency-centered theory with much attention on discrete innovations and human agency. Therefore, the theories discussed in section 2.4 are incorporated to provide insights from a systemic and structural perspective, focusing on the diffusion of 'systems' where technologies play crucial roles within broader social contexts.

2.4 Socio-technical Transition Theory

Socio-technical transition theory, as a system innovation framework, establishes a helpful basis for investigating how radical shifts can occur such that different components within the society can be aligned. It incorporates four main frameworks: the technology innovation system (TIS), multi-level perspective (MLP), strategic niche management (SNM), and transition management (TM). MLP and TM both embrace how technological transitions are involved with the interactions and dynamics between multiple levels of an innovation system, both internal and external processes and environments. This characteristic contrasts to that of the SNM and the TIS, both of which center more on the emergence of technological innovations and the internal dynamics and elements of innovation systems (Markard & Truffer, 2008; Schot & Geels, 2008). Therefore, the rest of this section argues that an understanding of how socio-technical change is unfolding could be situated within the multi-level, transition management, and geographical perspectives.

2.4.1 Multi-level Perspective (MLP)

The MLP in Figure 2.3, with its three hierarchical building blocks (elsewhere termed levels)—niches (micro level), regimes (meso level), and landscapes (macro level)—suggests that socio-technical change involves these three levels interacting with one another (Sovacool & Hess, 2017). Their interactions provide a systematic lens to comprehend tensions between stability and change and barriers or drivers that may hinder or foster transition appearance (Nykvist & Whitmarsh, 2008). Regimes, which are the main focus of this framework, include interrelated multiple-dimensions such as markets, user practices, infrastructures, cultural meanings, and policies. These interrelations create stability, making regimes resistant to niche innovations. Therefore, this inertia enables the MLP to explain why emerging innovations must struggle against incumbent systems to drive structural change (Geels, 2011).

Moreover, different kinds of interactions among the three levels lead to varied alignments, giving rise to the key concept of transition pathways that explain how technological transitions occur and evolve. Geels (2002), who initially developed the MLP concept, identified three mechanisms of transition patterns: "niche cumulation, technological add-on and hybridisation, and developments with market growth". The niche cumulation focuses on innovations' gradual development with their application in more markets. The second mechanism of breakthrough emphasizes symbiosis relations between old and new technologies. The occurrence of hybrid electric vehicles (HEVs) is a typical example of hybridisation, combining EVs and traditional vehicles. Developments with market growth explain new technologies advance along with growth in specific markets. Based on the three mechanisms, Geels and Schot (2007) further identified four transition pathways explicitly explaining the three levels' interactions and used historical cases to exemplify these pathways. These transition patterns and pathways characterize historical patterns of system change and provide insight into future transitions to sustainability. More importantly, a body of literature gives weight to the political character of pathways, arguing that actor interactions or governance can give rise to or influence transition processes (Loorbach et al., 2017; Meadowcroft, 2009; Rosenbloom et al., 2018). Consequently, understanding the way in which socio-technical change is shaped by governance is of significance, which further highlights the perspective of transition management.

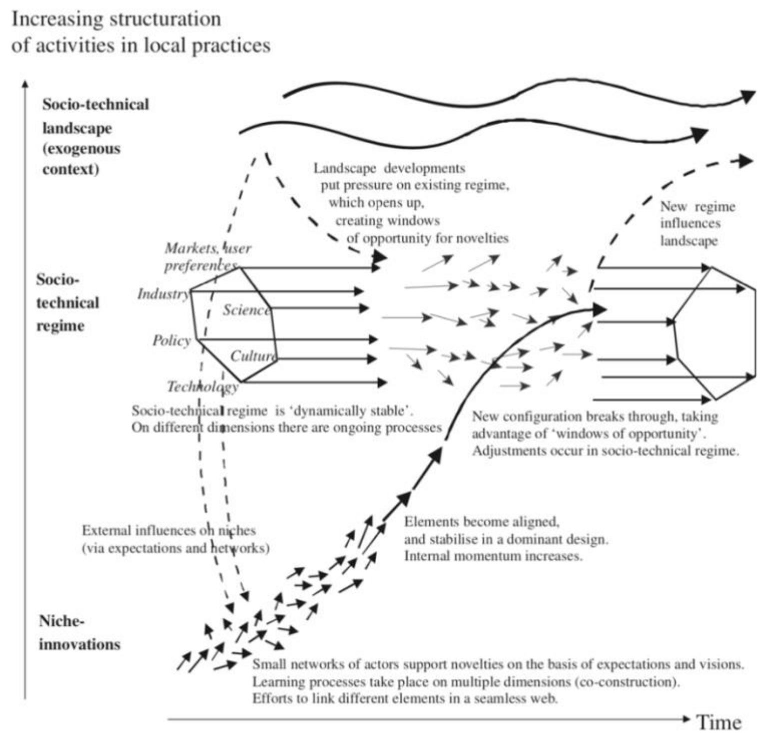


Figure 2.3 A dynamic multi-level perspective on transitions
Reproduced from Geels & Schot (2007, p. 401)

2.4.2 Transition Management (TM)

TM, as "a prescriptive and complexity-based governance framework", can be applied to understanding and operationalizing transition governance (Loorbach, 2010, p. 161). It guides the direction and speed of gradual and smooth transition to sustainability, ensuring gradual transition and a long-term perspective (Rotmans et al., 2001).

As a governance framework, TM can be incorporated into policy frameworks in practice for exploring solutions and policies, and it emphasize the participatory approach to engage different stakeholders during decision-making processes. The energy transition project implemented by the Dutch Ministry of Economic Affairs is a typical example, restructuring energy systems with a strategic long-term perspective to achieve sustainability. Nevertheless, a main criticism of TM is its difficulties in dealing with the politics of governance (Meadowcroft, 2009). It is tricky to decide whose social interests matter more and who wins or loses. Kern and Smith (2008) critically analysed TM's role in Dutch energy policy with the argument that incumbents (e.g., companies) dominated selection-criteria implementation for the themes, pathways, and experiments and became barriers to developing niches into regimes. Lachman (2013) also criticized TM for the same reasons: actors at niche level are paid less attention, and there is a bias towards existing actors at the regime level.

However, its four types of governance activities—strategic activities, tactical activities, operational activities, and reflexive activities—are useful in identifying opportunities and barriers in the formulation and implementation of related governance strategies and instruments. Shankar et al. (2019) utilized the first three activities to identify enablers of dedicated freight corridors in India for the transition from road mode to rail mode. They concluded that strategic level enablers are significant in the utilization of dedicated freight corridors to achieve sustainability in freight transportation. Instead of identifying the enablers, Farla et al. (2010) used TM to identify barriers that hinder the pathway to sustainable mobility transition in the Netherlands, particularly focusing on the four technological routes: hybridization, natural gas, hydrogen, and biofuel. They found that TM is deficient in considering competing technologies in guidelines and thus suggested a systemic horizon in institutional contexts rather on focusing on specific transition paths.

2.4.3 The Geography of (Sustainability) Transitions

Geographical literature, which utilizes socio-technical transition theories, has a central aim of understanding geographical differences/unevenness in transitions between cities, regions, or countries, including niche development and regime dynamics. These differences may not only involve transition consequences but also the processes and reasons underpinning them. The involvement of transition perspectives in geographical studies can be important in linking urban planning with transition thinking for transition to sustainability. Nonetheless, the space, place, and scale of transitions are still under-studied, especially geographical variation within regimes and alternative framework conduction rather than relying on existing four theoretical frameworks—TIS, MLP, SNM, and TM—with a spatial-sensitivity addition (Coenen et al., 2012; T. Hansen & Coenen, 2015; Hodson & Marvin, 2010).

‘Multi-scales’ and ‘institutional embeddedness’ of transitions have been the primary concerns of geographical studies (Coenen et al., 2012). Multi-scalarity of transitions refer to the flows of knowledge, technologies, and policies between local, regional, and global scale that underlie local transition processes. ‘Institutional embeddedness’ represents place institutional environments, which explains why different institutional configurations favour certain transition pathways or technologies over others. T. Hansen and Coenen (2015) made similar arguments about the importance of the geography of inter-organisational relations and place dependence for understanding transitions, and identified various place-specific constructs that affect transitions. These constructs will be explicitly incorporated in the macro-level analysis of the transition to EVs in this thesis, which will be elaborated in Chapter 4.

Geographical literature also gives an appreciation of cities’ role and capacity in shaping system innovation transitions from both theoretical and empirical aspects. Hodson and Marvin (2010) initially proposed a framework to conceptualise how cities fit the niche-regime-landscape within MLP and claimed that multi-level governance and actions in different scales are two predominant aspects in the conceptualization. More importantly, intermediary interventions play imperative roles in interrelations between transitions in different scales to understand how innovations within cities interact with transitions in broader levels—regional or country. Carvalho et al. (2012) examined how cities shape socio-technical transitions with the finding that sustainable urban transport policies can enhance the development of clean technology niches via ‘social-embedding processes’ and ‘learning processes’.

Socio-technical transition theories serve as an overarching lens for understanding the ongoing transition to EVs in this thesis, characterized as one representation of transformative socio-technical changes. It therefore contributes to a more structured, systematic, and macro-level understanding about how multiple dimensions interact, align, and co-evolve to give rise to the transition processes of EVs and ensure its smooth transition to sustainability. The geography of (sustainability) transitions is of particular relevance to uncover the process across different geographic scales and over time and its specific conceptualization and operationalization in the context of this thesis will be illuminated in Chapter 4. It can address the limitations of the two theories above with emphasis on system innovation, thereby paying limited attention to the internal states, processes of actors, or individuals (e.g., decision-making). Therefore, the three groups of theories are all used to underpin the thesis.

Chapter 3 Research Methodology

3.1 Introduction

This chapter provides an overview of the research design and methodological framework used to answer the research question and address the research objectives, as outlined in section 1.4. It discusses the integration between the two research components in terms of their respective emphasis on research levels (societal level/individual level), geographical scales (national scale/local scale), and time frames (between 2017 and 2022/2020 versus 2023) for collectively helping understand EV transition. Next, the chapter explains the values of using quantitative approach in this thesis from the perspectives of its general characteristics and its contributions within transitions literature, and also acknowledges its potential limitations. Finally, it specifically demonstrates the synergies between secondary data (official government statistics) and primary data (questionnaire surveys) for understanding the EV phenomena in Canada through an elaboration of their characteristics and an extensive review of existing national datasets relevant to the state of EV transition and existing official datasets relevant to EV transition in local contexts. Finally, it provides a high-level overview of the key methodological decisions made in the thesis; these pertain to the data sources used and dependent and independent variables in the statistical modeling and analysis.

3.2 The Complementarity of the Two Research Components

The respective emphasis of the two research components on societal levels (structure—Chapter 4) and individual levels (agency—Chapter 5) provides a complementary approach for the research focus on how the transition of EVs in Canada is unfolding. For one, despite a wide variety of conceptualization and interpretations of structure(s) in sustainability transition, e.g., concrete versus obscure and internal versus external to agents, structure(s) represent(s) broader contexts and macro levels, e.g., economic, technological, political, and societal components in societies, that to a considerable extent constrain and enable the agency of individuals in terms of how they live and behave (Kok, 2023). The investigation of transition processes and dynamics of EVs through the lens of structural contexts is necessary since the phenomenon itself is structural. Therefore, the transition cannot be achieved by individual behaviour changes merely but requires changes in the structure(s), especially impactful changes (Hirth et al., 2023). For another, structure is not isolated, instead it also interacts with agency to (re)produce societal dynamics. The perspective of individuals' behaviours has been paid much less attention within current transitions literature (less than 5% of peer-reviewed publications in sustainability transitions within the

Scopus academic database between 1990 and 2020), whereas how they reveal their abilities to take concrete actions or choose certain actions in specific contexts and exercise their agency to 'materialize' the structural changes are non-negligible in unpacking transition processes (De Roeck & Van Poeck, 2023; Kaufman et al., 2021). By bridging both aspects in this thesis, the thesis does not aim to contribute to a unifying theory about them, but instead seeks to critically explore and evaluate how the two aspects explain the same phenomenon of sustainability transition, specifically the spatial and temporal patterns of transition to EVs, in a similar or different way.

The two research components also focus on different geographic scales in investigating spatial dimensions of transition processes to EVs; one at national scale (Chapter 4) and the other at local scale (Chapter 5). From the perspective of the discipline of geography, the concepts of place, space, and scale have been the central foci inherently within the discipline. They are also relevant to the way in which transitions unfold and their manifestation is articulated in sub-section 2.4.3. The scale at which geographical contexts is examined (e.g., local, regional, and global) is crucial since it can influence the interpretation and conceptualization of transitions. Changes or observations at one scale can also be related to other scales, i.e. interconnections among scales. Therefore, this thesis aims to unpack the transition to EVs in Canada from an integrated way, from both the lens of spatial variation across provinces and the lens of contextual realities of a local municipality in one of the provinces, Ontario. The larger geographical scale on societal level (Chapter 4) and the smaller geographical scale on individual level (Chapter 5) enable the two research components, respectively, providing general and aggregated as well as detailed and disaggregated views of analyses. The former provides an overview of the pattern or trend of Canadian transition to EVs, while the latter is associated with richer and more complete contextualization of the phenomenon and deeper understanding and description of it from specific population groups at a specific place.

Additionally, the two components share similar time frames, including the COVID-19 lockdown years; the first empirical study covers the years between 2017 and 2022 (Chapter 4) and the other is based on data for the years 2020 and 2023 (Chapter 5). This allows both components to capture similar temporal variations in the transition processes to EVs. By doing so, this thesis can examine how societal and individual levels reveal and respond to these temporal variations, either differently or similarly. The COVID-19 pandemic, as a global health crisis, has had profound and lasting impacts on economies, work environments, travel mobility, and other aspects related to daily activities since late 2019. While some studies initially saw the lockdown as a change to shift towards more sustainable mobility and energy use (Kanda & Kivimaa, 2020; Schmidt et al., 2021), recent data from 2022 onwards (as mentioned in Chapter

1) shows increased travel and electricity demand, suggesting a rebound effect and calling for more research on the impact of COVID-19 on sustainability transition.

3.3 The Value and Limitations of a Quantitative Approach for Understanding EV Transition

This thesis mainly adopts a deductive and quantitative approach for the two research components. While the methodology for the field of geography is not unifying, the quantitative approach, which is primarily based on positivism and postpositivism claims, has been more used in physical geography and environmental geography compared to human geographical studies which more utilize qualitative approach. Ian Burton (1963) claimed that geography in the mid-20th century underwent a “quantitative revolution” which describes the rise of quantitative methods with more statistical and mathematical techniques and this shift further advanced geography into a more analytical and theoretically-driven science. This statement underlines the significance of the quantitative approach in geography over the past half century and its value in analysing spatial patterns and processes.

The quantitative approach is generally used to identify and assess the causes that influence outcomes through careful observation and numeric measurement of the reality “out there” (Creswell, W. John & Creswell, 2017). It includes methods such as surveys and experiments through which relevant variables can be measured and numerical data can be analysed using statistical and modelling procedures. In contrast to the qualitative approach which focuses on generating or inductively developing a theory, the quantitative approach highlights the need to further test, verify, and refine existing theories and models (Creswell, W. John & Creswell, 2017). In this regard, some would argue that the qualitative approach is most needed when the research question is exploratory and related theories are limited or biased in helping understand certain concepts and phenomena, while the quantitative approach adds value when relevant theories and the influential variables have been generally established. The transition to EVs in this thesis is such a phenomenon that ‘adoption-diffusion’ theories are available in helping anticipate and understand it, as elaborated in Chapter 2, and influential variables are identified and analysed in relevant empirical studies.

The quantitative approach, specifically, has recently been called for in transitions research because it provides a systematic and structured way to understand the complexity of transitions while incorporating the multi-dimensional essence and explaining specific causal mechanisms (Köhler et al., 2019; Sorrell, 2018). Since transformative socio-technical changes are inherently complex with non-linear and co-evolutionary processes and interactions between path dependence and radical emergence, single case-based research approach has thus been relied for detailed narratives or articulation of transition processes in particular regions, social domains, and technologies. This in-depth design, however, has its limitations in providing generalizable insights across cases and its context-specificity also poses challenges to uncovering the spatial and temporal dimensions and dynamics of transition processes in this thesis, especially the aspect of spatial similarities and differences. Quantitative approaches through formal modelling and measurable variables and appropriate indicator development are thus beneficial to provide explicit, rigorous, and comprehensive representations of transitions, make inference about the underlying processes and elements that give rise to transition consequences and patterns, and foster comparison across spaces and over time.

There remains, however, a debate over the use of the qualitative approach and quantitative approach in transitions literature (Geels, 2022). Although quantitative techniques can offer useful insights in certain circumstances, relevant limitations are also acknowledged in this thesis. On one hand, the utilization of quantitative approach may at the cost of oversimplification in representing the complex unfolding processes of transitions, while the qualitative approach has advantages in contextualizing transitions through unpacking more details or nuances of the phenomenon, for example, how the acceleration of specific innovations is shaped through alignment dynamics among actors and among dimensions within confined spatial and temporal boundaries. The quantitative approach needs more caution against failure or at least recognizing difficulties in defining and measuring phenomena. Given the above limitations, the two empirical components are respectively grounded in two different theoretically informed frameworks reviewed in Chapter 2, and also relevant empirical studies on EV diffusion and adoption for the development of a set of appropriate variables and further statistical modelling. Specific strategies for validity and reliability on data collection and analysis are also used to ensure the accuracy and consistency of the research findings.

3.4 Insights from Secondary versus Primary Data for Understanding EV Transition in Canada

This thesis adopts two different quantitative techniques based on differences in data types, secondary data analysis (Chapter 4) and questionnaire survey analysis (Chapter 5), in order to integrate insights from both secondary and primary data in understanding the ongoing EV transition process in Canada. The specific methods and data involved in the research design are determined by the topic of investigation and research questions.

The first research component aims to describe and explain the spatial and temporal patterns of Canadian transition to EVs from both societal and national perspectives (Chapter 4). This involves extensively identifying existing national datasets that can be utilized. Based on Table 3.1, national datasets that are related to the state of EV transition are limited in Canada. There were some surveys conducted by research institutes in Canadian universities that collected preferences and attitudes data from samples that were national in scope, focused on those who intended to purchase new vehicles but were not EV owners. However, the primary data gathered were dated and showed preferences from a 'stated' perspective instead of a 'revealed' perspective, i.e., what people often claim they will do does not always match what they do. Some organizations have gathered EV registration data from different sources, including automakers, information service providers, and governments, but there are inconsistences among datasets in terms of their temporal coverage and specific variables. Additionally, these datasets are available only in company newsletters or internal communications among members. Official data inventory related to Canadian transition to EVs has recently progressed since the federal government started to compile vehicle registration data from administrative files supplied by provincial and territorial governments in 2018, making them publicly available. Government agencies have also released detailed data to the public in terms of federal EV purchase incentive and infrastructure programs since the implementation of these programs.

Table 3.1 A summary of national datasets relevant to the state of EV transition in Canada

Publisher	Data titles	Year published/collected	Spatial and temporal foci	Data descriptions
SFU Sustainable Transportation Research Team	The Canadian Plug-in Electric Vehicle Survey (CPEVS)	2013	Provinces in Canada, 2013	An in-depth web-based survey completed by roughly 2,000 representative samples of Canadian new vehicle buyers who plan to purchase (or have recently purchased) a new vehicle, but did not own a PEV at the time of the survey about their awareness of and preferences for BEVs, PHEVs, and hydrogen fuel cell vehicles
	The Canadian Zero-Emissions Vehicle Survey (CZEVS)	2017	Provinces in Canada, 2017	Similar with the 2013 one
McMaster Institute for Transportation and Logistics	Survey for Preferences and Attitudes of Canadians towards Electric Vehicles (SPACE)	2015	Provinces in Canada, 2013	An in-depth web-based survey completed by roughly a representative sample of 2,000 Canadian households who are potential car buyers about their preferences and attitudes for EVs and to assess their sensitivities to various attributes of said vehicles
FleetCarma (acquired by Geotab in 2018)	Newsletter about EV registrations	2016-2018	Provinces in Canada (quarterly)	The number of registrations estimate of a particular model of EVs, including both BEVs and PHEVs

Electric Mobility Canada	EV registrations	2018-2019	Provinces in Canada (monthly)	The number of registrations estimate of a particular model of EVs (BEVs and PHEVs) and hybrid vehicles
Statistic Canada	New Motor Vehicle Registrations	2022/2023	(1) Province/territory in Canada since 2017 (quarterly); (2) Province/territory in Canada since 2017 (annually); (3) Census subdivision and Census metropolitan area in Canada since 2017 (quarterly)	The number of new motor vehicle registration by fuel type and vehicle type
Transport Canada	Statistics on the Incentives for Zero-Emission Vehicles (iZEV) Program	2022	Province/territory in Canada since the start of the program May 1, 2019 (monthly)	Details including province/territory and postal code of the dealership each vehicle was purchased/leased from, vehicle model type, fuel type, and year, recipient type (i.e., individual or organization and purchase or lease), and specific incentive amounts
Natural Resources Canada	Projects funded by the Electric Vehicle and Alternative Fuel Deployment Initiative (EVAFIDI) and Zero Emission Vehicle Infrastructure Programs (ZEVIP)	2022	Geographical coordinates in Canada since the start of the programs (EVAFIDI-2016, ZEVIP-2019)	Project details including project number, the number of chargers, the name of the promoter, the postal code, the geographical coordinates, the status, the opening date, and the type of contribution agreement for each project funded by the program.
Statistic Canada	Vehicle registrations	2023	Province/territory in Canada between 2017 and 2022 (annually)	The number of active vehicle registration counts of light-duty vehicles and medium-duty vehicles by type of vehicle and fuel type, heavy-duty vehicles, buses, and motorcycles and mopeds

The official statistics on new EV registration by province/territory in Canada, by quarter, are published by Statistic Canada, which has not been studied before, can be suitable and reliable secondary data for the first part of research, especially a representation of progress about EV transition or growth trend of EV adoption in Canada. First, the dataset is of high quality for secondary analysis. The sampling and data control procedures for official statistics have been well-established for ensuring data quality. Second, the dataset is acquired for a geographical area instead of individuals. The unit of analysis of the data is thus based on societal level and provincial ‘averages’ or ‘aggregates’, which is aligned with the research aim. The provincial/territorial level is selected as the geographic unit for spatial variation analysis since many EV-related influences (e.g., EV deployment policies and plans for EV assembly plants) vary at this level of governance in Canada and the inter-provincial variation in those influences is typically greater than the intra-provincial variation. Lastly, the dataset is compiled in a consistent way across time and space, allowing further longitudinal and cross-sectional analysis. The data can be employed to chart trends over time and conduct comparison across spaces, shedding lights on the spatial and temporal patterns of the ongoing transitions to EVs.

The second research component will uncover the ongoing transition to EVs from individual and local aspects through understanding and assessing changes of consumers' likelihood and perception of adopting EVs (Chapter 5). There have been some provincial governments publishing official datasets on the number of EV registration in smaller administrative units since 2020 to the public (Table 3.2). These secondary datasets, however, are collected to interpret aggregate results for a local area rather than individuals within that area. Given the research's foci on individual behaviours and attitudes and local contexts, this research relies on survey research design in which primary data and information are collected from respondents. Questionnaire surveys are selected due to (1) their ability to collect information from larger samples, which can be further used for statistical modelling and making inferences about populations; (2) their ability to acquire information about people's characteristics, behaviours, experiences, and opinions that is not usually available from published data sources; (3) their ability to effectively and efficiently reach a wide range of people from different locations by using emails, websites, and telephone calls. In this regard, tailored questions to address this particular research component about consumers' attitudes towards EVs can be designed and collected through questionnaire surveys, including customizing instruments to fit survey samples and research location and context where they live (Clifford et al., 2023).

Table 3.2 A summary of official datasets relevant to EV transition in local contexts in Canada

Publisher	Data titles	Year published/collected	Spatial and temporal foci	Data descriptions
Government and Municipalities of Québec	Electric and hybrid vehicles	2020	Administrative units in the city of Montreal in August in 2015	The number of electric and hybrid vehicles by vehicle type and administrative unit.
Government of Ontario	Electric Vehicles in Ontario By Forward Sortation Area	2022	Forward Sortation Areas in Ontario between 2022 and 2024 (quarterly)	Total counts of BEVs and PHEVs by FSA (the first three characters of the postal code) of the vehicle plate owner's registered address
Government of Nova Scotia	Electric Vehicle Registration Data	2024	County of Nova Scotia at some points in time between 2021 and 2024	The number of EVs registered in Nova Scotia with an active licence plate attached

Based on the above, secondary and primary data are divergent in their natures and can help understand EV transition in Canada from a complementary lens. The secondary data are generally less expensive and take less time and effort to obtain, especially when the study phenomena at large spatial and temporal scales (the first research component in this thesis), compared to primary data. However, secondary data sometimes may not be best suited to answering specific research question in terms of scale misalignment between data collection units and analysis units and less control on data collection and quality (Montello & Sutton, 2006). Publicly available and free obtainable data may also not be common sometimes. For example, Canada has only started to gather detailed inventory data of vehicle registration including new and old registrations since 2018, which is driven by motivations for estimating energy consumption in the transportation sector or broadly conducting pathways for climate targets (Global News, 2018). Since Canada is just beginning to accelerate its EV transition, the availability of EV-related data is still limited compared to countries like Norway and China, where EVs have already entered mainstream markets. Despite primary data are generally difficult to collect (in terms of money, time, and effort), they are still manageable in local contexts or cases studies. More importantly, they can be more well-suited to the research questions/phenomena since they are directly and strategically collected by researchers based on specific aims. Primary data is necessary to give rise to the 'voices' from individuals to understand their internal processes and dynamics towards EVs (the second research component in this thesis).

3.5 Data Sources Used

The official statistics on new EV registration by province/territory by quarter from Statistic Canada are used in the first part of research to represent the observed pattern of the transition to EVs in Canada over time and across spaces. The dataset includes different vehicle types, i.e., passenger cars, pickup trucks, multi-purpose vehicles (SUVs and crossovers), and vans (minivans and cargo vans) and BEVs and PHEVs two fuel types. Given the surge of e-commerce during and after the COVID-19 pandemic, many delivery and logistics companies, such as Amazon and GoBolt, have expanded the electrification of their delivery fleets (Friedman, 2024; Swallow, 2022). The commitments of private sectors and governments to electrified their commercial and municipal fleets have also contributed to the increase in new EV registrations, which would be reflected in the dataset (Federation of Canadian Municipalities, n.d.; International Energy Agency, 2024a).

In order to explain the above observed pattern, independent variables are developed from various data sources, specifically, government and public sector publications (e.g., Statistics Canada, Transport Canada, and Canada Mortgage and Housing Corporation) and industry reports (e.g., Dunsky Energy+Climate Advisor and Nanos Research Corporation). The data sources of each variable can be found in Appendix A.

In terms of the second part of the research, questionnaire survey data were collected in both 2020 and 2023 in Waterloo Region for understanding and assessing changes of consumers' likelihood and perception of adopting EVs. As part of the 2020 and 2023 "Waterloo Region Matters Survey" conducted by the Survey Research Centre at the University of Waterloo, the survey data were collected randomly from adults who live in the region through mixed modes of telephone (landline phone and cell phone) and online. The sample size was 541 in 2020 and 498 in 2023, and the respondents in the two years were respectively representative of the adult population in the region. The survey instruments in the two years were virtually identical and included three sets of questions: socio-demographics; perceived benefits, risks, and influential policies to EV adoption; and the ownership or the lease of an EV. The data collected are used in statistical modelling and analysis.

3.6 Dependent and Independent Variables in the Modelling and Analysis

Given the different research questions and objectives, the two research components incorporate different variables in the statistical modelling process and specific analytical methods or tools utilized are dependent on their respective independent and dependent variables. The detailed introduction of all variables and the statistical modelling and analysis process in the two components are elaborated respectively in Chapter 4 and Chapter 5.

The dependent variable of the national study is the number of new EVs registered in each quarter between 2017 and 2022 in each of seven Canadian provinces—British Columbia, Manitoba, New Brunswick, Ontario, Prince Edward Island, Quebec, and Saskatchewan. This is specifically represented by the number of new EV registrations (including both BEVs and PHEVs two fuel types altogether and separately) per 1000 people, for provincial comparison. EV registrations, BEV registrations, and PHEV registrations are individually modelled, and each begins with a whole set of 13 independent variables. The development of these variables to explain the spatial and temporal of EV transition in Canada is mainly based on the conceptualization and operationalization of the five constructs of the conceptual framework, "geographical transition framework"; nine variables directly correspond with each of the five constructs, while three variables can map onto multiple constructs. Considering the relationships between independent and dependent variables and the distribution of the dependent variable, generalized linear models (GLMs) with gamma distribution are employed to model how the independent variables interact in explaining the dependent variable.

As for the local study based on questionnaire data, the dependent variable is consumers' actual purchase behaviour or interest in/likelihood of EV purchase, which is based on the DOI's adopter categorization for segmenting consumers into five groups. The changes among the consumer segments over time are scrutinized for capturing dynamic preferences for EVs. The dependent variable is measured as a categorical variable with five scales of different readiness of EV purchase and is also further recoded as two scales of whether respondents have general interest in adopting EVs or not. The independent variables considered are socio-demographic factors and attitudinal and perception factors, i.e., perceived benefits, risks, and influential policies to EV purchase. They are mainly measured as categorical variables. Pearson’s Chi-Square tests are used to compare differences in consumers’ likelihood to purchase EVs and their perceptions over time and across groups. Binary logistic regressions are also applied to interpret how the influential independent variables contribute to the changes of consumers’ general interests in EVs in 2020 and 2023.

Chapter 4 Spatial and Temporal Pattern of EV Transition in Canada

4.1 Chapter Outline

This chapter presents the first research component of this thesis which aims to describe and explain the spatial and temporal patterns of transition to EVs from national and societal level between 2017 and 2022. It first elaborates the research approach through justifying the use of conceptual framework, "geographical transition framework", and further contextualizing it in EV transitions in Canada by reviewing relevant empirical studies on EV diffusion with a consideration of geographical aspects. It then clearly lays out a set of variables that are assessed crucial in influencing the spatial and temporal patterns of EV registrations in Canada and selected in the modelling process. The model specification is articulated by step from determining how to treat dependent variables, which regression model to use, and what independent variables to include, to ensuring the overall model fit. The spatial and temporal pattern of Canadian transition to EVs are visualized and the modelling results including model fit and coefficient estimates of variables are further analysed and interpreted to understand the observed pattern above. It also provides insights into the effectiveness of the conceptual framework and selected variables in helping understand the ongoing transition to EVs in Canada from a macro level.

4.2 Introduction

As noted in Chapter 1, the transition to EVs is geographically uneven across spaces and over time. More than 85% of new EV registrations worldwide were concentrated in China and Europe, while other regions are either just starting to adopt EVs or were in the early stages of accelerating their adoption. EV registrations within and across regions also vary with time, coinciding, at least in part, with different stimuli or stressors, such as the announcement and implementation of policies and programs, the COVID-19 pandemic, and variations in gas prices (International Energy Agency, 2024a). Spatial-temporal variations highlight the significance of geography for the emergence and diffusion of low-carbon innovations. They raise questions of what shapes patterns of transition—both generally and with specific reference to the adoption of EVs.

As reviewed in section 2.4 of the thesis, the socio-technical transitions literature provides a systematic approach for understanding how and why sustainability transitions take place. The literature has made impactful contributions on characterizing socio-technical processes, e.g., stability (of existing regimes) and change (to new regimes) as well as multi-actor process with power dynamics and also identified diverse elements that influence transition processes (Markard et al., 2012). Less attention, however, has been paid to the geographic aspects, i.e., why do transitions unfold faster in certain areas than others

(Geels et al., 2018). The geography of (sustainability) transitions, as a recent addition to the literature, has further emphasized the socio-spatial nature of transition and provided additional insights into the importance of context-specific constructs such as informal institutions and regional visions and policies (T. Hansen & Coenen, 2015; Truffer et al., 2015). By 'construct', I mean, "a construct is an abstract concept or a combination of a set of related concepts that is specifically chosen or created to explain a given phenomenon from the theoretical perspective" (Bhattacherjee, 2012, p. 10).

The transition to widespread EV adoption involves multi-dimensional interactions of technologies and social contexts, such as transport and energy policies, physical infrastructure, and consumer practices and preferences (Geels, 2002; Sovacool & Hess, 2017). Existing literatures provide a rich starting point for further exploring the EV transition. There are five aspects of the current literatures on EV transition that remain underexplored, which are the foci of this chapter:

1. Most studies focused on a limited number of constructs, typically with qualitative analysis of small-sample data sets. Few studies have taken a more comprehensive approach and explicitly conceptualized and operationalized the constructs in transitions and none have done so in the context of transition to EVs through a quantitative lens.
2. Most past studies have examined consumers' stated preferences, i.e., purchase intentions, instead of revealed preferences, the latter of which refers to actual sales, purchases, or registrations. This may be explained by the limited availability of EV sales or registrations data in early-stage EV markets and the relative ease with which survey data can be assembled on preferences and intentions to represent revealed preferences. But in many contexts, there is an 'attitude-action gap' that can result in the over-estimation of the acceptance of new products or services (Axsen et al., 2009; Wolinetz & Axsen, 2017) and a misinterpretation or misconception the factors and extent of what drives change (Jia & Chen, 2021).
3. Some relevant variables are not well understood, e.g., government incentives, charging infrastructure, and vehicle supply chain, and their influence on societal transition to EVs is inhibited by questions about how to represent these for inclusion in quantitative analysis.
4. The limited literature that has adopted a geographical perspective using EV sale or registration data has not been attentive to variations that occur both over time and across space.
5. The interactions between variables have not been carefully considered in most of the empirical studies.

This chapter thus aims to describe and explain both the spatial and temporal patterns of transition to EVs based on a unique dataset of EV registrations that is acquired from seven provinces in Canada between 2017 and 2022. To achieve this objective, the study will (1) measure, select, and evaluate a set of independent variables that are relevant to the transition to EVs by drawing upon the geography of transitions literature and existing empirical studies on EV diffusion with a consideration of geographical aspects; (2) then model and interpret how these variables interact in explaining the observed patterns of transition to EVs. From an empirical investigation, the study adds to our understanding of the geographical unevenness in the case of the transition to EVs through developing and applying the conceptual framework of the 'geography of transitions', as proposed by T. Hansen and Coenen (2015). Through measuring the critical constructs in different ways, either directly or through proxies, the study also makes a methodological contribution to how different influences can be better understood in the context of the transition to EVs. Additionally, it serves as an initial study utilizing the official national EV registrations data in a Canadian context. The application of this specific dataset can also help disentangle the Canadian EV market, which beyond the original aim of this dataset.

4.3 Research Context

4.3.1 Overall Approach

This chapter begins by elaborating and justifying the conceptual framework for this chapter, which is based on the geography of (sustainability) transitions. This framework is used as the foundation for exploring EV registrations over space and time. Next, the chapter outlines the conceptualization of five influential constructs within the framework; and then summarizes and synthesizes empirical studies that identify promising variables that potentially represent those constructs in the specific domain of EV transition. Based on the above, a set of variables will be defined for use in modelling spatial and temporal patterns of EV registrations in Canada.

4.3.2 The Geography of (Sustainability) Transitions

As explained in section 2.4, transition studies have employed different analytical frameworks to capture the multi-dimensionality and co-evolution of sustainability transitions (Köhler et al., 2019). They have taken a systemic lens in uncovering how sustainable innovations occur and diffuse. Despite these studies' insights into the complexity of transition processes, there is need for a more explicit consideration of geographically nuanced concepts and perspectives and a careful exploration of how they influence transitions (A. Smith et al., 2010). The geography of transitions literature (mentioned in sub-section 2.4.3) thus has been a relatively recent addition focused on comprehending transitions, especially geographical similarities and differences in transitions between cities, regions, or countries. These differences not only involve transition patterns, consequences, and trajectories, but more importantly, the underlying processes and reasons that give rise to them. Research on the geography of transitions has been primarily concerned with 'institutional embeddedness' or 'socio-spatial embedding' that relates to place-specificity or contextual conditions, which explains why certain technological creations happen in particular places instead of others and why different places favour certain transition pathways over others (Coenen et al., 2012; T. Hansen & Coenen, 2015; Truffer et al., 2015). Despite the consensus of place-specificity's significance, more theoretical and empirical attention is still required in order to better explain how it matters for transitions (T. Hansen & Coenen, 2015).

The proposed framework for the study draws on the work of T. Hansen and Coenen (2015), who have established a conceptual framework (this framework will be referred to "geographical transition framework" in the following sections) that includes five influential place-specific constructs—urban and regional visions and policies, informal localized institutions, local resource endowments, local technological and industrial specialization, and consumers and local market formation—in local, urban, and regional levels for sustainability transitions. It provides a multi-dimensional lens to highlight the importance of place specificity on transitions and mainly stems from a review of empirical studies on the geography of transitions (T. Hansen & Coenen, 2015). The five constructs are as follows:

1. Urban and regional visions and policies, which include governments' political goals, targets, and specific policies of relevant industries or technologies and the multi-governance perspective underpinning them, have been regarded as a main trigger to technology diffusion.

2. Informal localized institutions highlight informal rules, i.e., norms, values, and cognitive rules that give rise to social practices, which condition the development of environmental innovations.

3. Local resource endowments represent natural conditions and landscape characteristics that favour or hinder the investments in sustainability transition. For example, regions with abundant sunshine or wind and limited fossil fuel resources are more likely to have greater renewable energy generation.

4. Local technological and industrial specialization that includes aspects such as skilled labour, pre-existing knowledge bases, and research and development (R&D) capacities.

5. Consumers and local market formation, which have received limited attention in the geography of transitions, emphasizes the accessibility to engage or interact with local consumers.

This geographical transition framework has guided empirical studies that investigate how different place-based conditions affect and reflect transition trajectories and technological creation and diffusion across geographical scale, especially in transport and energy domains. For instance, urban and rural contexts foster different development pathways for the technologies of BEVs and autonomous driving in Germany; the emergence of BEVs might contribute to other transport modes in urban areas, e.g., car-sharing and taxis, while they may stabilize the established private-car regime in rural areas (Schippl & Truffer, 2020). Without focusing on landscape characteristics, Ferloni (2022) focused on technological and industrial specialization and explained the transition to EVs through exploring technological connections among EVs, smart grid, and batteries based on the U.S. patent dataset. Joshi et al. (2022) investigated the potentials of grassroots in Edmonton, Canada in niche creation (e.g., solar PV installation) of community energy transitions and identified their significant roles regarding the proximity to community members. Other studies examined the effect of various types of policies and multiple levels of governance and found that they differ in orientation and intensity (Vanheusden et al., 2022; Wesseling, 2016) and can further have multi-scalar and temporal effects on transitions (Skjølsvold & Ryghaug, 2020).

Studies above have concentrated on specific constructs, mostly through qualitative case studies, and only a few studies have applied the geographical transition framework in a comprehensive way or have considered and conceptualized the constructs in an explicit manner. Examples include the work of Rohe et al. (2023), which systematically assessed lead companies' embeddedness in regional energy transitions in Germany by translating the five constructs into a set of indicators. Another, by Ruggiero et al. (2021), examined how contextual conditions favour or hamper the development of community energy projects in the Baltic Sea Region based on actors' perspectives. They added to the five constructs by also incorporating socioeconomic conditions, i.e., income and education levels—something that also is considered for the current analysis.

The current study thus regarded the geographical transition framework as a foundation to conceptualize constructs in a holistic and an explicit way via enriching their meanings and interpretations in the context of transition to EVs and to further suggest influential variables that shape its geographical patterns. In this regard, this approach can enable the development of a set of essential variables that provide a structured view on the complexity of transitions while considering their multi-dimensional nature.

4.3.3 Conceptualization and Operationalization of Constructs

Constructs, which are conceptualized at a theoretical level, are generally abstract and can be hard to measure. Therefore, the processes of conceptualization and operationalization for defining and measuring them through variables and indicators at an empirical level become crucial (Bhattacherjee, 2012). Variables can be seen as measurable representations of constructs. Specifically, what should be included and not included as representation of a construct, what dimensions or concepts are involved in a construct, and what a set of indicators or variables are suitable to measure it? These questions are also relevant to constructs' specific contexts, and as such we might expect different answers in different contexts. Indeed, attention to geography requires that the five constructs that T. Hansen and Coenen (2015) have created should be contextualized differently in different domains. For example, local resource endowments in the context of urban energy transitions mainly would relate to existing energy sources, i.e., the availability, reliability, and costs of them (Collier et al., 2023; Joshi & Agrawal, 2021), while they would primarily relate to built form (e.g., urban or rural settlement) for transitions to sustainable transport (Schippl & Truffer, 2020).

Consequently, this study is intentionally to conceptualize and interpret each of the five constructs from the geographical transition framework in the domain of personal mobility and adoption and diffusion of pro-environmental products and services and to further draw upon existing empirical studies on EV adoption and diffusion so as to ascertain a set of relevant variables that represent and measure those constructs for the transition to EVs.

4.3.4 Existing Empirical Studies about EV Diffusion with a Consideration of Geographical Aspects

Empirical studies on EV adoption, which is interpreted here as the purchase, leasing, or registration of an EV, have increased over the past decade. They provide insights into the influential variables for consumers' behavior or preference towards EVs and mainly use stated preferences, i.e., adoption intention, to represent EV adoption behaviours. While most studies on EV adoption have used intention as the dependent variable, empirical studies over the past five years have begun to use vehicle sales or registration data to investigate how different variables affect the transition to EVs. Also, some recent work has taken an explicitly geographical perspective. Table 4.1 summarizes 11 key studies that combine the use of revealed preference data with a geographic perspective. Four observations can be made with regards to these 11 studies:

- Researchers have paid more attention to spatial variation than temporal variation.

- Spatial scales vary with some studies examining differences across countries and states or provinces and others focusing on small units (e.g., across cities or districts).
- Researchers have categorized the market differently with consideration of submarkets' sales or registration that may respond differently to conditions.
- Vehicle fuel types, e.g., BEVs and PHEVs/BEVs and ICEVs, models, and vehicle body types are often differentiated. For example, the sales of BEV have been found to be more sensitive to extreme temperatures and gas prices compared to those of PHEV (Li et al., 2017, 2023).

Table 4.2 also summaries the same 11 studies that are listed in Table 4.1, this time by explaining the conceptualizations of the five constructs outlined earlier, and listing the associated variables used to represent those constructs. Any one variable may only capture part of meaning or provide an imperfect or incomplete representation of a construct and thus multiple variables may be used to represent a construct. The remainder of this section provides a detailed summary of how different variables connected with each of the five constructs may influence EV registrations in the Canadian context.

Table 4.1 A summary of revealed-preference EV studies with a geographical aspect

Authors	Regions	Spatial focus	Temporal focus	Spatial or temporal variation?	Dataset of EV sales or registrations	Statistical analysis	Fuel type(s) studied
Javid & Nejat, 2017	The United States	58 California counties	2012	Spatial variation	2012 California Household Travel Survey including both EV and conventional car buyers' information	Logistic and probit regression analysis	BEVs and PHEVs together
Li et al., 2017	Worldwide	14 countries	2010-2015 (yearly)	Spatial and temporal variations	Annual EV sales from the International Energy Agency	Fixed-effects regression models	BEVs and PHEVs together and separately
Clinton & Steinberg, 2019	The United States	Multiple states	2011-2014 (quarterly)	Spatial and temporal variations	National dataset by R. L. Polk & Co. including vehicle registrations of each model, in each quarter, and in each state	Fixed-effects regression models	BEVs
Azarafshar & Vermeulen, 2020	Canada	10 provinces	September 2012-December 2016 (monthly)	Spatial and temporal variations	Monthly EV sales by model and make from IHS Automotive Canada and accessible by Green Car Canada	Generalized linear fixed-effect models	BEVs and PHEVs together and separately
Erutku, 2020	Canada	513 Ontario Forward Sortation Areas	January 2012-October 2018	Spatial variation	Electric Vehicle Incentive Program Database by the Ministry of Transportation of Ontario including purchase date, vehicle information, and the applicant's FSA	Ordinary Least Squares (OLS) regression and fractional probit regression	BEVs and PHEVs together
Guo et al., 2020	China	20 major cities	May 2014-April 2018 (monthly)	Spatial and temporal variations	Monthly sales volume of EVs in studied cities by the China Association of Automobile Manufacturers	Fixed-effects regression model	BEVs and PHEVs together and separately
Brisen˜o et al., 2021	Mexico	32 states	2016-2019	Spatial variation	Sales data reported by INEGI from the Mexican Association of the Automotive Industry	OLS regression	BEVs, PHEVs, and hybrid electric vehicles together
Brückmann et al., 2021	Switzerland	424 postcodes in Swiss Cantons Aargau, Schwyz, Zug, and Zurich	May 2018 and October 2018	Spatial variation	Survey data of car holders registered in the four Swiss Cantons	Logistic regression model and generalized linear mixed-effects models	BEVs and ICEVs separately
Ogunkunbi et al., 2022	Europe	15 European countries	2010-2018 (yearly)	Spatial and temporal variations	Annual BEV sales from the European Alternative Fuel Observatory and the European Automobile Manufacturers Association	Generalized linear model	BEVs
Khatua et al., 2023	Worldwide	30 countries	2011-2020 (yearly)	Spatial and temporal variations	EV sales from the International Energy Agency	Panel-corrected standard error multivariate regression analysis	BEVs and PHEVs together
Li et al., 2023	China	20 Chinese provinces	2010-2018 (yearly)	Spatial and temporal variations	Annual EV sales from the Statistical Yearbook of China's Energy Conservation and EVs 2011–2019	OLS and fixed-effects regression models	BEVs and PHEVs together and separately

Table 4.2 A summary of constructs with conceptualization and operationalization in relevant empirical studies

Constructs	Conceptualization in the context of transition to EVs	Variables used in relevant empirical studies in measuring the constructs	References for column three
Urban and regional visions and policies	Political goals, specific supply- and demand-side policies related to EVs (e.g., financial incentives and EV sale mandates), and policies related to other relevant domains (e.g., building code and electricity generation standard)	Financial and non-financial incentives of EV ownership; incentives for charging infrastructure installation; environmental regulations; mandates for EV sale targets; purchase/driving restriction for ICEVs	Clinton & Steinberg, 2019; Azarafshar & Vermeulen, 2020; Ogunkunbi et al., 2022; Khatua et al., 2023; Li et al., 2023
Informal localized institutions	Mobility practices and purchase behaviours, i.e., how people move around and make decisions to purchase pro-environmental or technology products and their underlying norms, cultures, and beliefs	The level of environmentalism; the level of technology affinity; usage of public transit and carsharing; trip duration (how far/how long people can access to the places they want)	Javid & Nejat, 2017; Clinton & Steinberg, 2019; Erutku, 2020; Briseño et al., 2021; Brückmann et al., 2021; Khatua et al., 2023
Local resource endowments	Dimensions of how sparse/dense the area is, environmental conditions, and related infrastructure or built environment	Population density (urban/rural area); charging infrastructure availability; air pollution; temperatures;	Javid & Nejat, 2017; Li et al., 2017; Clinton & Steinberg, 2019; Erutku, 2020; Guo et al., 2020; Brückmann et al., 2021; Ogunkunbi et al., 2022; Khatua et al., 2023; Li et al., 2023
Local technological and industrial specialization	Aspects of car manufacturers and dealers and R&D levels in batteries and vehicles	Availability of local manufacturers' plants; the number of patent applications for EVs; industrial development (GDP); vehicle-related attributes	Javid & Nejat, 2017; Li et al., 2017; Azarafshar & Vermeulen, 2020; Guo et al., 2020; Briseño et al., 2021; Ogunkunbi et al., 2022; Khatua et al., 2023; Li et al., 2023

Consumers and local market formation	Perspectives such as consumers' socio-economic characteristics and interactions between consumers and manufacturers/dealers	Affluent level; education attainment; vehicle ownership; property ownership and types; gender; age; employment status; household size; marriage status	Javid & Nejat, 2017; Li et al., 2017; Clinton & Steinberg, 2019 Azarafshar & Vermeulen, 2020; Erutku, 2020; Guo et al., 2020; Briseño et al., 2021; Brückmann et al., 2021; Ogunkunbi et al., 2022; Li et al., 2023
Variables used in relevant empirical studies but are related to multiple constructs			**References for column three**
Related to urban and regional visions and policies, informal localized institutions, local resource endowments, and local technological and industrial specialization		Gasoline prices and electricity prices	Javid & Nejat, 2017; Li et al., 2017; Clinton & Steinberg, 2019; Azarafshar & Vermeulen, 2020; Briseño et al., 2021; Ogunkunbi et al., 2022
Related to urban and regional visions and policies, informal localized institutions, local resource endowments, and local technological and industrial specialization		Lower carbon energy generation	Li et al., 2017; Khatua et al., 2023

First, urban and regional visions and policies can be strong ‘pushes’ for the EV transition. Most studies have assessed the effect of direct EV purchase incentives on this transition, with results showing that EV sales or registrations may increase by 2% to 15% per thousand dollars of incentives provided across different model specifications. The incentives have been found to have similar impacts on the sales of BEVs and PHEVs. In contrast, other financial incentives, e.g., tax credits or benefits, have been found to have no effect in past studies. Some studies have also incorporated an environmental regulation index and explored whether EV-supportive political goals are in place and these types of policies have been found to have significantly positive effects on EV diffusion. Only one study did not identify any significantly positive associations between most financial/non-financial incentives and the country’s BEV sales.

Informal localized institutions also play key roles in the transition to EVs, which have been represented by mobility practices (more broadly—sustainable practices) that are underpinned by social cultural and cognitive aspects such as environmental awareness, masculinity, and attitudes towards new technologies. Studies have primarily focused on trip duration and the involvement of public transits and car sharing, both of which are related to travel patterns and further affect vehicle choices. Trip duration is shown to be either insignificant or positively associated with EV adoption; for example, neighbourhoods characterized by people who have a short daily commute tend to have lower adoption of EVs. The usage of carsharing has been identified as a significant predictive variable; an individual that uses carsharing or shares the car is 2%-12% more likely to buy an EV than others. The level of environmentalism is also a main focus among studies and has been found to significantly affect EV penetration. However, directly capturing it at a societal level has been challenging. Measurements may relate to commitments or actions to environmental protection (e.g., waste disposal and separation and the number of issues of sustainability certificates) or political voting patterns.

Local resource endowments are mainly conceptualized in the selected studies as contextual and spatial characteristics such as development density, infrastructure availability, and environmental conditions. Population density/urban population and charging infrastructure availability are two main considerations and have shown mixed findings. Population density/urban population tends to either have a negligible impact on EV diffusion in small geographical units (e.g., counties and neighbourhoods) or have a positive or negative and statistically significant effect in large scales (country-levels). It also seems to be more related to the sales of BEVs, compared to the sales of PHEVs. The availability of charging infrastructure is demonstrated to have a significantly positive association with EV purchase via either separately considering private or public chargers or considering private and public chargers altogether. Specifically, two studies found fast charging facilities to be prominent. However, some other studies found public charging infrastructure insignificant in affecting EV purchase. Therefore, it begs a better understanding of relations between charging facilities and EV registrations across spaces and over time, especially differentiating between publicly available slow and fast chargers.

The fourth construct within the geographical transition framework is local technological and industrial specialization. In EV-related studies, EV technology performance and automotive and battery industries have been emphasized. The level of maturity in EV technology development significantly influences EV sales and the evidence supporting this relationship is clear; some studies have introduced vehicle prices, battery costs, vehicle ranges, and technological level index into analyses and found them all significant for EV sales with the former two negative and the latter two positive effects. The variable of gross domestic product has been commonly used to represent general industrial development and output and its effects on EV sales or registrations have been inconsistent – sometimes showing significant positive effects and other times no influence or even significantly negative influences. Less attention has been paid to EV-specific manufacturing and the associated battery industry; and their influence on EV sales remains unclear. Two studies have assessed whether the availability of local manufacturers' plants is influential for EV sales and presented two opposite findings; one with the focus of California counties, and it showed no statistical significance and the other with a multi-country scope, which concluded that it was the most influential variable. Given disruptions to international trade and global supply chains by the COVID-19 pandemic, the resilience of the automobile supply chain requires more empirical investigation, especially how the supply of EVs might influence its sales (Arribas-Ibar et al., 2021).

The fifth construct, consumers and local market formation, has been widely considered in the revealed-preference EV studies, particularly from the aspect of socio-economic characteristics, such as gender, property ownership and types, and employment status and some of them are used as control variables. They generally tend to have marginal effects on EV sales or registrations compared to other variables mentioned above. These effects are also not definitive in terms of direction and magnitude since they depend on specific models and contexts. Among the characteristics, education attainment and affluent levels are more likely to be positively related to EV penetration with stronger influence, except for one study that found education levels insignificant to BEV registration at the neighbourhood scale in Switzerland.

Other variables that have been included in empirical studies on EV adoption, for example lower-carbon energy generation, gasoline prices, and electricity prices, do not measure dimensions of any one of the aforementioned five constructs, but instead they seem to be related to multiple constructs. The share of renewables in electricity generation has been analysed in two cross-country studies as a representation of country-level environmental performance or societal-level environmental awareness and has been found to be positive and statistically significant. Intuitively, it is related to not only formal visions and policies and informal institutions, but also existing resource endowments and energy-related technological and industrial specialization. Gasoline and electricity prices, which represented similar constructs with lower-carbon energy generation, have been mostly investigated in the empirical studies. Generally, gasoline prices matter more than electricity prices in affecting EV demand and were found to be the strongest variable in two studies. Some studies, however, have found that the statistical significance and magnitude of gasoline prices' influence are not consistent across models and submarkets; time fixed-effect models could reduce the variation of gasoline price, making it less influential and it also seems to have more apparent effects on BEV sales than PHEV sales.

As shown above, there are many options for operationalizing each of the five constructs and for including additional variables in modeling the transition to EVs. Details on specific choices for the current study, and the rationale for these, are presented later in sub-section 4.4.1.2.

4.3.5 An Overview of the Canadian Electric Vehicle Market

The aforementioned empirical studies indicate that there is some inconsistency as to which variables account for the geographical unevenness of transition to EVs, and more investigation is needed. In this regard, Canada can be a suitable region of the world for investigating the spatial and temporal pattern of transition to EVs given its increasing adoption of EVs, its regional variations in physical, social, and political contexts, and increasing EV-related data availability.

Under the Paris Agreement on Climate Change, Canada has committed to the target of a 30% GHG emission reduction below 2005 levels by 2030, from 732 mega tonnes in 2005 to 523 mega tonnes in 2030; and has developed its first national climate plan in 2016 (Environment and Climate Change Canada, 2016). The transportation sector, which is the second largest source of GHG emissions, following the oil and gas industry, accounts for 22% of national emissions in 2022 and passenger transport accounts for nearly 60% within the sector (Environment and Climate Change Canada, 2023a). The decarbonization of the transportation section through acceleration of zero-emission vehicles (ZEVs) thus has become a main focus among federal plans and actions for meeting climate change targets; the Government of Canada committed to achieve 100% ZEV sales by 2035 for all new light-duty vehicles, including at least 20% by 2026 and 60% by 2030 (Environment and Climate Change Canada, 2023b). Specifically, widespread EV adoption has serious potential in helping Canada reduce emissions, given the large share of renewables (roughly 80%) in Canadian electricity generation.

In line with the transition to EVs, Canadian federal government has implemented both demand-side and supply-side policy initiatives since 2016, including ZEV sales mandate, support to build out EV assembly plants, financial incentives for ZEV purchase, tax write-off for business purchase, carbon taxes and pricing, and incentives for ZEV infrastructure. Despite the strong federal government support over the past few years, the share of Canadian vehicle stock that is EV was merely 1.6% by the end of 2022 (International Energy Agency, 2023b). Still, new registrations of EVs have been growing, from 0.18% in 2013 to 8.17% in 2022; BEVs account for roughly 80% of the new EV registrations in 2022 and PHEVs account for the rest. The market share of EVs has been on a steady upward trend, even as the total number of vehicle registrations decreased in 2020 during the COVID-19 pandemic (Statistics Canada, 2024c).

Provincial variation in the transition to EVs is also apparent in Canada. The three provinces of Quebec, British Columbia, and Ontario, with over 70% of Canada's population, over 85% of the funded charging ports from the Zero Emission Vehicle Infrastructure Program (Natural Resources Canada). As well, the most EV-supportive policies are in the three 'leading' provinces mentioned above in the transition to EVs, accounting for over 90% of new EV registrations throughout the studied timeframe (Melton et al., 2017; Office of the Auditor General of Canada, 2023). At the time of writing (November 2023), six provinces[1] offer EV purchase incentives of different amounts, which can be complemented with federal purchase incentives. Ontario previously had the most generous incentives with up to $14,000, but the program was cancelled in 2018. Quebec (January 2018 into effect) and British Columbia (May 2019 into effect) are the only two provinces that have provincial ZEV mandates, which requires major automotive manufacturers to sell a minimum percentage of EVs or hydrogen fuel-cell vehicles. These two provinces also have relatively high retail prices for gasoline, while for the three Prairie provinces (Alberta, Manitoba, and Saskatchewan), the average

[1] Quebec-January 2012, British Columbia-February 2016, Nova Scotia-February 2021, Prince Edward Island-April 2021, New Brunswick-August 2021, Newfoundland and Labrador-September 2021. The time represents the time when each province officially launched EV purchase incentives program.

gasoline prices can be roughly 20% lower, potentially leading to less interest in EV purchase. Atlantic provinces (New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island) have relatively lower income levels than other provinces, which may hinder the affordability of EVs. A detailed summary and comparison of context-specific variables across provinces will be in presented in sub-section 4.4.1.2.

4.4 Method

4.4.1 Data

Critical to an analysis of EV adoption is robust data on vehicle sales, leasing or registrations, broken out by geographic province or region, over time. Until recently, such data did not exist (as elaborated in section 3.4). Publicly available, free data for Canadian EV sales or registration became available only starting from 2016 when FleetCarma (acquired by Geotab in 2018) published EV registration data through newsletters. The dataset consists of quarterly EV registration data including both BEVs and PHEVs starting from the first quarter of 2016 until the third quarter of 2018 by vehicular model in each of the 10 Canadian provinces. Electric Mobility Canada later published monthly EV registration data between 2018 and 2019 in relatively granular units, but only for members. The federal government started to gather national data in 2018 related to existing and new vehicle registration in Canada for the estimation of energy consumption in the transportation sector. These data are based on the survey of New Motor Vehicle Registrations which includes different vehicle types and fuel types between 2017 and 2022 quarterly (Table 20-10-0024-01) or yearly (Table 20-10-0024-02) in each of 10 provinces at the time of analysis (February 2023) (Statistics Canada, 2024c, 2024d). These data are collected in a consistent way across time and space, and thus offer the most reliable data source for a Canadian-focused, spatial-temporal study of EV adoption.

4.4.1.1 Dependent variable: registrations of EVs

The dependent variable in this study is the registrations of EVs (including both BEVs and PHEVs two fuel types altogether and separately), represented as the number of vehicles registered per 1000 people in each quarter between 2017 and 2022, inclusive, in each of seven Canadian provinces (British Columbia, Manitoba, New Brunswick, Ontario, Prince Edward Island, Quebec, Saskatchewan). EV registration data are from the New Motor Vehicle Registration Survey published by Statistics Canada and is supplied by provincial and territorial governments. Data for Alberta, Newfoundland and Labrador, and Nova Scotia three provinces are currently not available due to contractual limitations of the existing data sharing agreement (Statistics Canada, 2024b). The spatial-temporal unit of analysis is the province-quarter year since it is how the data was gathered and can also maximize the number of observations. Data exclude buses, trailers, recreational vehicles, and 'others'. The dataset does include passenger cars, pickup trucks, multi-purpose vehicles (SUVs and crossovers), and vans (minivans and cargo vans).

The dataset consists of vehicle registration rather than sales data. Vehicle sales data may be preferable to registration counts in the Canadian context as purchase incentives are based on the location of vehicle sale instead of the location of vehicle registration, and a vehicle registered in one province may have originally been purchased in another. That said, the other four constructs speak to the operating environment, in which case, registrations would be the better option. Statistics Canada does provide new motor vehicle sales dataset by vehicle type and origin of manufacture based on Monthly New Motor Vehicle Sales Survey (Table 20-10-0001-01, formerly CANSIM 079-0003), whereas the dataset does not distinguish different vehicle fuel types. Regardless, registrations provide the best freely available estimates of EV uptake across Canada. Since the populations (and thus market sizes) vary, EV registrations per capita is a better representation for inter-jurisdictional comparison (Table 4.3). Since there are no publicly available datasets about the cumulative number of EV registrations, this study does not consider total EV registration per capita.

Table 4.3 The number of EV registrations and EV registrations per 1000 capita in the seven Canadian provinces between 2017 and 2022 quarterly

		British Columbia		Manitoba		New Brunswick		Ontario		Prince Edward Island		Quebec		Saskatchewan	
Year	**Quarter**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**	**New EV registrations**	**Registrations per 1000 capita**
2017	Q1	788	0.161	10	0.008	5	0.007	1319	0.094	0	0.000	1247	0.151	8	0.007
	Q2	760	0.155	16	0.012	7	0.009	2089	0.149	1	0.007	2029	0.245	7	0.006
	Q3	806	0.164	16	0.012	6	0.008	2130	0.151	0	0.000	2110	0.254	10	0.009
	Q4	788	0.159	12	0.009	8	0.010	2642	0.187	1	0.007	2409	0.289	7	0.006
2018	Q1	1366	0.275	15	0.011	10	0.013	2748	0.194	5	0.033	2565	0.307	11	0.010
	Q2	2458	0.493	49	0.036	16	0.021	6946	0.488	5	0.033	5121	0.612	24	0.021
	Q3	2453	0.490	40	0.030	9	0.012	5258	0.367	5	0.033	4432	0.528	23	0.020
	Q4	2041	0.405	55	0.041	21	0.027	1806	0.125	1	0.006	5725	0.679	29	0.025
2019	Q1	2785	0.552	26	0.019	12	0.016	1342	0.093	7	0.045	3795	0.449	25	0.021
	Q2	6485	1.280	96	0.070	61	0.079	2878	0.199	11	0.071	9369	1.107	50	0.043
	Q3	4504	0.884	98	0.072	53	0.068	3148	0.216	15	0.095	7822	0.920	53	0.045
	Q4	3206	0.625	69	0.050	40	0.051	2394	0.164	11	0.069	6085	0.712	57	0.048
2020	Q1	3705	0.721	64	0.046	37	0.047	2102	0.143	7	0.044	5638	0.659	47	0.040
	Q2	2593	0.503	65	0.047	31	0.040	1640	0.111	5	0.031	4472	0.522	35	0.030
	Q3	4517	0.876	101	0.073	66	0.084	3296	0.224	27	0.167	8618	1.005	76	0.064
	Q4	4396	0.853	81	0.059	46	0.059	3477	0.236	6	0.037	7374	0.860	41	0.035
2021	Q1	6119	1.186	99	0.072	67	0.085	3329	0.226	21	0.130	6901	0.804	104	0.088
	Q2	5756	1.112	154	0.111	117	0.149	5096	0.345	21	0.129	11784	1.373	100	0.085
	Q3	6480	1.246	194	0.139	182	0.230	5162	0.349	89	0.540	10611	1.234	131	0.111
	Q4	5495	1.049	184	0.132	106	0.133	6139	0.412	43	0.258	7504	0.870	143	0.121
2022	Q1	6705	1.277	201	0.144	156	0.195	7123	0.477	44	0.264	10399	1.204	130	0.110
	Q2	7097	1.346	235	0.168	204	0.254	9533	0.636	46	0.273	11105	1.284	193	0.162
	Q3	8293	1.559	313	0.222	253	0.312	11017	0.729	73	0.428	12194	1.402	203	0.170
	Q4	7594	1.415	298	0.210	248	0.302	10982	0.720	54	0.313	12153	1.389	178	0.148

The study uses three representations of EV registrations per 1000 capita: total, BEV, and PHEV. For each representation, the dataset includes 168 observations for the dependent variable, with 24 observations in each province. These variables are continuous, their values are positive (except for two observations of zero) and their distributions are right skewed (Table 4.4). British Columbia is the province with the largest rate of EV registrations per 1000 people with roughly 1.6 units registered followed by 1.4 units in Quebec, while there are no EVs registered in quarter 1 and quarter 3 of 2017 in Prince Edward Island. However, Prince Edward Island is one of the four provinces, with British Columbia, Quebec, and Ontario, that have larger EV registrations, based on population size, than the mean value. Manitoba, New Brunswick, and Saskatchewan have the lowest values among seven provinces, each with less than the mean value. Among the four vehicle types, the percentage of registrations of electric passenger cars has demonstrated a downward trend between 2017 and 2022 across all provinces (Figure 4.1). Meanwhile, the share of registrations for large EVs (i.e., pickup trucks, multi-purpose vehicles, and vans) has steadily increased over the same period, reaching roughly 62% of total EV registrations in 2022. The proportion of both BEVs and PHEVs also varies over time with increasing shares of BEVs in total EV registrations across seven provinces (Figure 4.2). Specifically, in the fourth quarter of 2022, the shares of BEVs among EV registrations ranged from 65% to 85% in these provinces. British Columbia and Ontario showed higher proportions of BEV registrations compared to New Brunswick, which had lower shares.

Table 4.4 Descriptive statistics of dependent variables

Variables	**Minimum (Province-quarter year)**	**Maximum (Province-quarter year)**	**Median**	**Mean**	**Standard deviation**
EV registrations per 1000 capita	0.00 (Prince Edward Island Q1/Q3 2017)	1.56 (British Columbia Q3 2022)	0.15	0.32	0.39
BEV registrations per 1000 capita	0.00 (Prince Edward Island Q1/Q3 2017)	1.41 (British Columbia Q3 2022)	0.08	0.22	0.30
PHEV registrations per 1000 capita	0.00 (Prince Edward Island Q1/Q3 2017, Q4 2018)	0.51 (Quebec Q2 2021)	0.06	0.10	0.11

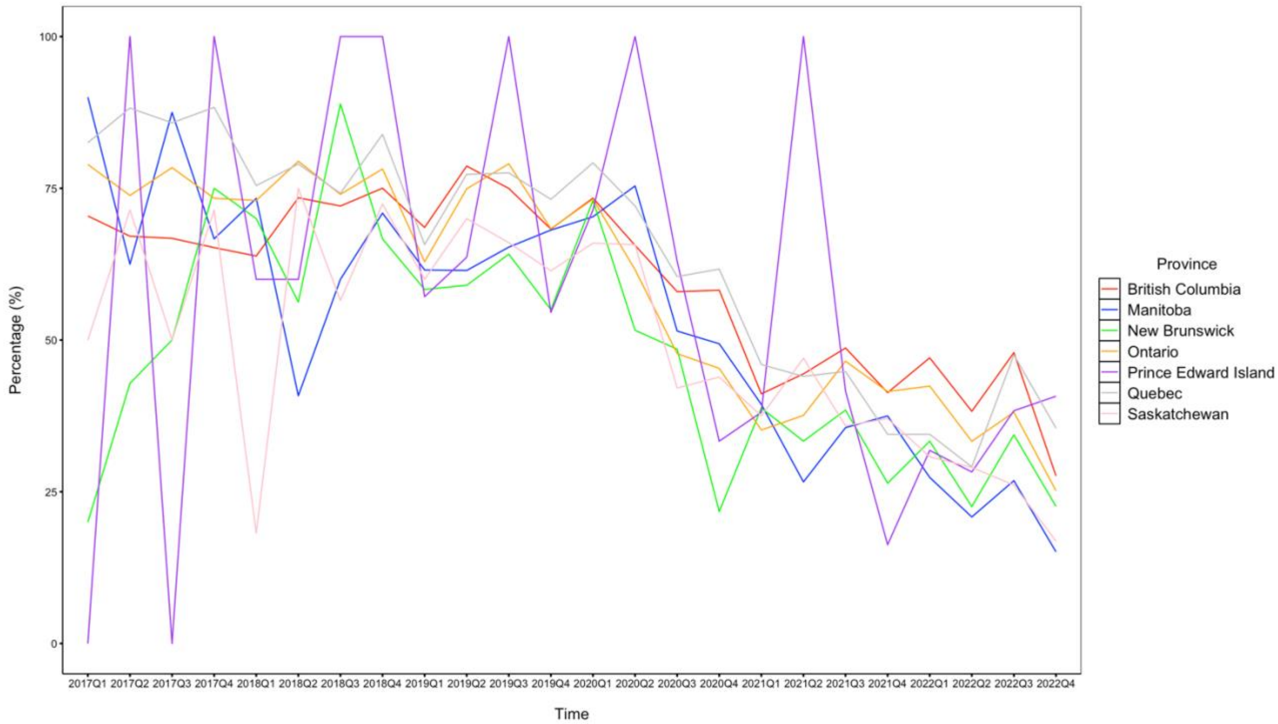


Figure 4.1 The percentage of new EV registrations for passenger vehicles across the seven Canadian provinces between 2017 and 2022

Figure 4.2 The percentage of new EV registrations for BEVs across the seven Canadian provinces between 2017 and 2022

4.4.1.2 Selected independent variables

Next, explanatory (independent) variables were selected for each of the five constructs. The choice of variables was based on face validity and alignment with the construct, relevance to EV adoption, and data availability. The intent is to develop a model with a high degree of explanatory value and a small number of explanatory variables for each of the five constructs (i.e., a parsimonious model). Table 4.5 lists both variables or proxies and alternative options considered for each construct. Then Table 4.6 summarizes these variables, statistically. Appendix A gives an overall summary of detailed information of the and dependent and independent variables that are chosen in this study in terms of their data sources and description. The comparison of the independent variables across provinces between 2017 and 2022 can be found in Appendix B with figures.

Variable representing urban and regional visions and policies:

- Point-of-sale EV incentives for consumers at both the federal and provincial levels (expressed in $1,000s)

The literature—both academic and popular—indicate that financial incentives at the point of sale provide an important catalyst to purchase/lease an EV. Over the period of this study, point-of-sale EV incentives reveal strong spatial and temporal variation. The federal government introduced The Incentives for Zero-Emission Vehicles Program in May 2019, and part of the program is to offer up to $5,000 off the purchase price of a qualifying new BEV, $2,500 or $5,000 on a PHEV (depending on whether electric ranges equal to or greater than 50 km) nationally. All provincial incentives are in addition the federal one, further reducing the purchase price for consumers. The three provinces of British Columbia, Ontario, and Quebec implemented incentives starting from 2010 with different rates, though Ontario's program was cancelled for EVs that were delivered, registered, and plated after September 2018. Prince Edward Island and New Brunswick respectively put into effect incentive programs in April and August 2021. Since incentive values varied for specific EV models, depending on fuel types, battery or seat capacity, electric ranges, or(and) manufacturer's suggested retail prices, this variable is expressed as registration-weighted average incentives. For example, most of the available BEV models on the market are eligible for the incentives of $12,000 in Quebec in quarter 3, 2022 (a combination of a provincial incentive of $7,000 and a federal incentive of $5,000) and most of the PHEVs are eligible for the incentives of $5,000 (equally sourced from the provincial and federal levels). The weighted average of EV incentive value is calculated as ($12,000*BEV registrations + $5,000*PHEV registrations)/total number of EV registrations, which turns out to be $10,620.

Variables representing informal localized institutions:

- The voting preference for the Green Party (expressed as a percentage of those polled)

Measuring societal leaning toward environmentalism is both important for the adoption of green products, as shown in previous studies, and also challenging in the Canadian context. This is principally because panel, national-scale surveys do not exist. Different kinds of proxies are thus investigated here in terms of data accessibility and availability and how they represent the construct; they measure societal environmentalism either from a holistic way or by focusing on one specific dimension. The ideal datasets here would be those that can reflect public attitudes and perceptions towards environmental issues or green products and services or individual environmental behaviors; and further would capture temporal and spatial variation. After considerable exploration of various alternatives, the fraction of voting preference for the federal Green Party is chosen; details and justification of the choice can be found in Appendix C. Despite the federal election's general cycle of four years, public opinions regarding Canadian politics, issues, or events, especially polling data related to party or party leader preferences, are tracked and collected over time by pollsters. Nanos Research Corporation, for instance, collects data on the percentage of Canadian voters who rank the Green Party of Canada as their top local preference among all parties they consider federally. These data collected by Nanos are shared with paid subscribers. It is based on the Weekly Federal Political Data Survey starting from 2014 and provides data in five regions, Atlantic, British Columbia, Ontario, Prairies, and Quebec. The temporal resolution of the data set is excellent, allowing the data to be averaged by every 13 weeks to get quarterly data. The spatial resolution is not ideal, however, resulting in Prince Edward Island and New Brunswick being given the same values (Atlantic) and similarly for Manitoba and Saskatchewan (Prairies).

- The percentage of detached and semi-detached houses in private dwellings (expressed as a percentage of all private dwellings in the province)

How people travel daily, i.e., either commuting duration or distances or proximity to services and amenities, is relevant to the adoption of EVs. Relevant datasets that were initially explored include Census Canada (commuting duration) and Statistics Canada and Canada Mortgage and Housing Corporation (ten proximity measures, e.g., to grocery stores, health care, and public transit). These datasets are not collected over time, however, and thus cannot be used directly in the modeling exercise. Therefore, proxies to measure how people travel were explored with the consideration of data availability and timeframe. The percentage of detached and semi-detached houses in private dwellings is chosen to represent housing densification and the level of rural and suburban areas, which are also associated with people's proximity to services and amenities; a higher percentage could mean lower housing densification and higher levels of rural and suburban areas and further lower proximity (Pârvulescu et al., 2024). It is calculated based on the housing stock units in May 2016 and added quarterly housing completion units.

Variables representing local resource endowments:

- Public charging stations per length of public road (count per 1000 km) and the level-3 chargers as a percentage of all public chargers

Charging station availability is critical to the operation of EVs. Much has been said about 'range anxiety', which refers to a fear that EVs have limited driving range and will run out of power before reaching a destination, and how limited charging infrastructure is an impediment to EV adoption. While approximately 72% of BEV drivers and 80% of PHEV drivers are able to sometimes charge their vehicles using regular plugs or specially installed chargers at their places of residence, there remains about 20% to 30% of EVs that rely fully upon public chargers, including both level-2 and level-3 chargers (PlugShare Research, 2023). As well, virtually all EV owners need to rely on public infrastructure at times, e.g. for longer trips, although slightly half of them reply on it for a minor ratio of their charging needs with less than 10% of needs (Pollution Probe & Mobility Futures Lab, 2024). There are different ways to represent public charging station availability. Electric Charging and Alternative Fueling Stations Locator, which was set up by Natural Resources Canada in 2017 and updated regularly, has been a reliable source providing a national comprehensive map with charging and fueling station locations for different fuel options, e.g., electric, compressed natural gas, and hydrogen. The numbers of level-2 public charging stations and level-3 stations per 1000 people and per square kilometer of land area were considered initially for the current study; however, these two variables are highly correlated. Therefore, level-2 and level-3 public charging stations per length of public road and level-3 chargers as a percentage of the total are chosen to represent both public slow and fast charger availability, incorporating the concepts that public chargers are required for people to travel generally and fast chargers are desired for long-distance travel or emergency charging.

Variables representing local technological and industrial specialization:

- The supply of EVs (EV inventories per 100,000 people)

While there has been considerable media coverage about the future manufacture of EVs and related components in Canada, the most relevant representations of this construct for the study period, 2017-2022, relates to ZEVs. This study initially considered using a dummy variable (0/1 values) or specific compliance ratio of ZEVs in light-duty motor vehicles each year indicating whether ZEV mandates are in effect in a jurisdiction as a proxy for the supply of EVs, since this provides an incentive for manufacturers to first assign their available EV stocks to the provinces of Quebec and British Columbia, both of which are the only two provinces that have ZEV mandates in place (Quebec—passed in October 2016 and British Columbia—passed in May 2019) across the study timeframe. However, this variable seems to only partially capture the variation of EV supply and lacks incorporation of the global EV supply chain disruption since 2021. Therefore, EV inventory across automakers and dealerships in Canada was chosen instead, which is collected by the Dunsky Energy + Climate Advisors at seven time points across the study timeframe, i.e., December 2018, March and November 2019, February and November 2020, February 2021, and March 2022. Despite its failure in covering the whole timeframe, it has been so far the best representation of EV supplies.

Variables representing consumers and local market formation:

- Affluence level—average wages and salaries per employed capita (expressed in $1,000s)

There are various representations that reflect affluence levels, such as household disposable income, median after-tax income, and assets. Different publicly available datasets from Statistics Canada were thus explored and compared, and the variable of average wages and salaries of employed persons is chosen due to its monthly data frequency and broad time range.

- Educational attainment—the percentage of adults (25 years and over) with post-secondary certificate, diploma, or degree (expressed as a percentage)

The fraction of the population aged 25 years and older with a post-secondary certificate, diploma, or degree is used to represent educational attainment in this study. The dataset is available monthly from Statistics Canada and is further averaged to arrive at quarterly.

- Median age (expressed in years)

The median age in each province is used in this study despite the fact that the dataset is available on a yearly basis, only. Therefore, the yearly value is repeated for each of the four quarters.

- Unemployment rate (expressed as a percentage of the labour force with 15 years old and over)

Unemployment rate is another aspect of socio-demographics in this study. The dataset is based on monthly labour force data from Statistics Canada and is further averaged quarterly.

Other variables that have been found to be influential in relevant empirical studies and that are related to multiple constructs include the following three variables that deal with the energy sector:

- Retail prices for gasoline ($/litre)

The variation of retail gasoline prices depends on different factors, such as crude oil costs, taxes at federal, provincial, and municipal levels, the costs of refining and transportation, and market demand in local areas. Therefore, datasets of gasoline prices are available only at the retailer, community, or city levels. The dataset of monthly average retail prices for regular unleaded gasoline at self-service filling stations in some of major Census Metropolitan Areas (CMAs) is used and those data are further averaged quarterly. The gasoline prices in one or two or three CMAs in each province are included, specifically: Quebec and Montreal in the province of Quebec, Charlottetown and Summerside in Prince Edward Island, Saint John in New Brunswick, Ottawa-Gatineau (Ontario part), Toronto, and Thunder Bay in Ontario, Winnipeg in Manitoba, Regina and Saskatoon in Saskatchewan, Vancouver and Victoria in British Columbia. The provincial prices are determined by calculating a population-weighted average of prices in the CMAs. For example, the average retail prices for gasoline in Saskatchewan is calculated as the price in Regina*0.44 + the price in Saskatoon*0.56.

- Electricity prices (cents/kilowatt-hour—kWh)

Electricity prices in general are more complex than gasoline prices in Canada since they depend on different factors including, potentially, various regulated rates for different customers, i.e., residential, commercial and industrial users, when the electricity is used (e.g., time-of-use rates), how much electricity is used (e.g., tiered rates), and different price structures or components in utilities and provinces. Even within a province, different utilities may involve different delivery and transmission charges (the costs of delivering the electricity on power lines from generation stations to customers). The complexity makes the comparison of electricity prices across provinces over time challenging. When it comes to electricity prices in the context of this study, the rates or bills for residential customers is the most relevant aspect, and thus available datasets regarding this are explored. The annual comparative analysis of electricity prices for residential customers across major North American cities, which is conducted by Hydro-Quebec, can be regarded as a reliable source. The dataset is based on surveys of utilities in selected cities of Canada and the United States. Those selected cities' average electricity prices are used to represent the provincial prices; for example, the electricity price of 9.31 cents/kWh in Charlottetown in 2017 is used to represent the 2017 value in Prince Edward Island. For electricity prices in Ontario, values in Toronto and Ottawa are weighted by their CMA populations (Toronto-85.4% and Ottawa-14.6%) to compute an average.

- The fraction of low-carbon electricity (expressed as a % of total electricity produced)

The majority of EVs' green attractiveness is based on a lower carbon energy source. Low-carbon electricity generation—including solar power, wind power, hydro energy, nuclear power, and biomass—provides such a clean energy source. For this study, nuclear is included as lower carbon energy, i.e., electricity generation from energy sources except non-renewable combustible fuels (i.e., coal, natural gas, petroleum) is included. The dataset of monthly electric power generation by different types of energy sources in provinces and territories from Statistics Canada is used and those data are further averaged quarterly.

Table 4.5 A summary of variables or proxies (and alternatives considered) in the models

Constructs	Variables or proxies used in the current model	Alternative variables or proxies
Urban and regional visions and policies	Point-of-sale incentives (federal and provincial levels)	
Informal localized institutions	Voting preference for Green Party of Canada (proxy of environmentalism); Detached and semi-detached housing (proxy of travel pattern, specifically trip duration, which links to the third construct as well)	Disaster occurrence/The percentage of GDP from environmental and clean technology products/Canadian public opinion towards climate change-related issues (environmentalism); The share of the provincial population that resides in CMAs/Proximity to services and amenities (travel pattern, specifically trip duration)
Local resource endowments	Public charging stations per length of public road; Level-3 charger ratio	Level-2 and level-3 public charging infrastructure per 1000(10,000) people
Local technological and industrial specialization	The supply of EVs (EV inventories per 100,000 people)	Whether zero-emission vehicle mandates are into effect (proxy of vehicle supply which links to the first construct as well)
Consumers and local market formation	Affluence level (average wages and salaries); educational attainment (adults with post-secondary certificate, diploma, or degree); age (median age); employment status (unemployment rate)	
Related to multiple constructs	Gasoline prices and electricity prices	
Related to multiple constructs	Low-carbon electricity generation	

Table 4.6 Descriptive statistics of independent variables chosen for inclusion in the models

Variables	Minimum (Province-quarter year)	Maximum (Province-quarter year)	Median	Mean	Standard deviation
Average EV incentives ($1,000)	0.00 (many)	11.20 (Quebec Q1 2022)	4.25	4.71	3.38
Average BEV incentives ($1,000)	0.00 (many)	14.00 (Ontario Q1 2017-Q3 2018)	5.00	5.80	4.18
Average PHEV incentives ($1,000)	0.00 (many)	7.73 (Ontario Q1 2017-Q1 2018)	2.50	2.91	2.12
Voting preference for Green Party of Canada (%)	1.63 (Manitoba and Saskatchewan Q4 2022)	18.53 (British Columbia Q2 2019)	6.19	7.06	3.64
Public charging stations per length of public road (count per 1000 km)	0.16 (Saskatchewan Q1 2017-Q3 2018)	49.04 (British Columbia Q4 2022)	5.37	10.06	11.75

Level-3 chargers (% of public chargers)	0.00 ((Prince Edward Island Q1 2017-Q4 2019)	56.86 (Saskatchewan Q2 2022)	16.34	19.86	15.32
Low-carbon electricity (%)	13.06 (Saskatchewan Q3 2017)	99.95 (Manitoba Q3 2022)	95.26	81.25	28.06
Electricity prices (c/kWh)	7.07 (Quebec 2017)	17.78 (Prince Edward Island 2022)	13.03	12.63	3.34
Gasoline prices ($/litre)	0.83 (Manitoba and New Brunswick Q2 2020)	2.14 (British Columbia Q2 2022)	1.22	1.28	0.27
EV inventories (per 100,000 people)	0.00 (Prince Edward Island Q1 2017-Q4 2018)	36.19 (Quebec Q1-4 2021)	6.44	9.50	9.15
Unemployment (%)	4.03 (Quebec Q4 2022)	14.43 (Quebec Q2 2020)	6.37	6.98	2.13
Wages and salaries per employed capita ($1,000)	9.47 (Prince Edward Island Q1 2017)	16.09 (Ontario Q4 2022)	12.20	12.45	1.41
Postsecondary education (%)	54.96 (New Brunswick Q1 2017)	69.04 (Ontario Q4 2022)	61.94	62.21	3.72
Detached and semi-detached houses in private dwellings (%)	45.17 (British Columbia Q4 2022)	75.34 (Saskatchewan Q1 2017)	70.01	63.83	11.23
Median age	37.20 (Saskatchewan Q1-Q4 2017)	46.20 (New Brunswick Q1-Q4 2021)	42.10	41.35	2.81

4.4.1.3 Model specification

In order to model and interpret how the above independent variables correlate with the registrations of EVs across provinces and over quarterly basis in Canada, generalized linear models (GLMs) with gamma distribution are employed. As mentioned in sub-section 4.4.1.1, the registrations of EVs are positive continuous data (except for two observations of zero) and their distributions align with gamma distributions. After data visualization of the relationships between the dependent and the independent variables through scatterplots, it is evident that they demonstrate non-linear relationships. Therefore, generalized linear models with gamma distribution and log-link are most appropriate. The mean of the dependent variable, μ_i, is related to the independent variables as the following formula. The log-link also enables a better interpretation where the effects of the independent variables are multiplicative.

$$\log(\mu_i)$$
$$\text{where } \mu_i = e^{b_0 + b_i * x_i}$$

The GLM, unlike linear regression models with strict assumptions, allows dependent variables with error distributions that are not normal distributions. However, errors and observations still need to be independent. GLM "does not assume linear relationships between dependent and independent variables, but instead generalizes the linear regression by allowing linear relationships between the transformed expected dependent variable in terms of a link function and the independent variables" (Salinas Ruíz et al., 2023, p. 48). It thus consists of “a random component, which specifies the probability distribution of the dependent variable, and a systematic component, which suggests how the expected value of the dependent variable relates to the linear combination of independent variables” (Dunn & Smyth, 2018, p. 211).

As for regression parameter estimation, maximum likelihood estimation procedures are used; this is different than ordinary least squares, which is used in linear regression models. This study considers both spatial and temporal variation (i.e., observations for multiple jurisdictions over multiple time periods) and the spatial-temporal unit of analysis is the province-quarter year. This opens up the possibility of violating the independence assumption due to autocorrelation—known as serial correlation of observations or errors between two successive time intervals—something that will require attention in the development and interpretation of the model.

Because EV registrations, BEV registrations, and PHEV registrations are individually modelled, each modelling exercise begins with a whole set of 13 independent variables. Multicollinearity is then checked in the data through the applications of variance inflation factor (VIF) and (partial) correlation—two complementary techniques. Multicollinearity could reduce the statistical significance of independent variables and lead to inaccurate parameter estimates. A large VIF on an independent variable indicates it is highly correlated to the other variables with the need to adjust or possibly eliminate variables; its value greater than 10 is often considered indicative of problematic multicollinearity. Correlation between two variables directly measures the direction and strength of their linear relationship and partial correlation also measures the same relationship but with the consideration of the influence of other variables in the model.

Based on the above examination, multicollinearity was found in the percentage of detached and semi-detached houses in private dwellings and also for low-carbon electricity. The former one has VIF value greater than 10 and shows statistically high associations with other variables, i.e., voting preferences for Green Party, electricity prices, and postsecondary education. Low-carbon electricity demonstrates statistically high association with electricity prices. Therefore, the percentage of detached and semi-detached houses in private dwellings and low-carbon electricity were dropped.

To decide whether other variables should be dropped for the final models, stepwise selection of the variables for regressions is used including both forward and backward selection steps; specifically, it started with the full model with 11 variables and iteratively added or removed independent variables based on the Akaike Information Criterion (AIC). I chose the set of variables for final models that provided the lowest AIC and still allowed for straightforward interpretation. Interactions between the variables are also considered in selection processes through adding one pair interaction at a time to check the changes of AIC. By including the interactions between charging station density and postsecondary education and between purchase incentives and wages and salaries two pairs, the model fit improved significantly.

To estimate the overall fit of models, three measures are utilized: deviance reduction, AIC, and residual analysis. Deviance reduction, calculated as the difference between the null deviance and the deviance of the fitted model, represents how much better the independent variables explain the variability in the dependent variables relative to null models. With respect to AIC, models with smaller AIC value represent better fit. Finally, residual analysis is also important because autocorrelation is intuitive for this dataset, which could violate the model assumption of independence and indicate model misspecification. The Durbin-Watson test statistic and autocorrelation function plots are used to test residual and observation autocorrelation. The test statistic value below 1.5 or above 2.5 could cause concern for positive autocorrelation (i.e., the dependent variable has a positive influence on itself over time) or negative autocorrelation (Azami et al., 2020; Dodge, 2008). Autocorrelation function plots, which depict correlations between the observation at the current time spot and the observations at previous time spots, are used for further checking.

EV registrations, BEV registrations, and PHEV registrations are individually modelled in R using the package of “glmm” and “glmmTMB”, which are both used to fit generalized linear mixed model but “glmmTMB” enables various extensions including autocorrelation (Brooks et al., 2017). The package of “glmm” were first used in the three models and autocorrelation is not identified in the PHEV registration model. The package of “glmmTMB” was further used in the other two models and autocorrelation is not identified in the total EV registration model. However, positive autocorrelation is found in the BEV registration model. It is intuitive due to the overall upward trends of BEV markets and some independent variables (e.g., wages and salaries, charging infrastructure density, and postsecondary education).Therefore, province panel-specific AR1 (autoregressive of order 1) autocorrelation structure is added into the final BEV model to control the autocorrelation, which allows observations within the same province correlated over six years, with the strength of correlation decreasing as the time lag between observations increases (for example, the correlation of BEV registrations in Ontario in 2017 and 2018 is stronger than the correlation of the registrations in 2017 and 2021). This statistical approach explicitly models the correlation between observations within the same province over time, accounting for potential variations of autocorrelation structures across provinces. However, only few studies have considered this aspect in their modelling, e.g., Khatua et al. (2023). Many studies (Table 4.1) have included time as a fixed effect (a categorical variable) to control for time-related variation in the observations. However, this strategy of addressing autocorrelation does not explicitly model the correlation.

4.5 Results: Summary and Interpretation

4.5.1 Spatial and Temporal Pattern of the Transition to EV in Canada

New EV registrations generally demonstrate an upward trend over time, as expected, but with distinct spatial variation across the seven jurisdictions. There was also temporal fluctuation over six years, as illustrated in Table 4.3 and Figure 4.3. The three provinces of British Columbia, Quebec, and Ontario led as the top three provinces in new EV registrations per 1000 capita, significantly outpacing other jurisdictions. However, new EV registrations, which reflect new additions, have dropped sharply in Ontario since quarter 2 2018. This drop was temporary and the number bounced back gradually after the quarter 2 of 2020. New EV registrations in the seven provinces rose during quarter 2 2019 with British Columbia and Quebec having large increases relative to the other five. During quarter 3 2021, new registrations per 1000 capita in Prince Edward Island surpassed those in Ontario, temporarily elevating it to the number three position.

When EV registrations are separated out for BEV versus PHEV—see Figures 4.4 and 4.5—a few new insights emerge. Recall from earlier that approximately 65%-85% of all EV registrations in the quarter 4 of 2022 were BEV—indicating the battery-only vehicles constitutes a large majority of the market. British Columbia led in BEV registrations among the seven provinces, while Quebec held the largest number of PHEV registrations in Canada. BEV registrations showed relatively steady increase, similar with the general trend of EV registrations, whereas an overall upward trend of PHEVs was not apparent.

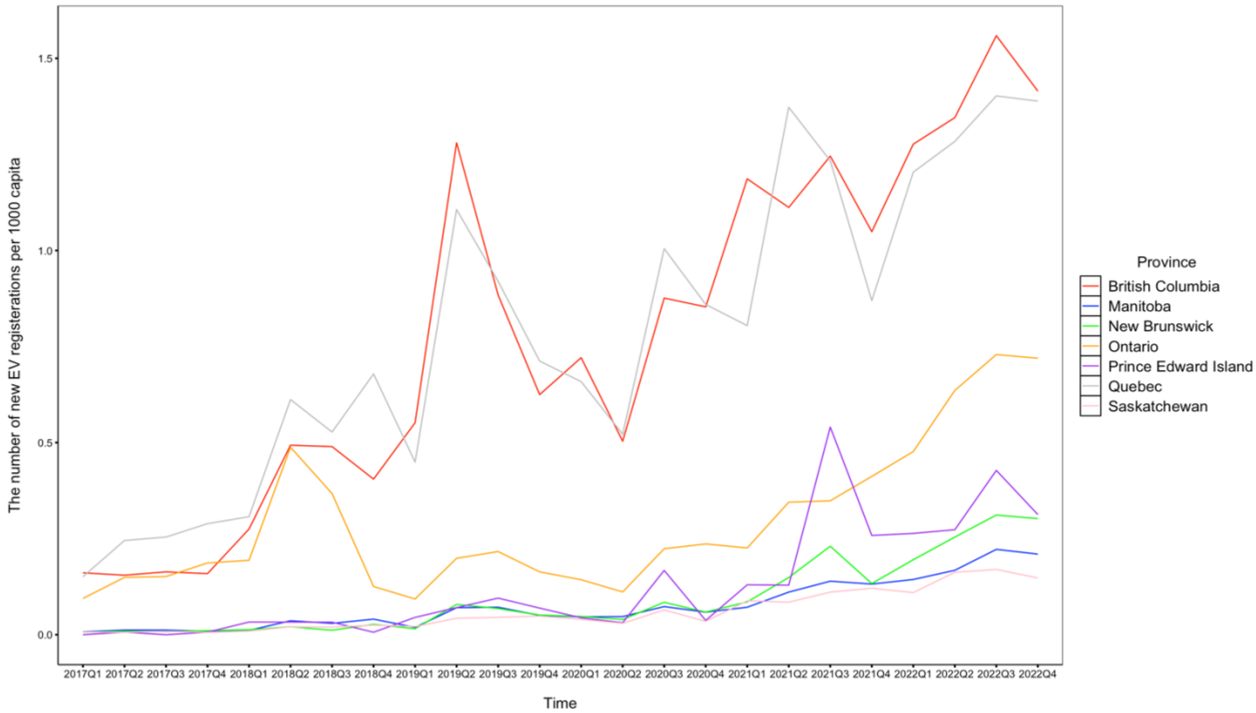


Figure 4.3 The number of new EV registrations per 1000 capita in the seven Canadian provinces between 2017 and 2022

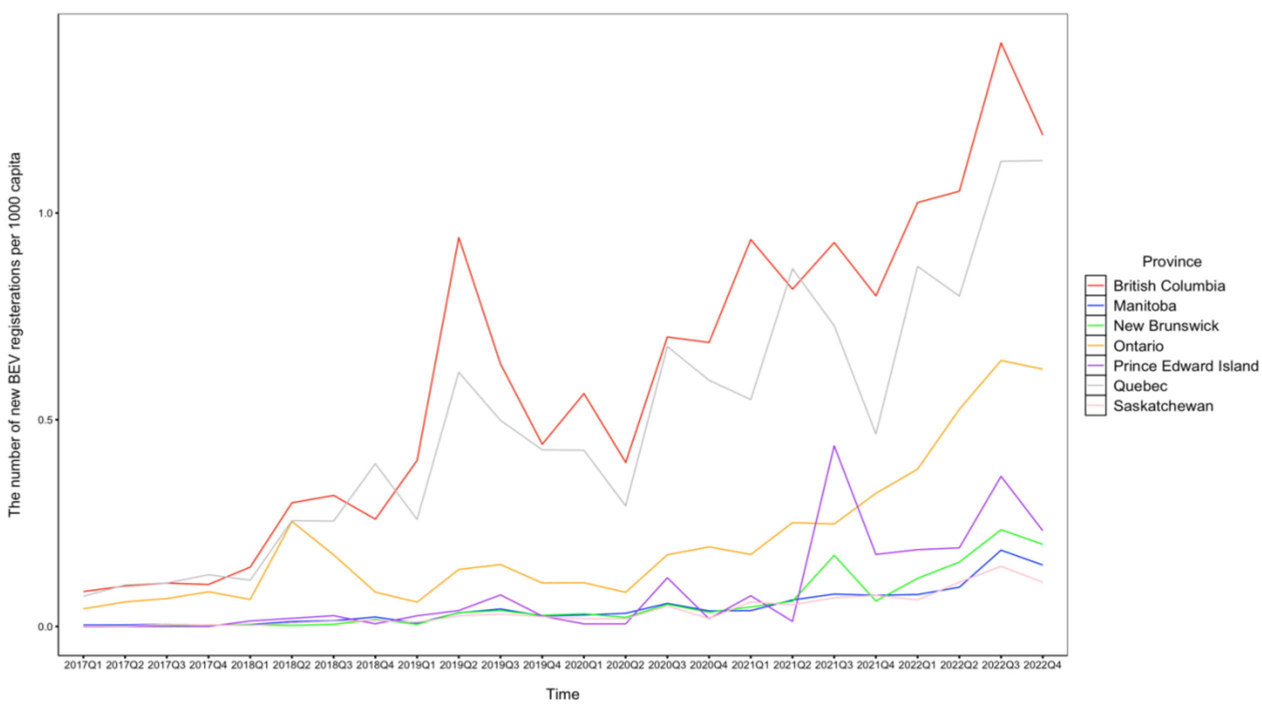


Figure 4.4 The number of new BEV registrations per 1000 capita in the seven Canadian provinces between 2017 and 2022

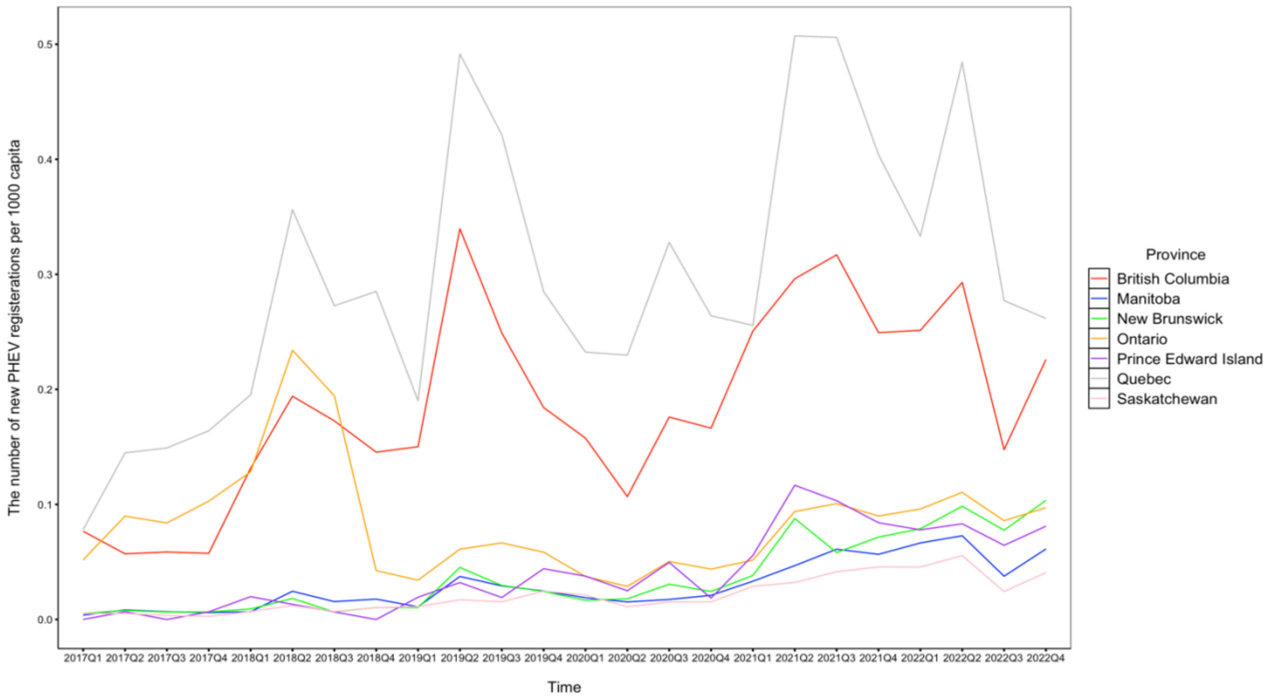


Figure 4.5 The number of new PHEV registrations per 1000 capita in the seven Canadian provinces between 2017 and 2022

4.5.2 Modelling Results

Each of the three models consists of 168 observations and in each case the deviance has been reduced by 75% to 95% compared to relevant null models (i.e., intercept-only models), indicating that the chosen independent variables have significant effect on the model fit, and thus on explaining the spatial-temporal pattern of EV adoption across Canada. Furthermore, the Durbin-Watson test statistic, which is used to test for autocorrelation in the residuals from a statistical model, has values between 1.5 and 2.5 in all three models. This indicates that there is no or little autocorrelation in the residual of each model, which is a favorable result for illustrating the independence of observations. To summarize, the model assumption of independence is not violated and the overall model fit is good.

The modelling outcomes are outlined in Table 4.7, showcasing the effect of each independent variable on the dependent variable, holding other independent variables constant. Among all variables that are included within the final models, variables that represent four of the five geography-of-transition constructs are statistically significant. These include urban and regional visions and policies (EV purchase incentives), informal localized institutions (voting preference for Green Party), local technological and industrial specialization (EV inventories), and consumers and local market formation (wages and salaries and percentage of postsecondary education). Two additional variables, gasoline prices and electricity prices, are also statistically significant. By contrast, the two variables, charger density and fast charger ratio, that represent the construct of local resource endowments are not statistically significant at the level of 5%. The interaction term between wages and salaries and EV purchase incentives is statistically significant and negative, implying the nuanced interactions among constructs.

4.5.2.1 Variables related to energy prices

Among all the significant variables, gasoline price variations are the most influential factor affecting new EV registrations across these seven Canadian jurisdictions over the six-year period from 2017 to 2022. As a reminder in the earlier sections, the two variables in this section can map onto multiple constructs. This observation aligns with the conclusion drawn by Javid and Nejat (2017), who also identified gasoline prices as the most significant determinant influencing EV adoption in California counties. The coefficient for this variable, using the total EV registrations model, indicates that the number of EV registrations per 1000 people will be roughly 4 times higher for a one dollar per litre increase in gasoline prices or will increase by roughly 16% for a 10 cents-per-litre increase in gasoline prices. The magnitude of effect on BEV and PHEV registrations is similar, with slightly higher influence on BEV registrations. This result is consistent with the result of a cross-country study which identified more apparent impacts of gasoline prices on BEV demands (Li et al., 2017).

The fluctuation in gasoline prices over time is more noticeable than provincial differences, especially the drop of roughly $0.50 per litre between the second quarter of 2019 and the second quarter of 2020, coincident with the emergence of the COVID-19 pandemic, followed by a subsequent surge of over $1 per litre two years later (Appendix B). The volatility appears to be mainly attributed to the global crude oil price collapse in the early days of the pandemic due to reduced demand, followed by economic recovery with rebounded demand. Singular events such as Hurricane Ida (starting on August 26, 2021) and ongoing events, such as the Russia-Ukraine conflict (starting on February 24, 2022), also have affected production and inventories (Kalibrate Canada, 2021, 2022c). According to Figure 4.6, the surge of crude oil prices and refining margins contributed to the majority of increase in Canadian average gasoline prices in 2021 and 2022 compared to 2011 to 2020. The other important component, which accounts for nearly 30% of Canadian gasoline price in 2022, is taxes that are Canada-specific influences on gasoline prices. Carbon tax is noteworthy for its increase by roughly 2.2 cents per litre in the carbon tax component of gasoline prices in both 2021 and 2022 among six provinces in this study (except Quebec which prices carbon through a cap-and-trade program instead of taxes with the prices embedded in gasoline prices). By the end of this study time period, quarter 4 2022, carbon taxes in those six jurisdictions reached 11 cents per litre. Some municipalities' additional taxes are also substantial, such as in Vancouver (18.5 cents per litre), Victoria (5.5 cents per litre), and Montreal (3 cents per litre), which helps to explain why the province of British Columbia has the highest gasoline prices in Canada. The provincial differences of HST/QST (e.g., HST in Atlantic provinces is 15% and in Ontario is 13%), which are calculated as a percentage, are also amplifiers for price volatility since higher prices would increase the amount of taxes charged (Kalibrate Canada, 2022a).

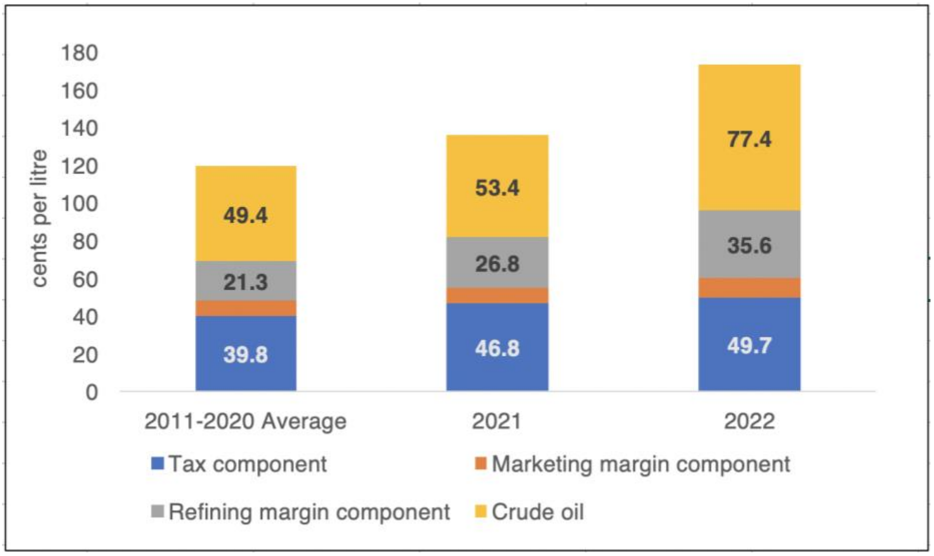


Figure 4.6 Canadian average gasoline price components (cents/litre)
2022 versus 2021 versus previous 10-year average

Data are from (Kalibrate Canada, 2021, 2022b)

Compared to gasoline prices, electricity prices have statistically significant but relatively minor effects on the number of EV registrations. This result is aligned with previous studies that generally found electricity prices have a smaller impact than gasoline prices and are sometimes statistically insignificant. In the current study, the effect is negative and is only statistically significant on total EVs and PHEVs. Interpretation of the coefficient for EVs (PHEVs) is as follows: With a one cent per kilowatt-hour increase in electricity prices, the number of EV (PHEV) registrations will fall by 6(7)%. Among the seven provinces, Quebec has the lowest electricity prices while Prince Edward Island has the highest prices. The difference of roughly 10 cents per kWh helps to explain the low uptake of EVs, especially notable for PHEVs, in Prince Edward Island. The seven jurisdictions did not demonstrate huge temporal variation within the six years, except for the province of Ontario, which experienced volatile electricity rates affected by different government announcements, e.g., Ontario Electricity Rebate between 2017 and 2019 and temporary electricity rate relief shifting from time-of-use rates to a fixed price of 10.1 cents/kWh during the COVID-19 emergency in 2020 (Ontario Energy Board, 2020, 2024).

4.5.2.2 Variables related to the Geography of Transitions constructs

Urban and regional visions and policies is one of the statistically significant constructs. This construct is represented by the magnitude of the government financial incentives to purchase EVs. The model results indicate a strong positive association with EV demand at a significance level of 0.1%; if EV incentives rise by $1,000, total number of EV registrations per 1000 people is estimated to be roughly two times. In terms of breakouts by BEVs versus PHEVs, registrations of BEVs are expected to 2.2 times when the incentives increase by $1,000 for most available BEV models; while PHEV registrations are predicted to be nearly 2.5 times for the same increase purchase subsidy. However, the significant and negative coefficients of the interaction terms between incentives and wages and salaries two variables in the three models suggest that as affluence level increases, those effects of incentives on EV registrations decreases; i.e., the effect of incentives on EV registrations being less pronounced at higher affluence levels. It is translated that if EV incentives rise by $1,000, total number of EV registrations per 1000 people is estimated to increase by 87%. In terms of BEV and PHEV registrations, the changes will be roughly 2 times and 2.3 times. Financial incentives available at the time of purchase are thus found to be effective in stimulating EV demand, especially for PHEVs which enable consumers to have the convenience of a gas engine that can also benefit from electrification.

The interactions of variables have only been considered in very few studies (Table 4.1). For example, Clinton and Steinberg (2019) investigated how purchase incentives, charging stations, and fuel costs interact with a Tesla indicator and found no differences in Tesla and non-Tesla buyers in response to those factors between 2011 and 2015 among selected American states. Interactions among constructs have also not been explicitly pointed out or elaborated in the geographical transition framework, rather as 'geographical interactions within places'. However, the interactions among constructs, especially the interactions between incentives and affluence levels in affecting EV demand, have been questioned and simulated within a specific geographic focus. Low-income and middle-income consumers have been found to have greater responsiveness to EV purchase incentives compared to high-income consumers in California (Muehlegger & Rapson, 2022). The interaction identified in this study echoes this finding and implies that an EV purchase incentive program that considers affluence heterogeneity could be more cost-effective (i.e., more increased EV registrations with less government costs) and more equitable (i.e., less influent consumers with more affordability of EVs due to additional incentives) compared to the current vehicle performance-based design of incentives program, which is aligned with the finding from the work of DeShazo et al. (2017) in California.

In the current study, the informal localized institutions, which is captured in this study by the voting preference for Green Party as a representation of societal level of environmentalism, also indicates positive and statistically significant impact on EV uptake. The number of EV registrations per 1000 people is projected to rise by 6% when people's voting preference for Green Party increases by one percentage point. The estimate is particularly high for BEV registrations (6% increase) as compared to PHEV registrations (4% increase). This result further reflects the importance of norms, values, and beliefs underpinned by people's pro-environmental purchase behaviours. Particularly, it corroborates the work of Brückmann et al. (2021) who observed a significant positive effect of respondents' preferences for green parties on BEV adoption in Switzerland; on average, individuals who express a preference for green parties are 15% more likely to adopt BEVs compared to those who express a preference for Swiss People's Party, considered as a far-right party. The voting inclinations towards the Green Party of Canada reveal apparent disparities among regions and fluctuations over time. As a reminder, the available data are by regions and thus Manitoba and Saskatchewan (part of Prairies) have the same values, as do New Brunswick and Prince Edward Island (part of Atlantic). British Columbia has the highest percentage among five regions, followed by Atlantic region, while Prairies has the lowest value. There is a noticeable spike in the second quarter of 2019 for every region, right before the 2019 federal election in October rising from the beginning of 2019, indicating a gradual increase in support for the Green Party in Canada. It could reflect the heightened public focus on and increasing popularities of climate change, corresponding global climate change strikes in Canada and across the world, the leader of the Green Party's greater number of climate change messages to the public, and people's greater engagement with climate change messages in social media (Boulianne et al., 2021). However, the voting preference went down later in the study period, which was probably attributed to the change in the leadership of the Green Party.

The construct of local resource endowments is represented as two variables related to EV charging stations: public charger density and the percentage of public charging stations that are level 3 (fast), is the only construct to not be statistically significant for the total EV registrations. This is inconsistent with most other studies, which concluded strong and positive influence of charging infrastructure availability on EV adoption. However, this result is aligned with Brückmann et al. (2021), who also identified public charger density as not being significant. The result might be largely driven by the fact that at least 70% of charging currently takes place at home and overnight in Canada, which to some extent reduces the vital role of public charger availability in driving EV demand. That said, as shown in Appendix B, except for Manitoba and Saskatchewan, Canada demonstrates increasing numbers of public charging installed over the studied period, especially after the May of 2019 when Natural Resources Canada introduced the ZEVIP to provide funding for extension of the EV charger network in locations including workplaces, public areas, and multi-unit residential buildings. Quebec has an abrupt increase of roughly 4 times more public chargers in the quarter 3 of 2019 compared to quarter 2, which is mainly contributed by the Electric Circuit, the largest public charging network in the province, and the Flo, one of the biggest networks of EV charging stations in North America. In terms of the ratio of fast chargers in total public chargers, Saskatchewan leads its way among all provinces with over 50% since the quarter one of 2020 and there is also a surge of fast chargers in Manitoba at the same time. All the increases were from newly installed fast chargers of Tesla in January 2020.

The construct related to local technological and industrial specialization is based on the availability of EV supply or inventories within the studied timeframe. EV inventory positively influences its demand with a significant effect observed at the level of 5%. Specifically, the model suggests that an increase of one additional vehicle per 100,000 people will increase the number of EV registrations per 1000 people by 2%. Notably, registrations for BEVs are more sensitive to supply changes compared to PHEVs. The EV inventories tend to be unevenly distributed between provinces with the majority of them in Quebec and British Columbia. It can further emphasize the significance of provincial ZEV mandates that drive automotive manufacturers to prioritize Canadian EV markets in these two provinces in order to meet the sales' criteria of ZEVs. The availability heterogeneity across provinces is also reflected by the number of EV automakers and models to consumers; consumers in Atlantic provinces and Manitoba only had less than 10 model choices in 2022 compared with over 20 options in Quebec, British Columbia, and Ontario (Dunsky Energy + Climate Advisors, 2022). The availability of EVs also varied significantly over time. The increase of Canadian inventory levels by approximately 75% in November 2020 compared to November 2019 suggest that automakers actively respond to the surge of EV demand (Dunsky Energy + Climate Advisors, 2021). However, if we roughly compare the number of EVs available across dealerships and the number of EV registrations within the same province and timeframe, the overall inventory levels appear to be inadequate. This challenge is further intensified by the sharp reduction of inventory levels in dealerships across the country in March 2022, which mirrors global supply chain disruptions in the automotive industry that are attributed to geopolitical tensions, regional lockdowns, and more importantly, global shortage of semiconductors. The shortage due to chip plant closures and surging demand has been estimated to account for over 60% of production deficit (Ducker Carlisle, 2022). Despite a general inventory reduction across Canada in 2022, inventory from North American automakers, e.g., Ford, Chrysler, and Chevrolet, seems to be less susceptible to global disruptions compared to others with more production and assemblies overseas (Dunsky Energy + Climate Advisors, 2022).

The final construct, consumers and local market formation, are also significantly associated with EV demand, especially regarding education and affluence levels among the four variables included in the final models. One percentage increase in postsecondary education is projected to boost EV registrations by more than 15%, with slightly higher effects observed for BEVs (15%) than PHEVs (11%). Additionally, if wages and salaries per employed capita rise by $1,000, there will be an estimated 36% increase in the total number of EV registrations per 1000 people on average. Apparently, this increase has a more pronounced effect on BEV registrations than on PHEV registrations. This disparity between BEVs and PHEVs is aligned with the results from Guo et al. (2020) who also found disposal incomes by capita in Chinese cities are significantly related to EV sales and BEV sales and its effect on BEVs is more salient. It is, however, worth nothing that the affluence level does not merely directly influence EV registration, but also change the positive influence of purchase incentives on EV registrations.

Table 4.7 Generalized linear modelling with gamma distribution for EV, BEV, and PHEV registrations

	EV registration per 1000 capita		**BEV registration per 1000 capita**		**PHEV registration per 1000 capita**	
	Coefficient (Std.error)		Coefficient (Std.error)		Coefficient (Std.error)	
Incentives ($1000)	1.955	***	2.186	**	2.440	***
	(0.022)		(0.260)		(0.202)	
*Wages and salaries ($1000) (interaction)	0.958	**	0.946	**	0.949	**
	(0.015)		(0.020)		(0.016)	
Percentage of Green Party vote preferences (%)	1.058	***	1.060	**	1.041	***
	(0.014)		(0.025)		(0.010)	
Percentage of low-density housing (%)						
Public level-2 and level-3 charging stations per length of public road (numbers per 1000 km)	1.236		1.771		1.237	
	(0.186)		(0.323)		(0.131)	
*Percentage of postsecondary education (interaction)	0.997		0.991		0.997	
	(0.003)		(0.005)		(0.002)	
Percentage of level-3 chargers in all public chargers (%)			1.014			
			(0.009)			
Vehicle inventory per 100k capita	1.017	*	1.071	***	1.026	***
	(0.008)		(0.019)		(0.006)	
Gasoline prices ($/litre)	4.274	***	3.47	**	3.610	***
	(0.217)		(0.389)		(0.142)	

Electricity prices (c/kWh)	0.944	**	0.990		0.934	***
	(0.017)		(0.046)		(0.012)	
Percentage of low-carbon power generation (%)						
Wages and salaries ($1000)	1.363	**	2.148	***	1.199	***
	(0.066)		(0.178)		(0.034)	
Percentage of postsecondary education (%)	1.164	***	1.145	*	1.113	***
	(0.026)		(0.056)		(0.018)	
Median age			0.953			
			(0.061)			
Percentage of unemployment (%)						
Intercept	0.000	***	0.000	***	0.000	***
	(1.386)		(4.039)		(0.94)	
Panel-specific AR1 autocorrelation structure?	No		Yes		No	
AIC	-406.5		-579.1		-705.8	
Null Deviance	343.2		446.3		288.1	
Residual Deviance	55.5		24.8		67.6	
Durbin-Watson Test statistics	1.567		2.064		1.653	

Note: *p*-value >= 0.05 (-), *p*-value < 0.05 (*), *p*-value < 0.01 (**), *p*-value < 0.001 (***).

4.6 Concluding Remarks

The transition towards widespread adoption of EVs in Canada has been progressing steadily, albeit somewhat slowly. The EV percentage of new passenger vehicle registrations was 8.17% in 2022, growing from 0.18% a decade ago. The upward trend remained, even during the COVID-19 pandemic when the total number of vehicle registrations declined in 2020. However, compared to new EV registrations of 14% at the global level in 2022, the figure in Canada was still much lower. From 2017 and 2022, the share of new registrations for both large EVs and BEVs within the total EV registrations steadily grow, reaching approximately 62% and 80%, respectively, by 2022.

The transition toward widespread adoption of EVs has also been uneven spatially, with dramatic regional differences. More specifically, British Columbia and Quebec are two provinces that are leading the way and are far ahead of the rest of Canada. British Columbia leads with the highest rate of EV registrations at about roughly 1.6 units per 1000 people, followed by Quebec with 1.4 units. In contrast, Manitoba, New Brunswick, and Saskatchewan have the lowest rates among the seven provinces, each with fewer than approximately 0.3 units per 1000 people. British Columbia also ranks first in Canada for BEV registrations, while Quebec holds the largest number of PHEV registrations.

The temporal and spatial variations across Canada were modeled in order to expose key explanatory factors and better understand transition processes. The modeling exercise drew on the “geographical transition framework” and thus included five influential place-specific constructs—urban and regional visions and policies, informal localized institutions, local resource endowments, local technological and industrial specialization, and consumers and local market formation. Each of these constructs was represented by one or more explanatory variables. The model also included a small number of other explanatory variables that have been included in empirical studies on EV diffusion, including lower carbon energy generation, gasoline prices, and electricity prices. This latter set do not map directly onto any one of the five constructs, but instead relate to multiple constructs. The modeling results highlight the importance of several key influences.

First, energy prices, especially fluctuation in at-the-pumps gasoline prices exert considerable influence. During the study period, 2017 to 2022, gasoline prices varied from a low of 0.83 $/litre in Manitoba and New Brunswick in quarter 2 of 2020 to a high of 2.14 $/litre in British Columbia in quarter 2 of 2022. While provincial/local decisions affect gasoline prices through taxation (and there are substantial regional differences in gasoline excise or carbon tax), it was primarily global markets and events that drove temporal variations in the price that Canadians paid during the study period. The volatility and uncertainty of gasoline prices has been a strong motivator for the transition to EVs in Canada; when and where gas prices are relatively high, EV adoption is also higher. This further corroborates the close relationship between gas prices and EV interest globally (Google Trends, 2024). Nonetheless, the normalization of gasoline prices after the peak in 2022 creates concern about how to maintain the EV momentum from policy directions. While electricity price is also a significant explanatory variable, it was found to have relatively minor and negative effects on the number of new EV registrations, i.e., when and where electricity prices are low, EV adoption is relatively high.

Another variable of importance that is affected by both global processes (production and trade) and local decisions (ZEV mandates) is the EV inventory that is available to Canadians in any given region at a particular point in time. This variable is related to local technological and industrial specialization. The modeling results demonstrate that EV inventory positively influences EV demand, especially for BEVs. While EV options have increased in Canada, they remain unevenly distributed with the best availability in Quebec and British Columbia.

The size of government financial incentives to purchase EVs is also playing an important role in Canada’s transition to EVs. The variable reflects regional visions and policies, and modeling results indicate a strong positive association with EV demand; if EV incentives rise by $1,000, total number of EV registrations per 1000 people is estimated to roughly double.

Also, the informal localized institutions, which is captured in this study by the voting preference for Green Party as a representation of societal level of environmentalism, also indicates positive and statistically significant impact on EV uptake. This reflects the importance of norms, values, and beliefs underpinned by people's pro-environmental travel or purchase behaviours, as has been found to be important in studies of other jurisdictions.

Finally, two socio-economic variables—namely income and education—were found to be positively associated with EV uptake. This was, as expected, given the findings of other studies and also the higher prices of EVs and the complex ways in which EVs map onto sustainability and mobility needs and wants.

Interestingly, the availability of public charging infrastructure was not identified as a significant factor in explaining the spatial-temporal patterns of EV registrations. This seems to be counterintuitive since some argue that the lack of publicly available charging stations has been one of the top barriers for purchasing EVs in Canadians' mind (Volvo Car Canada Limited, 2024) and has been the top concern in the stage of post-purchase as well (PlugShare Research, 2023). The current study implies that, while public charging availability is beneficial, it does not appear to explain variations of EV registrations across time and space, in Canada.

Beyond the insight of individual variables, there is evidence that interactions are important. The interaction between purchase incentives and income is particularly critical in understanding the nuanced spatial and temporal variation. For example, despite New Brunswick and Prince Edward Island with lowest affluence levels among the seven provinces, the introduction of purchase incentives in 2021 in the two provinces has had a more pronounced influence to increase new EV registrations compared to others provinces with purchase incentives. Similarly, although Ontario cancelled the provincial incentives in 2018, its relatively higher income, weakened the impact of this decision.

EV purchase incentive programs that provide different amounts for different affluence levels within and between provinces are suggested, especially to leverage New Brunswick and Prince Edward Island; In August 2022, British Columbia became the first Canadian jurisdiction to tie eligibility for EV incentives to individual income levels (British Columbia Government, 2022). Those incentives are particularly more compelling for those who may not be ready to commit to a full EV, but instead choose PHEVs.

The modeling results provide food for thought on policy options for supporting and accelerating the transition to EVs. Fuel taxes, carbon taxes, and electricity prices are tools that have been found to have strong influence on EV adoption in Canada. Also, ensuring a consistent and sufficient supply of EV inventory is crucial for sustaining the upward trend of EV adoption, especially for BEV adoption. Reducing disparities in EV inventory distribution among provinces can help alleviate the lock-in of regional discrepancies, underscoring the importance of federal and provincial government ZEV mandates to incentivize manufacturers. Positive signals for future development exist; Ontario, as the only jurisdiction in North America with five major automakers building vehicles: Stellantis, General Motors, Ford Motor, Honda, and Toyota, has increasing announcement of new EV assembly and battery plants. However, potential changes of political leadership and decision-making in both provincial and federal levels result in uncertainty about the development of ZEV mandates and EV-related investment in general.

Perhaps most importantly this study further underscores the significant role of geography in uncovering the transition of low-carbon innovations, not only through observed transition consequences and patterns but more importantly the underlying processes and contextual conditions that contribute to the patterns. The geographical transition framework, which conceptualizes those place-specific conditions in an integrated manner, serves as a useful tool in understanding what drives and hinders the ongoing transition to EVs in Canada. It not only generates an overview of EV transition in Canada with the consideration of five critical geography-of-transition constructs, but it also provides insights into the geography unevenness of EV transition in Canada and why it occurs.

However, some challenges in the application of the geographical transition framework also appear, which could be worthy of further investigation. For one, this framework to some extent understates the importance of interrelations among constructs in sustainability transition. The critical role of gasoline prices and electricity price highlights specific variables that conceptually reflect multiple constructs can be particularly important in specific domains or transition contexts. The interaction between urban and regional visions and policies and consumer and local market formation in this study is also noteworthy for nuanced understanding and policy relevance of transitions. On the other hand, this framework tends to be a spatial model with a secondary temporal dimension rather than a space-time model that has both spatial and temporal emphasis. The salience of volatile gasoline prices and vehicle supply chain disruption in this study indicates the significant impacts of events that happen at some point in time in the exogenous or global environment outside Canada (e.g., geopolitical shifts and COVID-19 pandemic) on the transition to EVs within Canada, which is not explicitly captured by the five constructs. In this regard, it manifests that place-specific settings and geographical relations across scales are inherently intertwined and a space-time model can help to uncover them simultaneously.

In conclusion, the findings illustrate the representation of the five constructs through different variables has been satisfactory, although results are sensitive to variables' different representation in the modelling process, which means the conceptualization and operationalization of the constructs tend to be adequate. However, several variables can be further scrutinized in future research. EV inventory, which represents the construct of local technological and industrial specialization, can be further distinguished into different types (e.g., PHEVs/BEVs, Tesla/non-Tesla, and the number of inventories across different models) or for a more nuanced understanding. For example, Tesla model 3 and model Y are two popular BEV models in Canada with high registration numbers, whereas Tesla uses factory-order business model for potential customized vehicle specifications with little inventory in dealerships. The percentage of detached and semi-detached houses in private dwellings, regarded as the proxy of mobility practices within the construct of informal localized institutions, was less satisfactory and was overgeneralized in the provincial level due to its high associations with other variables and its high value for Prince Edward Island that is a small province. This reminds us that modelling transition as it is occurring is complex and that quantitative approaches cannot fully capture its complexity. Therefore, the contextualization of constructs in specific domains (e.g., EVs and solar PV) and geographical locations and units are necessary for enriching empirical interpretation and theoretical solidness.

Chapter 5 Changes in Consumer Perceptions and Likelihood to Purchase EVs: A Comparison between 2020 and 2023

5.1 Chapter Outline

This chapter reveals the second research component of this thesis which aims to understand and assess changes of consumers' likelihood and perceptions to purchase EVs in a Canadian municipality, Waterloo Region, between 2020 and 2023. It demonstrates the research approach by using DOI as a guiding framework to segment consumers into five groups based on their actual purchase behaviour or interest in/likelihood of EV purchase and look at changes among those segments over time. It then reviews existing empirical studies on EV adoption with emphasis on attitudes and perceptions to identify the main variables that influence EV purchase intention and are included in the local consumer surveys in 2020 and 2023. It clearly outlines the context of the two surveys, including the research setting in Waterloo Region, the methods used for data collection and sampling, and the questionnaires and measures involved. The differences in consumers' likelihood to purchase EVs and their perceptions over time and across groups are further analysed. How variables related to perceptions contribute to consumers' general interests in EVs in 2020 and 2023 are also modelled and interpreted. The results help understand consumer preferences through the lens of longitudinal dynamics. This chapter offers further insights into policy design and implementation, along with communication strategies that account for the differences across consumer groups and helps to deepen an understanding of the ongoing transition to EVs from a micro level and local municipal context.

5.2 Introduction

Chapter 4 has identified several influential stimuli or stressors (e.g., gasoline prices, purchase incentives, and environmentalism) that help explain Canada's transition to EVs at a national scale and at an abstract lens. However, local contexts reveal unique opportunities and challenges that can impact those influential constructs and further the acceleration of the transition to EVs. Some municipal governments (e.g., Victoria and Montreal) have implemented local fuel taxes on retail gasoline prices. Local economic landscapes, characterized by differing dominant sectors and educational and income levels, play a crucial role in shaping green technology development. Local governance and community engagement strategies allow the realization of sustainable efforts for local needs, for example, different municipalities have different numbers of applications and varying implementation of federal EV-related projects, e.g., Zero-Emission Vehicle Awareness Initiative and ZEVIP. Also, despite multiple shifts in societies towards the transition to EVs (e.g., policies and technologies and industrial development), Canada is still at the beginning of an acceleration stage, as pointed out in section 1.4.

Additionally, those influential constructs are examined from a societal level and a province-aggregated view. However, individuals could be impacted differently by those constructs and could ‘respond’ differently to those structural conditions through behaviours and practices; for example, governments’ EV purchase incentives have been found positively related to EV demand at the national scale, whereas incentives may not be crucial for framing the purchase decisions of EVs by those who currently do not own an EV, or consumers are still largely unaware of the federal or provincial government incentives for EVs in Canada (Electric Mobility Canada, 2024). This nuance cannot be captured through aggregated data, instead more granular data with the unit of individuals are needed.

Therefore, it begs the question as to how those structural contexts are ‘translated’ and actualised in individuals’ decisions and behaviours, particularly in local contexts, i.e., how the demand side of the transition processes is unfolding accordingly. This relates to dynamic consumers’ preferences towards EVs; specifically, how consumer perceptions towards EVs and their likelihood to purchase EVs change in correspondence with changes in societies. As explained in section 1.3, people’s behaviours and decision-making are the demonstration of inseparable relationships between their free wills (agency) and broader social contexts (structure).

Consumers vary in their demographic characteristics and psychological profiles such as feelings, norms, and perceptions, which gives rise to preference heterogeneity for EVs at the individual level. It is thus useful to separate different consumer groups in the EV market. The way in which consumers are differentiated is critical in understanding their motivations and barriers in relation to EVs and is relevant to developing tailored EV adoption strategies for distinct submarkets. This study divides consumers into five levels by their actual behaviour of EV purchase or likelihood of/interest in purchasing an EV based on the DOI (which is specified in section 2.3) in terms of adopter categorization. Since adopter categorization represents consumers’ different adoption times, it can shed lights on societal transition processes of EVs when scrutinized over time or at different time points. This study also explores the heterogeneity in perceptions towards EVs, including perceived benefits and risks, over time and across different consumer segments based on existing empirical studies on EV adoption with emphasis on attitudes and perceptions.

Studies to date have rarely directly compared both the motivations and barriers that different consumer groups connect with EV purchase and, more importantly, they mainly focus on consumer preferences at a certain time point and from a static perspective instead of comparing preference differences over time. The study thus aims to fill the gaps through exploring the heterogeneity in perceptions, including perceived benefits, risks, and influential government initiatives, across different consumer segments which differ in their likelihood to purchase an EV based on conducting a survey in the same area in two time periods that are three years apart—separated by the COVID lockdown years. A longitudinal aspect/temporal variation is of great importance in explaining the transition to EVs, as has been highlighted in Chapter 4 regarding the salient role of geopolitical shifts and COVID-19 pandemic volatility in gasoline prices and vehicle supply chain disruption in the context of Canadian provinces' transition to EVs.

This chapter of the thesis aims to understand and assess changes of consumer perceptions and likelihood to purchase EVs in a Canadian municipality, Waterloo Region, between 2020 and 2023. To achieve this objective, this study will (1) identify and test whether consumers' likelihood to purchase EVs and their perceptions towards EVs change over time; if so, how they change over time; (2) compare if and how the perceptions change differently across different consumer segments; (3) interpret and elaborate on how influential attributes contribute differently to the changes of EV purchase interests; and (4) assess what this suggests about the state of the EV transition within the context of local municipalities. This part of research is based on survey data for the years 2020 and 2023 for one Canadian municipality, and is complementary to other Canadian studies that have used national or provincial survey samples to separate consumer markets by consumers' stated preferences for particular vehicular features, lifestyles, and socio-demographics (Axsen et al., 2015; Ferguson et al., 2018; Higgins et al., 2017; Kormos et al., 2019; Mohamed et al., 2016). The focus on one municipality allows for a deeper understanding of context, e.g., public charging infrastructure, socio-demographics. To ensure the inclusion of the most relevant socio-demographic and attitudinal and perception factors, a number of factors found to be significant in previous studies are considered.

5.3 Research Context

5.3.1 Separating Consumers into Different Segments

To better understand EV uptake, research on consumer purchase intentions and adoption has grown over the last decade, providing improved understanding of consumers' motivations and barriers in relation to EVs. These influencing factors, however, appear to differ across consumer groups in terms of their strength and significance. Existing scholarship divides consumer groups in various ways, e.g., based on:

- Preferences for different vehicle characteristics associated with sizes, body types, and drivetrain categories (Higgins, Mohamed, & Ferguson, 2017; Kormos et al., 2019; Nayum, Klöckner, & Mehmetoglu, 2016; Wang, Shaw, & Mokhtarian, 2022);
- The degree to which individuals tend to be earlier adopters for new products generally (Pettifor et al., 2017; Rodríguez-Brito et al., 2018; Schuitema et al., 2013);
- A mix of psychographic constructs (e.g., attitudes and life principles) or/and socio-demographic characteristics (Lee et al., 2019; Morton et al., 2017; Saleem et al., 2018);
- Actual purchase behaviour or interest in/likelihood of EV purchase (Bigerna & Micheli, 2018; Peters & Dütschke, 2014)
- Geographical locations related to regions with different latitudes and sizes of cities (Han & Sun, 2024; Huang et al., 2021)

Segmenting the current and potential future EV market in this study based on the fourth approach listed above—namely, actual purchase behaviour or interest in/likelihood of EV purchase—is useful since it reflects the positions different individual consumers experience in terms of EV adoption, from being reluctant to purchase to having interest in or intention to purchase, and finally making the decision to actually purchase. When the positions are 'captured' in an over-time sequence, the market evolution process through which EVs are diffused in societies by different consumers can be better understood. The DOI, which is specified in section 2.3, provides useful insights into the interconnections between the individual scale (the micro-level perspective of adoption) and the societal scale (the macro-level perspective of diffusion) through the time dimension. This temporal nature is different from other behavioural theories, e.g., Theory of Planned Behaviour, Technology Acceptance Model, and Value-Belief-Norm Model, all of which are mainly used for understanding behaviours at one specific time. Additionally, the DOI has been one of the first to suggest that the populations are heterogeneous in their propensity to adopt innovations and thus its adopter categorization with 'innovators', 'early adopters', 'early majority', 'late majority', and 'laggard', which form the basis for segmenting adopters of EVs in this study into five levels by their actual behaviour of EV purchase or different likelihood of/interests in purchasing an EV.

Despite DOI as the cornerstones of many theoretical frameworks within innovation adoption research (van Oorschot et al., 2018), it has received considerable criticism in the literature, especially from the socio-technical transitions literature. Critiques from the transitions literature mainly focus on DOI's assumption of 'linear' development processes of innovations (i.e., diffusion starts from a point source and proceeds further without uncertainty and failures) and overemphasis on single innovation/discrete technology instead of the diffusion of systemic innovations (Geels, 2018). By recognizing its limitations, the DOI still serves as a useful framework for this study regarding consumer perceptions and behaviours at an individual level and connecting those perceptions among different consumer groups to the rate of innovation adoption at a societal level.

However, it is also important to recognize some of its limitations of applying it in this study. For one, the DOI mainly explains preference differences observed in innovation diffusion processes from divergent preferences towards an innovation among different group of consumers (between-subject difference). However, it ignores that preference changes from the same consumers over time can also contribute to preference heterogeneity during diffusion processes. For another, while the DOI has identified five perceived attributes of an innovation that collectively influence its market acceptance and largely explain the rate of adoption of innovations (c.f. sub-section 2.3.1), it is inadequate in explaining how these key attributes differ among different groups; specifically, in this case, if and how perceptions towards EV attributes differ by consumer segments. Therefore, the next sub-section 5.3.2 reviews existing empirical studies on EV adoption with foci on attitudes and perceptions to help understand the expected differences in perceptions of EVs and characteristics across consumer groups.

5.3.2 Existing Empirical Studies on EV Adoption with Emphasis on Attitudes and Perceptions

The behavioural phenomenon underlying EV adoption is inherently complex, personalized, and multifaceted. In this analysis, the first time that an individual or household chooses an EV over an alternative vehicle is interpreted as “behaviour change”. Behaviour change has received much attention, and a number of explanatory factors, theories, and conceptual models have been developed. Studies may be organized into two streams: the economic perspective and the socio-psychological perspective (Liao et al., 2017).

In the context of EV adoption, studies from an economic perspective have applied choice models to investigate how objective attributes, i.e., trip and vehicle characteristics, policy attributes, as well as socio-demographics, affect consumers’ choice of EVs among vehicle alternatives; these studies also identify barriers to the widespread adoption of EVs (Abotalebi et al., 2019b; Ferguson et al., 2018). They are mainly based on the concept of consumers’ utility maximization with rational decision-making, though some studies have attempted to incorporate psychological variables in their models as well. However, as Egbue and Long (2012) have illustrated, an economic view is limited in its ability to fully reveal why consumers support or resist EV adoption, especially given the potential importance of social motivators or concerns of consumers that contribute to the complexity of decision-making processes.

Studies from a socio-psychological perspective are of interest since they focus on how consumers' socio-psychological variables (e.g., attitudes, personal norms, and knowledge), these subjective aspects, influence EV purchasing behaviour and sometimes the underlying mechanisms among those variables (R. Liu et al., 2020; Moon, 2021; Singh et al., 2020). Their focus is on how consumers perceive the objective attributes that affects their behaviour rather than the objective factors themselves (Lane & Potter, 2007). A recent study, for example, highlighted the significance of perceived and prospective charger accessibility in EV adoption in Montreal, Canada as opposed to objective measures (Renaud-Blondeau et al., 2023). The micro-level perspective of DOI, which is elaborated in section 2.3, belongs to this category. However, this perspective is also inadequate in systematically specifying EV attributes and considering other vehicle alternatives (e.g., ICEVs); i.e., it has limitations in quantifying how changes in EV attributes can lead to shifts of preferences for EVs among vehicle alternatives (Liao et al., 2017). A socio-psychological perspective thus can help more appropriately understand consumers' behaviour, as is done in the current analysis, to illuminate the motivations and barriers affecting intention and behaviour associated with the adoption of EVs.

The two streams also have different ways in operationalizing relevant influential factors based on the above; the economic perspective mainly defines and measures factors in an objective and a direct way (e.g., price per 100 km for operation costs), while the socio-psychological perspective tends to be from a subjective and an indirect way (e.g., perceptions towards operation costs). Factors affecting EV adoption from a socio-psychological perspective can be categorized into two broad groups, socio-demographic and attitudinal and perception factors (Lin & Wu, 2018; Rezvani et al., 2015). The following sections draw up a non-exhaustive list of those factors.

5.3.2.1 Socio-demographic factors of EV adoption

Existing studies have identified a clear socio-demographic profile of people who tend to have preference for or intention to purchase an EV. Empirical evidence indicates that these people are generally more likely to be married, employed, live in median to high urbanized areas, and have a higher education and income.

Results are relatively consistent with regard to the effects of employment, education, and income, and are thought to be connected with the higher purchase prices of EVs compared to conventional ICEV models (Rodríguez-Brito et al., 2018). Marital status, also, has been found to be associated with EV purchase in various studies; a plausible explanation offered is that people will presumably become more responsible and more interested in taking pro-environmental actions after marriage (Lin & Wu, 2018). Consumers who live in a more urbanized environment (e.g., suburban and urban areas) have increased likelihood of choosing an EV, no matter what the vehicle class is (e.g., economy and pickup). The importance of residential setting can be likely attributed to higher charging infrastructure density or shorter average travel distances in denser areas (Abotalebi et al., 2019a; Ferguson et al., 2018; Higgins et al., 2017).

For other socio-demographic factors, there are some contradictory results across studies. In terms of gender, according to several studies, males are more likely to have positive preferences for EVs (Morton et al., 2016), to show willingness to purchase an EV (Rodríguez-Brito et al., 2018), to own an EV (Sovacool et al., 2019), and to adopt and/or be willing to adopt new transport technologies (i.e., automated and electrified vehicles) (Spurlock et al., 2019). That said, a recent study in Spain found that young female consumers have a greater likelihood of being early adopters of hybrid vehicles and EVs (Higueras-Castillo, Molinillo, et al., 2020). In terms of age, several previous studies have shown younger adults have stronger preferences for or intention to own EVs (Abotalebi et al., 2019b; Sovacool et al., 2018); however, She et al. (2017) identified that older respondents hold a more optimistic attitude towards EVs than younger generations. Sovacool et al. (2018) specified age groups in a detailed way and suggested that those between 25 to 45 years old are most likely to own EVs in the five Nordic countries.

5.3.2.2 Consumer attitudes and perceptions of EV adoption

In general, existing studies have classified consumers' attitudinal and perception factors into four categories: technological, economic, environmental, and contextual factors, all of which help us to select specific important factors related to consumers' perceived benefits, risks, and influential government initiatives in the present study.

The technological group involves consumers' attitudes and perceptions towards EVs' performance features including driving range, safety and reliability, and noise. Range anxiety, which refers to a fear that EVs have limited driving range and will run out of power before reaching a destination, is often noted as one of the major barriers to EV ownership. While roughly 95% of vehicle trips in British Columbia in Canada are less than 30 km, a survey conducted in Vancouver demonstrated that range anxiety was the second most chosen barrier when considering owning an EV (B.C. Hydro, 2018). A survey in the United States demonstrated that a "technologically minded target group" ranked range as the biggest concern about EVs (Egbue & Long, 2012, p. 722). Whether EVs are safe and reliable is also a concern of consumers. She et al. (2017) conducted a survey in China, and safety and reliability ranked as the top two barriers to EV acceptance. Higueras-Castillo, Guillén, et al. (2020) identified range and reliability as the most crucial predictors of EV purchase intention. Low engine noise is also a distinctive EV characteristic relative to ICEVs. Through investigating Norwegian experiences with EVs, Ingeborgrud and Ryghaug (2019) found that BEV owners appreciate the quietness of EVs and treat it as an important element of their driving comfort.

The economic aspects of EVs are widely discussed in existing studies as well. The higher purchase price of EVs compared to conventional vehicles on average is regarded as one of the strongest barriers to consumers' purchase intention (B.C. Hydro, 2018; Rezvani et al., 2015). However, EVs are more cost-efficient than ICEVs in operation and maintenance, which has significantly positive effects on EV purchase decisions (Peters & Dütschke, 2014). The costs to charge an EV are usually lower than the costs to refuel a conventional vehicle via gasoline or diesel. The maintenance costs of EVs are also lower due to fewer vehicle moving parts and less complex powertrain systems, which is appreciated by those who are inclined to purchase BEVs (Ferguson et al., 2018).

The ways in which consumers perceive or hold attitudes towards the environmental aspects of EVs are also predictors of their purchase intention since EV adoption can be seen as a pro-environmental behaviour. Past studies predominantly measured the environmental aspects via people's personalities and beliefs, e.g., environmental concerns, awareness, and lifestyles (Axsen et al., 2016; Moon, 2021; Okada et al., 2019; Sang & Bekhet, 2015; B. Smith et al., 2017); they concluded that people with higher levels of general understanding and awareness of environmental issues and impacts or those who are more engaged in environmental-oriented lifestyles tend to be either EV owners or those with high adoption intentions. A few studies explored how the consumer perception of EVs' environmental performance impacts their purchase intention and attitudes (Bigerna & Micheli, 2018; Degirmenci & Breitner, 2017; S. Yang et al., 2019). Respondents who appreciate EVs' positive effects on air quality, global warming, and fuel economy, and worry less about electricity production and battery sustainability, are more inclined to have positive impressions/high purchase intention on EVs. This aspect directly associates consumers' perception of environmental outcomes in driving EVs with their EV acceptance, providing greater precision in understanding behaviours.

In terms of the contextual aspects, consumers' attitudes and perceptions towards charging infrastructure availability, government initiatives, and supply-side availability are relevant to their purchase. The ease of finding charging facilities is critical to adoption, given the limited driving range of EVs (Coffman et al., 2017). Sierzchula et al. (2014) asserted that charging infrastructure density is the best predictor of EV market share in country levels. She et al. (2017) also pointed out that the inadequacy of charging infrastructure, especially public charging points, is ranked as the largest infrastructure barrier to EV adoption. Additionally, there are policy measures that governments have implemented in encouraging consumer EV adoption, such as incentives for vehicle purchase and charging station installation at home (Sierzchula et al., 2014), fuel taxes (Egbue & Long, 2012), special operating privileges, e.g., free parking and free use of High Occupancy Vehicle (HOV) lanes (Langbroek et al., 2016), and more public charging infrastructure construction (She et al., 2017). Whether there are adequate EV models in the market and good dealership experiences also impact EV purchase decisions, something that is often neglected in studies. Fewer EV model options fail to meet different shopper expectations and thus pose a barrier to purchase (Kumar & Alok, 2020). De Rubens et al. (2018) showed that dismissive and deceptive car dealerships in five Nordic countries also pose a strong barrier to EV adoption intention. This issue was also found in the Canadian context where EV models are unavailable at the dealership for viewing and test driving (Matthews et al., 2017).

Based on the analysis above, the current study focuses on consumer demographics and attitudes and perceptions as the main factors that influence EV purchase intention. Previous research has identified key technological, economic, environmental, and contextual factors, all of which help us categorize consumers' perceived benefits and risks, as well as influential government initiatives for further analysis. These factors are summarized below (Table 5.1).

Table 5.1 Consumers' attitudinal and perception factors to be analysed in the present study

	Technological factors	**Economic factors**	**Environmental factors**	**Contextual factors**
Perceived benefits	Low noise	Low operation costs	Air quality improvement	NA
		Low maintenance costs	Climate change mitigation	
Perceived risks	Range anxiety	High purchase prices	Battery sustainability concern	Charging infrastructure availability
	Safety concern			Supply-side availability
Perceived influential government initiatives	NA	NA	NA	Subsidies for vehicle purchase
				More public charging infrastructure construction
				Subsidies for charging station installation at home
				Fuel taxes
				Special operating privileges

Note: NA represents not applicable.

5.3.3 Dynamic Preferences for EVs

Studies in both economic and socio-psychological streams mainly use stated preferences, i.e., adoption intention, to represent EV adoption behaviours; and both streams frequently use surveys. However, they mainly focus on consumer preferences at a certain time point and use cross-sectional data, ignoring the longitudinal dynamics of consumer preferences towards EVs and how the influence of aforementioned factors could change over time. Related findings tend to fall short in capturing the intricate and evolving nature of consumer preferences within the dynamic landscape of EV development. This is particularly important during the acceleration stage of EV adoption, as the market environment evolves with technological advancements and policies' implementation. Additionally, various structural forces since 2020, such as geopolitical shifts, the COVID-19 pandemic, and political uncertainties, have further influenced this process. For example, consumers' perceptions may be changing in a way such that sustainable consumption and environmental awareness will be more valued after the COVID-19 pandemic (Severo et al., 2021). Additionally, although existing scholarship has separated and characterized consumers into different segments, it remains unclear as to how consumer preferences evolve when looking at the differences among those segments over time. More empirical evidence is thus required to enrich the meaning and understanding of longitudinal dynamics of preference heterogeneity across different consumer segments (Huang et al., 2021; Qian et al., 2023).

There are some exceptions of studies that have incorporated a temporal perspective through collecting survey data at different points in time. Carley et al. (2019) explored car buyers' intention to purchase/lease BEVs and PHEVs across 21 American cities in the years 2011 and 2017. A second example is provided by Fan et al. (2020), who collected data on the extent of Chinese potential car buyers' acceptance of EVs in China in 2012 and 2017. These two studies are both from a socio-psychological aspect and focus on respondents' perceptions and attitudes towards EV-related policies and performance attributes. A third example is provided by Qian et al. (2023), who conducted stated-preference experiments between 2017 and 2019 from a same group of respondents in China and characterized consumers by generations and city sizes.

This current study complements the above studies in uncovering the dynamics of preference heterogeneity across consumer segments based on survey data in 2020 and 2023 for one Canadian municipality. Given the significance of broader social contexts and events in the transition to EVs in Canada, which have been identified in Chapter 4, how consumer preferences for EVs changed alongside with those changes in societies is worth investigating. Specifically, (1) whether and how consumers' likelihood to purchase EVs changed over time, interpreted as both composition changes among different groups of consumers over time and temporal variation in likelihood within the same group, and how their perceived EV benefits, barriers, and influential government initiatives changed over time; (2) if and how those perceptions towards EVs changed differently across different consumer segments with different likelihood of/interests in EVs; and (3) how the influential attributes have different importance levels of contributing to consumers' general interests in EVs over time. Scrutinizing the two time points, which are three years apart and separated by the COVID lockdown years, is crucial to disentangle the effects of complex structural contexts on consumer interests and preferences and to shed light on the transition process of EVs from consumers and individual perspectives.

5.4 Methods

5.4.1 Research Location and Context

Waterloo Region, which is a mid-sized metropolitan area located in Southwestern Ontario of Canada, had an estimated population of 665,188 in 2023 (Statistics Canada, 2024f). It consists of three urban cities—Kitchener, Waterloo, and Cambridge—and four rural townships (i.e., Woolwich, Wilmot, Wellesley, and North Dumfries). According to the recent Census data, it ranked fourth in population among CMAs in Ontario and ranked tenth in Canada (Statistics Canada, 2021). The region is one of the fastest growing and diversifying communities in Canada, with population growth between 2016 and 2021 exceeding the national and provincial growth rates. It is also well known for rapid economic growth in leading and innovative technology industries and companies, e.g., automotive, aerospace, and financial. The region's geographical position in Ontario, combined with the phase-out of coal and the adoption of a cleaner electricity grid in the province after 2014, puts it in a favourable position for a transition to low-carbon solutions, especially the shift towards EVs.

The region has official community GHG emission reduction target and climate action plan. The transportation sector, as the single largest contributor to GHG emissions in the region since 2010, accounted for 47.2% of the community's total GHG emissions in 2022 (ClimateActionWR, 2024). Nearly 90% of the employed labour force commutes to work using cars, trucks, or vans either as drivers or as passengers. However, the average commute time for Waterloo Region residents was roughly 22 minutes in 2021, which was relatively short compared to other Canadian CMAs such as Toronto, Vancouver, Ottawa-Gatineau, and Edmonton (Statistics Canada, 2021). To support sustainable development and emission reduction, the region provides different travel choices. The 19-km Light Rail Transit line connecting Kitchener and Waterloo with over 20 stops started service in 2019, and these complement the extensive bus services in supporting demand for public transit. GO Rail, GO Bus, and Waterloo

International Airport help enhance inter-regional connections. On-road and off-road bike lines and trails and walking networks and facilities are also provided for encouraging active transportation. TravelWise, as a Transportation Demand Management Program, allows participating employees in the region to access a peer-to-peer ride-sharing platform.

Accelerating EV adoption is also one of the community-wide transformative changes that is required to achieve a GHG reduction target of 80% in 2050 based on 2010 levels. The widespread adoption of EVs in both personal and commercial levels is expected to contribute to 35% of those emission reduction ambitions among different initiatives (e.g., fuel switching and reduced travel) (ClimateActionWR, 2021). Despite a slight decline in 2019 and stagnation in 2020 (Figure 5.1), EV adoption in Waterloo Region experienced a significant increase from 2017 to 2023, mirroring the trend observed in Ontario (Figure 4.3 in sub-section 4.5.1). However, the ratio of new EV registrations in the region among those of Ontario remained to be low at 4-5% (Statistics Canada, 2024e) and the regional target of 50% of vehicles on roads be EVs by 2030 is ambitious and tends to be falling behind the planned timeline (MacDonald et al., 2024). The current strategies and actions for the transition to EVs in the region have focused on implementing public outreach and communication strategies for personal vehicles and building charging infrastructure networks (ClimateActionWR, 2021). Based on a report provided by ChargeHub (2021), Waterloo Region ranked in the top ten and top five in the number of charging ports among Canadian CMAs and Ontario CMAs, respectively. Therefore, understanding preference heterogeneity of EVs across consumers is beneficial to further develop tailored strategies for different consumer submarkets in the region. The results are also expected to be potentially comparable and inferable to other relevant Canadian municipalities, particularly those with similar population sizes and capabilities of climate change actions.

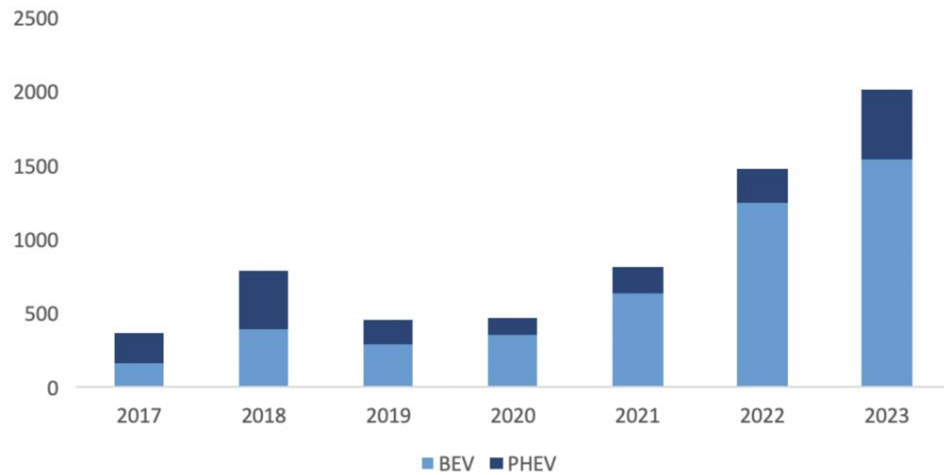


Figure 5.1 The number of new EV registrations in Waterloo Region between 2017 and 2023

Data are from Table 20-10-0025-01 (Statistics Canada, 2024e)

5.4.2 Sample and Data Collection Procedure

Survey data were collected in both 2020 and 2023 in Waterloo Region from those who live in the region and are 18 years old and above. The survey instrument was virtually identical in the two years and recorded people's socio-demographics, perceived benefits, risks, and influential policies to EV adoption, and intention to purchase an EV. In designing the survey questions, all of the key socio-demographic variables found to be important in earlier studies (i.e., marital status, gender or sex, age, employment status, residence area, education, and household income) are included. Specific attitudinal and perception factors that are considered are shown in Table 5.1, presented earlier.

Data were collected through mixed modes including an online survey with a designed and structured questionnaire from 29 January to 24 February 2020 and from 8 May to 3 July 2023 and a telephone survey (using both landline and cell phone telephone numbers) with the same questionnaire as the online survey from 5 February to 24 February 2020 and from 15 May to 3 July 2023 in the Region of Waterloo. The survey for this study was part of the 2020 and 2023 "Waterloo Region Matters Survey" which was conducted by the Survey Research Centre at the University of Waterloo. The Survey Research Centre, as a specialist in survey research services and the expert administrator of the "Waterloo Region Matters Survey", used random-digit dialed sampling of households within the region population and random selection within the household and was in charge of the quality control of recruitment.

A total number of 694 possible eligible participants were requested to complete the online survey via emails and 307 participants completed the survey (44.3%) in 2020. For 2023, a total number of 830 participants were emailed an online survey invitation and 275 respondents completed the survey (33.1%). For telephone respondents, 235 surveys were completed among a total of potential eligible 1,293 records were called and dialed at least once (18.2%) in 2020. In 2023, the response rate achieved 29.5% with 225 surveys completed among 763 records. Therefore, a total of 542 responses were received in 2020 (56.6% respondents over the web and 43.4% respondents over the telephone) and a total of 500 responses were received in 2023 (55% respondents over the web and 45% over the telephone). One respondent in 2020 and two in 2023 were eliminated since the respondents did not answer the survey question about their intention to purchase or lease an EV. This resulted in 541 respondents for 2020 and 498 respondents in 2023. It could happen that the same individuals were answering in both two years, but it is not the aim of this study to be longitudinal.

Table 5.2 summarizes the demographic characteristics of survey samples in 2020 and 2023. In 2023, relative to 2020, only slightly more participants were/had:

- not married
- employed (including categories of full-time, part-time, and self-employed)
- female
- household income $100,000 or more before taxes
- aged 65 or above years old
- living in one of the three cities in Waterloo Region instead of one of the four rural townships

None of the above differences were statistically significant between the two years, as evidenced by Chi-Square tests which will be briefly described in sub-section 5.4.4.1. However, the proportion of participants with post-secondary certificate, diploma, or degree was roughly 72% in 2023 compared to 78% in 2020, with statistical significance shown by the Chi-Square test on education level change between two years. In comparison to the 2016 Census data and the 2021 Census data for Waterloo Region respectively, the sample in 2020 and 2023 were more highly educated and relatively older (i.e., lower proportions of those under the age of 34) than the population of the Region of Waterloo, which is commonly experienced by many surveys. Furthermore, the sample in the two years was already fairly representative of the adult population residing in the region. Additionally, weight variables were computed and produced by the Survey Research Center and assigned to each observation to ensure that survey respondents better represent the adult population of Waterloo Region with respect to the gender (sex), age, residence area (cities and townships), and education characteristics.

Table 5.2 Demographic characteristics of the unweighted samples in 2020 and 2023

Sample characteristics	Category	2020	2023	Longitudinal differences
Marital status	Married	80.7%	76.2%	χ^2=3.10, p=0.078
	Not married	19.3%	23.8%	
Gender	Male	42.8%	48.2%	χ^2=3.10, p=0.078
	Female	57.2%	51.8%	
Age	18-24	6.5%	5.2%	χ^2=7.00, p=0.221
	25-34	15.0%	15.3%	
	35-44	21.2%	21.9%	
	45-54	16.3%	15.9%	
	55-64	18.2%	13.7%	
	65 or older	22.8%	28.1%	
Employment status	Employed	62.7%	59.8%	χ^2=0.87, p=0.351
	Not employed	37.3%	40.2%	
Residence area	Cities	86.9%	87.3%	χ^2=0.052, p=0.820
	Townships	13.1%	12.7%	
Education level	Grade school or high school or some college and university	22.1%	28.2%	χ^2=5.20, p=0.023
	With post-secondary certificate, diploma, or degree	77.9%	71.8%	
Household income (before taxes)	Less than $50,000	24.7%	22.8%	χ^2=4.89, p=0.180
	$50,000 to less than $80,000	22.7%	20.9%	
	$80,000 to less than $100,000	16.9%	13.9%	
	$100,000 or more	35.8%	42.4%	

5.4.3 Questionnaire and Measures

The questions asked in 2020 and 2023 were kept consistent in order to enable comparison (Appendix D). They included three types of questions about EVs, the definition of which was provided based on that provided by the Ministry of Transportation in Ontario (Ministry of the Transportation, 2023).

- First, respondents were asked to describe their own situation with regards to the ownership or lease of an EV, by choosing the category that described them best. Five response categories were provided as follows: “You own or lease one or more electric vehicles”, “You plan to purchase or lease your first electric vehicle as your next vehicle”; “You are interested in learning more about electric vehicles to inform your next vehicle decision”, “You may consider purchasing or leasing an electric vehicle sometime later on”, and “You do not expect to purchase or lease an electric vehicle anytime soon”. This question provides information about respondents’ EV adoption or their likelihood of or interest in purchasing an EV and is the “dependent” variable in the statistical analysis that follows.

- A set of questions related to socio-demographic variables were asked: marital status, gender (sex), age, employment status, residence area, education, and household income (before taxes). Even though the 2020 survey asked about gender and the 2023 survey asked about birth sex, the data provided are comparable. Additionally, the categorization of education level and household income varied slightly between the two years; and thus were restructrued to facilitate comparision. The above variables were all introduced as independent, categorical variables in the analysis later, except for age and household income, both of which were regarded as categorical variables in Chi-Square tests but as continuous variables in binary logistic regressions for improving model accuracy.
- All respondents then were asked to choose two reasons among five that would motivate them most and next most to purchase or lease an EV, two reasons among seven that would most and next most likely prevent them from purchasing or leasing an EV, and one government initiative among five that would most increase their likelihood of buying or leasing an EV (similar to ranking quesitons). Options for “nothing can motivate or prevent me”, “don’t know or refused”, and “other, please specify” were also provided to allow respondents to express their thinking beyond the closed-ended options. The “other, please specify” was later scrutinized and categorized into existing categorical responses, if relevant. For example, the answer of “reliability and longevity of batteries in cold climates” was further put into the category of range anxiety.
- One question that was added in 2023 survey—“Compared to three years ago, are you now more or less likely to purchase/lease an electric vehicle?”—with responses from “much more likely”, “more likely”, “neither likely nor unlikely”, “less likely”, to “much less likely”. This is the only question that provides insight into how individuals’ preferences for EVs changed over time.

5.4.4 Statistical Methods

5.4.4.1 Pearson’s Chi-Square tests

Given the research aim to compare differences in consumers’ likelihood to purchase EVs and their perceptions over time and across groups (objective one and two) and the measurement of variables as categorical, Pearson’s Chi-Square tests are thus used for analysing group differences and testing for significance. The tests can provide information not only on the significance of any observed differences, but also provide detailed information on which categories account for the differences found. The values highlighted in bold in the following tables of section 5.5 emphasize that these values in specific cells (absolute values or counts) during Chi-Square tests are statistically significant at a significance level of 5% (adjusted residual is more than 1.96 or less than 1.96). Pearson's correlation coefficient (χ^2) is used to indicate the strength of the relationship between the two categorical variables being tested and the *p*-value is applied to define statistically significant evidence between them. Among the assumptions of Chi-Square tests, one assumption that is worth noting is that at least 80% of the cells should have expected count/value equal to 5 or above.

Since the comparison is not only among different groups of consumers, i.e., respondents in 2020 and 2023 (between-subject difference), but also from the same consumers, i.e., respondents' responses to different questions within the same year, the Chi-Square test of homogeneity, which is used to test the differences for two independent groups, and the Chi-Square test of independence, which is used to test differences between two variables measured from a single sample from the same population, are both involved. Since Chi-Square tests are sensitive to sample size, especially when the sample size is very large, small differences will lead to statistically significant results. Unweighted sample data are thus used for the first and second parts of the analysis.

5.4.4.2 Binary logistic regressions

Given the research aim of interpreting how influential attributes, i.e., socio-demographics and perceptions and attitudes, contribute to consumers' general interests in EVs in 2020 and 2023 (objective three) and the measurement of the dependent variable as two outcomes (i.e., whether consumers have general interests in EVs or not), binary logistic regressions are thus used for estimating the associations between the dependent variable and independent variables across the two years. Instead of predicting the value of dependent variables, logistic regressions (e.g., binary and multinomial logistic regressions) predict the probability of falling into a certain level of the categorical dependent variables. Specifically, logistic coefficients reflect the effects of one unit change in the independent variable on the log odds of the dependent variable occurring by holding other independent variables constant, where "the odds of an event occurring is the ratio of the probability that an event will occur to the probability that it will not" (Haan & Godley, 2017, p. 215).

As part of the generalized linear models, binary logistic regressions also follow the assumptions of linearity (i.e., the relationship between independent variables and the log odds of the dependent variable are linear), independence (i.e., observations and errors should be independent of each other), and multicollinearity (i.e., independent variables should not be highly correlated) (Dunn & Smyth, 2018).

Additionally, they allow the variable weights to be incorporated, ensuring that the contribution of each observation to the estimation of model parameters is proportional to its weights. The results are expected to be more reliable and valid since the models more accurately reflect the population structure. Therefore, for the third part of the following analysis, weighted sample data are used.

Weights for different sample observations are respectively normalized to make sure the sum of their weights match the sample sizes in 2020 and 2023, which is a typical weighting normalization method for survey data analysis (Heeringa et al., 2017). In this regard, survey data can accurately reflect an unbiased representation of the population and enable a meaningful comparison between two years. Specifically, the following formula shows how the normalized weights are calculated.

$$W_i^{normalized} = W_i \times \frac{N}{\sum_{i=1}^{n} W_i}$$

Where:

- W_i is the original weight for observation i.
- *N* is the total number of observations (after the deletion of missing data).
- $\sum_{i=1}^{n} W_i$ is the sum of original weights.

5.4.5 Analysis

In terms of all the analyses involved in this study, statistical significance is set at the 5% level; *p*-values should be below 0.05 as determining statistical significance. In the first part of the analysis (sub-sections 5.5.1 and 5.5.2), the differences in consumers' likelihood to purchase EVs, which are interpreted as either proportion changes of the five consumer groups differing in likelihood of purchasing or leasing an EV between 2020 and 2023 or the sample groups' preferences for EVs changed over time, and variations in perceptions (i.e., perceived benefits, risks, and influential policies) between 2020 and 2023 are compared and tested for significance through Pearson's Chi-Square tests.

In the second part of the analysis (sub-section 5.5.3), the differences in perceptions across consumer segments are separately compared in 2020 and 2023 and tested for significance through Pearson's Chi-Square tests, while ensuring that the test assumption related to expected counts is not violated. Given the small number of respondents who owned or leased an EV (n=9) in Waterloo Region in 2020, this group were combined with the second group ("plan to purchase or lease as next vehicle"), which results in four scales of readiness. This recategorization has also been used in other studies, e.g., Ye et al. (2023). Additionally, among perception variables, the option of "less noisy" and "safety concern" were respectively excluded in the first perceived benefit variable and the first and second perceived risk variables because these response options were chosen so infrequently in both 2020 and 2023. The two options of “limited models” and “limited EVs at the dealership” were also further combined into one option of “supply-side availability” in both years.

In the third step of the analysis (sub-section 5.5.4), how influential variables affect consumers’ interests in EV adoption is examined through two separate binary logistic regression models in 2020 and 2023. I collapse readiness responses into whether respondents have general interest in adopting EVs (scale 1,2,3, or 4, coded as “1”) or not (scale 5, coded as “0”). Independent variables are socio-demographic factors, perceived benefits, risks, and influential policies to EV purchase. Different motivation and barrier variables are separately coded as dummy variables with the value from 0 to 2 assigned. For instance, if the respondent regarded EVs’ cost saving in operation as the first motivation and EVs’ favourable impact on air quality as the second motivation, the value of “low operation costs” variable and “air quality improvement” would be coded as 2 and 1, respectively, and other motivation variables would be coded as 0. Other variables were similarly coded as 2-1-0 or sometimes 1-0 (if the respondent chose “others” as the first motivation and “low maintenance costs” as the second motivation).

For each binary logistic model, all the socio-demographic and perception variables were included. Before establishing both models, the check of multicollinearity was conducted. VIF, as a measure of the extent of linear correlations among independent variables, gave a value of less than 10 for each independent variable, which indicates that the collinearity is weak and the accuracy and stability of the models are not affected. The process is similar to that undertaken in sub-section 4.4.1.3. To improve the estimations of the two models, a stepwise variable selection method was used based on the AIC to eliminate insignificant explanatory variables. AIC, as one of the indicators to measure the fitting degree of estimated models, can be used to determine which multiple models are likely to be the best models. The smaller the AIC value is, the better the model is. Interactions between the variables are also considered in the selection processes.

5.5 Results: Summary and Interpretation

5.5.1 Consumers’ Likelihood to Purchase EVs, 2020 and 2023

Table 5.3 shows the size of the five consumer segments relative to the DOI’s five adopter categorizations. Those who owned or leased an EV accounted for 1.73% and 4.35% in 2020 and 2023, respectively—as compared to the 2.5% normally associated with ‘innovators’ in the DOI model. This would suggest that the most recent purchasers of EVs in Waterloo Region are no longer innovators, but rather early adopters, of a technology that has been on the market for some time. The second group, i.e., those who plan to purchase, accounted for 5.32% and 7.68% in each of the two years—considerably smaller than the 13.5% that would be expected for 'early adopters' in the DOI model. This suggests that EV adoption in the local context is unfolding slowly and that it will take some time before EVs are mainstream. The next two categories, which in the DOI model are referred to as 'early majority' and 'late majority', would be expected to each account for roughly one-third of the population once the diffusion process is nearly complete. In Table 5.3, those respondents who said that they are "interested in learning more" or "would consider an EV sometime later" are aligned with these two categories—and both have percentages that are considerably smaller, indicating that the diffusion process will be only partial or at best significantly delayed. Finally, the 'laggards' in the DOI normally represents only 16% of the population, but the large percentage of people who indicate that they "do not expect to purchase or lease an EV anytime soon" is much larger—47.34% in 2020 and even larger at 49.62% in 2023.

Similar to previous studies that have applied the concepts of DOI's adopter segmentation, this study also demonstrates the meaningfulness of categorizing consumers; a few pioneers are differentiated from a bigger group of early adopters, who are distinguished from other sub-markets that are more reluctant or indeed resistant to the innovation. However, it also echoes previous studies that note that the model's categorization is established rigidly and adopter segments for different innovations (e.g., Airbnb and health programs) fail to map onto those segments that the DOI proposes (Guttentag & Smith, 2022; Ye et al., 2023). The significantly higher percentage of 'laggards' hints at the likelihood of non-adopters of EVs in this group, i.e., EVs are not likely to fully penetrate the market in the region, which has also been underlined by other empirical studies that the DOI's assumption of 100% innovation adoption often will not occur (D'Souza et al., 2024; Guttentag & Smith, 2022; Ruokamo et al., 2023).

The rest of the section will introduce the shifts that have occurred in the likelihood to purchase or lease an EV between 2020 and 2023. These shifts include both changes in the composition among different groups of consumers over time (between-subject difference), as well as changes in the likelihood within the same group over time. The results suggest a differentiated transition to EVs in the local context. The discussion begins with between-subject differences.

The first insights come from the relative sizes of the five consumer groups in 2020 versus 2023, as summarized above in Table 5.3. Of note are the increased percentages of respondents in consumer groups 1 and 2 ("already own or lease EV" or "plan to purchase first EV as next vehicle") in 2023 relative to the earlier year and the corresponding lower percentages of respondents in consumer groups 3 and 4 ("interested in learning more about EVs" and "considering an EV sometime later on"). The final group, i.e., those who "do not expect to purchase or lease an EV anytime soon", accounts for nearly one-half of the population in both years and actually increased between 2020 and 2023. The differences between years (based on counts) are statistically significant (χ^2=17.68, p=0.001), for specific consumer groups 1, 2, and 3 and overall. The results reveal that the transition to EVs is occurring but appears to be concentrated among only half of the population—thus the earlier comment on differentiation, as visualized in Figure 5.2).

Table 5.3 Differences in EV purchase likelihood (unweighted frequency and weighted percentage) in Waterloo Region between 2020 and 2023

	2020		2023			Adopter categorization (%) from Rogers' DOI model
	Unweighted Frequency	Weighted percentage (%)	Unweighted Frequency	Weighted percentage (%)		
Own/lease one or more electric vehicles	9	1.74	25	4.35		Innovators 2.5
Plan to purchase/lease 1st electric vehicle as your next vehicle	33	5.32	49	7.68		Early adopters 13.5
Interested in learning more about electric vehicles	111	18.59	77	15.04		Early majority 34
Consider purchasing/leasing an electric vehicle sometime later on	149	27.01	126	23.31		Late majority 34
Not expect to purchase/lease an electric vehicle anytime soon	239	47.34	221	49.62		Laggards 16
Total	541	100.00	498	100.00		100

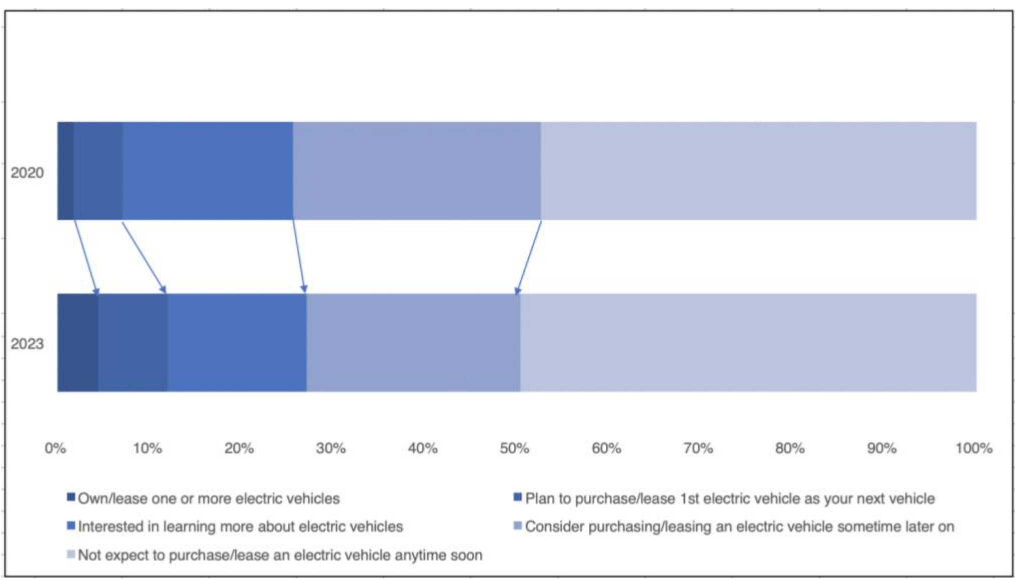


Figure 5.2 Relative sizes of the five consumer groups (weighted percentage) in Waterloo Region in 2020 versus 2023

Next, the discussion turns to focus on responses to the 2023 question “Compared to three years ago, are you now more or less likely to purchase or lease an electric vehicle?”. Tables 5.4 and 5.5 summarize responses to this question. Specifically, Table 5.4 describes how a larger proportion of adults in Waterloo Region were likely to purchase or lease an EV in 2023 as compared to 2020; roughly 45% of the population demonstrated higher likelihood in 2023 than 2020, while 35% of the population held a neutral position and the remaining 20% were less or much less likely to consider EVs. In Table 5.5, the five responses to this same question represent the rows of the table, and data on the consumer categories of respondents define the columns. The five responses for each consumer category add to 100%. Examining each consumer category in turn, it is clear that those who currently own or lease or plan an EV as their next purchase were more likely or much more likely to purchase or lease an EV in 2023 than they were in 2020—demonstrating a shift in thinking at the individual level. The majority of those who expressed interest in learning more about EVs or would consider purchasing or leasing an EV sometime later also indicated that they were “more likely” to become an EV owner in 2023 than they were 2020. As for those respondents who were not interested in EVs in 2023, they either maintained their stance from 2020 or their doubts intensified. The changes in likelihood over time for different consumer groups are statistically significant, as shown in the *p*-value in Table 5.5.

Table 5.4 Changes of EV purchase likelihood (weighted percentage) in 2023 Waterloo Region compared to 2020

	Unweighted Frequency	Weighted percentage (%)
Much more likely	68	12.29
More likely	168	32.40
Neither likely nor unlikely	173	34.74
Less likely	54	13.15
Much less likely	34	7.42
Total	497	100.00

Table 5.5 Changes of EV purchase likelihood (unweighted percentage) compared to 3 years ago within five groups of respondents in 2023 survey

	Own/lease one or more electric vehicles	**Plan to purchase/lease 1st electric vehicle as your next vehicle**	**Interested in learning more about electric vehicles**	**Consider purchasing/leasing an electric vehicle sometime later on**	**Not expect to purchase/lease an electric vehicle anytime soon**	**Pooled**	**Pearson Chi-Square (χ^2)**	***p*-value**
Much more likely	**41.7%**	**49.0%**	19.5%	10.3%	**2.7%**	13.7%	232.62	<0.001

More likely	45.8%	38.8%	**55.8%**	**51.6%**	**13.6%**	33.8%		
Neither likely nor unlikely	**8.3%**	**10.2%**	**20.8%**	34.1%	**48.4%**	34.8%		
Less likely	4.2%	**2.0%**	**2.6%**	**4.0%**	**20.4%**	10.9%		
Much less likely	0.0%	**0.0%**	**1.3%**	**0.0%**	**14.9%**	6.8%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%.

5.5.2 Changes of Consumers' Perceptions towards EVs between 2020 and 2023

In order to better understand the changes of consumers' likelihood to purchase EVs above, this section turns to uncover how their perceptions changed over time. The survey data also indicate statistically significant changes between 2020 and 2023 in consumers' perceptions of EVs, linked to respondents' motivations for purchasing an EV (first most important) and also barriers to purchasing an EV (first and second most important). However, how consumers perceive the most influential policies did not show statistical differences between years. The data are summarized in Table 5.6 as percentages, with the listed motivations, barriers, and influential policies adding to 100%, respectively.

The main motivations in both years are the environmental issues of a need for "climate change mitigation" and "air quality improvement", as well the benefits of lower operation and maintenance costs. There was a change over time, however, with consumers attaching higher importance to EVs' operational cost savings and lower significance to environmental benefits in 2023 as compared to 2020. The increasing importance of cost as a key driver for EV adoption in a local context is aligned with the finding in Chapter 4 that the most influential motivator of the EV transition at the national scale is high gasoline prices. Additionally, a higher percentage of respondents decided that nothing can motivate them to purchase or lease EVs in 2023 relative to 2020, which echoes the findings in sub-section 5.5.1 that respondents who were skeptical about EVs in 2020 tend to remain skeptical about EVs in 2023.

Important barriers across the two survey years include the "high purchase price" of EVs relative to comparable ICEVs, the two related issues of "range anxiety" and "charging infrastructure", "battery sustainability", and to a lesser extent factors associated with EV supply. There were notable and statistically significant differences in the primary and secondary barriers for respondents to buy or lease an EV between 2020 and 2023. In addition to the shifts away from high upfront costs to battery sustainability, respondents also worried much less about the limited numbers of EV models but much more about the limited availability of EVs at the dealership for viewing and test driving in 2023. The shifts of perceptions towards EV supply-side availability can be regarded as corresponding with market trends: the number of EV models available in Canada has increased from roughly 30 models in 2020 to more than 50 models in 2023 and the absolute inventory levels dropped across provinces in Canada during the three years, the latter of which is identified in Chapter 4. Respondents indicated less anxiety over access to charging infrastructure, such as home or public chargers, as a secondary barrier to purchasing or leasing an EV, which reaffirms findings made by Carley et al. (2019) that the growth of availability of charging stations was observed and perceived by American consumers over time between 2011 and 2017. Instead, the unease over battery sustainability has become more prominent, perhaps reflecting a deepening understanding of the life-cycle implications of EV technologies.

Table 5.6 Comparison of consumers' perceptions towards EVs (unweighted percentage) between 2020 and 2023

		2020	**2023**	**Pooled**	**Pearson Chi-Square (χ^2)**	***p*-value**
First motivations	Low operation costs	**18.0%**	**24.4%**	**21.1%**	15.26	0.018
	Low maintenance costs	7.2%	6.7%	7.0%		
	Air quality improvement	16.0%	11.9%	14.0%		
	Climate change mitigation	**34.9%**	**28.4%**	**31.8%**		
	Less noisy	0.9%	0.8%	0.9%		
	Others	8.3%	8.3%	8.3%		
	Nothing would motivate	**14.7%**	**19.6%**	**17.0%**		
Second motivations	Low operation costs	27.8%	26.6%	27.2%	8.15	0.148
	Low maintenance costs	19.7%	20.5%	20.1%		
	Air quality improvement	31.5%	24.8%	28.4%		
	Climate change mitigation	15.8%	21.8%	18.5%		
	Less noisy	3.9%	4.6%	4.2%		
	Others	1.3%	1.8%	1.5%		
First barriers	High purchase price	**40.2%**	**32.6%**	**36.6%**	33.51	<0.001
	Charging infrastructure	15.8%	14.7%	15.3%		
	Limited models	**3.5%**	**0.8%**	**2.2%**		
	Limited EVs at the dealership	**0.7%**	**2.4%**	**1.5%**		
	Range anxiety	22.0%	21.9%	22.0%		
	Safety concern	1.1%	1.2%	1.2%		
	Battery sustainability	**8.6%**	**17.1%**	**12.7%**		
	Others	3.9%	5.2%	4.5%		
	Nothing would prevent	4.1%	4.0%	4.1%		
Second barriers	High purchase price	18.2%	21.5%	19.8%	20.90	0.004
	Charging infrastructure	**25.9%**	**18.8%**	**22.5%**		
	Limited models	10.0%	7.2%	8.7%		
	Limited EVs at the dealership	2.5%	4.5%	3.5%		
	Range anxiety	22.4%	21.1%	21.8%		
	Safety concern	3.1%	1.7%	2.5%		
	Battery sustainability	**15.3%**	**20.3%**	**17.7%**		
	Others	2.5%	4.9%	3.7%		
Most influential policies	Subsidies for vehicle purchase	51.9%	45.8%	49.0%	5.61	0.346
	More public charging facility construction	16.0%	18.4%	17.2%		
	Subsidies for charging station installation	15.8%	18.6%	17.2%		
	Fuel taxes	4.8%	6.0%	5.4%		
	Special operating privileges	4.4%	3.3%	3.9%		
	Others	7.1%	7.9%	7.4%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%

5.5.3 Comparison of Perceptions among Different Consumer Segments in 2020 and 2023

Sub-sections 5.5.1 and 5.5.2 have demonstrated how consumers' likelihood to purchase EVs and their perceptions towards EV changed between 2020 and 2023. This section further dives into how those perceptions changed differently across different consumer segments with different likelihood of or interests in purchasing or leasing EVs. The data are summarized as percentages in tables, with the listed motivations, barriers, and influential policies adding to 100%, respectively. It is worth noting that those percentages of perceptions in different tables are recalculated based on the subset of the respondents for choosing certain responses in order to show the results in a more apparent way.

The findings from Table 5.7 and 5.8 indicate a general move away from motivations, either economic or environmental benefits of EVs, to distinguish different consumer groups in 2020 toward barriers, e.g., lack of supply availability and issues about battery sustainability. Respondents with varying likelihoods of adopting EVs exhibited distinct primary motivations and secondary barriers in 2020, while the most notable variation was seen in the primary and secondary barriers among groups in 2023.

Based on the 2020 survey, the respondents with reluctance to purchase or lease an EV were disproportionately less driven by EVs' beneficial role in climate change, and instead more by cost savings. Their second biggest concern about adopting an EV was related to charging infrastructure availability, which accounted for significantly higher proportions than other consumer groups. Conversely, they had the lowest percentage of supply-side availability as their secondary barrier among different groups. EV owners and respondents that had purchase intention were distinguished from other groups by their appreciation of EVs' financial benefits. However, those respondents with "interest in knowing more about EVs" and those "considering purchasing/leasing an EV sometime later on" were the most likely to be motivated by EVs' environmental friendliness and the least likely to be motivated by cost savings. This disparity seems to be inconsistent with the 2013 Canadian study which found that fuel cost was not a significant factor for the 'very early' EV adopters who prefer both PHEVs and EVs but was for those who prefer PHEVs and HEVs (Axsen et al., 2015).

Table 5.7 Comparison of consumers' perceptions towards EVs (unweighted percentage) across five groups of respondents in 2020

		EVs owners or plan to own/lease the first EV	**Be interested in learning more about EVs**	**Consider purchasing/Leasing an EV sometime later on**	**Not expect to purchase/lease an EV anytime soon**	**Pooled**	**Pearson Chi-Square (χ^2)**	***p*-value**
First motivations	Low operation costs	**36.6%**	**11.3%**	23.2%	**30.4%**	23.7%	28.74	0.001
	Low maintenance costs	7.3%	8.5%	7.2%	13.6%	9.5%		
	Air quality improvement	17.1%	17.9%	21.7%	24.0%	21.0%		
	Climate change mitigation	39.0%	**62.3%**	47.8%	**32.0%**	45.9%		
Second motivations	Low operation costs	23.8%	33.9%	26.4%	26.9%	28.2%	13.78	0.315
	Low maintenance costs	23.8%	15.6%	21.5%	20.5%	20.0%		
	Air quality improvement	35.7%	35.8%	34.7%	25.6%	31.9%		
	Climate change mitigation	14.3%	11.9%	12.5%	22.4%	16.0%		
	Less noisy	2.4%	2.8%	4.9%	4.5%	4.0%		
First barriers	High purchase price	50.0%	52.8%	46.5%	37.3%	44.3%	19.15	0.085
	Charging infrastructure	8.8%	16.0%	17.4%	19.6%	17.4%		
	Supply-side availability	11.8%	4.7%	4.9%	3.4%	4.7%		
	Range anxiety	23.5%	17.9%	25.7%	26.5%	24.2%		
	Battery sustainability	5.9%	8.5%	5.6%	13.2%	9.4%		
Second barriers	High purchase price	22.9%	19.0%	17.4%	20.3%	19.3%	23.98	0.020
	Charging infrastructure	20.0%	23.8%	22.9%	**34.0%**	27.4%		
	Supply-side availability	22.9%	17.1%	**18.8%**	**5.6%**	13.3%		
	Range anxiety	20.0%	24.0%	21.5%	25.9%	23.7%		
	Battery sustainability	14.3%	16.2%	19.4%	14.2%	16.2%		
Most influential policies	Subsidies for vehicle purchase	67.5%	60.4%	51.4%	54.1%	55.9%	11.48	0.488
	More public charging facility construction	15.0%	13.2%	19.7%	18.0%	17.2%		
	Subsidies for charging station installation	10.0%	16.0%	21.1%	16.0%	17.0%		
	Fuel taxes	5.0%	7.5%	2.7%	5.7%	5.1%		
	Special operating privileges	2.5%	2.8%	4.8%	6.2%	4.7%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%.

Table 5.8 Comparison of consumers' perceptions towards EVs (unweighted percentage) across five groups of respondents in 2023

		EVs owners	Plan to own/lease the first EV	Be interested in learning more about EVs	Consider purchasing/Leasing an EV sometime later on	Not expect to purchase/lease an EV anytime soon	Pooled	Pearson Chi-Square (χ^2)	*p*-value
First motivations	Low operation costs	41.7%	42.6%	31.1%	32.8%	32.3%	34.2%	6.64	0.881
	Low maintenance costs	8.3%	6.4%	12.2%	8.6%	9.7%	9.3%		
	Air quality improvement	4.2%	14.9%	16.2%	17.2%	20.4%	16.7%		
	Climate change mitigation	45.8%	36.2%	40.5%	41.4%	37.6%	39.8%		
Second motivations	Low operation costs	24.0%	16.3%	34.2%	24.4%	30.5%	27.1%	11.51	0.486
	Low maintenance costs	24.0%	28.6%	20.5%	18.7%	19.5%	20.9%		
	Air quality improvement	16.0%	30.6%	20.5%	28.5%	24.6%	25.3%		
	Climate change mitigation	36.0%	20.4%	17.8%	22.8%	22.0%	22.2%		
	Less noisy	0.0%	4.1%	6.8%	5.7%	3.4%	4.6%		
First barriers	High purchase price	47.8%	48.8%	33.3%	41.2%	**30.3%**	36.4%	34.34	0.005
	Charging infrastructure	8.7%	14.0%	20.0%	16.0%	16.8%	16.4%		
	Supply-side availability	17.4%	7.0%	4.0%	3.4%	**1.1%**	3.6%		
	Range anxiety	17.4%	**11.6%**	26.7%	25.2%	27.0%	24.5%		
	Battery sustainability	8.7%	18.6%	16.0%	14.3%	**24.9%**	19.1%		
Second barriers	High purchase price	14.3%	23.3%	27.0%	23.9%	21.9%	23.1%	27.96	0.032
	Charging infrastructure	14.3%	16.3%	14.9%	17.1%	**25.7%**	20.1%		
	Supply-side availability	28.6%	**23.3%**	18.9%	12.0%	**6.0%**	12.6%		
	Range anxiety	23.8%	23.3%	23.0%	19.7%	24.0%	22.6%		
	Battery sustainability	19.0%	14.0%	16.2%	27.4%	22.4%	21.7%		
Most influential policies	Subsidies for vehicle purchase	68.2%	56.5%	50.0%	52.1%	48.2%	51.5%	12.95	0.373
	More public charging facility construction	22.7%	19.6%	25.7%	18.2%	20.5%	20.7%		
	Subsidies for charging station installation	0.0%	21.7%	20.3%	24.0%	21.7%	21.0%		
	Fuel taxes	9.1%	2.2%	4.1%	5.8%	9.6%	6.8%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%.

As for the 2023 survey, respondents who were in the fifth group still exhibited stark differences in perceptions towards EVs compared to other four categories. Their disproportionately greater recognition of EVs' cost savings and lesser admiration of their beneficial effects on climate change which was identified in the key motivations in 2020 was also reflected in the primary barriers in 2023. They expressed significantly higher apprehensions regarding the sustainability of EV batteries and less fears of high initial costs. Their second major worry about owning or leasing EVs in terms of charging facilities was consistent with that in 2020. Unlike the 2020 survey, respondents in the other four categories cannot be distinguished by their motivations for EV purchase. Instead, those who "planned to purchase or lease their first EV" demonstrated a significantly lower percentage in choosing range anxiety as a key issue relative to other groups. This group and the first group of EV owners also showed disproportionately larger shares of those who regarded EVs' limited supply-side availability as their second main barrier to purchase or lease an EV. This can be explained by the fact that consumers who are not considering adopting an EV soon are not likely to be at the stage of approaching dealerships and searching for available EV models, while consumers who at least have some interest in EVs may experience difficulties in finding EV models that meet their expectations or are available in dealerships for test driving.

Given differentiated perceptions towards EVs between those who were in the fifth group and other four categories in the two years above, Table 5.9 and Table 5.10 thus categorize respondents into two subgroups (group 1, 2, 3, 4 versus group 5) and demonstrate how the perceptions changed for these two subgroups over time, respectively.

Table 5.9 Comparison of consumers' perceptions towards EVs (unweighted percentage) between 2020 and 2023 for group 1, 2, 3, and 4

		2020	**2023**	**Pooled**	**Pearson Chi-Square (χ^2)**	***p*-value**
First motivations	Low operation costs	**20.7%**	**34.9%**	27.5%	15.50	0.001
	Low maintenance costs	7.7%	9.2%	8.4%		
	Air quality improvement	19.6%	15.3%	17.6%		
	Climate change mitigation	**51.9%**	**40.6%**	46.5%		
Second motivations	Low operation costs	28.8%	25.6%	27.3%	13.48	0.009
	Low maintenance costs	19.7%	21.5%	20.5%		
	Air quality improvement	**35.3%**	**25.6%**	30.6%		
	Climate change mitigation	**12.5%**	**22.2%**	17.2%		
	Less noisy	3.7%	5.2%	4.4%		
First barriers	High purchase price	**49.3%**	**40.8%**	45.2%	21.71	0.001
	Charging infrastructure	15.8%	16.2%	16.0%		
	Limited models	**4.6%**	**1.2%**	2.9%		
	Limited EVs at the dealership	**1.1%**	**4.2%**	2.6%		
	Range anxiety	22.5%	22.7%	22.6%		
	Battery sustainability	**6.7%**	**15.0%**	10.7%		
Second barriers	High purchase price	18.7%	23.9%	21.2%	9.71	0.084
	Charging infrastructure	22.9%	16.1%	19.7%		
	Limited models	14.8%	10.6%	12.8%		
	Limited EVs at the dealership	3.9%	6.7%	5.2%		
	Range anxiety	22.2%	21.6%	21.9%		
	Battery sustainability	17.6%	21.2%	19.3%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%.

Table 5.10 Comparison of consumers' perceptions towards EVs (unweighted percentage) between 2020 and 2023 for group 5

		2020	2023	Pooled	Pearson Chi-Square (χ^2)	*p*-value
First motivations	Low operation costs	18.7%	15.9%	17.3%	7.58	0.108
	Low maintenance costs	8.4%	4.8%	6.6%		
	Air quality improvement	14.8%	10.1%	12.5%		
	Climate change mitigation	19.7%	18.5%	19.1%		
	Nothing can motivate me	38.4%	50.8%	44.4%		
Second motivations	Low operation costs	26.9%	30.5%	28.5%	0.575	0.966
	Low maintenance costs	20.5%	19.5%	20.1%		
	Air quality improvement	25.6%	24.6%	25.2%		
	Climate change mitigation	22.4%	22.0%	22.3%		
	Less noisy	4.5%	3.4%	4.0%		
First barriers	High purchase price	37.3%	30.3%	33.9%	11.15	0.025
	Charging infrastructure	19.6%	16.8%	18.3%		
	Supply-side availability	3.4%	1.1%	2.3%		
	Range anxiety	26.5%	27.0%	26.7%		
	Battery sustainability	**13.2%**	**24.9%**	18.8%		
Second barriers	High purchase price	20.3%	21.9%	21.1%	5.97	0.202
	Charging infrastructure	34.0%	25.7%	30.0%		
	Supply-side availability	5.6%	6.0%	5.8%		
	Range anxiety	25.9%	24.0%	25.0%		
	Battery sustainability	14.2%	22.4%	18.2%		

Note: The values highlighted in bold emphasize that they are statistically significant at a significance level of 5%.

Table 5.9 and 5.10 further demonstrate that the two subgroups exhibit different changes of perceptions towards EVs across three years, which is also complementary with the findings of sub-section 5.5.2. On one hand, group 1, 2, 3, and 4 demonstrated dynamic perceptions for the time period and their changes of perceptions were statistically significant, linked to both their motivations and barriers to purchase EVs. The changes within the four groups echo the results from sub-section 5.5.2 that consumers attached higher importance to EVs' operational cost savings but lower significance to environmental benefits to climate and they had less concern about EVs' high purchase prices and available EV models but more doubts regarding the sustainability of batteries and EV availability in dealerships. On the other hand, group 5 maintained relatively stable perceptions between 2020 and 2023. However, like group 1, 2, 3, and 4, they became increasingly skeptical about the sustainability of batteries.

5.5.4 Changes in the Importance Level of Influential Factors to EV Purchase in 2020 and 2023

Previous result sections uncovered the heterogeneity of consumers' likelihood and perceptions of EV purchase over time and among groups, and this section continues to demonstrate how the influential factors that explain variation in consumers' general interests in EV adoption also changed over time. Consumers' perceived benefits of EVs are highly associated with their general interests in purchasing or leasing EVs and their primary motivation is more significant than their secondary motivation in influencing their interests. Perceived benefits have also more substantial influence compared to their perceived risks and influential policy initiatives and socio-demographics in both years.

This result is aligned with findings from other studies. Perceived risks did not correlate with consumers' intention to purchase EVs, but rather they were related to their attitudes towards EVs; their effects were smaller than or similar with that of perceived benefits on attitudes (C. Yang et al., 2020; Zhang et al., 2018). Some studies have found that respondents' perceptions of financial incentive policies do not significantly influence their intention to adopt EVs (Lashari et al., 2021; S. Wang et al., 2018). However, cash and non-cash incentives (e.g., free municipal parking and access to HOV lanes) have been found to be important in shaping consumers' preferences for different vehicle powertrains in Ontario and British Columbia provinces in Canada in 2015 (Abotalebi et al., 2019b). This study observed that there are no statistically significant differences in the effects of EV-related policy options across consumers groups. This discrepancy could be due to different approaches in conceptualizing government policies and segmenting consumers. Additionally, consumer characteristics in general have been found to be less influential in consumers' acceptance of EVs compared to their perceptions (Higueras-Castillo, Guillén, et al., 2020; Mohamed et al., 2018; Morton et al., 2017).

Compared to results in 2020, results in 2023 demonstrate that perceived environmental benefits are still more influential than economic benefits, whereas the effect of economic benefits increased over time (Table 5.11). Specifically, Waterloo residents who regarded EVs' environmental friendliness as the most important motivation are roughly 26 times (climate change mitigation, Odds Ratio, $OR=e^{3.26}=26.05$) and 15 times (air quality, Odds Ratio, $OR=e^{2.72}=15.18$) more likely to have interests in EVs compared to those who think highly of EVs' cost savings or other motivations in 2023. The numbers were also larger than those (climate change mitigation—15 times and air quality—10 times) in 2020. This could suggest that the increasing severity of environmental issues has influenced the global public agenda, driving consumers' perception change to take actions in environmental protection, having Canada do its part in the global context. A recent study echoes the finding that consumers attach more importance of sustainable consumption and environmental awareness since the pandemic (Severo et al., 2021). Those who regarded either low operation or maintenance costs as the top motivation were separately 9 times and 17 times more likely, respectively, to have general interests in EVs compared to others, while their probabilities were 5 times and 3 times, respectively, in 2020. The increasing importance of economic perspectives was also reflected by the additional significant impact of high purchase prices on consumers' general interests in EVs in 2023; those who regarded EVs' high purchase prices as their top concern were roughly 3 times more likely to be interested in EVs than those who chose other barriers.

The increasing sensitivity to the economics of EVs is inconsistent with the conclusions made by Qian et al. (2023) that Chinese consumers became less sensitive to running costs between 2017 and

2019. The misalignment could be explained by the fact that the lingering effects of the pandemic from 2020, coupled with continued high inflation rates and economic uncertainties (e.g., the fluctuation of gasoline prices and global supply chain disruptions), reduced consumers' general spending, especially on non-essential goods and services (McKinsey & Company, 2023). The outcomes are consistent with the conclusions drawn in the study conducted by Balla et al. (2023), which analysed public tweets between 2012 and 2022 to uncover the evolution of sentiments and discourse on EVs. They found that the environmental concern and events constantly increased people's interest in EVs and consumers' financial sufficiency and constraints have a higher influence on the surge or decrease of positive perceptions. Additionally, the dominating resistance towards EV adoption post-pandemic shown in negative tweets was related to financial constraints.

Among all the barriers considered, consumers' concern about accessing EV charging facilities was the only one that significantly influenced their interests towards EVs in both years; those who expressed concern about accessing charging infrastructure (as their second choice of barrier) were much less likely (Odds Ratio, $OR=e^{-0.8}=0.45$) to be interested in EVs compared to those who chose other barriers. This result echoes to the results shown in Table 5.7 and 5.8 that respondents from the fifth group had disproportionately higher proportions in choosing charger availability as their second concern in both years. This can be explained by the lack of information, low familiarity, or inadequate experience related to EV charging that have been still common in Canada (Abacus Data, 2023; Long et al., 2019). As shown by Bucher et al. (2020) and PlugShare Research (2023) worries about the charging infrastructure availability diminish when consumers actually own an EV.

In terms of socio-demographics, household income (before taxes) was the only characteristic that had significant influence on level of interest in EVs in both years; those who had higher household income were more likely to have interest in EV purchase or lease, with the probability being 1.4 and 1.7 times respectively in 2020 and 2023. Factors that additionally had significant impact were gender, employment status, and residence area in 2020 and were marital status and age in 2023, indicating that consumers who were male, employed, and lived in cities tended to have interests in EVs in 2020 and residents who were married and younger were more inclined to be interested in EVs in 2023.

Table 5.11 Binary logistic modelling consumers' general interests in purchasing EVs (weighted data) between 2020 and 2023

		Whether consumers have general interests in EVs (2020)		**Whether consumers have general interests in EVs (2023)**	
		Beta	Std. error	Beta	Std. error
Socio-demographics	Marital (ref: not married)				
	Married			1.52	(0.38)***
	Gender (ref: female)				
	Male	1.05	(0.27)***		
	Age	-0.12	(0.08)	-0.36	(0.10)***
	Employment status (ref: non-employed)				
	Employed	0.74	(0.28)**		
	Residence area (ref: townships)				
	Cities	1.33	(0.43)**		
	Education (ref: Grade school or high school or some college and university)				
	With post-secondary certificate, diploma, or degree				
	Household income (before taxes)	0.36	(0.11)**	0.53	(0.13)***
Perceived benefits	Low operation costs (ref: not chosen)				
	Chosen as the first motivation	1.54	(0.46)***	2.23	(0.71)***
	Chosen as the second motivation	1.47	(0.57)*	1.08	(0.71)
	Low maintenance costs (ref: not chosen)				
	Chosen as the first motivation	1.19	(0.58)*	2.84	(0.67)***
	Chosen as the second motivation	1.37	(0.55)*	2.32	(0.71)**
	Air quality improvement (ref: not chosen)				
	Chosen as the first motivation	2.31	(0.50)***	2.72	(0.60)***
	Chosen as the second motivation	1.82	(0.60)**	0.67	(0.75)
	Climate change mitigation (ref: not chosen)				
	Chosen as the first motivation	2.70	(0.48)***	3.26	(0.60)***
	Chosen as the second motivation	0.57	(0.62)	1.86	(0.70)**
	Less noisy (ref: not chosen)				
	Chosen as the first motivation	2.81	(1.07)**	0.34	(1.30)
	Chosen as the second motivation	1.23	(0.76)	1.61	(0.85)
Perceived risks	High purchase prices (ref: not chosen)				
	Chosen as the first barrier			0.98	(0.33)**
	Chosen as the second barrier			0.64	(0.36)
	Lack of charging stations (ref: not chosen)				
	Chosen as the first barrier	-0.51	(0.35)	0.11	(0.39)
	Chosen as the second barrier	-0.81	(0.30)**	-0.84	(0.36) *
	Range anxiety (ref: not chosen)				
	Chosen as the first barrier				
	Chosen as the second barrier				
	Supply-side availability (ref: not chosen)				
	Chosen as the first barrier				
	Chosen as the second barrier				
	Battery sustainability concern (ref: not chosen)				
	Chosen as the first barrier	-0.77	(0.45)		
	Chosen as the second barrier	0.40	(0.35)		
Constant		-5.22	(0.87)***	-5.08	(0.76)***
AIC		491.64		370.03	
Null Deviance		609.74		571.77	
Residual Deviance		419.54		356.99	

Note: *p*-value >= 0.05 (-), *p*-value < 0.05 (*), *p*-value < 0.01 (**), *p*-value < 0.001 (***)

5.6 Concluding Remarks

Consumers' likelihood and perceptions to EV purchase are multi-faceted and dynamic over time. The analysis presented in Chapter 5 is based on primary data collected in the Region of Waterloo, Ontario, Canada from a medium-scale survey that was administered first in 2020, in the early days of the COVID-19 pandemic, and then again in 2023. The study adopts DOI as a guiding framework, and the focus is on understanding changes in consumer perceptions and likelihood to purchase EVs—and how this links with Canada's societal transition to electrified mobility. Overall, the study shows that EV adoption in this local municipal context has been increasing, which appears similar to the national transition process of EVs identified in Chapter 4. There is an important aspect of this change, however, that has not been identified in previous work, with important implications for understanding and supporting a fuller transition to EVs.

The DOI framing of the study categorizes respondents according to five consumer groups. The first two groups—those who currently own or lease an EV or plan to as their next vehicle—represent small but growing proportions of the population of Waterloo Region. Together these two groups accounted for approximately 7% and 12%, in 2020 and 2023, respectively; which is roughly equivalent to the combined size of the 'innovator' and 'early adopter' groups in the DOI. The next two groups, i.e., those who said that they are "interested in learning more" or "would consider an EV sometime later" were both reduced over time, and together represented approximately 38% in 2023, down from more than 45% in 2020—considerably less than the percentages normally associated with the 'early majority' and late majority' adopters in the DOI. And, correspondingly, the fifth group, i.e., those who indicate that they "do not expect to purchase or lease an EV anytime soon" has grown over time from 47.34% in 2020 to 49.62% in 2023. Thus, approximately one-half of the population appears to be embracing the transition to EVs while the other half being rigidly reluctant. Ferguson et al. (2018) found that approximately 4% of households surveyed in the Waterloo Region showed a preference for EVs in 2015. This placed the region in the top one-third among the 35 Canadian CMAs and the top three among 14 CMAs in Ontario. Given Waterloo Region's relatively high openness to EVs among Canada and Ontario and its favourable contextualization in terms of the transition to EVs, its state of EV adoption underscores the slowness of the transition and also suggests that the transition is not likely to be complete because of apparent polarization in people's positions about this technology option.

To help explain the above data, some of the key changes in consumers' motivations and barriers to EV purchase that were observed between the two study years are highlighted. First, in both time periods, the recognition of EVs' environmental benefits, has been a strong predictor of their likelihood to purchase an EV. Consumers who appreciate EVs' positive environmental impacts more than their functional and economic benefits are much more likely to be interested in an EV purchase. However, the importance of EVs' economic benefits, i.e., cost savings in operation and maintenance, is increasing as time unfolds, which seems to connect with the salient role of big events (e.g., COVID-19 pandemic and Russia-Ukraine conflicts) in shaping economic landscapes and broader social contexts concluded in Chapter 4.

Encouraging consumers' pro-environmental attitudes has been found to stimulate the adoption of green technology in various contexts. This is because the influence of pro-environmental attitudes is more substantial than the impact of technology maturity levels on consumers' first-time purchases (Zeng et al., 2020). In some regions of the world, the surge of EV market shares has resulted in EVs being normalized as regular vehicle choices. Linking this to the DOI model, it appears that recent Norwegian EV purchasers are 'majority adopters'. Norwegian EV buyers were found to not associate EV adoption with environmental concern or with the reduction of households' environmental impacts (Orlov & Kallbekken, 2019). The proportions of Norwegian ICEV owners who viewed the environmental effects of EVs as a major advantage decreased between 2016 and 2018, while the proportion who regarded as neutral increased (Figenbaum et al., 2019), which suggests that the environmental characteristics of EVs could be perceived as being less significant when the market becomes more mature. In Waterloo Region, by contrast, recent purchasers of EVs are still 'early adopters', given the limited market penetration here and indeed in much of North America.

Some of the most interesting findings of the current study relate to those who were not interested in EVs at all, as indicated by their response that they did "not expect to purchase or lease an EV any time soon". They were notably contributors to the increased concerns about battery sustainability and decreased doubt about EVs' purchase prices. This result to some extent reflected the contested media frames of EVs in Canada (but not limited to Canada), particularly the increasing misinformation and negative frames that discredit EVs, e.g., EVs' easiness to catch fire and more GHG emissions in lifecycles (Melanson & Kyriazis, 2024). Interestingly, despite the overall general decline of worries about accessing charging facilities, this group of respondents still focused on charging as a barrier to EV purchase. This may suggest that 'non-adopters' hold the rhetoric of reaction regarding EVs, which refers to arguments that oppose progressive changes from conservatives. Their concern about sustainability and charging availability is thus more of an excuse and bias to EV adoption instead of a true barrier. Noel et al. (2019) confirmed the existence of rhetoric of reaction, especially jeopardy thesis, regarding range anxiety among consumers and experts in five Nordic countries. The nuanced and contextualized understanding of why 'non-adopters' perceived certain risks calls for further investigation.

Differences across consumer groups raises considerations for policy design and implementation as well as communication strategies. For the 'innovators' and 'early adopters' of EVs, increasing the variety of EV models in the automobile markets for different needs and the number of available EV models in dealerships for viewing and test driving is imperative to reduce their perceived risks and thus accelerate their adoption processes. As for 'late' and 'non-adopters', effective communication strategies and persuasive language in changing their perceptions and clarifying the characteristics of EVs can be as crucial as addressing practical issues (e.g., the installation of more chargers and the increase of battery ranges). There may be value in local governments working with dealerships, salespeople, or non-profit organizations (e.g., Plug'n Drive and EV Society) to improve EV uptake by encouraging the presence of floor models and vehicles for test-driving on site. The processes are also good opportunities to increasing the accuracy of information being provided to customers and reducing misinformation and false narratives. A municipal EV study in Canada found that information sessions by municipalities can significantly increase people's intention to purchase EVs (Fuller et al., 2021). More nuanced understanding about consumers' perceptions through community engagement, consultation, and research is also needed for tailored policy solutions, particularly to tease out the components of concern about EVs' battery sustainability and infrastructure accessibility, e.g., technical aspects, social equity, or/and bias.

This study highlights the importance of investigating consumer preferences towards EVs through the lens of longitudinal dynamics, which has been under-addressed from both theoretical and empirical settings. The DOI with its uniqueness among behavioural theories incorporates the temporal nature of change through adopter categorization. This is useful in uncovering how societal transition processes of EVs unfold when the proportions of different consumer groups are scrutinized in different time points. However, the theory primarily focuses on explaining how different groups of consumers have varying preferences for the EV diffusion process and it overlooks the aspect that the same consumers could change preferences over time during these processes. These two aspects complement with each other for a better understanding of the transition process of EVs in local municipal contexts. The considerable deviation between the sample data and the proposed percentages from the DOI hints at a much slower diffusion or even a partial adoption process for the transition to EVs in Waterloo Region.

Chapter 6 Discussion and Conclusion

6.1 Summary

The climate crisis poses the greatest threat to humanity and natural environments, and unsustainable consumption and production patterns across various social domains have significantly contributed to this crisis. Energy supply, for example, is confronted with fossil fuel depletion, increasing GHG emissions, uncertainties related to short- and long-term energy security, and stranded energy infrastructure. Personal mobility is challenged by fossil fuel combustion, local air pollution, carbon-intensive physical infrastructure, and reliance on private vehicles in daily travels. Other domains, e.g., food system and water sanitation, also face similar challenges. Therefore, the acceleration of transformative changes with the goal of sustainability is urgently required for coping with those fundamental societal challenges and meeting climate targets. These changes involve systemic, large-scale, and structural changes in complex systems, which is divergent from incremental changes that are not sufficient to cope with long-term lock-ins and path-dependence.

Some of the necessary changes are approached through technologies; they require not merely technological advancements but rather their interplay with societal contexts, including changes in consumer practices and lifestyles, institutional (e.g., cultural and regulatory) structures, business models, and political structures. They are framed as socio-technical transitions, which have received increasing attention in contemporary policy agenda (Schot & Steinmueller, 2018), investment rules (Penna et al., 2023), and social science scholarship (Markard et al., 2012). The concept of socio-technical transitions highlights the fact that multiple elements inherently interact with each other in a co-evolutionary process to give rise to the complexity and dynamics of transitions. How to promote and govern such transitions from established socio-technical systems towards more sustainable modes of production and consumption has thus become a priority. And, the progress of some ongoing transitions has been slow and fragmented; their future prospects are uncertain, and this uncertainty is heightened by the COVID-19 pandemic and other landscape-level events. Societal transition to EVs is an example of a much-need transition and was chosen as the focus of this thesis. As pro-environmental technological innovations in transportation, EVs are indispensable for decarbonizing personal mobility and strengthening the linkages between energy and transport sectors.

Despite scholarship's significant contribution to conceptualizing and explaining the complex transition processes, the way in which transitions are unfolding is still challenged by a lack of understanding of dynamic processes involved in aligning multiple dimensions, especially their geographical aspects. Specifically, what are the spatial and temporal transition contexts and how can these be analysed and addressed from both conceptual and empirical viewpoints. This is the motivation and research objective for the thesis—to explicitly and systematically uncover the geographical contexts of transitions, generally and with specific reference to the transition to EVs. It is also crucial to note that there is a broad range of relevant theoretical approaches, which have been used to study and explain the adoption and diffusion of technological innovations in societies. These approaches are generally from two lenses, macro level and micro level, which respectively emphasize societal 'structure' and individual 'agency'. These two-level analyses also touch upon the long-standing debate about whether structure or agency plays a more crucial role in driving sustainable transitions, which has not been understood in a collective way. For example, transitions research has mostly focused on socio-technical regimes, structural contexts in meso levels, but has often neglected agency in the context of transition processes. The collective lens of both two aspects in transition processes is another main position that this thesis stands and another research objective, to critically explore and evaluate their interrelations in change processes.

The thesis specifically asks the research question that how macro-level (Chapter 4) and micro-level (Chapter 5) lenses can help explain the spatial and temporal patterns of EV transition process, with specific reference to Canada where EV registrations are geographically variable and represent an early stage for acceleration. It illuminates the complexity of how multiple dimensions align with one another in the transition process from a structured, systematic, and comprehensive perspective by adopting quantitative approaches through the development of influential indicators and statistical modelling. It involves two complementary research components:

The first research component (Chapter 4) aims to describe and explain the spatial and temporal patterns of transition to EVs at national level between 2017 and 2022 based on the geography of transitions literature and existing empirical studies on EV diffusion with a consideration of geographical aspects. By conceptualizing and operationalizing each of the five constructs from the geographical transition framework, as well as other cross-cutting variables, it measures, selects, and evaluates a set of 13 independent variables that are relevant to the transition to EVs in a holistic manner. These variables are used to model and interpret the spatial-temporal variation of new EV registrations, which are based on secondary data acquired from seven provinces by quarter.

The data presented in Chapters 4 has demonstrated that an EV transition is underway across Canada, especially for the transition of BEVs which account for roughly three fourths of total new EV registrations. That said, distinct spatial variation and temporal fluctuation exits. The variation of how

EVs are adopted geographically is largely influenced by energy prices, particularly gasoline prices over time that are caused by the occurrence of landscape-level events with varying scale, speed, and duration, such as the COVID-19 pandemic, geopolitical conflicts, and natural disasters. Specifically, the model results suggest that the number of EV registrations per 1000 people would be roughly 4 times higher for a one dollar per litre increase in gasoline prices (or would increase by approximately 16% for every 10-cent per litre rise in gasoline prices), all else being held constant. Other variables that represent four of the five geography-of-transition constructs also play a role in shaping the transition pattern, despite their lesser impact compared to gasoline prices. These include urban and regional visions and policies (purchase incentives (+)), informal localized institutions (societal environmentalism (+)), local technological and industrial specialization (the availability of EV supply or inventory (+)), and consumers and local market formation (education (+) and affluence (+) levels). However, the two variables, public charger density and fast charger ratio, that represent the construct of local resource endowments were not able to explain temporal-spatial variations in Canadian EV transition.

Registrations for BEVs or PHEVs have distinct sensitivities to some of the above constructs and variables; reliable and abundant supply of inventory, supported by advanced technological and industrial specialization, is more influential to sustain BEV adoption compared to PHEV adoption, while purchase incentives and electricity prices become particularly more significant for the societal uptake of PHEVs. Furthermore, Chapter 4 explicitly pointed out the importance of nuanced interactions among constructs to give rise to the geographic contexts of EV transition, especially between urban and regional visions and policies and consumers and local market formation; the effect of incentives on EV registrations becomes less noticeable at higher affluent levels.

The second research component (Chapter 5) aims to understand and assess changes of consumers' likelihood and perceptions to purchase EVs in a local municipality, Waterloo Region, between 2020 and 2023 based on the DOI and existing empirical studies on EV adoption with emphasis on attitudes and perceptions. It distinguishes consumers into five segments by their actual behaviour of EV purchase or likelihood of/interest in purchasing an EV based on DOI's adopter categorization and identifies how their stated likelihood to purchase EVs changed over time. It also compares how their perceptions towards EVs, including perceived benefits, risks, and influential government initiatives, changed over time and across different consumer segments. It further uses those influential variables related to perceptions to model and explain how they contribute differently to the changes of consumers' general interests in EV adoption over time. It thus suggests the trend of EV transition from the lens of individuals based on primary data from local consumer surveys in 2020 and 2023.

Consumers' dynamic likelihood and perceptions to EV purchase in the local municipality context have demonstrated a progressive trend of EV transition, whereas such process is differentiated with half of the population 'embracing' the transition to EVs and the other half being rigidly reluctant. Considering Waterloo Region's relatively high acceptance of EVs in Canada and Ontario, as well as its favourable conditions and capacities for EV transition, there is concern about whether other municipalities are experiencing similar situations or even more. Consumers' perceived benefits of EVs, especially the recognition of EVs' environmental friendliness, have been significant predictors for the above differentiation between two sub-groups; consumers who were motivated by EVs' positive environmental impacts more than their functional and economic benefits were much more likely to be interested in purchasing EVs. Consumers' characteristics as well as their perceived risks of EV purchase have minor influence on their interests in EVs, with only household income (before taxes) (+) and consumers' concern about accessing EV facilities (–) significantly influencing their interests towards EVs for both years. Concern about EVs' high purchase prices had additional significant impact on their general interests in EVs in 2023 (+). Surprisingly, consumers perceptions of various government policy levers show no significant differences in their effects on EV interests.

Consumers' perceptions are dynamic over time with different emphases of motivations and barriers to EV purchase in 2020 versus 2023. Specifically, respondents attached higher importance of EVs' economic benefits, i.e., cost savings in operation, and lower significance to environmental benefits, i.e., mitigating climate change, in 2023 as compared to 2020. Their concern shifted away from high upfront costs and access to charging infrastructure to battery sustainability, and they also worried much less about the limited numbers of EV models but much more about the limited availability of EVs at the dealership for viewing and test driving in 2023. Furthermore, perception changes varied among individuals, with respondents in the fifth group, i.e., those who "do not expect to purchase/lease an EV anytime soon" showing dramatically different perceptions towards EVs compared to other four categories. Respondents who were in the group 1, 2, 3, or 4 demonstrated similar perception changes with overall perception variation over time, while group 5, i.e., those who "do not expect to purchase or lease an EV anytime soon", maintained relatively stable perceptions between 2020 and 2023, except their increasing skepticism about the sustainability of batteries.

6.2 Conclusions

Based on the above two research components, their integration, synergy, and complementarity foster a better understanding of the EV phenomena in Canada. The macro-level and micro-level analyses both suggest a positive development of ongoing transition to EVs in Canada, whereas the process has been geographically uncertain and socially differentiated, raising doubt about whether Canada can achieve the commitment of 100% ZEV sales by 2035 and whether EVs can fully penetrate the Canadian market. They also highlight the alignment between longitudinal dynamics of consumers' perception to EV purchase and dynamic societal landscape of EV development. The importance of EVs' economic perspectives in individuals' likelihood to adopt EVs increased between 2020 and 2023, which echoes the salient role of big events in driving the surge of gasoline prices and, more broadly, shaping social and economic contexts. The changes of perceptions related to the number of EV models in market and the availability of EVs at the dealership were also in accordance with increasing EV options in terms of body types, brands, and prices and the global supply chain disruptions in automotive industry between 2020 and 2023. Consumers' perceived environmental benefits have the most substantial influence on their EV interests for both years, which also echoes the significance of societal environmentalism, as one of the representations of informal localized institutions, in impacting the transition pattern of EVs.

The two lenses, however, also demonstrate variation in their insights into understanding the geographical contexts of EV transition. On one hand, urban and regional visions and policies have been found vital in driving EV diffusion across provinces in Canada, especially for the provinces with relatively low affluence level, nonetheless how consumers perceive both cash- and non-cash governmental initiatives suggests no significant differences in the effects of these policy options on their likelihood to adopt EVs. On the other hand, local resource endowments, which are represented by public charging availability by province, are not important in the nationwide spread of EVs. However, individuals' perception towards accessing to chargers in general, either home or public chargers, is a strong predictor of their interests of EVs; those who are reluctant to purchase EVs consistently identified it as a major barrier to EV adoption over both years, despite a general decline in concerns among respondents.

6.3 Practical Implications of the Thesis

The findings of this thesis present several practical implications for planning and government policy strategies. The transition process of EVs in Canada is a co-evolutionary process with multiple elements interacting with each other. Therefore, no single policy or action can individually accelerate the process but rather in a collective way. The interaction between EV purchase incentives and affluence levels suggest provincial and federal incentive programs to provide different amounts based on income levels within and between provinces, especially for leveraging areas in relatively low affluence levels and facilitating the uptake of PHEVs. It can be an effective and efficient way to reduce regional disparities and foster a more equitable transition. The implementation of provincial ZEV mandates to incentivize automakers and increasing investment for supporting them in building EV assembly and battery plants across Canada are also useful for sustaining a growth trajectory of EV adoption, especially for BEVs, and alleviating regional disparities in EV inventory distribution. Fuel taxes, carbon taxes, and electricity prices are essential tools for various government levels to regulate EV technology, especially given the inherent volatility and complexity of global crude oil prices.

They also demonstrate practical implications for other stakeholders (e.g., dealerships, automakers, communities, and non-profit organizations) in terms of the development of communication and marketing strategies. The heterogeneity of likelihood and perception to EV purchase across consumers highlights the importance of tailored strategies for different consumer segments and the significance of longitudinal dynamics in investigations. An emphasis on the benefits of EVs can be an overarching strategy. The provision of a variety of EV choices from automakers and sufficient models at dealerships for viewing and test driving are crucial for those who are owners or plan to purchase one soon to 'move forward'. Different stakeholders can also cooperate with each other in organizing activities or events related to EV test driving and model demonstration, thereby increasing information accuracy for consumers. The contrasting findings of EV charging facilities from two research components further underline that the availability of charging facilities is embedded with perceptions. This further begs the question that if social equity issues of charging placement exist in Canadian municipality contexts. Inequitable distribution of different types of charging infrastructure (i.e., home, workplace, and public chargers) has been evident in some American areas (Hopkins et al., 2023; Rouhana et al., 2024). Although there has been evidence about limited strategic plans of equitable distribution of charging facilities across geographical areas in Canada (Office of the Auditor General of Canada, 2023), specific infrastructure gaps in municipal, provincial, and regional levels have not been clear. To counteract those who remain concerned about charging infrastructure accurate information is critical in informing purchase decisions, which are always contextual, and also have important equity implications. Similarly, Canadians need clear information on battery sustainability, which remains a concern amongst many.

6.4 Future Research

This thesis calls for three directions of future research. The first would extend the empirical analysis, distinguishing EVs especially by its propulsion system; inclusion of hybrid electric vehicles, which run on two systems but do not need to plug into an external source of electricity to recharge, would help to understand both motivations and barriers to the adoption of vehicles that are different than the internal-combustion-engine models that have dominated the industry for the past century. Second, an investigation of how EVs affect people's travel behaviour is crucial with the increasing number of EVs on roads, which can be directly intertwined with whether EVs will be co-evolve with automation and shared mobility to give rise to a true mobility revolution. Related to this is how utilities can prepare, accommodate, or adjust the existing energy systems to meet the increasing electricity demand over time and across spaces. Finally, this thesis highlights the importance of both 'agency' and 'structure' in sustainability transitions, which reflects an academic need to better theorize their interactions in understanding transition processes.

References

Abacus Data. (2023). *Perceptions of Electric Vehicles*.

Abotalebi, E., Scott, D. M., & Ferguson, M. R. (2019a). Can Canadian households benefit economically from purchasing battery electric vehicles? *Transportation Research Part D: Transport and Environment*, *77*(November), 292–302. https://doi.org/10.1016/j.trd.2019.10.014

Abotalebi, E., Scott, D. M., & Ferguson, M. R. (2019b). Why is electric vehicle uptake low in Atlantic Canada? A comparison to leading adoption provinces. *Journal of Transport Geography*, *74*(January), 289–298. https://doi.org/10.1016/j.jtrangeo.2018.12.001

Anderson, C. D., & Stephenson, L. B. (2011). Environmentalism and party support in Canada: Recent trends outside Quebec. *Canadian Journal of Political Science*, *44*(2). https://doi.org/10.1017/S0008423911000138

Aoyama, H. (2020). *Environmental Attitudes and Voting Behaviour in the 2019 Canadian Federal Election*. https://dalspace.library.dal.ca//handle/10222/79175

Arbib, J., & Seba, T. (2017). *Rethinking transportation 2020-2030 : the disruption of transportation and the collapse of the internal-combustion vehicle and oil industries*.

Arribas-Ibar, M., Nylund, P. A., & Brem, A. (2021). The Risk of Dissolution of Sustainable Innovation Ecosystems in Times of Crisis: The Electric Vehicle during the COVID-19 Pandemic. *Sustainability 2021, Vol. 13, Page 1319*, *13*(3), 1319. https://doi.org/10.3390/SU13031319

Axsen, J., Bailey, J., & Castro, M. A. (2015). Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics*, *50*, 190–201. https://doi.org/10.1016/j.eneco.2015.05.003

Axsen, J., Goldberg, S., & Bailey, J. (2016). How might potential future plug-in electric vehicle buyers differ from current "Pioneer" owners? *Transportation Research Part D: Transport and Environment*, *47*, 357–370. https://doi.org/10.1016/j.trd.2016.05.015

Axsen, J., Mountain, D. C., & Jaccard, M. (2009). Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. *Resource and Energy Economics*, *31*(3), 221–238. https://doi.org/10.1016/J.RESENEECO.2009.02.001

Azami, M., Sharifi, H., & Alvandpur, S. (2020). Evaluating the relationship between information literacy and evidence-based nursing and their impact on knowledge and attitude of nurses working in hospitals affiliated to Kerman University of Medical Sciences on medication errors. *Journal of Family Medicine and Primary Care*, *9*(8), 4097. https://doi.org/10.4103/JFMPC.JFMPC_5_20

B.C. Hydro. (2018). *Unplugged : Myths block road to the electric car dream* (Issue April).

Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L., & Sugiyama, T. (2018). Strengthening and implementing the global response. *Global Warming of 1.5 C an IPCC Special Report*, 1–82.

Balla, S. N., Pani, A., Sahu, P. K., & González-Feliu, J. (2023). Examining shifts in public discourse on electric mobility adoption through Twitter data. *Transportation Research Part D: Transport and Environment*, *121*, 103843. https://doi.org/10.1016/J.TRD.2023.103843

Barr, S., & Prillwitz, J. (2014). A Smarter Choice? Exploring the Behaviour Change Agenda for Environmentally Sustainable Mobility. *Http://Dx.Doi.Org/10.1068/C1201*, *32*(1), 1–19. https://doi.org/10.1068/C1201

Bergek, A., Berggren, C., Magnusson, T., & Hobday, M. (2013). Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation? *Research Policy*, *42*(6–7), 1210–1224. https://doi.org/10.1016/J.RESPOL.2013.02.009

Bhattacherjee, A. (2012). Social Science Research: Principles, Methods, and Practices. *Textbooks Collection*. https://digitalcommons.usf.edu/oa_textbooks/3

Bigerna, S., & Micheli, S. (2018). Attitudes toward electric vehicles: The case of Perugia using a fuzzy set analysis. *Sustainability (Switzerland)*, *10*(11). https://doi.org/10.3390/su10113999

Bloomberg New Energy Finance. (2024). *Electric Vehicle Outlook 2024*. https://assets.bbhub.io/professional/sites/24/847354_BNEF_EVO2024_ExecutiveSummary.pdf

Boulianne, S., Belland, S., Sleptcov, N., & Larsson, A. O. (2021). Climate Change in the 2019 Canadian Federal Election. *Climate 2021, Vol. 9, Page 70*, *9*(5), 70. https://doi.org/10.3390/CLI9050070

Brackin, R. C., Jackson, M. J., Leyshon, A., & Morley, J. G. (2019). Taming Disruption? Pervasive Data Analytics, Uncertainty and Policy Intervention in Disruptive Technology and its Geographic Spread. *ISPRS International Journal of Geo-Information 2019, Vol. 8, Page 34*, *8*(1), 34. https://doi.org/10.3390/IJGI8010034

British Columbia Government. (2022). *Rebate improvements make electric vehicles more accessible*. https://news.gov.bc.ca/releases/2022EMLI0049-001204

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Mächler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R Journal*, *9*(2), 378–400. https://doi.org/10.32614/RJ-2017-066

Brückmann, G., Willibald, F., & Blanco, V. (2021). Battery Electric Vehicle adoption in regions without strong policies. *Transportation Research Part D: Transport and Environment*, *90*, 102615. https://doi.org/10.1016/J.TRD.2020.102615

Bucher, D., Martin, H., Hamper, J., Jaleh, A., Becker, H., Zhao, P., & Raubal, M. (2020). Exploring Factors that Influence Individuals' Choice Between Internal Combustion Engine Cars and Electric Vehicles. *AGILE: GIScience Series*, *1*, 1–23. https://doi.org/10.5194/agile-giss-1-2-2020

Burton, I. (1963). The quantitative revolution and theoretical geography. *Canadian Geographer*, *7*(4), 151–162. https://doi.org/10.1111/J.1541-0064.1963.TB00796.X

Carley, S., Siddiki, S., & Nicholson-Crotty, S. (2019). Evolution of plug-in electric vehicle demand: Assessing consumer perceptions and intent to purchase over time. *Transportation Research Part D: Transport and Environment*, *70*, 94–111. https://doi.org/10.1016/J.TRD.2019.04.002

Carvalho, L., Mingardo, G., & van Haaren, J. (2012). Green Urban Transport Policies and Cleantech Innovations: Evidence from Curitiba, Göteborg and Hamburg. *European Planning Studies*, *20*(3), 375–396. https://doi.org/10.1080/09654313.2012.651801

Cascetta, E., & Henke, I. (2023). The seventh transport revolution and the new challenges for sustainable mobility. *Journal of Urban Mobility*, *4*, 100059. https://doi.org/10.1016/J.URBMOB.2023.100059

ChargeHub. (2021). *Identification of current and future infrastructure deployment gaps*. https://publications.gc.ca/collections/collection_2023/rncan-nrcan/M4-218-2022-eng.pdf

Chen, T. D., Kockelman, K. M., & Hanna, J. P. (2016). Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions. *Transportation Research Part A: Policy and Practice*, *94*, 243–254. https://doi.org/10.1016/j.tra.2016.08.020

Christensen, C. M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*.

Christensen, C. M., Raynor, M., & McDonald, R. (2015). What is disruptive innovation? *Harvard Business Review*, *2015*(December).

Clifford, N. J. ., Cope, M., & Gillespie, T. W. . (2023). *Key methods in geography*. SAGE.

ClimateActionWR. (2021). *TransformWR Waterloo Region's Transition to an Equitable, Prosperous, Resilient Low Carbon Community*.

ClimateActionWR. (2024). *2022 Waterloo Region Community Greenhouse Gas Inventory Report*. https://climateactionwr.ca/wp-content/uploads/2024/09/CA-2022-GHG-Inventory-Report_FINAL-05.10.24.pdf

Clinton, B. C., & Steinberg, D. C. (2019). Providing the Spark: Impact of financial incentives on battery electric vehicle adoption. *Journal of Environmental Economics and Management*, *98*, 102255. https://doi.org/10.1016/J.JEEM.2019.102255

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy*, *41*(6), 968–979. https://doi.org/10.1016/j.respol.2012.02.014

Coffman, M., Bernstein, P., & Wee, S. (2017). Electric vehicles revisited: a review of factors that affect adoption. *Transport Reviews*, *37*(1). https://doi.org/10.1080/01441647.2016.1217282

Collier, S. H. C., House, J. I., Connor, P. M., & Harris, R. (2023). Distributed local energy: Assessing the determinants of domestic-scale solar photovoltaic uptake at the local level across England and Wales. *Renewable and Sustainable Energy Reviews*, *171*, 113036. https://doi.org/10.1016/J.RSER.2022.113036

Cornet, A., Conzade, J., Schaufuss, P., Schenk, S., Hertzke, P., Heuss, R., von Laufenberg, K., & Möller, T. (2021). Why the automotive future is electric. In *McKinsey & Company*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/why-the-automotive-future-is-electric

Corsi, S., & Di Minin, A. (2014). Disruptive Innovation … in Reverse: Adding a Geographical Dimension to Disruptive Innovation Theory. *Creativity and Innovation Management*, *23*(1), 76–90. https://doi.org/10.1111/CAIM.12043

Creswell, W. John & Creswell, J. D. (2017). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. In *Sage publications* (Vol. 53, Issue 9).

D'Souza, G. C., Pinto, C. N., Exten, C. L., Yingst, J. M., Foulds, J., Anderson, J., Allen, R., & Calo, W. A. (2024). Understanding factors associated with COVID-19 vaccination among health care workers using the Diffusion of Innovation Theory. *American Journal of Infection Control*, *52*(5), 509–516. https://doi.org/10.1016/j.ajic.2023.11.019

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management*, *21*(4), 246–258. https://doi.org/10.1111/J.0737-6782.2004.00076.X

De Roeck, F., & Van Poeck, K. (2023). Agency in action: Towards a transactional approach for analyzing agency in sustainability transitions. *Environmental Innovation and Societal Transitions*, *48*, 100757. https://doi.org/10.1016/J.EIST.2023.100757

De Rubens, G. Z., Noel, L., & Sovacool, B. K. (2018). Dismissive and deceptive car dealerships create barriers to electric vehicle adoption at the point of sale. *Nature Energy*, *3*(6), 501–507. https://doi.org/10.1038/s41560-018-0152-x

Degirmenci, K., & Breitner, M. H. (2017). Consumer purchase intentions for electric vehicles: Is green more important than price and range? *Transportation Research Part D: Transport and Environment*, *51*(2017), 250–260. https://doi.org/10.1016/j.trd.2017.01.001

Deloitte. (2022). 2022 Global Automotive Consumer Study: Global focus countries. In *Deloitte* (Issue January).

DeShazo, J. R., Sheldon, T. L., & Carson, R. T. (2017). Designing policy incentives for cleaner technologies: Lessons from California's plug-in electric vehicle rebate program. *Journal of Environmental Economics and Management*, *84*, 18–43. https://doi.org/10.1016/J.JEEM.2017.01.002

Dijk, M., Wells, P., & Kemp, R. (2016). Will the momentum of the electric car last? Testing an hypothesis on disruptive innovation. *Technological Forecasting and Social Change*, *105*, 77–88. https://doi.org/10.1016/J.TECHFORE.2016.01.013

Dodge, Y. (2008). Durbin–Watson Test. In *The Concise Encyclopedia of Statistics* (pp. 173–175). Springer, New York, NY. https://doi.org/10.1007/978-0-387-32833-1_122

Dodman, D. (2009). Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *Environment and Urbanization*, *21*(1), 185–201. https://doi.org/10.1177/0956247809103016

Downes, L., & Nunes, P. (2014). *Introduction. In Big Bang Disruption: Strategy in the Age of Devastating Innovation*. Penguin. https://books.google.ca/books?hl=en&lr=&id=iV82AAAAQBAJ&oi=fnd&pg=PA1&dq=Big+Bang+Disruption:+Strategy+in+the+Age+of+Devastating+Innovation&ots=KCMdFfqkoM&sig=9UnvTbgSD5RJ5drCmAgPW-9EE5U#v=onepage&q=Big Bang Disruption%3A Strategy in the Age of Devastating Innovation&f=false

Ducker Carlisle. (2022). *2022 Supply-Chain Disruptions For Automotive Industry*.

Dunn, P. K., & Smyth, G. K. (2018). *Generalized Linear Models With Examples in R*. Springer New York. https://doi.org/10.1007/978-1-4419-0118-7

Dunsky Energy + Climate Advisors. (2021). *Zero Emission Vehicle Availability Estimating Inventories in Canada 2020/2021 Update*. www.dunsky.com

Dunsky Energy + Climate Advisors. (2022). *Zero Emission Vehicle Availability Estimating Inventories in Canada: 2022 Update*. www.dunsky.com

Egbue, O., & Long, S. (2012). Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy*, *48*(2012), 717–729. https://doi.org/10.1016/j.enpol.2012.06.009

Electric Mobility Canada. (2024). *EV Knowledge and Perceptions Survey*.

Environment and Climate Change Canada. (2016). *Pan-Canadian Framework on Clean*

Growth and Climate Change: strategic environmental assessment.
Environment and Climate Change Canada. (2023a). *Canada's Official Greenhouse Gas Inventory - Open Government Portal*. https://data-donnees.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/B-Economic-Sector/?lang=en
Environment and Climate Change Canada. (2023b, December 19). *Canada's Electric Vehicle Availability Standard (regulated targets for zero-emission vehicles)*. https://www.canada.ca/en/environment-climate-change/news/2023/12/canadas-electric-vehicle-availability-standard-regulated-targets-for-zero-emission-vehicles.html
Fan, J. L., Wang, Q., Yang, L., Zhang, H., & Zhang, X. (2020). Determinant changes of consumer preference for NEVs in China: A comparison between 2012 and 2017. *International Journal of Hydrogen Energy*, *45*(43), 23557–23575. https://doi.org/10.1016/J.IJHYDENE.2020.06.002
Farla, J., Alkemade, F., & Suurs, R. A. A. (2010). Analysis of barriers in the transition toward sustainable mobility in the Netherlands. *Technological Forecasting and Social Change*, *77*(8), 1260–1269. https://doi.org/10.1016/J.TECHFORE.2010.03.014
Federation of Canadian Municipalities. (n.d.). *Article series: How communities across Canada are electrifying their municipal fleets*. Green Municipal Fund. Retrieved January 16, 2025, from https://greenmunicipalfund.ca/resources/article-series-how-communities-across-canada-are-electrifying-their-municipal-fleets
Ferguson, M., Mohamed, M., Higgins, C. D., Abotalebi, E., & Kanaroglou, P. (2018). How open are Canadian households to electric vehicles? A national latent class choice analysis with willingness-to-pay and metropolitan characterization. *Transportation Research Part D: Transport and Environment*, *58*, 208–224. https://doi.org/10.1016/j.trd.2017.12.006
Ferloni, A. (2022). Transitions as a coevolutionary process: The urban emergence of electric vehicle inventions. *Environmental Innovation and Societal Transitions*, *44*, 205–225. https://doi.org/10.1016/J.EIST.2022.08.003
Figenbaum, E., Nordbakke, S., Economics, I. of T., & Norway, R. C. of. (2019). Battery Electric Vehicle User Experiences in Norway's Maturing Market. In *TØI Report* (Issue 1719/2019). https://www.toi.no/getfile.php?mmfileid=50956%0Ahttps://trid.trb.org/view/1659499
Friedman, G. (2024, December 17). *Amazon and the e-commerce boom redraws Canadian cities | Financial Post*. Financial Post. https://financialpost.com/feature/e-bikes-cargo-vans-traffic-headaches-business-opportunities
Fuller, J., Baxter, J., & Skimming, J. (2021). Social and municipal influences on intention to purchase electric and hybrid electric vehicles in London Ontario, CA. *Canadian Planning and Policy / Aménagement et Politique Au Canada*, *2021*, 69–88. https://doi.org/10.24908/cpp-apc.v2021i2.13928
Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8
Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geels, F. W. (2018). Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016). *Energy Research & Social Science*, *46*, 86–102. https://doi.org/10.1016/J.ERSS.2018.07.008
Geels, F. W. (2022). Causality and explanation in socio-technical transitions research: Mobilising epistemological insights from the wider social sciences. *Research Policy*, *51*(6), 104537. https://doi.org/10.1016/J.RESPOL.2022.104537
Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003
Geels, F. W., Schwanen, T., Sorrell, S., Jenkins, K., & Sovacool, B. K. (2018). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Research and Social Science*, *40*(June 2017), 23–35. https://doi.org/10.1016/j.erss.2017.11.003
Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. In *Science* (Vol. 357, Issue 6357). https://doi.org/10.1126/science.aao3760
Global News. (2018). *Feds to gather data on every new vehicle registered in Canada, plus most older ones*. https://globalnews.ca/news/4065923/database-cars-trucks-canada-government-climate/
Google Trends. (2024). *electric vehicles, gasoline prices - Explore*. https://trends.google.com/trends/explore?date=2017-01-01 2022-12-31&q=electric vehicles,gasoline prices&hl=en-US
Guo, J., Zhang, X., Gu, F., Zhang, H., & Fan, Y. (2020). Does air pollution stimulate electric vehicle sales? Empirical evidence from twenty major cities in China. *Journal of Cleaner Production*, *249*. https://doi.org/10.1016/j.jclepro.2019.119372
Guttentag, D., & Smith, S. L. J. (2022). The diffusion of Airbnb: a comparative look at earlier adopters, later adopters, and non-adopters. *Current Issues in Tourism*, 1–20. https://doi.org/10.1080/13683500.2020.1782855
Haan, M., & Godley, J. (2017). *An introduction to statistics for Canadian social scientists*. Oxford University Press.
Hägerstrand, T. (1966). Aspects of the spatial structure of social communication and the diffusion of information. *Papers of the Regional Science Association*, *16*(1), 27–42. https://doi.org/10.1007/BF01888934/METRICS
Hajebrahimi, A., Kamwa, I., & Huneault, M. (2018). A novel approach for plug-in electric vehicle planning and electricity load management in presence of a clean disruptive technology. *Energy*, *158*, 975–985. https://doi.org/10.1016/J.ENERGY.2018.06.085
Han, H., & Sun, S. (2024). Identifying Heterogeneous Willingness to Pay for New Energy Vehicles Attributes: A Discrete Choice Experiment in China. *Sustainability (Switzerland)* , *16*(7), 2949. https://doi.org/10.3390/SU16072949/S1
Handy, S. (2005). Smart growth and the transportation-land use connection: What does the research tell us? In *International Regional Science Review* (Vol. 28, Issue 2, pp. 146–167). https://doi.org/10.1177/0160017604273626
Hansen, G., & Stone, D. (2015). Assessing the observed impact of anthropogenic climate change. *Nature Climate Change 2015 6:5*, *6*(5), 532–537. https://doi.org/10.1038/nclimate2896
Hansen, T., & Coenen, L. (2015). The geography of sustainability transitions: Review,

synthesis and reflections on an emergent research field. *Environmental Innovation and Societal Transitions*, *17*, 92–109. https://doi.org/10.1016/j.eist.2014.11.001

Heeringa, S. G., West, B. T., & Berglund, P. A. (2017). Applied survey data analysis. In *Applied Survey Data Analysis, Second Edition*. CRC Press. https://doi.org/10.1201/9781315153278

Henderson, J. (2020). EVs Are Not the Answer: A Mobility Justice Critique of Electric Vehicle Transitions. *Annals of the American Association of Geographers*, *110*(6), 1993–2010. https://doi.org/10.1080/24694452.2020.1744422

Hensher, D. A. (2017). Future bus transport contracts under a mobility as a service (MaaS) regime in the digital age: Are they likely to change? *Transportation Research Part A: Policy and Practice*, *98*, 86–96. https://doi.org/10.1016/J.TRA.2017.02.006

Higgins, C. D., Mohamed, M., & Ferguson, M. R. (2017). Size matters: How vehicle body type affects consumer preferences for electric vehicles. *Transportation Research Part A: Policy and Practice*, *100*, 182–201. https://doi.org/10.1016/j.tra.2017.04.014

Higueras-Castillo, E., Guillén, A., Herrera, L. J., & Liébana-Cabanillas, F. (2020). Adoption of electric vehicles: Which factors are really important? *International Journal of Sustainable Transportation*, *0*(0), 1–15. https://doi.org/10.1080/15568318.2020.1818330

Higueras-Castillo, E., Molinillo, S., Coca-Stefaniak, J. A., & Liébana-Cabanillas, F. (2020). Potential early adopters of hybrid and electric vehicles in Spain-Towards a customer profile. *Sustainability (Switzerland)*, *12*(11). https://doi.org/10.3390/su12114345

Hirth, S., Kreinin, H., Fuchs, D., Blossey, N., Mamut, P., Philipp, J., & Radovan, I. (2023). Barriers and enablers of 1.5° lifestyles: Shallow and deep structural factors shaping the potential for sustainable consumption. *Frontiers in Sustainability*, *4*, 1014662. https://doi.org/10.3389/FRSUS.2023.1014662/BIBTEX

Hodson, M., & Marvin, S. (2010). Can cities shape socio-technical transitions and how would we know if they were? *Research Policy*, *39*(4), 477–485. https://doi.org/10.1016/J.RESPOL.2010.01.020

Hölscher, K., Wittmayer, J. M., & Loorbach, D. (2018). Transition versus transformation: What's the difference? *Environmental Innovation and Societal Transitions*, *27*, 1–3. https://doi.org/10.1016/j.eist.2017.10.007

Hopkins, E., Potoglou, D., Orford, S., & Cipcigan, L. (2023). Can the equitable roll out of electric vehicle charging infrastructure be achieved? *Renewable and Sustainable Energy Reviews*, *182*, 113398. https://doi.org/10.1016/J.RSER.2023.113398

Huang, Y., Qian, L., Tyfield, D., & Soopramanien, D. (2021). On the heterogeneity in consumer preferences for electric vehicles across generations and cities in China. *Technological Forecasting and Social Change*, *167*. https://doi.org/10.1016/j.techfore.2021.120687

Huttunen, S., Kaljonen, M., Lonkila, A., Rantala, S., Rekola, A., & Paloniemi, R. (2021). Pluralising agency to understand behaviour change in sustainability transitions. *Energy Research and Social Science*, *76*, 102067. https://doi.org/10.1016/j.erss.2021.102067

Ingeborgrud, L., & Ryghaug, M. (2019). The role of practical, cognitive and symbolic factors in the successful implementation of battery electric vehicles in Norway. *Transportation Research Part A: Policy and Practice*, *130*(January), 507–516. https://doi.org/10.1016/j.tra.2019.09.045

International Energy Agency. (2022). *World Energy Outlook 2022*. https://www.iea.org/reports/world-energy-outlook-2022
International Energy Agency. (2023a). *CO2 Emissions in 2022*. https://doi.org/10.1787/12ad1e1a-en
International Energy Agency. (2023b). *Global EV Outlook 2023: Catching up with climate ambitions*. www.iea.org
International Energy Agency. (2023c). *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach - 2023 Update*. www.iea.org/t&c/
International Energy Agency. (2023d). *Tracking Clean Energy Progress*. https://www.iea.org/reports/tracking-clean-energy-progress-2023
International Energy Agency. (2023e). *World Energy Outlook 2023*. www.iea.org/terms
International Energy Agency. (2024a). *Global EV Outlook 2024*. www.iea.org
International Energy Agency. (2024b). *Global EV Policy Explorer*. https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer
International Organization of Motor Vehicle Manufacturers. (2023). *Global registrations or sales of new passenger vehicles 2019-2023* . https://www.oica.net/category/sales-statistics/
International Renewable Energy Agency. (2019). *Global Energy Transformation: A Roadmap to 2050 (2019 Edition)*. www.irena.org
International Renewable Energy Agency. (2023). *Renewable Power Generation Costs in 2022*. www.irena.org
International Transport Forum. (2021). *ITF Transport Outlook 2021*. OECD Publishing. https://doi.org/10.1787/16826a30-en
International Transport Forum. (2023). *ITF Transport Outlook 2023*. https://doi.org/10.1787/b6cc9ad5-en
IPCC. (1990). IPCC First Assessment Report Overview. In *Climate Change: The 1990 and 1992 IPCC Assessments*.
IPCC. (2018a). Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. In *IPCC special report Global Warming of 1.5 ^oC*.
IPCC. (2018b). Summary for Policy Makers. In *IPCC special report Global Warming of 1.5 ^oC*.
IPCC. (2022a). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In *Cambridge University Press* (Issue 1). www.ipcc.ch
IPCC. (2022b). Synthesis report - Climate change 2023. *An Assessment of the Intergovernmental Panel on Climate Change*, *335*(7633).
Jansson, J., Pettersson, T., Mannberg, A., Brännlund, R., & Lindgren, U. (2017). Adoption of alternative fuel vehicles: Influence from neighbors, family and coworkers. *Transportation Research Part D: Transport and Environment*, *54,* 61–73. https://doi.org/10.1016/J.TRD.2017.04.012
Javid, R. J., & Nejat, A. (2017). A comprehensive model of regional electric vehicle adoption and penetration. *Transport Policy*, *54*(November 2016), 30–42. https://doi.org/10.1016/j.tranpol.2016.11.003
Jia, W., & Chen, T. D. (2021). Are Individuals' stated preferences for electric vehicles (EVs)

consistent with real-world EV ownership patterns? *Transportation Research Part D: Transport and Environment*, *93*, 102728. https://doi.org/10.1016/J.TRD.2021.102728
Jorgenson, A. K., Fiske, S., Hubacek, K., Li, J., McGovern, T., Rick, T., Schor, J. B., Solecki, W., York, R., & Zycherman, A. (2018). Social science perspectives on drivers of and responses to global climate change. *Wiley Interdisciplinary Reviews. Climate Change*, *10*(1), e554. https://doi.org/10.1002/WCC.554
Joshi, N., & Agrawal, S. (2021). Understanding the uneven geography of urban energy transitions: insights from Edmonton, Canada. *Cambridge Journal of Regions, Economy and Society*, *14*(2), 283–299. https://doi.org/10.1093/CJRES/RSAB009
Joshi, N., Agrawal, S., & Welegedara, N. P. Y. (2022). Something old, something new, something green: community leagues and neighbourhood energy transitions in Edmonton, Canada. *Energy Research & Social Science*, *88*, 102524. https://doi.org/10.1016/J.ERSS.2022.102524
Kahn, M. E. (2007). Do greens drive Hummers or hybrids? Environmental ideology as a determinant of consumer choice. *Journal of Environmental Economics and Management*, *54*(2), 129–145. https://doi.org/10.1016/J.JEEM.2007.05.001
Kalibrate Canada. (2021). *Quarterly Report of Petroleum Pricing in Canada (Fourth Quarter 2021)*. https://kalibrate.com/wp-content/uploads/2022/01/Kalibrate-Canada-Quarterly-Report-December_2021_Eng.pdf
Kalibrate Canada. (2022a). *Quarterly Report of Petroleum Pricing in Canada (First Quarter 2022)*.
Kalibrate Canada. (2022b). *Quarterly Report of Petroleum Pricing in Canada (Fourth Quarter 2022)*.
Kalibrate Canada. (2022c). *Quarterly Report of Petroleum Pricing in Canada (Second Quarter 2022)*.
Kanda, W., & Kivimaa, P. (2020). What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? *Energy Research & Social Science*, *68*, 101666. https://doi.org/10.1016/J.ERSS.2020.101666
Kane, M., & Whitehead, J. (2017). How to ride transport disruption –a sustainable framework for future urban mobility*. *Australian Planner*, *54*(3), 177–185. https://doi.org/10.1080/07293682.2018.1424002
Kanger, L., Geels, F. W., Sovacool, B., & Schot, J. (2019). Technological diffusion as a process of societal embedding: Lessons from historical automobile transitions for future electric mobility. *Transportation Research Part D: Transport and Environment*, *71*, 47–66. https://doi.org/10.1016/j.trd.2018.11.012
Kaufman, S., Saeri, A., Raven, R., Malekpour, S., & Smith, L. (2021). Behaviour in sustainability transitions: A mixed methods literature review. *Environmental Innovation and Societal Transitions*, *40*, 586–608. https://doi.org/10.1016/J.EIST.2021.10.010
Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*, *36*(11), 4093–4103. https://ideas.repec.org/a/eee/enepol/v36y2008i11p4093-4103.html
Khatua, A., Ranjan Kumar, R., & Kumar De, S. (2023). Institutional enablers of electric vehicle market: Evidence from 30 countries. *Transportation Research Part A: Policy and Practice*, *170*, 103612. https://doi.org/10.1016/J.TRA.2023.103612
Klitkou, A., Bolwig, S., Hansen, T., & Wessberg, N. (2015). The role of lock-in mechanisms

in transition processes: The case of energy for road transport. *Environmental Innovation and Societal Transitions*, *16*, 22–37. https://doi.org/10.1016/J.EIST.2015.07.005

Knittel, C. R., & Murphy, E. (2019). *Generational Trends in Vehicle Ownership and Use: Are Millennials Any Different?*

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., … Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, *31*, 1–32. https://doi.org/10.1016/J.EIST.2019.01.004

Kok, K. P. W. (2023). Politics beyond agency? Pluralizing structure(s) in sustainability transitions. *Energy Research & Social Science*, *100*, 103120. https://doi.org/10.1016/J.ERSS.2023.103120

Kormos, C., Axsen, J., Long, Z., & Goldberg, S. (2019). Latent demand for zero-emissions vehicles in Canada (Part 2): Insights from a stated choice experiment. *Transportation Research Part D: Transport and Environment*, *67*, 685–702. https://doi.org/10.1016/J.TRD.2018.10.010

KPMG. (2024). *24th Annual Global Automotive Executive Survey-Getting real about the EV transition*.

Kumar, R. R., & Alok, K. (2020). Adoption of electric vehicle: A literature review and prospects for sustainability. *Journal of Cleaner Production*, *253*, 119911. https://doi.org/10.1016/j.jclepro.2019.119911

Lachman, D. A. (2013). A survey and review of approaches to study transitions. *Energy Policy*, *58*, 269–276. https://doi.org/10.1016/J.ENPOL.2013.03.013

Lane, B., & Potter, S. (2007). The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. *Journal of Cleaner Production*, *15*(11–12), 1085–1092. https://doi.org/10.1016/j.jclepro.2006.05.026

Langbroek, J. H. M., Franklin, J. P., & Susilo, Y. O. (2016). The effect of policy incentives on electric vehicle adoption. *Energy Policy*, *94*, 94–103. https://doi.org/10.1016/j.enpol.2016.03.050

Lashari, Z. A., Ko, J., & Jang, J. (2021). Consumers' intention to purchase electric vehicles: Influences of user attitude and perception. *Sustainability (Switzerland)*, *13*(12). https://doi.org/10.3390/su13126778

Lee, J. H., Hardman, S. J., & Tal, G. (2019). Who is buying electric vehicles in California? Characterising early adopter heterogeneity and forecasting market diffusion. *Energy Research and Social Science*, *55*(June), 218–226. https://doi.org/10.1016/j.erss.2019.05.011

Li, X., Chen, P., & Wang, X. (2017). Impacts of renewables and socioeconomic factors on electric vehicle demands – Panel data studies across 14 countries. *Energy Policy*, *109*, 473–478. https://doi.org/10.1016/J.ENPOL.2017.07.021

Li, X., Zhao, X., Xue, D., & Tian, Q. (2023). Impact of regional temperature on the adoption of electric vehicles: an empirical study based on 20 provinces in China. *Environmental Science and Pollution Research*, *30*(5). https://doi.org/10.1007/s11356-022-22797-0

Liao, F., Molin, E., & van Wee, B. (2017). Consumer preferences for electric vehicles: a literature review. *Transport Reviews*, *37*(3).

https://doi.org/10.1080/01441647.2016.1230794
Lin, B., & Wu, W. (2018). Why people want to buy electric vehicle: An empirical study in first-tier cities of China. *Energy Policy*, *112*(October 2017), 233–241. https://doi.org/10.1016/j.enpol.2017.10.026
Liu, R., Ding, Z., Jiang, X., Sun, J., Jiang, Y., & Qiang, W. (2020). How does experience impact the adoption willingness of battery electric vehicles? The role of psychological factors. *Environmental Science and Pollution Research*, *27*(20), 25230–25247. https://doi.org/10.1007/s11356-020-08834-w
Liu, Z., Deng, Z., Davis, S., & Ciais, P. (2023). Monitoring global carbon emissions in 2022. *Nature Reviews Earth & Environment 2023 4:4*, *4*(4), 205–206. https://doi.org/10.1038/s43017-023-00406-z
Long, Z., Axsen, J., & Kormos, C. (2019). Consumers continue to be confused about electric vehicles: Comparing awareness among Canadian new car buyers in 2013 and 2017. *Environmental Research Letters*, *14*(11). https://doi.org/10.1088/1748-9326/ab4ca1
Loorbach, D. (2010). Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. *Governance*, *23*(1), 161–183. https://doi.org/10.1111/J.1468-0491.2009.01471.X
Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. In *Annual Review of Environment and Resources*. https://doi.org/10.1146/annurev-environ-102014-021340
MacDonald, A., Telfer, L., Clarke, A., Meaney, M., Giordano, A., Linton, S., & Zhou, Y. (2024). *Municipal Net-Zero Action Research Partnership: Current state of local climate action in Canadian municipalities - part 1 survey responses*. https://waterlooclimatedata.ca/nzap/
Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967. https://doi.org/10.1016/J.RESPOL.2012.02.013
Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, *37*(4), 596–615. https://doi.org/10.1016/J.RESPOL.2008.01.004
Matthews, L., Lynes, J., Riemer, M., Del Matto, T., & Cloet, N. (2017). Do we have a car for you? Encouraging the uptake of electric vehicles at point of sale. *Energy Policy*, *100*(September 2016), 79–88. https://doi.org/10.1016/j.enpol.2016.10.001
McDowall, W. (2018). Disruptive innovation and energy transitions: Is Christensen's theory helpful? *Energy Research & Social Science*, *37*, 243–246. https://doi.org/10.1016/J.ERSS.2017.10.049
McKay, D. I. A., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockström, J., & Lenton, T. M. (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science*, *377*(6611). https://doi.org/10.1126/SCIENCE.ABN7950/SUPPL_FILE/SCIENCE.ABN7950_DATA_S1.ZIP
McKinsey & Company. (2016). Automotive Revolution & Perspective Towards 2030: How the Convergence of Disruptive Technology-Driven Trends Could Transform the Auto Industry. In *Advanced Industries*.
Meadowcroft, J. (2009). What about the politics? Sustainable development, transition

management, and long term energy transitions. *Policy Sciences*. https://doi.org/10.1007/s11077-009-9097-z

Melanson, T., & Kyriazis, J. (2024). The real problem with electric vehicles is the bad press they get. *Canada's National Observer*. https://www.nationalobserver.com/2024/03/11/opinion/real-problem-electric-vehicles-bad-press-they-get

Melton, N., Axsen, J., & Goldberg, S. (2017). Evaluating plug-in electric vehicle policies in the context of long-term greenhouse gas reduction goals: Comparing 10 Canadian provinces using the "PEV policy report card." *Energy Policy*, *107*, 381–393. https://doi.org/10.1016/J.ENPOL.2017.04.052

Ministry of the Transportation. (2023). *Low carbon vehicles and electric vehicles*. https://www.ontario.ca/page/low-carbon-vehicles-and-electric-vehicles

Mock, M., & Wankat, K. (2024). Why do sustainable shared mobility practices not proliferate more widely? Insights from digital mobility diaries. *Journal of Cleaner Production*, 143582. https://doi.org/10.1016/J.JCLEPRO.2024.143582

Mohamed, M., Higgins, C. D., Ferguson, M., & Réquia, W. J. (2018). The influence of vehicle body type in shaping behavioural intention to acquire electric vehicles: A multi-group structural equation approach. *Transportation Research Part A: Policy and Practice*, *116*(August 2017), 54–72. https://doi.org/10.1016/j.tra.2018.05.011

Mohamed, M., Higgins, C., Ferguson, M., & Kanaroglou, P. (2016). Identifying and characterizing potential electric vehicle adopters in Canada: A two-stage modelling approach. *Transport Policy*, *52*, 100–112. https://doi.org/10.1016/j.tranpol.2016.07.006

Montello, D. R., & Sutton, P. C. (2006). An introduction to scientific research methods in geography. In *An Introduction to Scientific Research Methods in Geography*. SAGE Publications Inc. https://doi.org/10.4135/9781452225814

Moon, S. J. (2021). Effect of consumer environmental propensity and innovative propensity on intention to purchase electric vehicles: Applying an extended theory of planned behavior. *International Journal of Sustainable Transportation*, *0*(0), 1–15. https://doi.org/10.1080/15568318.2021.1961950

Mora, C., McKenzie, T., Gaw, I. M., Dean, J. M., von Hammerstein, H., Knudson, T. A., Setter, R. O., Smith, C. Z., Webster, K. M., Patz, J. A., & Franklin, E. C. (2022). Over half of known human pathogenic diseases can be aggravated by climate change. *Nature Climate Change*. https://doi.org/10.1038/s41558-022-01426-1

Morton, C., Anable, J., & Nelson, J. D. (2016). Exploring consumer preferences towards electric vehicles: The influence of consumer innovativeness. *Research in Transportation Business and Management*, *18*, 18–28. https://doi.org/10.1016/j.rtbm.2016.01.007

Morton, C., Anable, J., & Nelson, J. D. (2017). Consumer structure in the emerging market for electric vehicles: Identifying market segments using cluster analysis. *International Journal of Sustainable Transportation*, *11*(6), 443–459. https://doi.org/10.1080/15568318.2016.1266533

Muehlegger, E., & Rapson, D. S. (2022). Subsidizing low- and middle-income adoption of electric vehicles: Quasi-experimental evidence from California. *Journal of Public Economics*, *216*, 104752. https://doi.org/10.1016/J.JPUBECO.2022.104752

National Academy of Sciences. (2020). *Climate Change: Evidence and Causes: Update 2020*. The National Academies Press. https://doi.org/10.17226/25733

Nayum, A., Klöckner, C. A., & Mehmetoglu, M. (2016). Comparison of socio-psychological characteristics of conventional and battery electric car buyers. *Travel Behaviour and Society*, *3*, 8–20. https://doi.org/10.1016/j.tbs.2015.03.005

Neckermann, L. (2015). *The Mobility Revolution: Zero Emissions, Zero Accidents, Zero Ownership*. Troubador Publishing Ltd.

Nehme, E. K., Pérez, A., Ranjit, N., Amick, B. C., & Kohl, H. W. (2016). Behavioral theory and transportation cycling research: Application of Diffusion of Innovations. *Journal of Transport & Health*, *3*(3), 346–356. https://doi.org/10.1016/J.JTH.2016.05.127

Noel, L., Zarazua de Rubens, G., Sovacool, B. K., & Kester, J. (2019). Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. *Energy Research & Social Science*, *48*, 96–107. https://doi.org/10.1016/J.ERSS.2018.10.001

Nykvist, B., & Whitmarsh, L. (2008). A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change*, *75*(9), 1373–1387. https://doi.org/10.1016/J.TECHFORE.2008.05.006

Office of the Auditor General of Canada. (2023). *Reports of the Commissioner of the Environment and Sustainable Development to the Parliament of Canada—The Zero Emission Vehicle Infrastructure Program-Natural Resources Canada (Independent Auditor's Report)*. www.oag-bvg.gc.ca.

Okada, T., Tamaki, T., & Managi, S. (2019). Effect of environmental awareness on purchase intention and satisfaction pertaining to electric vehicles in Japan. *Transportation Research Part D: Transport and Environment*, *67*(January 2019), 503–513. https://doi.org/10.1016/j.trd.2019.01.012

Oliver Wyman. (2023). *Mobility Startup Radar: Funding Slowdown Threatens Mobility Revolution*. https://www.oliverwyman.com/our-expertise/insights/2022/dec/funding-slowdown-threatens-mobility-revolution.html#

Ontario Energy Board. (2020). *COVID-19 - Off-peak electricity pricing extended to May 31, 2020*. https://www.oeb.ca/newsroom/2020/covid-19-peak-electricity-pricing-extended-may-31-2020

Ontario Energy Board. (2024). *Historical electricity rates*. https://www.oeb.ca/consumer-information-and-protection/electricity-rates/historical-electricity-rates

Oreskes, N. (2004). The Scientific Consensus on Climate Change. *Science*, *306*(5702), 1686. https://doi.org/10.1126/SCIENCE.1103618

Orlov, A., & Kallbekken, S. (2019). The impact of consumer attitudes towards energy efficiency on car choice: Survey results from Norway. *Journal of Cleaner Production*, *214*(January), 816–822. https://doi.org/10.1016/j.jclepro.2018.12.326

Parkes, S. D., Marsden, G., Shaheen, S. A., & Cohen, A. P. (2013). Understanding the diffusion of public bikesharing systems: evidence from Europe and North America. *Journal of Transport Geography*, *31*, 94–103. https://doi.org/10.1016/J.JTRANGEO.2013.06.003

Pârvulescu, R. A., Chen, W., & Kavaslar, C. (2024). *New housing supply: Urban sprawl and densification Housing Statistics in Canada*. www.statcan.gc.ca

Penna, C. C. R., Schot, J., & Steinmueller, W. E. (2023). Transformative investment: New rules for investing in sustainability transitions. *Environmental Innovation and Societal Transitions*, *49*, 100782. https://doi.org/10.1016/J.EIST.2023.100782

Peters, A., & Dütschke, E. (2014). How do Consumers Perceive Electric Vehicles? A

Comparison of German Consumer Groups. *Journal of Environmental Policy and Planning*, *16*(3), 359–377. https://doi.org/10.1080/1523908X.2013.879037
Pettifor, H., Wilson, C., McCollum, D., & Edelenbosch, O. Y. (2017). Modelling social influence and cultural variation in global low-carbon vehicle transitions. *Global Environmental Change*, *47*(January), 76–87. https://doi.org/10.1016/j.gloenvcha.2017.09.008
PlugShare Research. (2023). *The Voice of the Canadian Electric Vehicle Driver*. https://www.caa.ca/app/uploads/2023/03/CAA-Canadian-EV-Driver-Study2023_EN.pdf
Pollution Probe, & Mobility Futures Lab. (2024). *2023 Canadian Electric Vehicle Owner Charging Experience Survey*. https://www.pollutionprobe.org/wp-content/uploads/2024/03/EV-charging-report_2023_Non-Embargoed-03-24.pdf
Poushter, J., Fagan, M., & Gubbala, S. (2022). Climate Change Remains Top Global Threat Across 19-Country Survey. In *Pew Research Center*. https://www.pewresearch.org/global/2022/08/31/climate-change-remains-top-global-threat-across-19-country-survey/
Public Safety Canada. (2022). *The Canadian Disaster Database*. https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx
Qian, L., Huang, Y., Tyfield, D., & Soopramanien, D. (2023). Dynamic consumer preferences for electric vehicles in China: A longitudinal approach. *Transportation Research Part A: Policy and Practice*, *176*, 103797. https://doi.org/10.1016/J.TRA.2023.103797
Renaud-Blondeau, P., Boisjoly, G., Dagdougui, H., & He, S. Y. (2023). Powering the transition: Public charging stations and electric vehicle adoption in Montreal, Canada. *International Journal of Sustainable Transportation*, *17*(10), 1097–1112. https://doi.org/10.1080/15568318.2022.2152403
Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D: Transport and Environment*, *34*, 122–136. https://doi.org/10.1016/j.trd.2014.10.010
Rode, P., Floater, G., Thomopoulos, N., Docherty, J., Schwinger, P., Mahendra, A., & Fang, W. (2017). *Accessibility in Cities: Transport and Urban Form*. 239–273. https://doi.org/10.1007/978-3-319-51602-8_15
Rodríguez-Brito, M. G., Ramírez-Díaz, A. J., Ramos-Real, F. J., & Perez, Y. (2018). Psychosocial traits characterizing EV adopters' profiles: The case of Tenerife (Canary Islands). *Sustainability (Switzerland)*, *10*(6), 1–26. https://doi.org/10.3390/su10062053
Rogers, E. (2003). The Diffusion of Innovations (Fifth Edition). In *The Free Press, New York*.
Rohe, S., Schmidt-Scheele, R., & Mattes, J. (2023). The embeddedness of companies in regional energy transitions. *European Planning Studies*. https://doi.org/10.1080/09654313.2023.2179389/SUPPL_FILE/CEPS_A_2179389_SM4390.DOCX
Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., Scamman, D., Arnell, N., Ayeb-Karlsson, S., Ford, L. B., Belesova, K., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., van Daalen, K. R., Dalin, C., Dasandi, N., … Costello, A. (2022). The 2022 report of the Lancet Countdown on

health and climate change: health at the mercy of fossil fuels. In *The Lancet* (Vol. 400, Issue 10363). https://doi.org/10.1016/S0140-6736(22)01540-9

Rosenbloom, D., Haley, B., & Meadowcroft, J. (2018). Critical choices and the politics of decarbonization pathways: Exploring branching points surrounding low-carbon transitions in Canadian electricity systems. *Energy Research and Social Science*, *37*(May 2017), 22–36. https://doi.org/10.1016/j.erss.2017.09.022

Rotmans, J., Kemp, R., & Van Asselt, M. (2001). More evolution than revolution: Transition management in public policy. *Foresight*, *3*(1), 15–31. https://doi.org/10.1108/14636680110803003/FULL/XML

Rouhana, F., Zhu, J., Chacon-Hurtado, D., Hertel, S., & Bagtzoglou, A. C. (2024). Ensuring a just transition: The electric vehicle revolution from a human rights perspective. *Journal of Cleaner Production*, *462*. https://doi.org/10.1016/j.jclepro.2024.142667

Ruggiero, S., Busch, H., Hansen, T., & Isakovic, A. (2021). Context and agency in urban community energy initiatives: An analysis of six case studies from the Baltic Sea Region. *Energy Policy*, *148*. https://doi.org/10.1016/j.enpol.2020.111956

Ruhrort, L., & Allert, V. (2021). Conceptualizing the Role of Individual Agency in Mobility Transitions: Avenues for the Integration of Sociological and Psychological Perspectives. *Frontiers in Psychology*, *12*(April). https://doi.org/10.3389/fpsyg.2021.623652

Ruokamo, E., Laukkanen, M., Karhinen, S., Kopsakangas-Savolainen, M., & Svento, R. (2023). Innovators, followers and laggards in home solar PV: Factors driving diffusion in Finland. *Energy Research & Social Science*, *102*, 103183. https://doi.org/10.1016/J.ERSS.2023.103183

S&P Global. (2023). *S&P Global Mobility Survey Finds EV Affordability tops Charging and Range Concerns in Slowing EV Demand - Nov 8, 2023*. https://press.spglobal.com/2023-11-08-S-P-Global-Mobility-Survey-Finds-EV-Affordability-tops-Charging-and-Range-Concerns-in-Slowing-EV-Demand

Saleem, M. A., Eagle, L., & Low, D. (2018). Market segmentation based on eco-socially conscious consumers' behavioral intentions: Evidence from an emerging economy. *Journal of Cleaner Production*, *193*, 14–27. https://doi.org/10.1016/j.jclepro.2018.05.067

Salinas Ruíz, J., Montesinos López, O. A., Hernández Ramírez, G., & Crossa Hiriart, J. (2023). Generalized Linear Models. In *Generalized Linear Mixed Models with Applications in Agriculture and Biology* (pp. 43–84). Springer, Cham. https://doi.org/10.1007/978-3-031-32800-8_2

Sang, Y. N., & Bekhet, H. A. (2015). Modelling electric vehicle usage intentions: An empirical study in Malaysia. *Journal of Cleaner Production*, *92*, 75–83. https://doi.org/10.1016/j.jclepro.2014.12.045

Schippl, J., & Truffer, B. (2020). Directionality of transitions in space: Diverging trajectories of electric mobility and autonomous driving in urban and rural settlement structures. *Environmental Innovation and Societal Transitions*, *37*, 345–360. https://doi.org/10.1016/J.EIST.2020.10.007

Schmidt, K., Sieverding, T., Wallis, H., & Matthies, E. (2021). COVID-19 – A window of opportunity for the transition toward sustainable mobility? *Transportation Research Interdisciplinary Perspectives*, *10*, 100374. https://doi.org/10.1016/J.TRIP.2021.100374

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy: R&D, systems of innovation and transformative change. *Research Policy*, *47*(9), 1554–1567. https://doi.org/10.1016/J.RESPOL.2018.08.011

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, *48*, 39–49. https://doi.org/10.1016/j.tra.2012.10.004

Seba, T. (2014). *Clean disruption of energy and transportation: how silicon valley will make oil, nuclear, natural gas, coal, electric utilities and conventional cars obsolete by 2030*. Tony Seba.

Severo, E. A., De Guimarães, J. C. F., & Dellarmelin, M. L. (2021). Impact of the COVID-19 pandemic on environmental awareness, sustainable consumption and social responsibility: Evidence from generations in Brazil and Portugal. *Journal of Cleaner Production*, *286*. https://doi.org/10.1016/j.jclepro.2020.124947

Shankar, R., Pathak, D. K., & Choudhary, D. (2019). Decarbonizing freight transportation: An integrated EFA-TISM approach to model enablers of dedicated freight corridors. *Technological Forecasting and Social Change*, *143*, 85–100. https://doi.org/10.1016/j.techfore.2019.03.010

She, Z. Y., Qing Sun, Ma, J. J., & Xie, B. C. (2017). What are the barriers to widespread adoption of battery electric vehicles? A survey of public perception in Tianjin, China. *Transport Policy*, *56*(February), 29–40. https://doi.org/10.1016/j.tranpol.2017.03.001

Shokouhyar, S., Shokoohyar, S., Sobhani, A., & Gorizi, A. J. (2021). Shared mobility in post-COVID era: New challenges and opportunities. *Sustainable Cities and Society*, *67*, 102714. https://doi.org/10.1016/J.SCS.2021.102714

Shove, E. (2010). Beyond the ABC: Climate change policy and theories of social change. *Environment and Planning A*, *42*(6). https://doi.org/10.1068/a42282

Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy*, *68*, 183–194. https://doi.org/10.1016/j.enpol.2014.01.043

Singh, V., Singh, V., & Vaibhav, S. (2020). A review and simple meta-analysis of factors influencing adoption of electric vehicles. *Transportation Research Part D: Transport and Environment*, *86*(August), 102436. https://doi.org/10.1016/j.trd.2020.102436

Skjølsvold, T. M., & Ryghaug, M. (2020). Temporal echoes and cross-geography policy effects: Multiple levels of transition governance and the electric vehicle breakthrough. *Environmental Innovation and Societal Transitions*, *35*, 232–240. https://doi.org/10.1016/J.EIST.2019.06.004

Smith, A., Voß, J. P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy*, *39*(4), 435–448. https://doi.org/10.1016/J.RESPOL.2010.01.023

Smith, B., Olaru, D., Jabeen, F., & Greaves, S. (2017). Electric vehicles adoption: Environmental enthusiast bias in discrete choice models. *Transportation Research Part D: Transport and Environment*, *51*, 290–303. https://doi.org/10.1016/j.trd.2017.01.008

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective.

Research Policy, *47*(7), 1267–1282. https://doi.org/10.1016/J.RESPOL.2018.04.008
Sovacool, B. K., & Hess, D. J. (2017). Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Studies of Science*, *47*(5), 703–750. https://doi.org/10.1177/0306312717709363
Sovacool, B. K., Kester, J., Noel, L., & de Rubens, G. Z. (2018). The demographics of decarbonizing transport: The influence of gender, education, occupation, age, and household size on electric mobility preferences in the Nordic region. *Global Environmental Change*, *52*(June), 86–100. https://doi.org/10.1016/j.gloenvcha.2018.06.008
Sovacool, B. K., Kester, J., Noel, L., & Zarazua de Rubens, G. (2019). Are electric vehicles masculinized? Gender, identity, and environmental values in Nordic transport practices and vehicle-to-grid (V2G)preferences. *Transportation Research Part D: Transport and Environment*, *72*, 187–202. https://doi.org/10.1016/j.trd.2019.04.013
Sperling, D. (2018). *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*. Island Press. https://doi.org/10.5822/978-1-61091-906-7
Sprei, F. (2018). Disrupting mobility. *Energy Research and Social Science*, *37*(September 2017), 238–242. https://doi.org/10.1016/j.erss.2017.10.029
Spurlock, C. A., Sears, J., Wong-Parodi, G., Walker, V., Jin, L., Taylor, M., Duvall, A., Gopal, A., & Todd, A. (2019). Describing the users: Understanding adoption of and interest in shared, electrified, and automated transportation in the San Francisco Bay Area. *Transportation Research Part D: Transport and Environment*, *71*(January), 283–301. https://doi.org/10.1016/j.trd.2019.01.014
Statistics Canada. (2021). *2021 Census data*. https://www12.statcan.gc.ca/census-recensement/index-eng.cfm
Statistics Canada. (2024a). *Environmental and Clean Technology Products Economic Account, gross domestic product*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610063001
Statistics Canada. (2024b). *New Motor Vehicle Registration Survey (NMVRS)*. https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5307
Statistics Canada. (2024c). *New motor vehicle registrations, annual sum*. https://doi.org/https://doi.org/10.25318/2010002401-eng
Statistics Canada. (2024d). *New motor vehicle registrations, quarterly*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002401
Statistics Canada. (2024e). *New zero-emission vehicle registrations, quarterly*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010002501
Statistics Canada. (2024f). *Population estimates, July 1, by census metropolitan area and census agglomeration, 2021 boundaries*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1710014801
Straub, E. T. (2009). Understanding Technology Adoption: Theory and Future Directions for Informal Learning. *Source: Review of Educational Research*, *79*(2), 625–649. https://doi.org/10.3102/0034654308325896
Strömberg, H., Rexfelt, O., Karlsson, I. C. M. A., & Sochor, J. (2016). Trying on change – Trialability as a change moderator for sustainable travel behaviour. *Travel Behaviour and Society*, *4*, 60–68. https://doi.org/10.1016/J.TBS.2016.01.002
Swallow, T. (2022, July 21). *Rivian enters logistics, rolling out first EVs for Amazon*. EV

Magazine. https://evmagazine.com/sustainability/rivian-enters-logistics-rolling-out-first-evs-for-amazon

Synek, S., & Koenigstorfer, J. (2018). Exploring adoption determinants of tax-subsidized company-leasing bicycles from the perspective of German employers and employees. *Transportation Research Part A: Policy and Practice*, *117*, 238–260. https://doi.org/10.1016/J.TRA.2018.08.011

Tartaruga, I., Sperotto, F., & Carvalho, L. (2024). Addressing inclusion, innovation, and sustainability challenges through the lens of economic geography: Introducing the hierarchical regional innovation system. *Geography and Sustainability*, *5*(1), 1–12. https://doi.org/10.1016/J.GEOSUS.2023.10.002

Therrien, S., Brauer, M., Fuller, D., Gauvin, L., Teschke, K., & Winters, M. (2014). Identifying the Leaders. *Https://Doi.Org/10.3141/2468-09*, *2468*, 74–83. https://doi.org/10.3141/2468-09

Truffer, B., Murphy, J. T., & Raven, R. (2015). The geography of sustainability transitions: Contours of an emerging theme. In *Environmental Innovation and Societal Transitions* (Vol. 17, pp. 63–72). Elsevier B.V. https://doi.org/10.1016/j.eist.2015.07.004

United Nations. (2021). Climate Change 'Biggest Threat Modern Humans Have Ever Faced', World-Renowned Naturalist Tells Security Council, Calls for Greater Global Cooperation. *UN Press Release*, *February*. https://press.un.org/en/2021/sc14445.doc.htm

United Nations Environment Programme. (2023). *Emissions Gap Report 2023*. https://doi.org/10.59117/20.500.11822/43922

United Nations Framework Convention on Climate Change. (2015). *Paris Agreement*. https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf?gad_source=1&gclid=Cj0KCQjwi5q3BhCiARIsAJCfuZn24eqTSEMNIba6_PkGJK4YXreNFlff1smovy9sU28LHCidmd8QdgwaAn1NEALw_wcB

Utriainen, R., & Pöllänen, M. (2018). Review on mobility as a service in scientific publications. *Research in Transportation Business & Management*, *27*, 15–23. https://doi.org/10.1016/J.RTBM.2018.10.005

van de Ven, D. J., Mittal, S., Gambhir, A., Lamboll, R. D., Doukas, H., Giarola, S., Hawkes, A., Koasidis, K., Köberle, A. C., McJeon, H., Perdana, S., Peters, G. P., Rogelj, J., Sognnaes, I., Vielle, M., & Nikas, A. (2023). A multimodel analysis of post-Glasgow climate targets and feasibility challenges. *Nature Climate Change 2023 13:6*, *13*(6), 570–578. https://doi.org/10.1038/s41558-023-01661-0

van Oorschot, J. A. W. H., Hofman, E., & Halman, J. I. M. (2018). A bibliometric review of the innovation adoption literature. *Technological Forecasting and Social Change*, *134*, 1–21. https://doi.org/10.1016/J.TECHFORE.2018.04.032

Van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., Van Den Berg, M., Bijl, D. L., De Boer, H. S., Daioglou, V., Doelman, J. C., Edelenbosch, O. Y., Harmsen, M., Hof, A. F., & Van Sluisveld, M. A. E. (2018). Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies. *Nature Climate Change 2018 8:5*, *8*(5), 391–397. https://doi.org/10.1038/s41558-018-0119-8

Vanheusden, W., van Dalen, J., & Mingardo, G. (2022). Governance and business policy impact on carsharing diffusion in European cities. *Transportation Research Part D: Transport and Environment*, *108*. https://doi.org/10.1016/j.trd.2022.103312

Volvo Car Canada Limited. (2024). *Volvo Car Canada 2024 Mobility Trend Report*. https://www.media.volvocars.com/ca/en-ca/media/documentfile/327444/volvo-car-canada-2024-mobility-trend-report

Wang, S., Wang, J., Li, J., Wang, J., & Liang, L. (2018). Policy implications for promoting the adoption of electric vehicles: Do consumer's knowledge, perceived risk and financial incentive policy matter? *Transportation Research Part A: Policy and Practice*, *117*(May), 58–69. https://doi.org/10.1016/j.tra.2018.08.014

Wang, X., Shaw, F. A., & Mokhtarian, P. L. (2022). Latent vehicle type propensity segments: Considering the influence of household vehicle fleet structure. *Travel Behaviour and Society*, *26*(February 2020), 41–56. https://doi.org/10.1016/j.tbs.2021.08.002

Weiss, J., Hledik, R., Lueken, R., Lee, T., & Gorman, W. (2017). The electrification accelerator: Understanding the implications of autonomous vehicles for electric utilities. *Electricity Journal*, *30*(10), 50–57. https://doi.org/10.1016/j.tej.2017.11.009

Wesseling, J. H. (2016). Explaining variance in national electric vehicle policies. *Environmental Innovation and Societal Transitions*, *21*, 28–38. https://doi.org/10.1016/J.EIST.2016.03.001

Williams, J. H., DeBenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Morrow, W. R., Price, S., & Torn, M. S. (2012). The technology path to deep greenhouse gas emissions cuts by 2050: The pivotal role of electricity. *Science*, *335*(6064), 53–59. https://doi.org/10.1126/SCIENCE.1208365/SUPPL_FILE/WILLIAMS.SOM.PDF

Wilson, C. (2018). Disruptive low-carbon innovations. *Energy Research & Social Science*, *37*, 216–223. https://doi.org/10.1016/J.ERSS.2017.10.053

Winkler, L., Pearce, D., Nelson, J., & Babacan, O. (2023). The effect of sustainable mobility transition policies on cumulative urban transport emissions and energy demand. *Nature Communications 2023 14:1*, *14*(1), 1–14. https://doi.org/10.1038/s41467-023-37728-x

Wolfram, P., Weber, S., Gillingham, K., & Hertwich, E. G. (2021). Pricing indirect emissions accelerates low—carbon transition of US light vehicle sector. *Nature Communications 2021 12:1*, *12*(1), 1–8. https://doi.org/10.1038/s41467-021-27247-y

Wolinetz, M., & Axsen, J. (2017). How policy can build the plug-in electric vehicle market: Insights from the REspondent-based Preference And Constraints (REPAC) model. *Technological Forecasting and Social Change*, *117*, 238–250. https://doi.org/10.1016/J.TECHFORE.2016.11.022

Yang, C., Tu, J. C., & Jiang, Q. (2020). The influential factors of consumers- sustainable consumption: A case on electric vehicles in China. *Sustainability (Switzerland)*, *12*(8). https://doi.org/10.3390/SU12083496

Yang, S., Cheng, P., Li, J., & Wang, S. (2019). Which group should policies target? Effects of incentive policies and product cognitions for electric vehicle adoption among Chinese consumers. *Energy Policy*, *135*(96), 111009. https://doi.org/10.1016/j.enpol.2019.111009

Yang, Z., Huang, H., & Lin, F. (2022). Sustainable Electric Vehicle Batteries for a Sustainable World: Perspectives on Battery Cathodes, Environment, Supply Chain, Manufacturing, Life Cycle, and Policy. *Advanced Energy Materials*, *12*(26), 2200383. https://doi.org/10.1002/AENM.202200383

Ye, R., Wu, Y., Sun, C., Wang, Q., Mao, Y., Zhou, H., & Raat, H. (2023). Diffusion of a micronutrient home fortification program for infants and toddlers in a multi-ethnic population in rural western China. *BMC Public Health*, *23*(1), 1–12. https://doi.org/10.1186/S12889-023-15746-0/TABLES/2

Zeng, Y., Dong, P., Shi, Y., Wang, L., & Li, Y. (2020). Analyzing the co-evolution of green technology diffusion and consumers' pro-environmental attitudes: An agent-based model. *Journal of Cleaner Production*, *256*, 120384. https://doi.org/10.1016/j.jclepro.2020.120384

Zhang, X., Bai, X., & Shang, J. (2018). Is subsidized electric vehicles adoption sustainable: Consumers' perceptions and motivation toward incentive policies, environmental benefits, and risks. *Journal of Cleaner Production*, *192*, 71–79. https://doi.org/10.1016/j.jclepro.2018.04.252

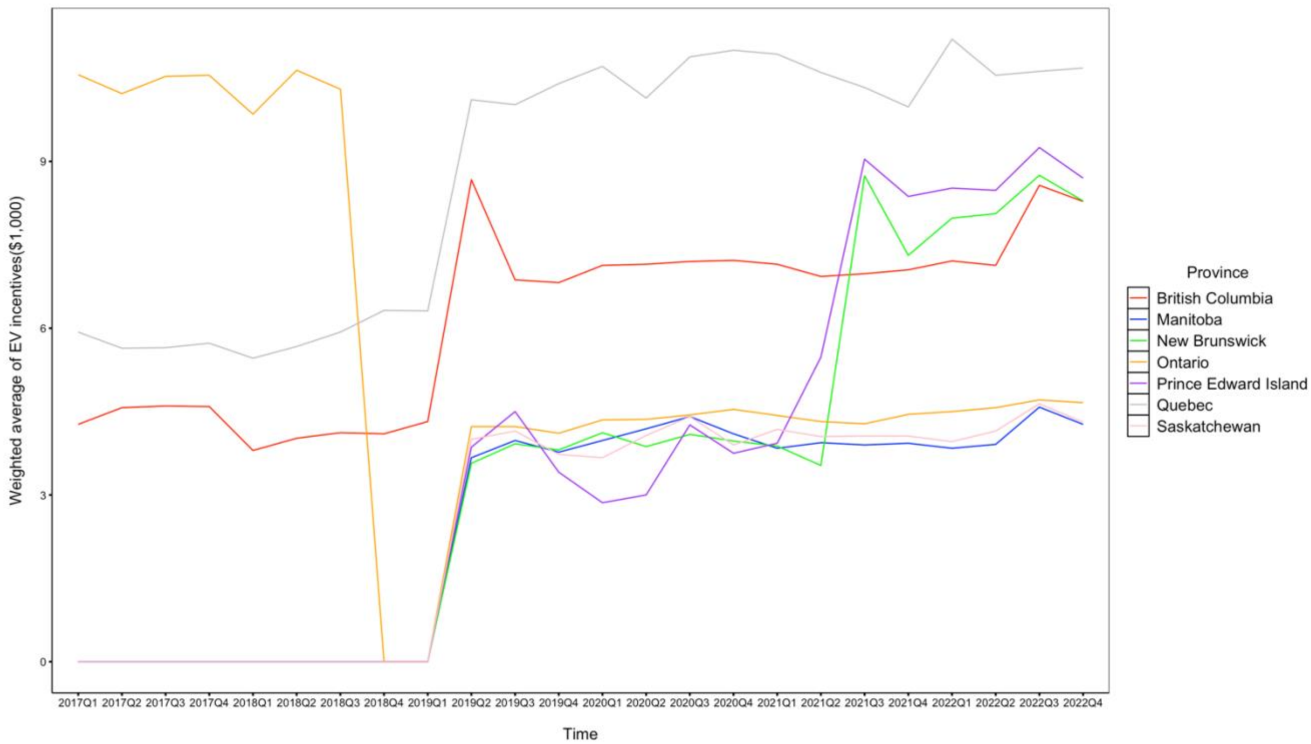
Appendix A—A summary of dependent and independent variables chosen in the national EV models (Chapter 4)

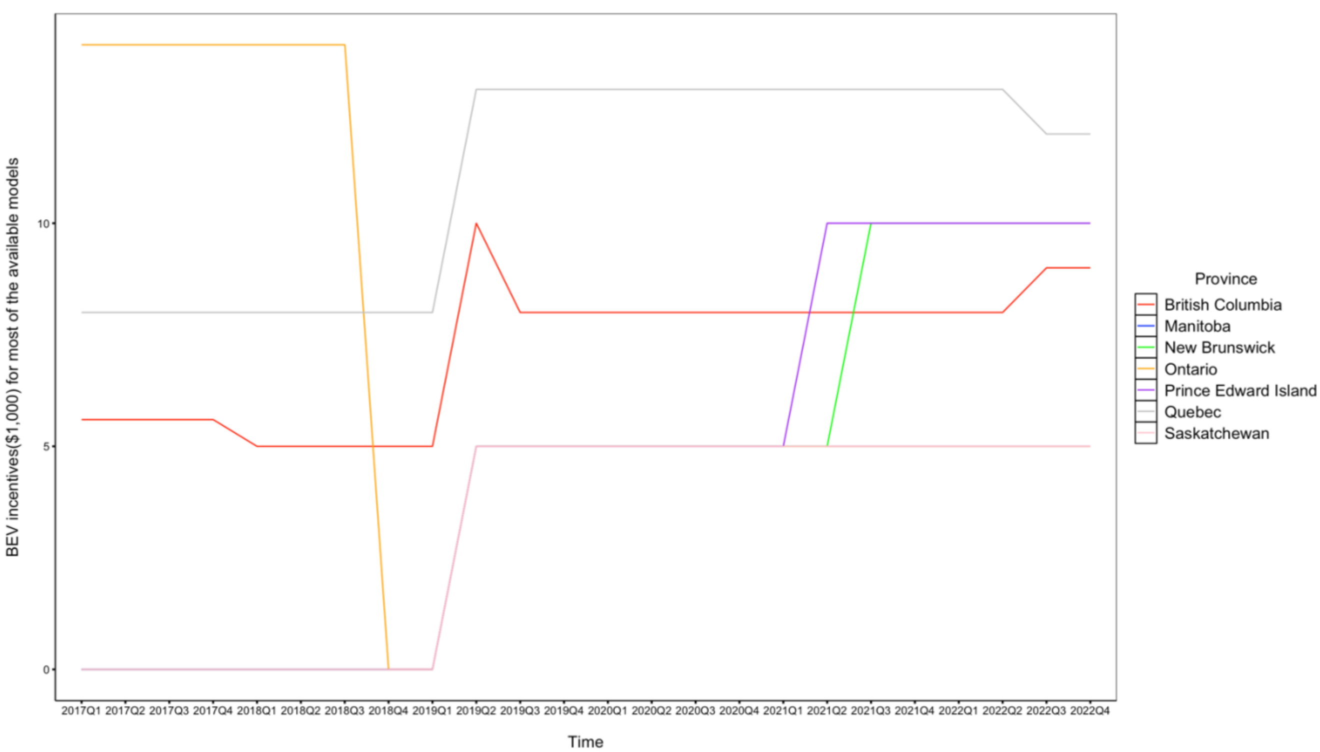
Types	Variables	Definitions of variables	Data titles	Sources	Data descriptions
Dependent	Registrations of EVs (BEVs and PHEVs)	New EV registrations per 1000 people; seven provinces except NF, NS, AB (quarterly)	New motor vehicle registrations-2017Q1-2022Q4 (quarterly)	Statistics Canada-New Motor Vehicle Registration Survey Table 20-10-0024-01	7*24=168 observations
			Population estimates (quarterly)	Statistics Canada-Quarterly Demographic Estimates Table17-10-0009-01 (formerly CANSIM 051-0005)	Q1 = January 1; Q2 = April 1; Q3 = July 1; Q4 = October 1.
Independent	Charger density and fast charger ratio	Public charging stations per length of public road (count per 1000 km); Level-3 charger ratio (quarterly)	Electric Charging and Alternative Fuelling Stations Locator (daily)	Natural Resources Canada	Retrieved on 04/30/2023
			National highway system (2009) and public road network (2003)	Transport Canada	The lengths of different highway routes and public roads across provinces
	Detached and semi-detached housing	Quarterly fraction of private dwellings that are either single detached or semi-detached houses	Census Canada 2016-Household and dwelling characteristics	Statistics Canada	Housing stock in May 2016
			housing starts, under construction and completions, all areas (quarterly)	Canada Mortgage and Housing Corporation Table: 34-10-0135-01 (formerly CANSIM 027-0008)	Housing stock added quarterly since 2016Q3
	EV purchase incentives	The registration-weighted average of EV point-to-sale EV purchase incentives per $1000 (included federal incentives since 2019Q2)	EV Incentive Program (federal and provincial levels)	Transport Canada, government websites of ON, BC, NB, PEI, QC	
	EV inventories	Zero-emission vehicle inventory (BEVs and PHEVs) by province by automaker per 100K people	Zero Emission Vehicle Availability: Estimating inventories in Canada	Dunsky Energy+Climate Advisors	Vehicle inventory in 2018 Dec, 2019 Mar, 2019 Nov, 2020 Feb, 2020 Nov, 2021 Feb, and 2022 Mar

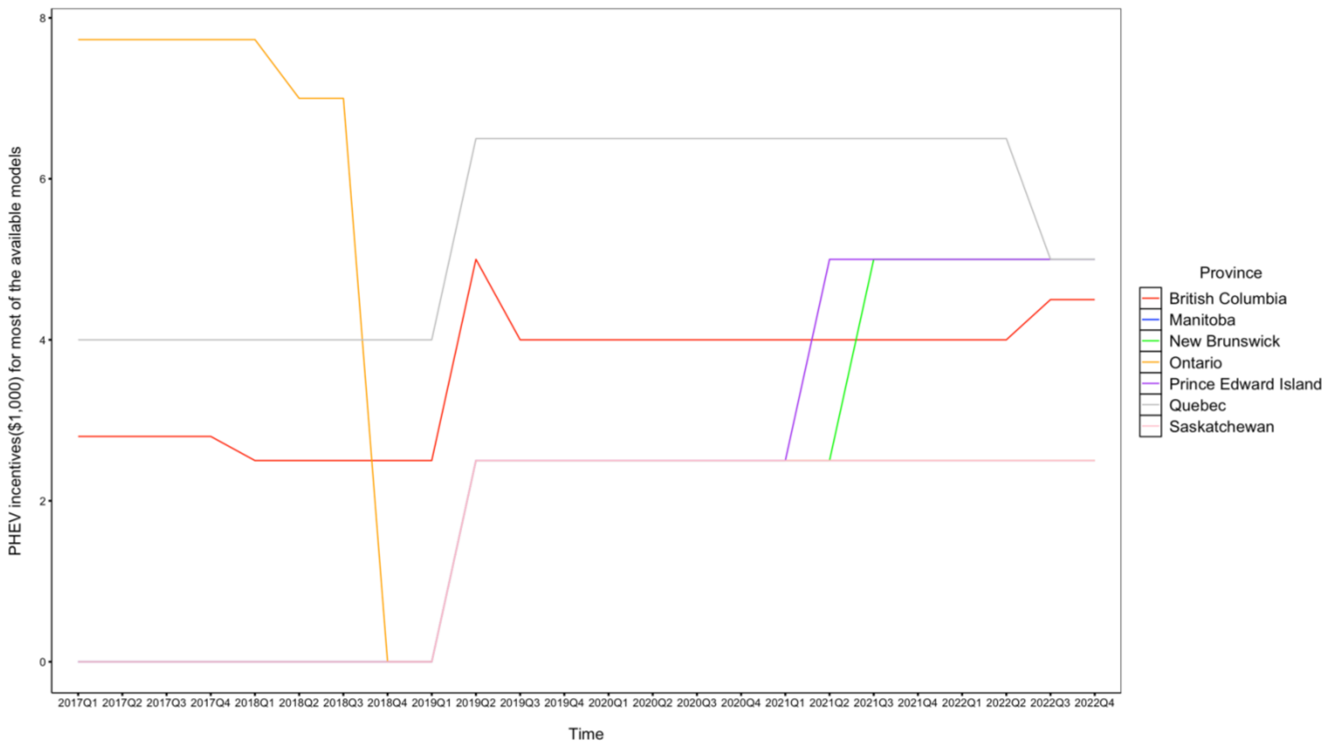
	Voting preference for Green Party	The percentage of Canadian voters who rank the Green Party of Canada as their top local preference among all parties they consider vote federally	Weekly Federal Political Data Survey	Nanos Research Corporation	
	Gasoline prices	Quarterly average retail prices for gasoline and fuel oil ($/litre)	Monthly average retail prices for gasoline and fuel oil (monthly)	Statistics Canada-Consumer Price Index-Table: 18-10-0001-01 (formerly CANSIM 326-0009)	Regular unleaded gasoline at self-service filling stations in one or two or three CMAs in each province. For example, Quebec and Montreal in the province of Quebec. Vancouver and Victoria in the province of British Columbia.
			Population estimates, July 1, by census metropolitan area and census agglomeration (annually)	Statistics Canada-Annual Demographic Estimates: Subprovincial Areas Table: 17-10-0135-01	The provincial gasoline prices are average values, weighted by CMA population ratios.
	Electricity prices	Annually average electricity prices (c/kWh)	Comparison of Electricity Prices in Major North American Cities (annually)	Hydro-Quebec	Average prices (excluding taxes) for residential customers with monthly consumption of 1000kWh, with the consideration of time-of-use rates and no optional programs based on basic rates in Montreal, Charlottetown, Moncton, Ottawa, Regina, St. John's, Toronto, Vancouver, Winnipeg etc. Monthly bills have been calculated based on rates in effect on April 1 each year.
	Percentage of adults (25 years and over) with post-secondary certificate, diploma, or degree	Quarterly average fraction of the population aged 25 years and older with a post-secondary certificate, diploma, or degree (%)	Labour force characteristics by educational attainment, monthly, unadjusted for seasonality (15 years old and older)	Statistics Canada-Labour Force Survey Table: 14-10-0019-01 (formerly CANSIM 282-0003)	Population with 25 years and older who attain post-secondary certificate, diploma, or degree divided by total population with 25 years and older

	Median age	Annual median age by provinces	Population estimates on July 1st, by age and sex (annually)	Statistics Canada-Annual Demographic Estimates Table: 17-10-0005-01 (formerly CANSIM 051-0001)	
	Unemployment rate	Quarterly average unemployment rate (%)	Labour force characteristics, monthly, seasonally adjusted and trend-cycle	Statistics Canada-Labour Force Survey Table: 14-10-0287-01 (formerly CANSIM 282-0087)	The number of unemployed persons expressed as a percentage of the labour force (15 years and over)
	Wages and salaries per employed capita	Quarterly average wages and salaries per employed capita ($1,000)	Wages, salaries and employers' social contributions (X1,000) (monthly), seasonally adjusted	Statistics Canada-Estimates of Labour Income Table: 36-10-0205-01 (formerly CANSIM 382-0006)	Compensation of employees comprises wages and salaries as well as employers' social contributions. It is defined as all compensation paid to employees. Earnings received by self-employed persons or working owners of unincorporated businesses are not included in compensation of employees. Target population are Canadian population of working age.
			Labour force characteristics, monthly, seasonally adjusted and trend-cycle	Statistics Canada-Labour Force Survey Table: 14-10-0287-01 (formerly CANSIM 282-0087)	The population of employment
	Low-carbon electricity	Quarterly average fraction of low-carbon electricity (%)	Electricity power generation, monthly generation by type of electricity	Statistics Canada-Monthly Electricity Supply and Disposition Survey Table: 25-10-0015-01 (formerly CANSIM 127-0002)	January 2020 is the starting month with specific biomass generation values. The dataset includes all classes of electricity producer, both electric utilities and industries.

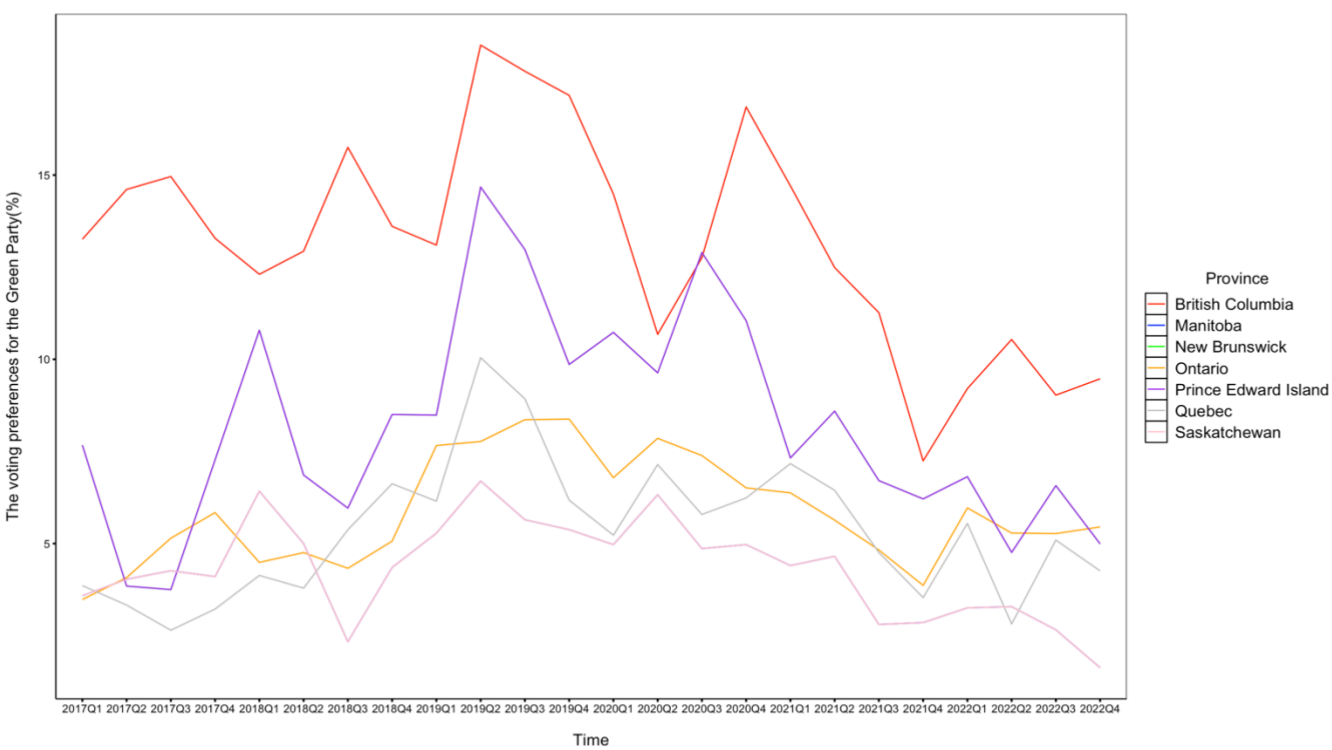
Appendix B—The comparison of 13 independent variables across seven Canadian provinces between 2017 and 2022 (Chapter 4)



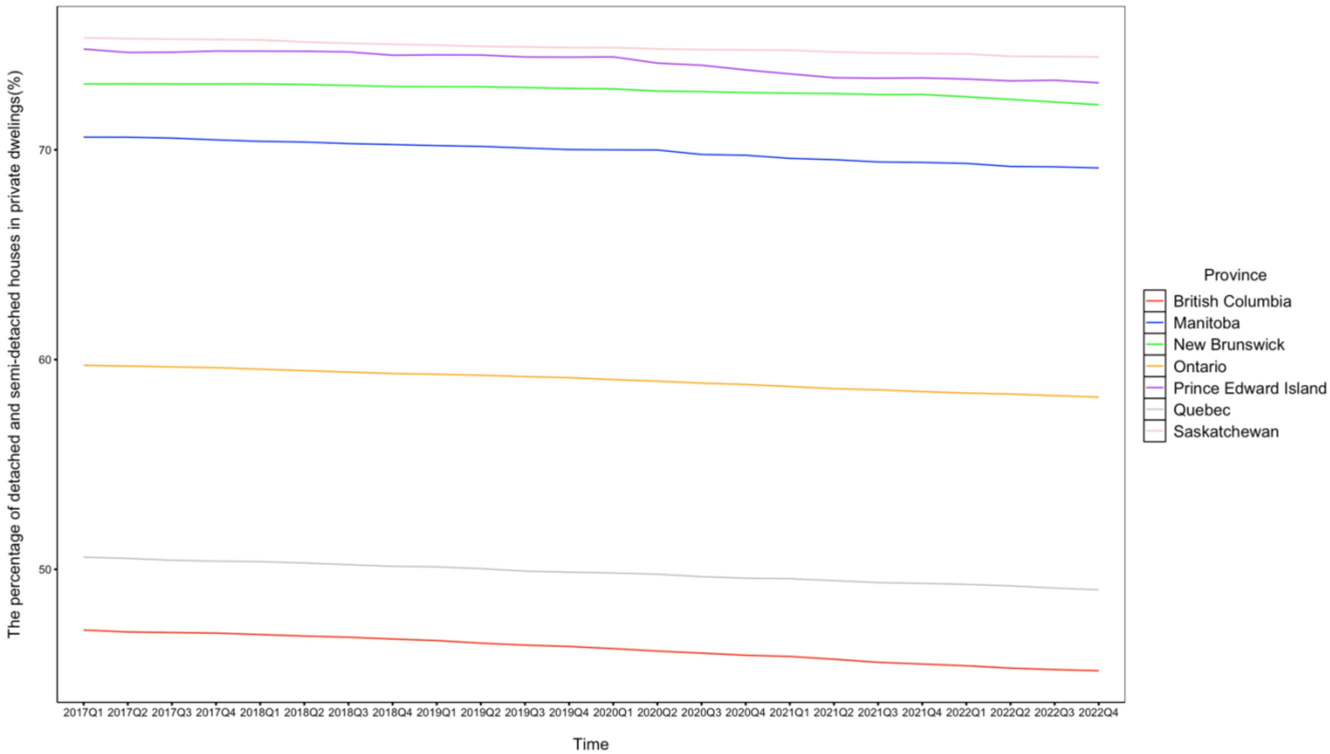




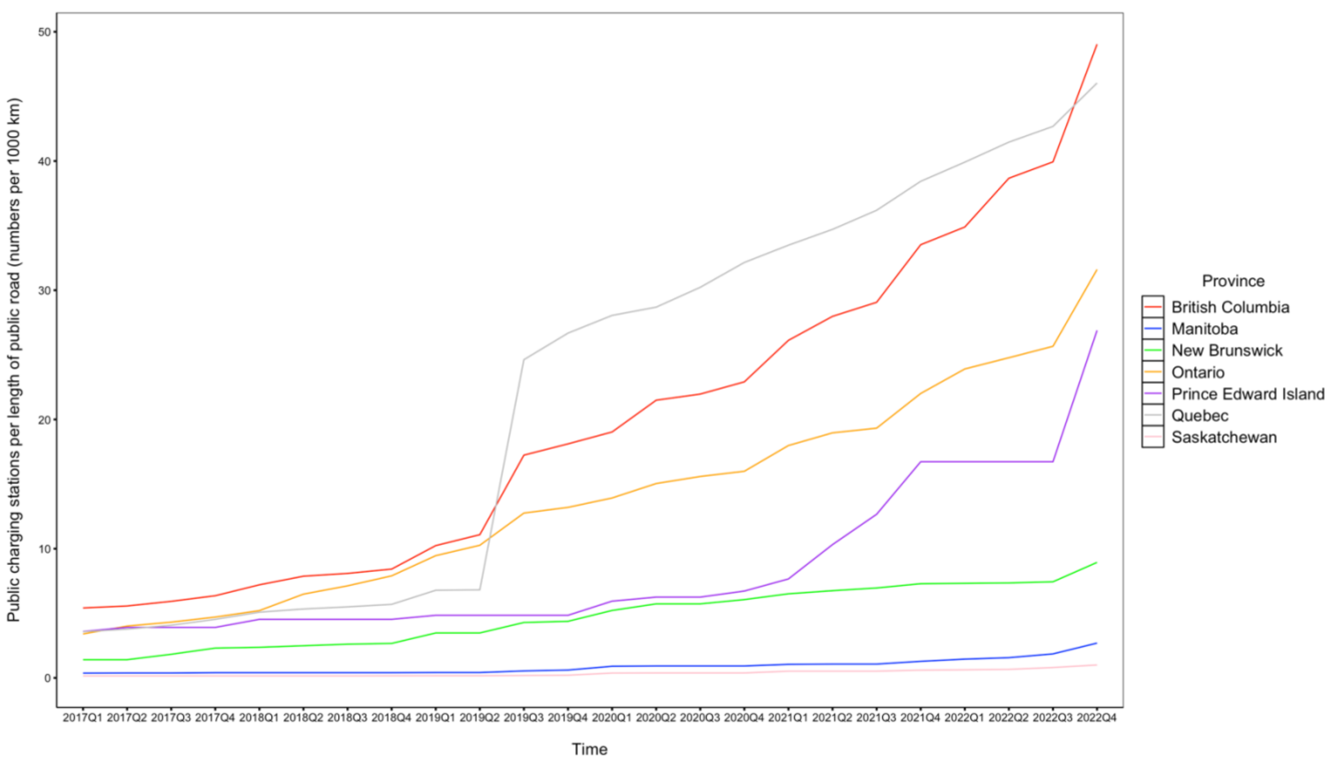
PHEV incentives($1,000) for most of the available models
8
6
4
2
0
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan



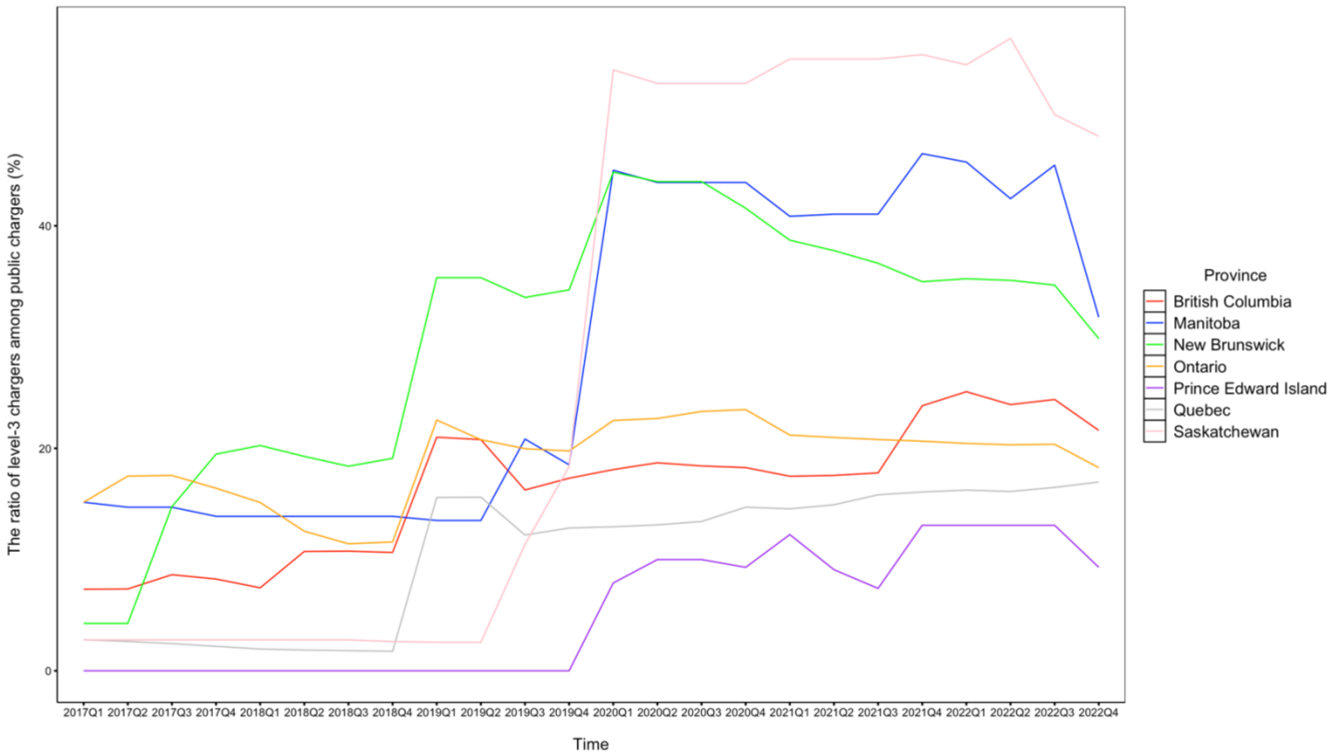
The voting preferences for the Green Party(%)
15
10
5
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

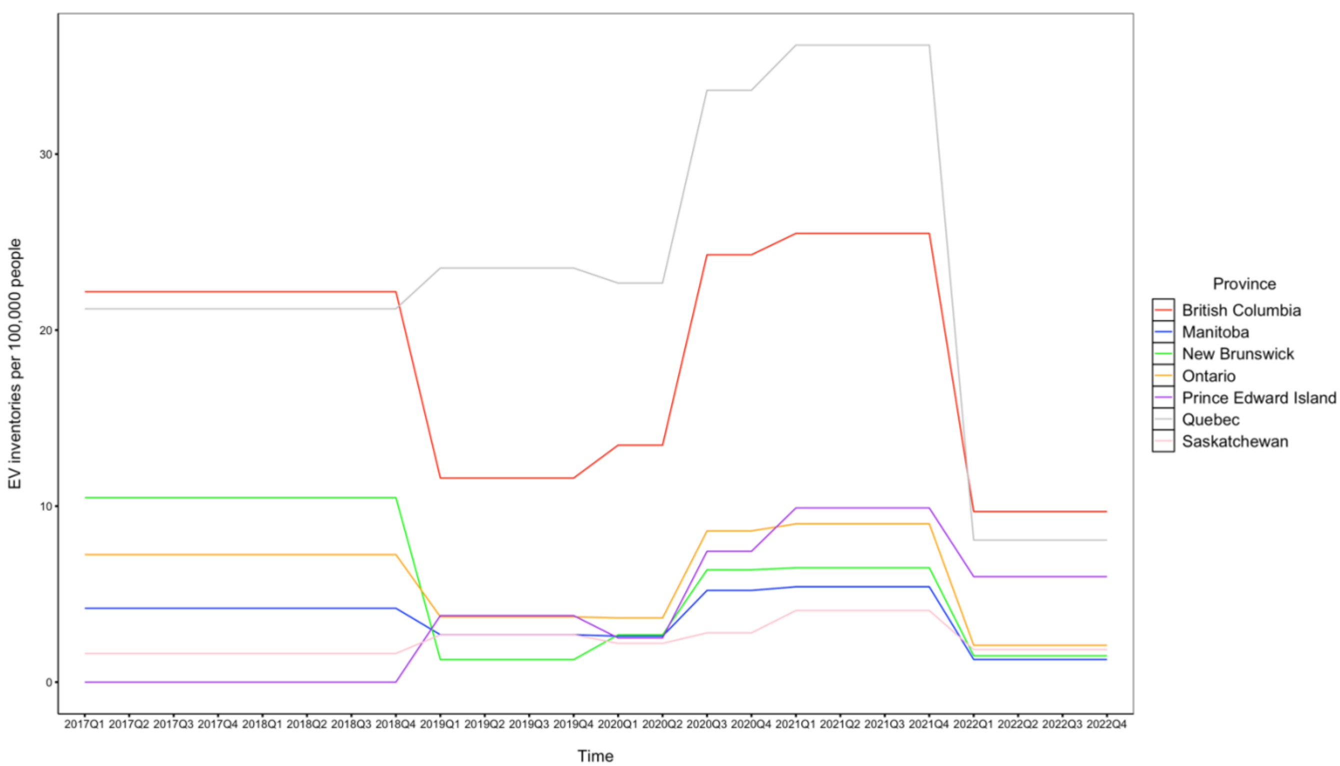


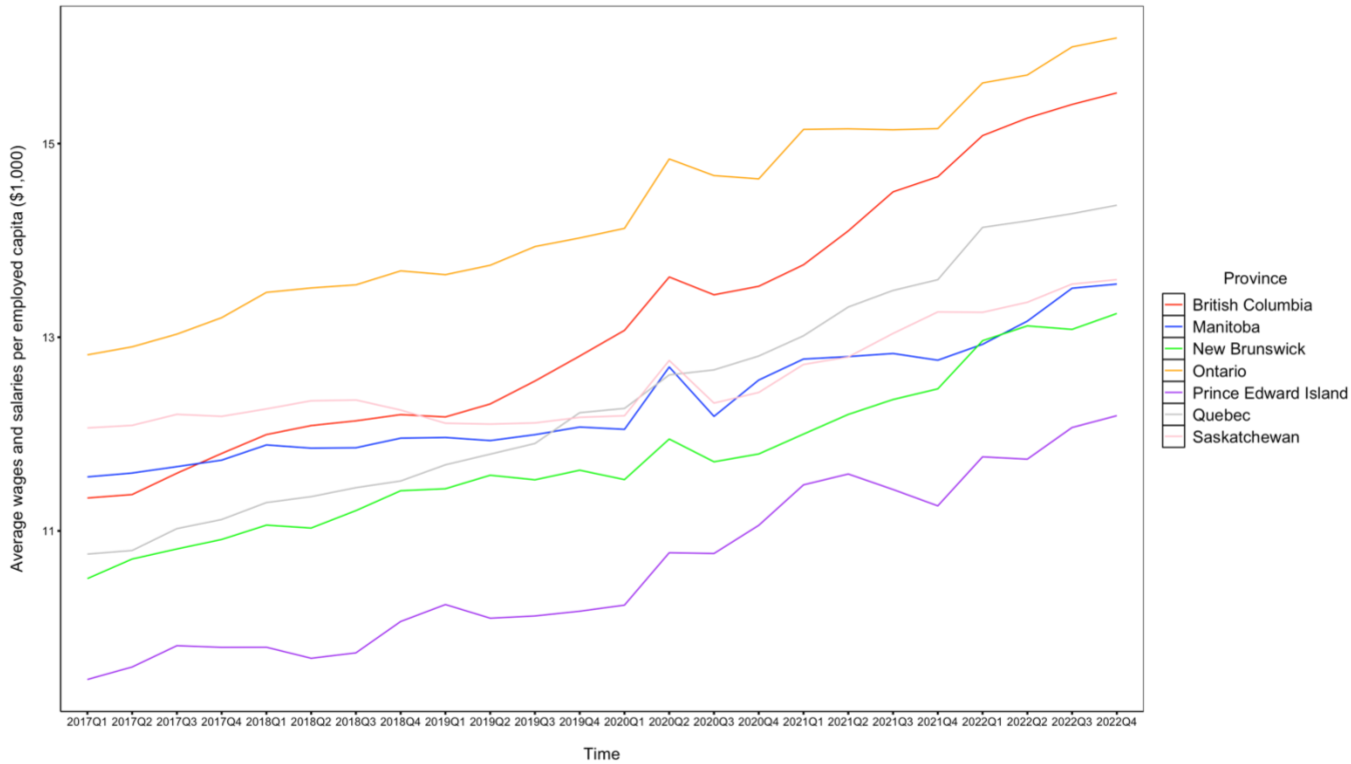
The percentage of detached and semi-detached houses in private dwellings(%)
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

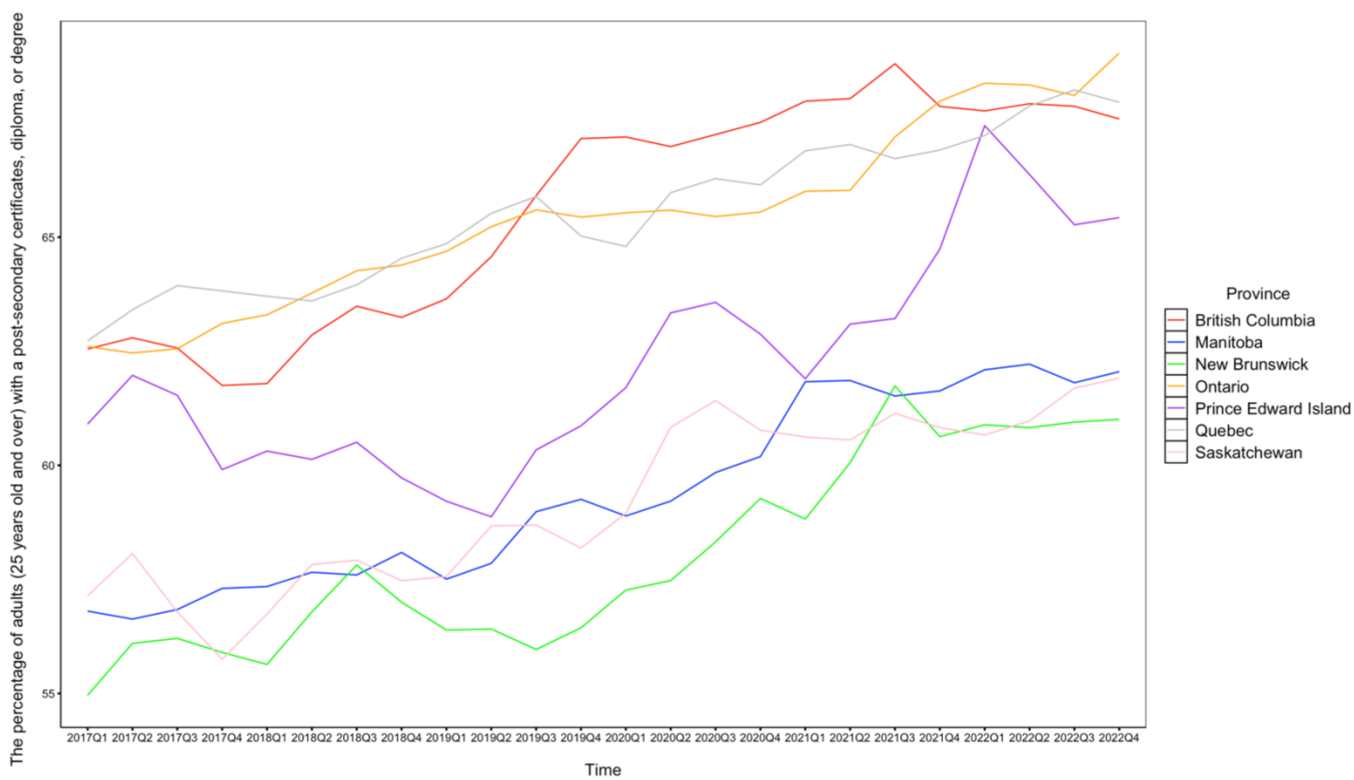


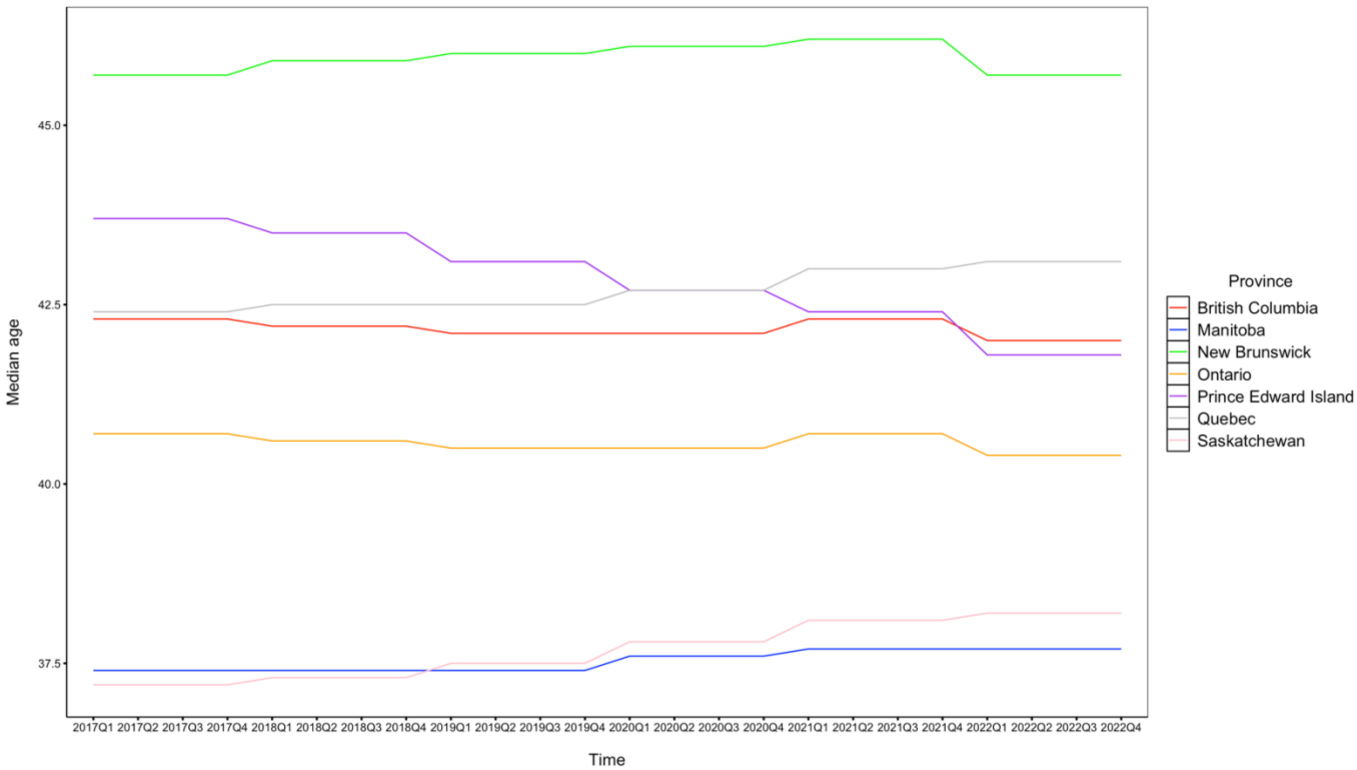
Public charging stations per length of public road (numbers per 1000 km)
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

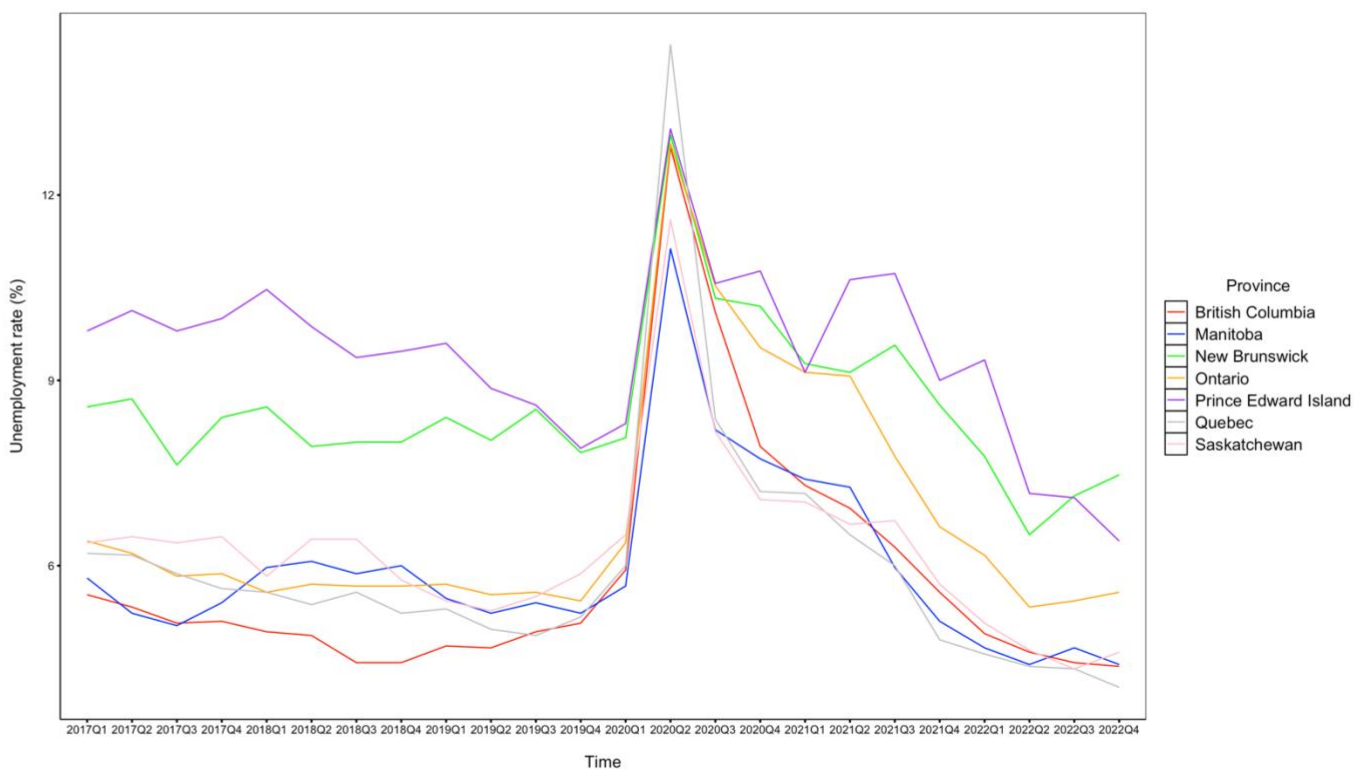

The ratio of level-3 chargers among public chargers (%)
0
20
40
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

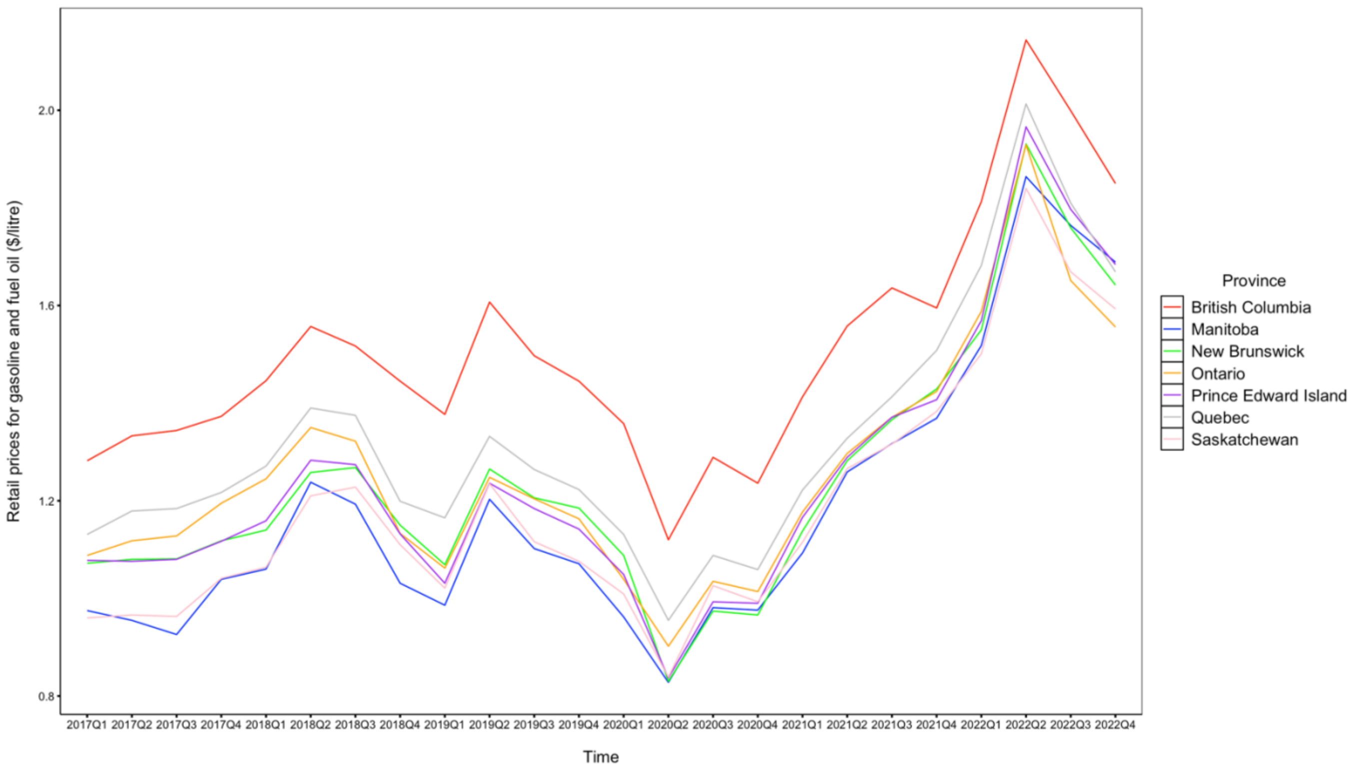

EV inventories per 100,000 people
0
10
20
30
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

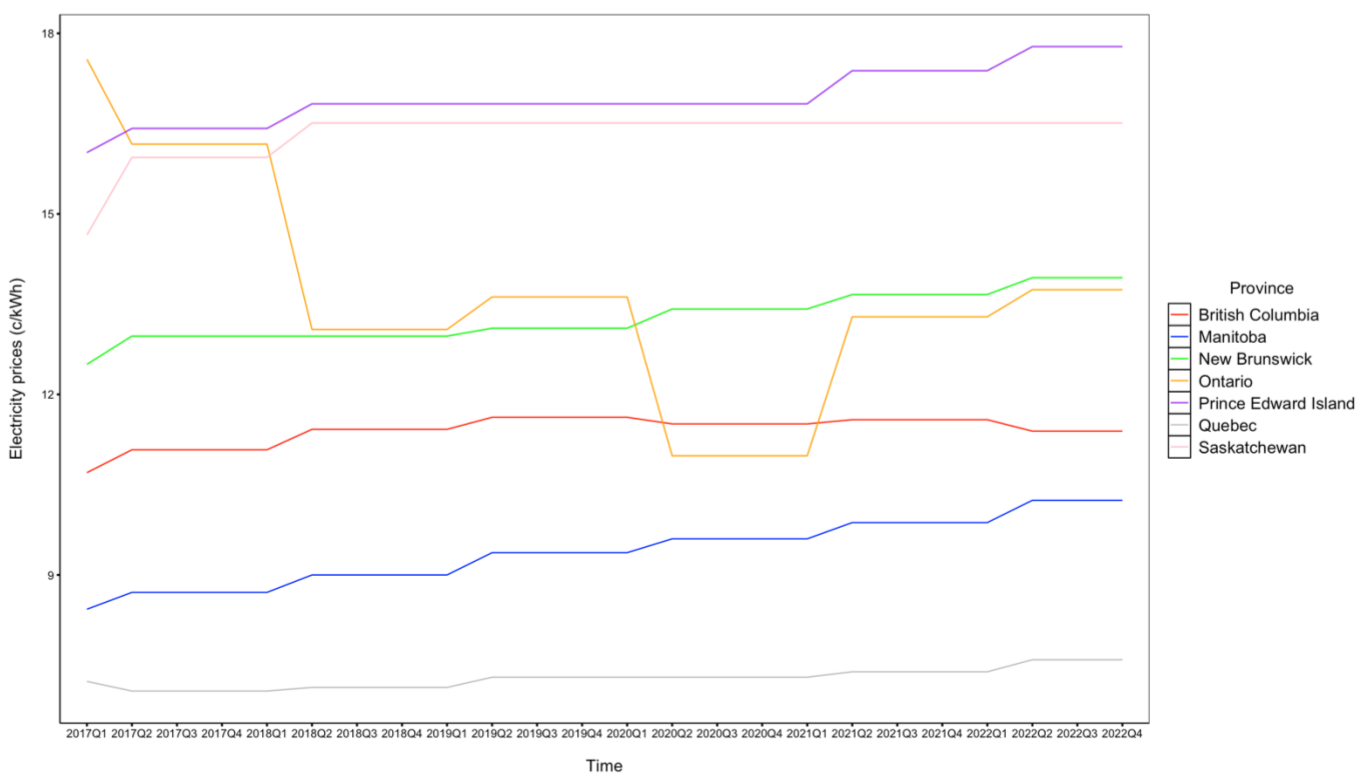

Average wages and salaries per employed capita ($1,000)
15
13
11
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

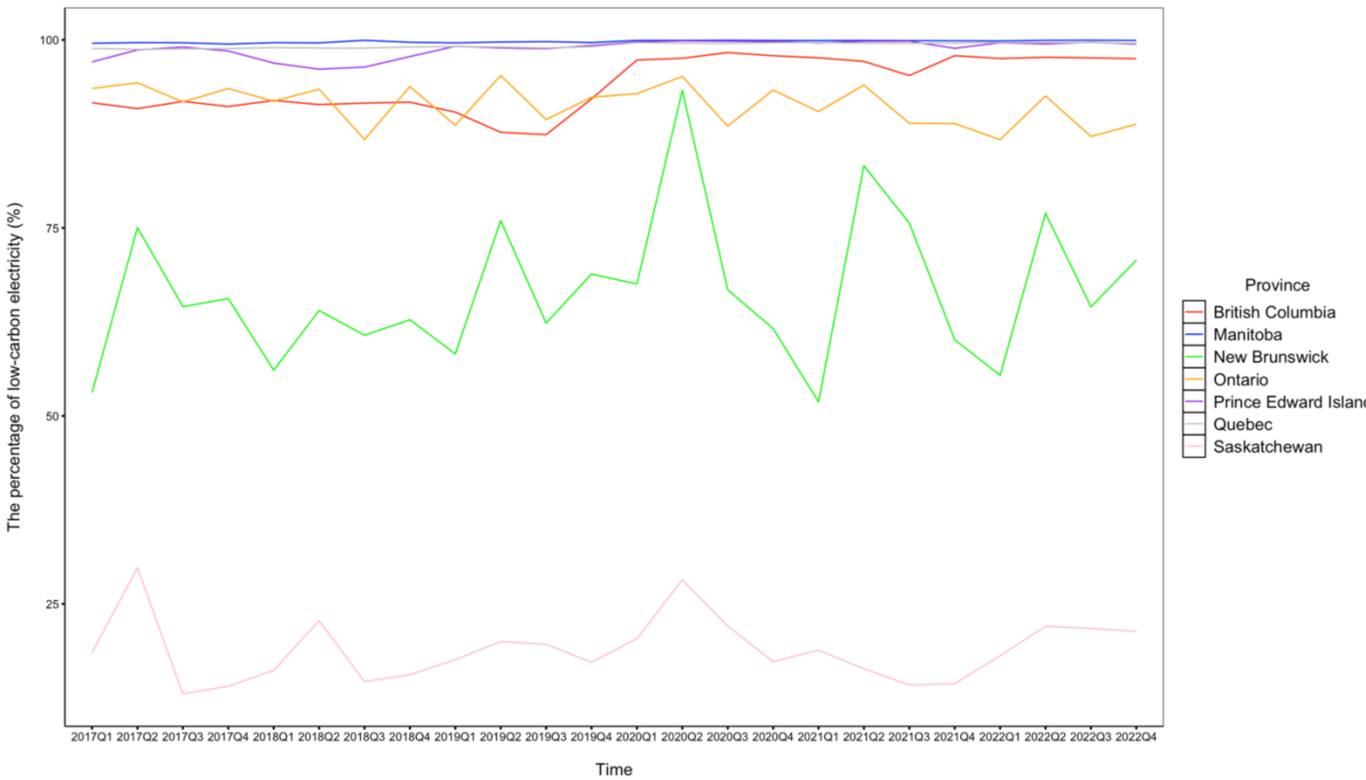

The percentage of adults (25 years old and over) with a post-secondary certificates, diploma, or degree
65
60
55
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan


45.0
42.5
40.0
37.5
Median age
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan


12
9
6
Unemployment rate (%)
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan


Retail prices for gasoline and fuel oil ($/litre)
2.0
1.6
1.2
0.8
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan


Electricity prices (c/kWh)
18
15
12
9
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan



100
75
50
25
The percentage of low-carbon electricity (%)
2017Q1 2017Q2 2017Q3 2017Q4 2018Q1 2018Q2 2018Q3 2018Q4 2019Q1 2019Q2 2019Q3 2019Q4 2020Q1 2020Q2 2020Q3 2020Q4 2021Q1 2021Q2 2021Q3 2021Q4 2022Q1 2022Q2 2022Q3 2022Q4
Time
Province
British Columbia
Manitoba
New Brunswick
Ontario
Prince Edward Island
Quebec
Saskatchewan

Appendix C—Different representations of societal-level environmentalism (Chapter 4)

Capturing societal-level environmentalism has been regarded as a challenging task and different types of proxies to measure it are thus thoroughly considered at the first place. The following is some detailed information about those proxies.

1. The Canadian Disaster Database (Public Safety Canada, 2022) with detailed disaster information across provinces is one of the options, with the assumption that people's concern about environmental issues and further actions for environmental protection are related to the occurrence of disasters around them. However, the latest data in the database is in 2020.

2. Annual fraction of GDP from environmental and clean technology products (goods and services) (Table 36-10-0630-01) is also considered since this indicator directly represents how 'green' the economics is in different provinces (Statistics Canada, 2024a). However, this indicator is highly correlated with the percentage of low-carbon electricity.

3. Canadian public opinion towards climate change-related issues is one of the two main types of proxies that are carefully explored. The following table demonstrates a summary of relevant publicly available national datasets/surveys from different sources, with questions such as do you think climate change is happening, do you think human and industrial activity is the main cause of climate change, and perceptions of carbon pricing/tax, being asked. The datasets are across provinces but none of them covers the whole time period of this study between 2017 and 2022. The variation of questions that are asked and methodologies that are involved in each survey raise caution about direct comparison among them. For example, although Canadian Election Study and Democracy Checkup both involve a question about the cause of climate change, the options they provide are different.

Titles of the survey/datasets	**Sources**	**Time of data collected**	**Link**
The distribution of Canadian climate change opinion	Mildenberger et al.,	January 2011 to October 2018	https://climatecommunication.yale.edu/visualizations-data/ccom/
Perceptions of Carbon pricing in Canada	Abacus Data	February 9 to 15, 2018	https://ecofiscal.ca/wp-content/uploads/2018/04/Ecofiscal_Polling_February2018_FINAL_RELEASE.pdf

Canadian Election Study (Post-election survey)	Stephenson et al.,	October 24 to November 11, 2019; September 23 to October 4, 2021	http://www.ces-eec.ca/2019-canadian-election-study/
Democracy Checkup	Harell et al.,	May 5 to May 12, 2020; May 20 to June 7, 2021	http://www.ces-eec.ca/democracy-checkup-surveys/
Canadian public opinion towards climate change	Abacus Data	October 15 to 20, 2021	https://abacusdata.ca/climate-change-cop26-canada/

4. Canadians' political leaning/voting party preferences is the other predominant types of proxies that are investigated in details. The relationships and dynamics between societal-level of environmentalism and political voting are essentially complex. However, it is widely acknowledged that citizen's increasing environmental concern and value changes will impact their demands of government, thus linking to how they vote and politics. Anderson and Stephenson (2011) explicitly examined those dynamics in Canada and argued that environmental issues can be regarded as a partisan topic; the division in Canadian opinions on environmental issues among different political parties from left to right is noticeable.

2019 and 2021 federal political party platforms are thus explored to see different political parties' policies and promises of climate change and green energy issues. All parties (except the People's Party) are more or less committed to policies and programs to tackle climate change, albeit in different measures. The only comparable and measurable index for their environmental efforts is GHG emission reduction targets by 2030. Based on that, the ideological spectrum position from left to right in terms of environmental issues could be the Green Party, the New Democrat, the Liberal Party, the Conservatives, and the People's Party (The Bloc Québécois is not mentioned here due to its main dominance in the province of Quebec). People's voting behaviours or intention of certain parties could reflect their levels of environmentalism; 'strong' environmentalism is shown by voting (preferences) to 'far-left' parties and 'soft' environmentalism is related to left-wing parties including both 'far-left' and 'centre-left' parties.

This study uses the voting preference for the Green Party of Canada as the proxy of societal-level of environmentalism across provinces within the studied timeframe as the following justification.

- This variable could capture those who have 'strong' environmentalism since the Green Party of Canada is the only major party with an explicit ideology of environmentalism.

Brückmann et al. (2021) found that respondents in Switzerland who have preferences to 'far-left' parties (Green Party and Green Liberal Party) are positively correlated with EV adoption; however, this effect does not appear among those who think more central and right-wing parties best represent their opinions. In the context of the United States, the share of voters for minor parties or groups (e.g., Green Party and the League of Conservation) is used as a proxy for community/state environmentalism (Clinton & Steinberg, 2019; Kahn, 2007).

- The variable is from the Weekly Nanos Political and Issue Tracking Survey and the question asks participants their top current local preference among those parties they would consider voting for federally. The question is about voting preference instead of actual voting, which eliminates the impacts of strategic voting that is used to describe people voting for a party that is not the most preferred but has better chance of winning. On the other hand, the effects of strategic voting on election outcomes overall in Canada are generally considered as minimal and one study showed the percentage of surveyed Dalhousie students who did not vote strategically was highest for those who voted for the Green Party of Canada in the 2019 Canadian federal election (Aoyama, 2020).

Appendix D—2020 and 2023 Waterloo Region Survey (Chapter 5)

(2023 version)

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB# 45257) and the Laurier Research Ethics Board (REB# 8509). University of Waterloo Contact: Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca. Wilfrid Laurier University Contact: Jayne Kalmar, PhD, Chair, University Research Ethics Board, Wilfrid Laurier University, 519-884-1970, extension 3131 or REBChair@wlu.ca. If you have questions about the study, please contact the Survey Research Centre at srcccinb@uwaterloo.ca.

(2020 version)

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE# 41687). If you have questions for the Committee, contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca. If you have questions about the study, please click the Contact Information button at the top of this screen.

Please answer a few classifying questions to ensure that questions later in the survey are relevant for you.

In which city or township do you live?

01 Cambridge

02 Kitchener

03 North Dumfries

04 Waterloo

05 Wellesley

06 Wilmot

07 Woolwich

08 Other city or township

To qualify to complete this survey, please confirm which age group do you belong to:

01 18 to 24

02 25 to 34

03 35 to 44

04 45 to 54

05 55 to 64

06 65 or older

07 Under18

The first set of questions are about Electric Vehicles (cars and trucks that must be plugged in to recharge the battery, including both fully electric and plug-in hybrid electric vehicles).

A1

Which of the following statements best describes your situation? **(SELECT ONE ONLY)**

01 You own or lease one or more electric vehicles

02 You plan to purchase or lease your first electric vehicle as your **next** vehicle

03 You are interested in learning more about electric vehicles to inform your **next** vehicle decision

04 You may consider purchasing or leasing an electric vehicle sometime later on

05 You do not expect to purchase or lease an electric vehicle anytime soon

A2A

Which of the following reasons would **motivate** you the **most** to purchase or lease an electric vehicle? **(SELECT ONE ONLY)**

01 Cheaper to run because electricity replaces gasoline

02 Cheaper to maintain

03 Better for air quality

04 Better for mitigating climate change

05 Less noisy

06 Other, please specify: ______________

07 Nothing would motivate me to purchase or lease an electric vehicle (SKIP TO A3A)

PROGRAMMER: please remove reason chosen in A2A for A2B

A2B

Which of the following reasons would be the **next most likely** to **motivate** you to purchase or lease an electric vehicle? **(SELECT ONE ONLY)**

01 Cheaper to run because electricity replaces gasoline

02 Cheaper to maintain

03 Better for air quality

04 Better for mitigating climate change

05 Less noisy

06 Other, please specify: _____________

A3A

Which of the following reasons would **most prevent** you from purchasing or leasing an electric vehicle? **(SELECT ONE ONLY)**

01 Higher initial cost

02 Need to install a charging station at home or find a place to charge

03 Limited number of models of electric vehicles

04 Limited availability of electric vehicles at the dealership for viewing and test driving

05 Worry about running out of battery charge before reaching the next charging station (range anxiety)

06 Concerns about your safety

07 Concerns about the sustainability of batteries, especially in their production and disposal

08 Other, please specify: _____________

09 Nothing would prevent me from purchasing or leasing an electric vehicle (SKIP TO A4)

PROGRAMMER: please remove reason chosen in A3A for A3B

A3B

Which of the following reasons would be the **next most likely** to **prevent** you from purchasing or leasing an electric vehicle? **(SELECT ONE ONLY)**

01 Higher initial cost

02 Need to install a charging station at home or find a place to charge

03 Limited number of models of electric vehicles

04 Limited availability of electric vehicles at the dealership for viewing and test driving

05 Worry about running out of battery charge before reaching the next charging station

(range anxiety)

06 Concerns about your safety

07 Concerns about the sustainability of batteries, especially in their production and disposal.

08 Other, please specify: ______________

A4

Sometimes governments take action to support the development of new technologies. For you, which of the following government initiatives would most increase your likelihood of buying or leasing an electric vehicle? **(SELECT ONE ONLY)**

01 Increased subsidies for vehicle purchase

02 More electric charging stations in your region

03 Subsidies for installing a charging station at your home

04 Higher carbon tax on gasoline prices

05 Special operating privileges, such as free parking or free use of high occupancy lanes

06 Other, please specify: ______________

A5

Compared to **three years** ago, are you now more or less likely to purchase/lease an electric vehicle? **(SELECT ONE ONLY)**

01 Much more likely

02 More likely

03 Neither likely nor unlikely

04 Less likely

05 Much less likely

This section asks about you and your household. The answers to these questions are used for broad analysis purposes only. When analysed, all of the data will be summarized and anonymized so that no individual can be identified from these summarized results.

B1

What is your current employment status? **(SELECT ONE ONLY)**

01 Full-time

02 Part-time

03 Retired

04 Unemployed

05 Student

06 Homemaker

07 Other (Please specify: ______________)

B2 (2020 version)

What is your current household income before taxes? **(SELECT ONE ONLY)**

01 Less than $20,000

02 $20,000 to less than $50,000

03 $50,000 to less than $80,000

04 $80,000 to less than $100,000

05 $100,000 or more

B2 (2023 version)

What is your current household income before taxes? **(SELECT ONE ONLY)**

01 Less than $20,000

02 $20,000 to less than $50,000

03 $50,000 to less than $80,000

04 $80,000 to less than $100,000

05 $100,000 to less than $150,000

06 $150,000 or more

B3 (2020 version)

What is the highest level of formal education that you have completed? **(SELECT ONE ONLY)**

01 Grade school

02 High school

03 College or trade apprenticeship

04 University degree

05 Other (Please specify: ______________)

B3 (2023 version)

What is the highest level of education you have achieved to date? **(SELECT ONE ONLY)**

01 Primary school

02 High school

03 Some college or university

04 College or trade apprenticeship

05 University degree

06 Postgraduate degree

07 Other, please specify: ______________

B4

At present, are you married, living with a partner, widowed, divorced, separated, or have you never been married? **(SELECT ONE ONLY)**

01 Married

02 Living with partner/common-law

03 Widowed

04 Divorced or separated

05 Never married

B5 (2020 version)

Please confirm your gender: **(SELECT ONE ONLY)**

01 Male

02 Female

03 Transgender

B5 (2023 version)

What sex were you assigned at birth, as indicated on your original birth certificate? **(SELECT ONE ONLY)**

01 Male

02 Female

03 Intersex

04 I prefer not to answer