INSTALLATION OF CHARGING INFRASTRUCTURE FOR ELECTRIC VEHICLES IN MULTI-UNIT RESIDENTIAL BUILDINGS IN BRITISH COLUMBIA

by

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Abstract

Electric Vehicles (EVs) contribute to the mitigation of climate change through reduced greenhouse gas emissions, when powering with sustainable sources of electricity. The province of British Columbia (BC) is an attractive location for EV deployment since most of its electricity is sourced from clean renewable energy sources. Due to their driving range and potential to reduce local emissions, EVs work well in urban contexts, where most residential buildings are located. As a result, residents from Multi-Unit Residential Buildings (MURBs) are among those interested in becoming EV owners, thus requiring access to charging infrastructure, especially overnight home charging, which is the preferred charging alternative. However, most residential buildings are not equipped with charging infrastructure and its installation can have numerous challenges that can turn into barriers. This thesis explores the implications, challenges and decision-making processes of EV charging infrastructure installation in MURBs to identify present and future barriers to infrastructure provision, as well as potential policy-driven interventions to address them. The methods used to conduct the research study include the utilization of conceptual frameworks and the application of systems thinking principles to map the interrelation and causalities of the problem domains as causal loop diagrams. A review of the literature identified the key problem domains. Policy recommendations were then classified based on each problem domain. First, financial or fiscal policy measures include creating incentives for EV owners and extending them to the building owners, as well as programs to incentivize and provide financial aid for building owners to develop building retrofit plans. Second, regulatory policy measures include revising the regulations and addressing the rights and obligations of the stakeholders, as well as making mandatory the installation of charging stations in new MURBs. Third, information and awareness policy measures include expanding the existing guidelines and informing the

development of a long-term EV charging infrastructure plan. These policy recommendations are relevant to different stakeholders as they have the potential to inform the decisions and policy programs of the municipal and provincial government of BC, as well as other governmental and non-governmental agencies and associations.

Lay Summary

Electric Vehicles (EV) are an environmentally friendly alternative to traditional fossil fuel vehicles. EVs are powered using electricity from the grid, therefore, they can be plugged-in and charged at home. However, households are not yet equipped with the proper infrastructure to do so. Because vehicles are parked in common areas, installing charging stations in residential buildings has numerous implications and challenges that can turn into barriers. The goal of this research study was to conduct an in-depth analysis of these implications and identify present and future barriers to infrastructure provision. The analysis included mapping the underlying causes for insufficient charging infrastructure provision. The main contributions are policy recommendations, which can inform charging infrastructure investment strategies for various stakeholders including municipal and provincial governments and agencies, EV consumers, and building developers.

Preface

For this thesis, the author had the major contribution in designing the research program, conducting the research activities and writing the thesis. The author received continuous support and feedback from supervisor Dr. Thomas Froese, and co-supervisor Dr. Martino Tran. The thesis topic was identified by Dr. Martino Tran.

This research was not previously published in whole or in part.

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List of Abbreviations

AC / DC	Alternating Current / Direct Current
AFV	Alternative Fuel Vehicle
ANSI	American National Standards Issue
ASHRAE	American Society for Heating, Refrigerating and Air-Conditioning Engineers
BC	British Columbia
BEV	Battery Electric Vehicle
BOMA BC	Building Owners and Managers Association of British Columbia
CaGBC	Canada Green Building Council
CLD	Causal Loop Diagram
CHOA	Condominium Home Owners Association of British Columbia
CV	Conventional Vehicle
EBOM	Existing Buildings Operations and Maintenance
EVSE	Electric Vehicle Supply Equipment
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
HOV	High Occupancy Vehicle
IES	Integrated Environmental Solution
LEED	Leadership in Energy and Environmental Design
MURB	Multi-Unit Residential Building
NC	New Construction
PHEV	Plug-in Hybrid Electric Vehicle
R&D	Research and Development
SD	System Dynamics
USGBC	United States Green Building Council

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To my four pillars.

Chapter 1: Introduction

1.1 Problem Background

Electric vehicles (EVs), as an alternative to traditional fossil fuel vehicles, have become a reality for many countries including Canada. EVs contribute to the reduction of fossil fuel dependency of the transportation sector, promotion of sustainable energy development and grid resilience, and improvement of air quality and mitigation of climate change through reduced GHG emissions (Egbue and Long 2012; Natural Resources Canada 2009). Since the first EV sold in Canada in 2011, the market has been growing and sales have been increasing significantly as manufacturers release new models, and consumer understanding and trust of the technology continues to increase (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.).

Powering EVs with sustainable sources of electricity has added benefits in terms of sustainability metrics such as reduced petroleum consumption and further GHG emissions reductions (Bradley and Frank 2009). In this sense, the Canadian province of British Columbia (BC) is considered as one of the most attractive locations in the world for EVs since 85% of its electricity is sourced from large hydropower, a clean renewable energy source (Whiticar 2016). In addition, current residential electricity rates mean the cost of charging a vehicle at home is less than fueling a conventional vehicle with gasoline, with a gasoline cost of $1.29 per liter[1] and an electricity cost of $0.30 per equivalent liter for EVs (Condominium Home Owners Association of BC 2014). BC is also the Canadian province with the third highest EV sales in 2017, as well as the second highest increase in the adoption rate, a 48.6% increase over 2016 (R.L. Polk & Company and Stevens 2017).

[1] Yearly average price in BC as of September 2017

EVs, understood in this study as light-duty vehicles partially or fully fueled by grid electricity, have the commonality of having to be plugged in to charge the vehicle's battery pack. Charging times and driving ranges can vary widely depending on the type of power level and the capacity of the vehicle's battery. Charging for EVs can be made possible in workplaces and public spaces, but research suggests that 80-90% of charging happens at home where it is most convenient for drivers (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.). Because of this, most early adopters reside in single family homes where it is easy to have a charging station installed in a private garage.

Due to their driving range and capacity to reduce emissions significantly, EVs work well with urban driving patterns where most trips are relatively short in range and therefore fit well in city contexts. Thus, there is growing interest from vehicle drivers in cities, including residential building inhabitants, to have access to EV charging infrastructure, which is considered a prerequisite to EV ownership (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.; City of Vancouver 2016).

The deployment of charging infrastructure in residential buildings in BC, also known as Multi-Unit Residential Buildings (MURBs), has been receiving attention recently from the provincial and municipal governments and from residential building associations. For instance, the expansion of access to home charging is one of the three major strategic approaches to support the transition to renewably-powered transportation, as stated in the City of Vancouver's EV Ecosystem Strategy. The inclusion of EV charging access within the parking stalls of new MURBs is recognized as a priority to achieve this (City of Vancouver 2016). These stakeholders have recognized the importance of home charging in promoting EV adoption, but also the fact that achieving charging infrastructure access in MURBs has an additional layer of complexity compared to detached homes.

MURBs are buildings with three or more dwelling units that feature common interior and exterior spaces shared among the residents, often including a common parking lot within the building or in the surrounding premises. Because of the nature of MURBs, there are several challenges that the majority of condominium residents face when considering the acquisition and installation of a charging station. There are usually limitations for accessing power outlets in MURB parking lots to be able to connect an EV. In a 2007 study by Axsen and Kurani (2012), where more than two thousand new car-buying households in the U.S. were surveyed, it was found that only 16% of the respondents living in apartments have access to 120V outlet to charge their EV within 25 ft. from where they park their current vehicle, compared to 59% in detached homes. This is also the case for the respondents who park their cars in parking lots (only 5% have access to an outlet), and usually, residential building occupants park in parking lots. In a survey, conducted in California in 2011 (Axsen and Kurani 2012), the results were consistent with the 120V outlet access study and showed that even fewer respondents (very few to none) had access to a 220/240 V outlet, both for apartment residents and parking lot users.

The lack of access to power outlets poses a major challenge for EV charging infrastructure installation, but availability is not the only concern. MURBs have a mix of private and common use areas on their premises, and parking lots generally fall under the latter category. Charging an EV in a common area means that all building residents would be billed for the charging power as part of the common area electricity use since there is no way of allocating electricity consumption from a single occupant outside of their private suite. In addition, factors such as the desire to install charging stations with higher power capacity for faster charging add even more complexity to the problem.

Impey (2013) exposes some of the obstacles of installing charging infrastructure in MURBs, such as unfamiliarity by the public with electricity and EV technology, strata governance and installation cost issues, and building electrical distribution system limitations regarding power capacity. According to this study, these obstacles combined can slow the rate of EV charging infrastructure installation in MURBs.

It is evident that EV charging infrastructure installation in existing MURBs can become quite complex because of all the aspects that need to be considered. In addition, the varying interests of the multiple stakeholders (including two very different industries, EVs and MURBs, as well as the MURB residents) add to the complexity of the problem.

1.2 Motivation

This study is motivated by the lack of in-depth studies focused on EV charging infrastructure installation in existing buildings. It is also motivated by the relevance and importance of the problem, which arises from the fact that the EV market is and will continue to grow, and that MURBs in BC account for 28.6% of the total households[2] (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.). Limited EV charging infrastructure is one of the main barriers to EV uptake, which means that an important portion of the EV market will become affected by this problem.

The arrival of EVs to the mainstream vehicle market is shifting the way transportation modes interact with the built environment, which in turn has also evolved to become more

[2] Calculated based on the 2011 Census of Population and Statistics Canada.

environmentally conscious with the introduction of “green buildings”. Exploring this shift in paradigms is also part of the motivation for this study.

1.3 Research Statement and Objectives

In order to reduce the GHG emissions of the transportation sector, the provincial government of BC and a number of municipal city governments are aiming to incentivize EV uptake among vehicle buyers and users (City of Vancouver 2016). Residents from MURBs located in cities throughout the province are among those interested in becoming EV owners, thus requiring access to charging infrastructure (Plug’n Drive and Canadian Condominium Institute-Toronto n.d.). Overnight home charging is usually the most convenient form of charging for EV users, which establishes the importance of having charging infrastructure available within MURBs (Transportation Research Board and National Research Council 2013).

However, most of these MURBs are not equipped with EV charging infrastructure in their parking lots, and access to power outlets within reach of the parking stalls is usually not possible (Axsen and Kurani 2012). Even if there were, charging an EV with power from an outlet located in a common area, such as the MURB parking lot, means all residents are proportionally paying for power that only one resident, the EV owner, is using. Therefore, building modifications and dedicated charging infrastructure provisions are required to enable home charging for MURB residents (Impey 2013). Installing new infrastructure in existing buildings is a complex task with numerous implications and challenges that can turn into obstacles and barriers, which hinders the installation of charging infrastructure in MURBs. The lack of access to overnight charging can, in turn, reduce EV uptake among MURB residents, which accounts for more than one-fourth of the province households.

In response to this problem, this thesis aims to explore the implications, challenges and decision-making process of EV charging infrastructure installation in MURBs and to identify present and future barriers to infrastructure provision, as well as potential actions that can be taken to address them. The overarching approach used is to analyze this problem as a system, which can be understood as the interrelated elements involved in the installation or provision of charging infrastructure for EVs in MURBs located in the province of BC.

Two main objectives were identified for this study:

1. Identify and categorize the elements of the system and the major relationships between these components.
2. Map and analyze the system and its interrelations to identify potential policy-driven interventions to address the system barriers.

1.4 Research Methodology

The research methodology consists of five major activities to achieve the two objectives, as illustrated in Figure 1. First, the problem and scope definition and categorization are the means for identifying the system components and their relationships. Second, mapping and analyzing the system through diagrams enable the identification of key leverage points and potential policy-driven interventions to address the barriers.

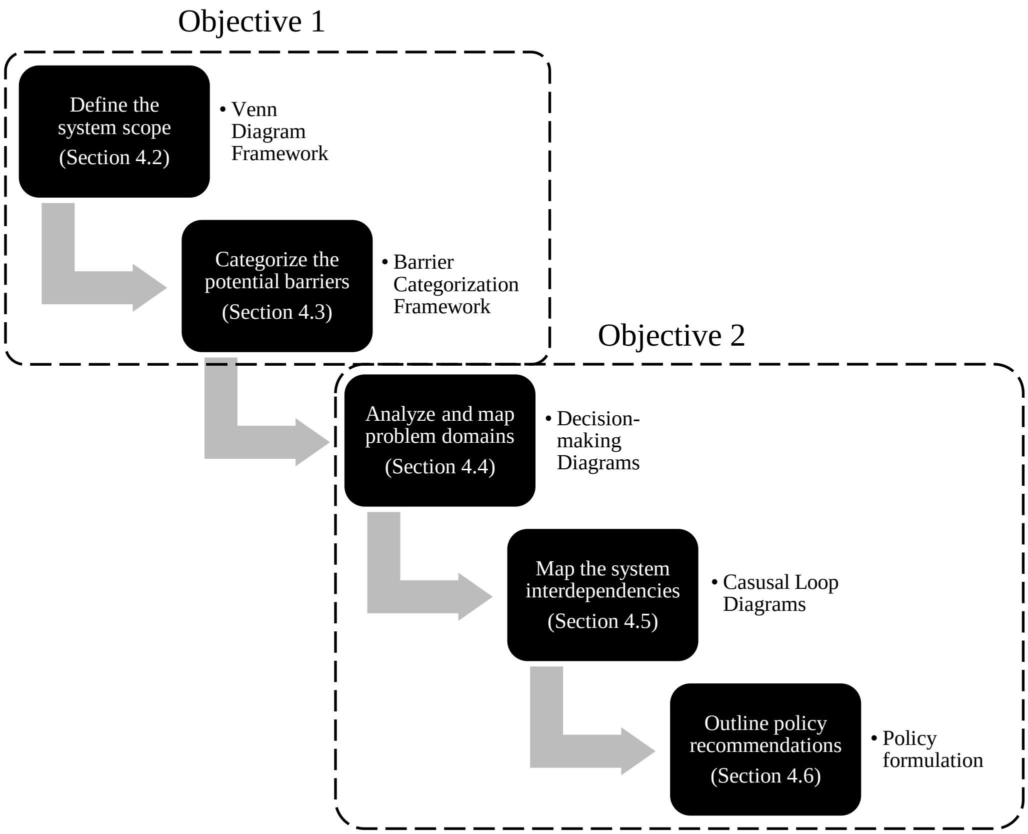

Figure 1. Research activities roadmap

The five major research activities are:

1. **Define the system scope:** analyze and define the system and its boundaries from the perspective of the three main dimensions identified from the literature review, and applying a Venn Diagram Framework.
2. **Categorize the potential barriers:** identify and analyze the potential barriers by applying the Barrier Categorization Framework.
3. **Analyze and map the problem domains:** identify, analyze and map the main stakeholders and decision-making criteria and outcomes for each problem domain using Decision-making Diagrams.

4. **Map the system interdependencies:** identify and analyze the relevant interdependencies and causal links that connect the problem domains, and explain the feedback loops that emerge using Causal Loop Diagrams.
5. **Outline the policy recommendations:** based on the results of the four previous activities, identify the most applicable policy measures in terms of the barriers each one addresses, and explain potential interventions.

1.5 Research Context

The geographical context chosen for this study is the province of British Columbia, Canada. As mentioned, this province is an attractive location for EVs because of its high degree of renewable energy, low electricity costs, and high adoption of new green technologies regarding alternative fuel vehicles.

Within the province, the focus of this study is on the main metropolitan areas because of the already established compatibility of EVs with urban settings. Although for BC, this territory accounts only for 1% of the total province, these areas concentrate 70% of the light-duty vehicle fleet that could potentially be replaced by EVs, as well as the majority of MURBs that exist in the province (Impey 2013). The analysis also takes into consideration the current EV and MURB market conditions, such as EV adoption and MURB construction trends. Changes to these conditions in the future are likely to change the results of this analysis.

1.6 Thesis Outline

This thesis has the following organization:

- Chapter 1 is the introduction, which outlines the problem background and the motivation, as well as the research objectives, methodology, and context.

- Chapter 2 contains the literature review explaining main concepts and existing research from the main bodies of knowledge relevant to the research, which are EVs and charging infrastructure, MURBs, the regulatory context and the policy and government role.
- Chapter 3 explains the methods employed as part of the research methodology for this thesis, which consists of two conceptual frameworks, the Venn Diagram and Barrier Categorization, as well as the Causal Loop Diagrams.
- Chapter 4 consists of the analysis framed by the five research activities: system and scope definition, problem domain categorization, decision-making analysis, system interdependencies mapping, and policy recommendations.
- Chapter 5 completes the dissertation by summarizing the research and discussing the contributions and future work.

Chapter 2: Literature Review

2.1 Electric Vehicles and Charging Infrastructure

2.1.1 Electric Vehicle Overview

The term Plug-in Electric Vehicles (referred to as EVs in this thesis) encompasses a wide range of light-duty vehicles that employ different technologies in their engines, but have the commonality of being partially or fully fueled by grid electricity (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.). The types of vehicles included in the term "EVs" in this thesis include the following:

- Plug-in Hybrid Electric Vehicles (PHEVs): this type of vehicle has both a gas and an electric motor, as well as an onboard battery, so it can be powered by gasoline, grid electricity, or both. Some PHEVs can also recover kinetic energy from the vehicle during operation, and transform and store it as electric energy in their batteries. Depending on their mode of operation, they can be subdivided into two categories (Axsen and Kurani 2012).
    - Blended operation: vehicles under this driving mode use both electricity and gasoline at the same time during operation, meaning that they rely on both sources of energy (although not necessarily in equal proportions). There is the option on some vehicle models to "lock-out" the EV motor so the electric energy stored in the battery is saved to be used when gas is less efficient (e.g. city traffic) (Axsen and Kurani 2012; Heyman 2015).
    - All-electric operation: also known as Range Extended EV, vehicles with this configuration operate as a Full-EV if there is a charge in the battery, or in other words, it uses only electric power from the battery first, and it proceeds to use

gasoline only when the charge from the battery is depleted. Thus, they require a larger battery that can deliver more power and store more energy than blended PHEVs (Axsen and Kurani 2012; Heyman 2015).

- Battery Electric Vehicles (BEVs): also known as Full-EVs or simply EVs, are the vehicles that are powered exclusively by electricity; they do not use gasoline and must be plugged into an electrical outlet to charge. They require larger battery packs with the capacity to store more energy, and larger electric motors than PHEVs (Fernandez et al. 2011).

There are also Hybrid Electric Vehicles (HEVs) that also use electricity but sourced from the recapture of kinetic energy and not from the grid. Although they have a small but relatively high-power onboard battery, they do not have the capacity to be plugged in and be charged with electricity from the grid, therefore they are not included in the scope of this thesis. However, it is worth mentioning that, although their main and only external source of fuel is fossil fuels, which makes them dependent on a non-renewable source of energy, HEVs have a more efficient and overall lower use of gasoline per km than conventional Vehicles (CVs). This translates into less GHG emissions and overall less fossil fuel depletion, which makes them a more environmentally friendly alternative to CVs.

Of all EV types, BEVs are the most environmentally friendly since they do not utilize fossil fuels; therefore, the car itself does not have any GHG emissions, but they are also the most expensive model and offer the least driving range (ceteris paribus with other EV types). On the other hand, PHEVs, because of their hybrid nature, solve deficiencies of both CVs and BEVs, having a longer driving range than BEVs while using less gasoline and having less GHG emissions than CVs (Axsen and Kurani 2012; Bradley and Frank 2009). For this reason, PHEVs tend to be more popular than the other two models, both among Canadians and U.S. car buyers, and in the near future, they could become the most adopted vehicle type (Axsen, Bailey, and Castro 2015; Axsen and Kurani 2012, 2013).

However, the tendency toward PHEVs might change in time as the technology of BEVs continues to improve, along with fossil fuel depletion and a possible increase in gasoline prices, which could shift the market more towards BEVs. In fact, during the first three quarters of 2017 (January-September), BEV sales in BC have been higher than PHEV sales (66% and 34% respectively of the total EV sales) (R.L. Polk & Company and Stevens 2017). BEV sales in the province have been led by the Tesla Model S and Model X, which together account for 43% of BEV sales, although these models are not comparable in driving range, charging capacity, and vehicle cost to all other BEVs in the market. But even excluding Tesla sales from the total EV sales, BEVs still have a higher sales percentage (52%) than PHEVs (48%) in BC in 2017. This shows that, in this province, the tendency towards BEV adoption is already, and might continue to be, higher than that of PHEVs.

2.1.2 Home Charging Benefits

Based on their location and level of accessibility, charging infrastructure for EVs can be classified as either public or private. Private infrastructure is usually found in workplaces and in homes. Because of the convenience of overnight charging, private home charging is considered the basis for achieving high rates of EV deployment (Yilmaz and Krein 2013).

As shown in a report by the National Research Council of the U.S., Figure 2 shows a pyramid in which the relative importance of residential charging over workplace and publicly accessible charging is represented. This is supported by other studies which found that the majority of people charge their vehicles at home (Plug'n Drive and Canadian Condominium Institute-Toronto n.d.), therefore early adopters do not require a high-density public charging network, but only the capability to charge at home (Greene, Park, and Liu 2014a).

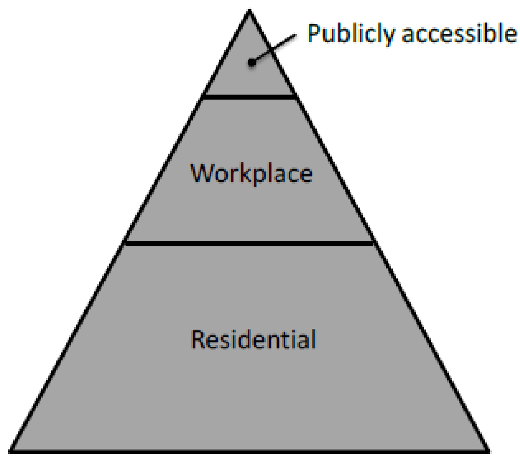

Figure 2. EV charging infrastructure pyramid (Source: National Research Council) represents the relative importance of residential, workplace, and publicly accessible charging indicating the ratio of charging occurrence by location

As established before, EVs work well with urban driving patterns, therefore most EV early adoption will happen in cities. The average distance that vehicle users commute within cities daily is lower than most EV driving ranges (the distance an EV can travel on one full battery charge). Based on the results of a study conducted by Egbue and Long (2012), where they surveyed around 500 people living in a city in the U.S., 71% of people travel less than 32 km per day, and 87% travel less than 65 km per day. The National Household Travel Survey (2011) also shows that, on average, a person in the U.S. travels 47 km per day on a vehicle. In the City of Vancouver, for example, most trips (70%) do not exceed 10 km and almost none exceed 30 km (only 5%), falling well under the average driving range of an EV (City of Vancouver 2016).

The BEV models available in the North American market as of 2017 have a driving range between 100 and 380 km (excluding Tesla models, which have a driving range between 375 and 580 km) (Schmidt 2017). Therefore, even with a lower driving range than CVs (in some cases), EVs have the capacity to fulfill most drivers' daily travel needs on one charge, assuming batteries can be charged daily.

These facts indicate that fully charging the battery once a day is usually enough for daily city commuting, therefore most EV charging infrastructure is likely to remain at residences where EVs can be charged overnight and for the longest time (Transportation Research Board and National Research Council 2013). As a result, charging is more complicated for people who lack access to charging at their household (Kurani, Heffner, and Turrentine 2008). In addition, because of the battery size and the gasoline back-up motor, non-residential charging infrastructure might not even be necessary for the operation of PHEVs in urban settings, and substantial gasoline savings can be achieved with overnight home charging only (Peterson and Michalek 2013).

Increasing home charging availability can also help solve the "chicken-and-egg" problem that alternative fuel vehicles (AFVs) in general face: "people will not purchase AFVs without adequate fueling infrastructure, and fuel providers will not invest in infrastructure until a critical mass of AFVs is achieved" (Greene, Park, and Liu 2014b; Meyer and Winebrake 2009; Struben and Sterman 2008). In this case, and especially as EVs make their way into the mainstream urban market, charging their EV overnight at home should meet the charging needs of EV owners and be perceived as "adequate fueling infrastructure". This reduces significantly the need for publicly accessible charging infrastructure, which can be quite costly for governments and EV manufacturers to deploy, especially fast charging stations. However, the "chicken-and-egg" problem still prevails to some extent among residential building developers acting as fuel providers when installing charging infrastructure in new buildings: they would not invest in charging stations for their buildings' parking lots, nor in a larger building power distribution system with extra capacity available for charging stations, if there are no demand, competitive advantage, or direct profit benefits.

2.1.3 Charging Levels

EV charging can also be classified by the level of charging, according to the power provided by the electricity source. These levels refer to the voltage (V) and power type (Alternating Current or AC, and Direct Current or DC) that each use to charge the EV's battery pack. The charging times refer to the time in hours that it takes for a battery to become fully charged, and it depends on the charging level and the EV battery capacity (measured in kWh). Table 1 summarizes the current state of the available technology regarding these concepts.

In Canada, Level 1 or Opportunity charging is sourced from convenience outlets and used mostly for charging at home or office because of the longer charging time ranging between 4 and 36 hours. Level 2 or Primary usually requires a dedicated, more complex interphase and a connection installation, and is used on a variety of public and private locations (including homes and offices) because of the relative shorter charging time of 1 to 6 hours. A Level 3 or Fast charging also exists but is mainly for commercial purposes since it operates with a 480 V or higher three-phase circuit and with DC, which makes it rarely feasible for residential areas (Yilmaz and Krein 2013).

Table 1. Charging levels and times per EV type

Charging Levels	Voltage (V) & Power	Battery capacity (kWh)	Power Level (kW)	Charging Times (hours)
Level 1 (Opportunity)	120 (AC)	PHEVs (5-15)	1.4	4-11
		EVs (16-50)	1.9	11-36
Level 2 (Primary)	240 (AC)	PHEVs (5-15)	4	1-4
		EVs (16-30)	8	2-6
		EVs (30-50)	19	2-3
Level 3 (Fast)	480 + (DC)	EVs (20-50)	50-100	0.2 – 1

EVs have onboard chargers, the charging device that is factory-installed in the vehicle and that converts the AC power to DC power that charges the EV battery. The equipment that serves as an intermediary between the power source and the vehicle's charging port is known as the electric vehicle supply equipment (EVSE) and can include elements such as EV charge cords, charge stand, power outlet, vehicle connectors and protection devices. They can have one of two configurations: a specialized cord set and/or a pedestal or wall-mounted box, depending on factors like location, country, and voltage, among others. Examples of these EVSEs are illustrated in Figure 3.

Figure 3. Example of cord set (left) and box (right) connector configurations

For Level 1, the charging interface consists of the single-phase grounded 120 V outlet, as mentioned previously, and a connector that goes in the vehicle's AC port that is usually included with the vehicle. Level 2 usually uses an external EVSE to provide power at 240 V when allowed by the power installation. (Yilmaz and Krein 2013).

To determine the most suitable charging level for residential buildings, several aspects must be considered. First, Level 1 charging requires only a convenience outlet of 120 V (common to all residential building power installations) but it is considered slow charging because it requires between 4 and 11 hours to fully charge a PHEV battery, and between 11 and 36 to do the same for a BEV battery, depending on the battery capacity. This means that for PHEV batteries, full-battery overnight charging could be possible at this level, especially considering that the battery state of charge is most likely not zero. On the other hand, this might not be the case for BEVs because the battery takes more time to charge than what can be considered overnight (8-12 hours) and, since they rely solely on electrical energy, their battery will likely be closer to full depletion.

Level 2 charging is a faster option that is capable of fully charging the battery of both PHEVs and BEVs in under 6 hours, but this requires a 240 V installation available, which some residential buildings can provide. This charging level usually also requires additional dedicated equipment and connection installation, as well as a separate billing meter. EV owners seem likely to prefer Level 2 technology over Level 1 because of its faster charging time and standardized vehicle-to-charger connection.

In summary, Level 1 charging can be considered enough for PHEVs. However, there is a preference from this same market to achieve a full charge faster than what Level 1 can offer, and Level 1 has not proven to be enough for overnight charging of BEVs. In addition, as technology evolves and battery capacity improves, faster charging will be prioritized. For these reasons, considerations for Level 2 charging installation should be considered in MURBs, even if there is not a strong need for it in the present.

2.1.4 National, Provincial and Municipal Initiatives

Several efforts have been made throughout the country—by different governmental and non-governmental agencies and organizations—to analyze, incentivize and regulate EVs in the mainstream market. In 2009, the Government of Canada funded a project led by industry to develop the "Electric Vehicle Technology Roadmap for Canada", a strategic vision for highway-capable EVs (Natural Resources Canada 2009). This report highlighted strategic initiatives to ensure the development and adoption of EVs within the following four categories:

- **Technology:** advance batteries and improve energy storage, reduce cost and weight of EV components and test options for charging infrastructure.

- **Codes, standards, regulations, and infrastructure readiness:** review regulations that impact EV use and manufacturing, harmonize standards in North America and develop action plans for infrastructure readiness, including amending the building codes to require that at least the rough-in for outlets for charging EVs is included in all new buildings.
- **Studies and assessments:** create a research institute for EVs, assess incentive programs, and estimate the electrical energy demand increase due to EVs, among others.
- **Education and outreach:** develop education programs and incentivize the creation of technical and non-technical courses on EVs.

In the province of BC, PlugIn BC is a collaborative program between government, utilities, industry, NGOs, academic institutions and EV owners created by the Fraser Basin Council. It mainly serves as a central source of information and initiatives supporting EVs throughout the province, including access to incentives, information about charging stations, and support for EV owners, among others (PlugIn BC 2017).

The City of Vancouver, the biggest city in BC with the goal of becoming the greenest city in the world by 2020, created an EV Ecosystem Strategy in 2016. This strategy seeks to formalize the municipal government's role in expanding EV charging options and access in the near future. The main barriers that they identify for widespread EV adoption include the people's lack of access to charging at home or workplace parking stalls; other barriers are inadequacy of public charging networks, EV's range being too limited to be considered a primary vehicle, the high-risk business case for EV infrastructure deployment, and insufficient building code requirements to achieve vehicle electrification goals. The strategy aims to solve these barriers and support the transition to 100% renewable transportation before 2050.

2.2 Multi-Unit Residential Buildings and Green Buildings

2.2.1 MURB Ownership

As defined previously, Multi-Unit Residential Buildings (MURBs) are buildings with residential occupancy with three or more dwelling units, as well as common interior and exterior spaces shared among the residents.

In British Columbia, there are mainly two types of building ownership in MURBs: purpose-built rental buildings, and strata or self-owned buildings. Purpose-built rentals are designed and built expressly as long-term rental accommodation, so the entire building is usually owned by a single organization and administered by property managers. In this case, a residential tenancy agreement between the landlord and the tenant exists that complies with the Residential Tenancy Act.

On the other hand, strata or self-owned condominiums are formed by self-owned suites that can either be occupied by their owner or rented to another occupant. In strata housing, owners own their individual strata lots and together own the common property and assets as a strata corporation. Owners and residents in all strata properties must follow the Strata Property Act as well as the strata's bylaws and rules.

2.2.2 MURB Electrical System

Electricity produced by the electric utility, in this case, BC Hydro, is transmitted from power plants at high voltages via an extensive transmission system within the province. The electricity is then converted into low voltages at load centers and distributed within the local utility distribution system that provides connections to residential buildings, among others. The electricity fed through a meter and into the building is distributed to every unit and other areas by the building's power distribution system. This system is composed of meters, transformers, panels, wires, protection devices, etc. The particular characteristics of each system vary among buildings, but the overall design is governed by the 2012 BC Building Code and other applicable City Bylaws.

2.2.3 Green MURBs

Buildings have diverse environmental impacts and consume numerous resources (e.g. energy, water, etc.), generating waste and other emissions (Vierra 2016). Green buildings, also known as sustainable buildings, employ processes and procedures considered environmentally responsible and resource efficient throughout their life cycle, including planning, design, construction, operation, maintenance, renovation and demolition (USEPA 2016). The vision of green buildings consists of amplifying the positive and mitigating the negative effects on the natural environment and building inhabitants. The most important building aspects are energy and water use, indoor air and environmental quality, as well as site and material selection (Kriss 2014). In Canada, as in many other parts of the world, the green building market is and will continue to grow rapidly, as the share of this type of building in the construction market will continue to increase significantly in the near future (McGraw Hill Construction 2014). A move towards greener buildings is becoming the norm for residential and commercial buildings in the urban contexts of Canada and BC.

2.3 Regulatory Context

2.3.1 Types of Regulations

There are several types of mandatory and non-mandatory regulatory instruments used by different levels of government, industries, and organizations. Government and organizations use standards and codes to regulate activities within an industry. Standards are guidelines against which something can be measured. These guidelines are created by national or international organizations through consensus processes among subject experts, and the most widespread eventually become the basis for the evolution of industry norms. Standards usually serve as incentives for improved performance (Vierra 2016).

Legislated codes are developed and published by government institutions and have the characteristic of being mandatory. The language of codes can be: prescriptive, containing rigorous requirements and identifying methods of achievement; performance-based, stating expectations to achieve certain results; or outcome-based, which establish target levels and ways to measure and report results (Vierra 2016).

2.3.2 Regulatory Context for EVs

In terms of regulation, as EVs become available on a wider market, different stakeholder organizations have advocated for the creation of unifying standards that can guide the industry. These standards address technical and common elements between the vehicle and the charging infrastructure regarding compatibility, power management, communication, and safety, among others. Although standards differ among regions of the world and charging equipment is not the same, they are all focused on supporting growth and industry advancements. The Society of Automotive Engineers, also known as SAE International, is the leading organization for EV standards in North America. The "SAE Surface Vehicle Recommended Practice J1772, SAE Electrical Vehicle Conductive Charge Coupler" standard covers physical, electrical, communication protocol and performance requirements for EV electrical connectors. Due to the continuous technological advances that exist around EVs and charging stations, this document is under constant review and update, but it has been endorsed by the leading EV manufacturing organizations (Impey 2013).

EV government regulations are similar in focus and content to these standards, but through them, governmental organizations seek to control the way in which this new technology is adopted. The document that regulates EV charging stations in Canada is the Canadian Electrical Code, specifically Section 86 – Electric Vehicle Charging Systems (Impey 2013).

2.3.3 Regulatory Context for MURBs and Green MURBs

The BC Building Code is the provincial regulation that governs new construction, building alterations, repairs, and demolitions. Each municipality within BC can also develop their own bylaws that address issues outside of the scope of the BC Building Code. These bylaws can also serve as a means to achieve specific goals or targets. The City of Vancouver, for example, has a Building Bylaw that states additional requirements considered by the government as important within the City level context, and it is only enforceable within the City limits.

In terms of green buildings, different standards, codes, certification systems, and rating systems that focus on mitigating the environmental impact of buildings have emerged. First, one of the most relevant green buildings standards in North America is the *Standard for the Design of High Performance Green Buildings Except Low-Rise Residential Buildings* developed jointly by the American National Standards Issue (ANSI), the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the U.S. Green Building Council (USGBC), and Integrated Environmental Solution (IES). This is a comprehensive standard that provides minimum requirements for planning, construction, and operation of green buildings (Vierra 2016).

Second, green codes are based on green building standards and rating systems, adopted by some governments to push the building design and construction practices to higher levels of sustainability and performance. Due to their mandatory nature, the adoption of green codes can change the built environment more rapidly than voluntary certification and rating systems (Vierra

2016). As of 2015, 67% of the C40 Cities Climate Leadership Group (C40) have adopted green building and energy codes to reduce GHG emissions of private sector buildings, including the City of Vancouver in BC (U.S. Green Building Council, World Green Building Council, and C40 Cities 2015).

Third, green building rating/certification systems are designed to assess buildings' performance and level of compliance with specific environmental requirements and targets. They are created by national or global organizations to more clearly define and measure green buildings and are mostly voluntary to implement. There are numerous rating systems that target varied buildings (new constructions or existing buildings, high-rise or low-rise buildings and even neighborhoods) with equally varied building lifecycle scope (planning, design, construction, operations and/or maintenance) (Vierra 2016). Being mostly conducted by independent third-parties, these systems are encouraged to be science-based (i.e. reproducible), transparent and open for examination, objective, and progressive (i.e. advance industry practices) (RSMeans). As well as standards, rating systems also incentivize building stakeholders to promote sustainable building practices and improve their overall performance. For the case of residential buildings in BC, the most popular certification is known as Leadership in Energy and Environmental Design (LEED), a multi-attribute holistic system that, in terms of residential housing, has several relevant certifications such as New Construction (NC), Existing Buildings Operations and Maintenance (EBOM), and Homes. In Canada, this standard is managed by the Canada Green Building Council (CaGBC). The main attributes that it addresses are location and transportation, site selection, water and energy efficiency, materials and resources and indoor environmental quality (CaGBC 2017).

2.4 Policy and Government Role

2.4.1 Policy and Creation Process

Policy can be defined as *a course or principle of action adopted or proposed by a government, party, business, or individual* (from Oxford Dictionary). It serves as an interface between the government and the rest of society to address needs (policy demand) and incentivize certain conduct patterns (policy outcomes). Policy analysis is understood as research tasks pursued by both governmental and non-governmental organizations directed at designing, implementing and evaluating policies that have been or might be adopted by an entity, generally regarding public problems. As part of the policy analysis, understanding the policy process is important to identify the stages in which it is possible to exert the greatest influence. The policy process is a sequence of activities to transform situations that need addressing (problems) into actions and measures expected to address them (policies) (Campbell and Corley 2012).

In the context of urban environmental policy, Corley and Campbell (2012) propose a model of policy process with the following stages: problem identification, agenda setting, and policy formulation, legitimation, implementation, and evaluation. The process is not linear and a number of feedback loops between these stages have been identified. The following paragraphs provide a brief overview of each of the policy process stages, as well as the role of policy analysis on each one and the interactions between them (Campbell and Corley 2012).

1. **Problem identification:** society identifies as problematic certain attributes that have failed to be solved in the past, thus creating a feedback loop between policy evaluation and problem identification. During this stage, policy analysis should provide guidance on problem prioritization.

2. **Agenda setting:** an important step in identifying the problem and determining its significance and importance is including it in the official government agenda.
3. **Policy formulation:** at this stage, specific policy responses are developed and detailed to reach the desired outcome. Although usually followed by the agenda setting, this stage can also happen directly after problem identification, especially if it is a citizen initiative. Policy analysis can help design and analyze policy outcomes to inform decision makers.
4. **Policy legitimation** refers to the review and authorization processes that policies go through to become accepted, therefore forming a feedback loop between legitimation and formulation.
5. **Policy implementation** can be accomplished through governmental agencies or in collaboration with non-profit and/or private organizations. This process might involve additional formulation because of limitations on existing legislation, thus forming another feedback loop. Policy analysis at this stage is crucial and should provide information that can help tweak implementation details not covered in policy formulation stage.
6. **Policy evaluation** can happen while the policy is in the process to assess the implementation, or after it is completed to evaluate the policy results. Evaluation can also involve a formal process through government officials and researchers, or a more informal process based on public opinion. Policy analysis is useful in determining policy outcomes and is mostly based on the formal evaluations, although informal processes are also important and should not be overlooked. As mentioned before, evaluation results can help inform both the problem identification and the policy formulation stages.

2.4.2 Policy Role and Context for EVs

Conventional fossil fuel vehicles have been on the market for over 100 years and have established a clear market lead relative to other AFVs, which could be defined as a case of technological lock-in (Cowan and Hulten 1996). EVs as an emerging technology can benefit widely from external private and public support. Governments, through policy instruments such as regulation, taxation, subsidies, and incentives have helped shape the current EV market globally. Other initiatives such as setting long-term goals and providing R&D funding further support EV and infrastructure technical development (Ahman 2006). The role of policy around EVs has been studied in more detail recently to enable the understanding of its potential influence and overall relevance in encouraging EV market development and diffusion. The methodology of these studies usually consists of creating or using models that forecast EV uptake based on several factors, and then perform policy analysis to measure the effects certain policies could have compared to a base case "no policy" scenario.

An example is a study conducted by Wolinetz and Axsen (2017). According to them, a large-scale transition to EVs is likely to require strong government support through a combination of demand-focused and supply-focused policies. Demand-focused policies seek to directly increase consumer interest in EVs through purchase subsidies, making available charging infrastructure and other non-financial subsidies such as free parking. On the other hand, supply-focused policies incentivize vehicle suppliers to develop and sell better and more efficient EVs, as well as increase the type and models available in the market. Although a balance between these types of policies is recommended, the focus of this study is charging infrastructure which falls under the demand-focused category.

There are numerous examples of demand-focused policy geared towards increasing private charging infrastructure. The U.S. National Research Council has made some recommendations as to actions that can be implemented by the U.S. federal government with support from local governments to reduce obstacles to EV residential charging. These range from tax incentives and subsidies for the installation of residential charging units, to regulatory initiatives, such as permit streamlining and building code revisions. Also, several U.S. states have EVSE tax credits and rebate programs to offset a portion of the cost of installing charging infrastructure for EV buyers.

Norway, as another example, has a very demand-oriented EV policy which focuses their incentives on purchase tax savings and other non-economic perks such as free municipal parking, no tolls on roads or ferries, and access to bus lanes. This strategy has led them to be the world leader in EV new market share at 22% in 2015. Regarding charging infrastructure, they focus on providing a large number of public charging stations (1 for every 10 EVs), especially for long distance trips (Norway 2017).

In Canada, the majority of incentive programs are also demand-oriented and have been mostly at the provincial level, concentrated in the provinces of BC, Quebec, and Ontario (Lambert 2017). As an example, BC through its "Program Re-Charged" offers between $2,500 and $5,000 CAD rebate when purchasing an EV.

The policy has been found to be of great use and even necessary to increase EV market share and sales to eventually transition from a niche to a mainstream market. This is true even if other factors such as battery costs decline with further technological advancements and scale economies. However, policy instruments like economic incentives and subsidies have best results if kept for a long time (approx. 15 years), which is usually not the case (Wolinetz and Axsen 2017). These kinds of economic support from the government are usually deployed in programs that last between 2 to 5 years, although they are sometimes renewed or new programs are deployed, depending on the market needs of the time.

There is certainly a challenge for policy and regulation to keep up with technology's fast evolution. In this sense, Greene (2014a) highlights the importance of adaptive strategies, which can change in response to future developments, to successfully accomplish a transition to EVs.

Chapter 3: Methods

3.1 Conceptual Frameworks

A conceptual framework can be understood as a simplification of reality used to analyze topics under different perspectives and to keep the analyst's attention focused solely on those specific factors important to the task at hand. As part of the research methodology, two conceptual frameworks were created, as described in the following sections.

3.1.1 Venn Diagram Framework

A Venn diagram-based conceptual framework was developed to analyze the issues of installing EV charging infrastructure in MURBs to promote EV uptake among building residents. A Venn diagram is defined as "a graphic organizer constructed by overlapping circles to indicate features common or unique to two or more concepts" (Harris and Hodges 1995). It has numerous applications in fields such as logic and mathematics, among others. As a conceptual tool, it has also been used to explain the notion of sustainability, for example. By organizing the three pillars of sustainability in overlapping circles, it is possible to visualize important concepts that fall within the intersections and that could otherwise be ignored if the concepts were analyzed or explain as separate entities. This characteristic of Venn diagrams to easily identify and visualize the interactions and overlaps between two or more concepts or dimensions is what makes it a useful tool to analyze the problem at hand.

In addition, Venn diagrams are also a suitable tool to help define systems, as well as setting the system boundaries, thus establishing the pertinent scope. In this context, a system can be understood as a set of concepts working together as parts of an interconnected network that form a complex whole (from Oxford Dictionary). In this case, the system definition and scope were defined through the following activities. It was important to first identify the most relevant parts or dimensions of the problem through the literature review. Then the diagram circles were populated with the identified dimensions, and the intersections were analyzed based on their location to determine the information overlaps that existed. On the complete Venn diagram, the circle's outside perimeters represent the system boundaries, and the content of circles forms the problem scope. Therefore, any concept or dimension that falls outside of the circles can be considered out of the scope of the research study.

Articulating the problem and selecting the boundaries through this framework is used later in the research methodology as the basis for the Causal Loop Diagram construction, according to the SD modeling process (see Section 3.2.1).

3.1.2 Barrier Categorization Framework

Browne, O'Mahony, and Caulfield (2012) designed a methodological framework to identify and qualitatively evaluate barriers to widespread AFV deployment. The framework was adapted to identify and analyze the potential barriers of installing EV charging infrastructure in MURBs since some of the categories and criteria did not apply to this issue, which is smaller in scale, scope, and context. Never-the-less, it provides a useful guide to think through the barriers and implications as well as for more general problems.

The problem categorization is geared towards assisting in the identification and organization of the potential barriers. The categories based on Banister (2005) and Browne, O'Mahony, and Caulfield (2012) refer to the following:

1. Financial: additional or increased monetary costs of charging infrastructure.
2. Technical: technological barriers referring to charging infrastructure installation feasibility.

3. Institutional and administrative: resistance from stakeholders due to an aversion to new technologies or established administrative procedures.
4. Public acceptability: acceptance from the general public of charging infrastructure installation as a new technology.
5. Legal or Regulatory: refers to regulatory and policy gaps, potential legal challenges and planning restrictions.
6. Physical: spatial constraints for charging infrastructure installation and availability.

The potential barriers can also be analyzed in terms of the following criteria:

- Timeline: refers to the timeframe in which the barrier could be eliminated or mitigated through policy actions; it can be short-term (1-2 years), medium term (2-5 years), and long-term (5-10 years).
- Significance: subjective evaluation of the likelihood of the barrier being an obstacle, classified in high, medium and low significance.
- Type of policy measure required: refers to the policy tool that is most appropriate to address the barrier; categories are: fiscal incentives or taxes, financial incentives such as rebates or discounts, regulatory, technical improvements, institutional, and education and awareness campaigns.
- Implementation scale: refers to the appropriate scale for policy implementation, which can be national, provincial or local.
- Policy developers: refers to the stakeholders or actors which are most likely to take action to overcome or mitigate a barrier; the relevant actors are the government, associations and organizations, the industry and the general public.

This information can be organized into a table and it provides a general context of the potential barriers that are now, or can eventually, hinder home charging infrastructure deployment in residential buildings, thus potentially impacting EV adoption among building residents.

3.2 Causal Loop Diagrams

A Causal Loop Diagram (CLD) is a conceptual modeling framework used to identify and explain feedback loops and to help visualize the interrelation of variables in a system. This tool was developed within the context of System Dynamics (SD) to help explain the logic behind SD simulation models.

3.2.1 System Dynamics and Systems Thinking Background

System Dynamics is an approach for representing and simulating the dynamic (non-linear) behavior of complex systems, with a focus on policy analysis and design (Morecroft 2015). It was created by Forrester (1958), and it is based on concepts like system theory, information science, organizational theory, control theory, and systems thinking (Shepherd 2014). It later provided a foundation for building and simulating computer-aided models with the ability to test strategies and policies and to explore trade-offs, without compromising or affecting the real-world system (Kanti Bala, Mohamed Arshad, and Mohd Noh 2017).

SD modeling has varied applications in fields like business management, healthcare, urban studies, and transportation. Recently, it has been used in several applications for modeling the uptake of AFVs (Ford 1995; Gillingham and Leaver 2008), as it is a good modeling tool to study technology and product diffusion. Most of these studies focus on creating quantitative models that can predict the AFV market share over time (Shepherd 2014). However, Stepp et al. (2009) developed a qualitative approach using Causal Loop Diagrams to investigate the potential policy implications of supporting high-efficiency vehicles, demonstrating the usefulness and applicability of qualitative studies in policy analysis.

Systems thinking, one of the bases of SD, aims to “improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects” (Arnold and Wade 2015). SD and CLDs are characterized by a particular type of systems thinking, known as feedback systems thinking, where the problems and solutions are intertwined in feedback loops and, therefore, are interdependent (Morecroft 2015).

This type of thinking differs from the traditional event-oriented linear thinking, where solutions are designed to fix a problematic event, sometimes without questioning the underlying cause of the problem or the potential effects of the solutions (Morecroft 2015). An example of the two perspectives is illustrated in Figure 4.

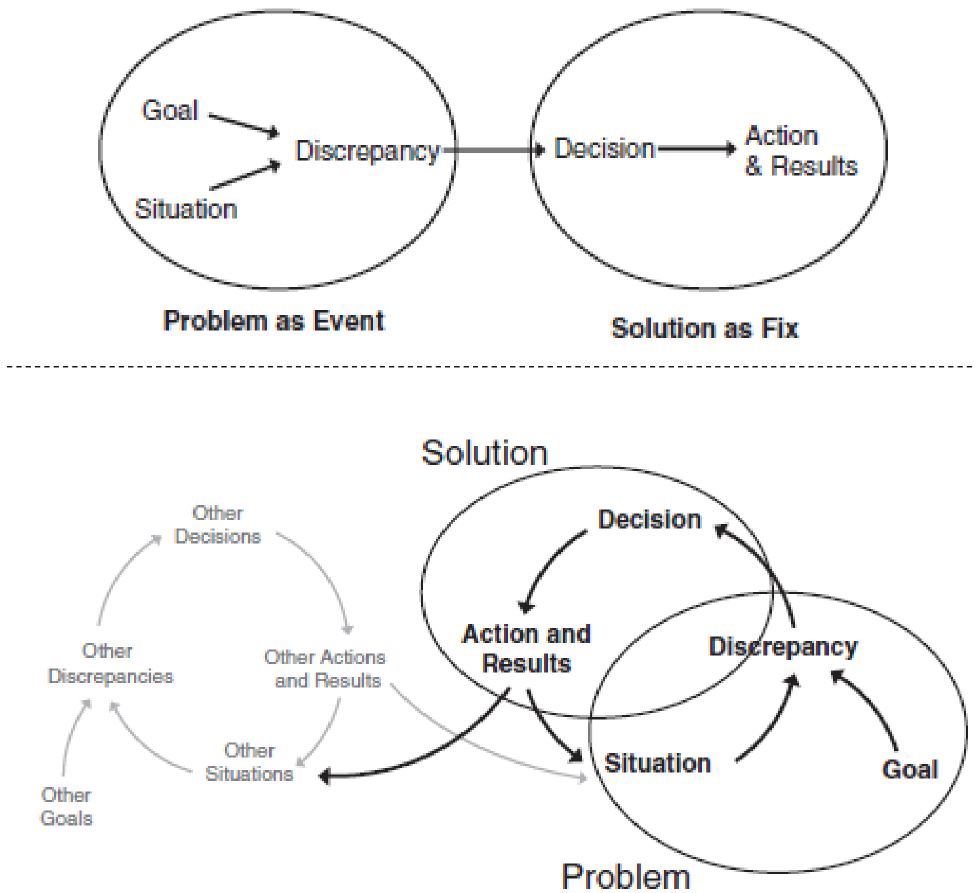

Figure 4. Event-oriented thinking (top) vs. feedback systems thinking (bottom) (Source: Morecroft 2015)

The reason for using the systems thinking and system dynamics approach for the methodology of this study is that installing EV charging infrastructure in existing residential buildings can be considered a complex system because it involves two very different industries: vehicle manufacturing and residential building development, as well as numerous stakeholders such as EV owners, building residents, strata councils, among others.

The complexity of the problem can also be illustrated through an example of an event-oriented thinking solution, such as giving a monetary incentive to MURB residents to help offset the EVSE and installation costs, which EV owners can perceive as high. Although the incentive might work at first, making charging stations less expensive will cause more residents to install one on their parking stall located within the building, which can eventually cause an overload in the building's power distribution system.

In the first part of the example, the solution of providing an incentive to fix the discrepancy of high installation costs can be considered appropriate. But analyzing it under the light of feedback systems thinking, we can identify undesired effects of the incentive, as well as the creation of other discrepancies. Solutions that emerge from event-oriented thinking may solve part of the problem in the short term, or mitigate part of the potential effects of the problem, but these actions will most certainly not be sufficient or sustainable in the long-term, and can even create more problems, as illustrated in the example.

The SD modeling process to achieve a reliable simulation model consists of iterations between five main steps: problem articulation and boundary selection, dynamic hypothesis, formulation, testing, and policy formulation and evaluation. CLDs in this context are used in the second step as a tool to identify and describe the main interactions and feedback loops that can explain observed or anticipated behaviors. The first and second steps form the first phase of this process focused on defining the problem, as well as the scope and architecture of the model, and have a qualitative nature (Morecroft 2015). The second phase, where the simulation model is built, has an inherently quantitative nature and involves activities such as writing equations, sketching graphical functions, and running diagnostic simulations, among others.

The research activities of this study are mostly encompassed within the first phase of the SD approach and are focused on understanding the problem, as well as exploring the feedback loops that create and maintain it. This analysis provides an in-depth holistic vision of the problem and makes it possible to identify key leverage points and potential intervention strategies.

3.2.2 Structure of Causal Loop Diagrams

As stated, CLDs are causal diagrams that illustrate and explain feedback loops formed by the interrelation between variables in a system. In a CLD, entities are connected to each other using causal links to form feedback loops (Shepherd 2014). The links between entities can be positive (+) or negative (-), known as link polarity and represented by a + or - sign next to the arrows in the diagram. A positive polarity between two linked entities means that an increase in the first entity causes an increase in the second entity. On the contrary, a negative polarity means an increase in the first entity causes a decrease in the second entity (Shepherd 2014). Two parallel lines on an arrow indicate that there is a time delay between the change in the first entity and the corresponding change in the second entity. A series of causal links can then form feedback loops.

The loops in a CLD can be reinforcing or balancing, identified with an R and a B respectively. On one hand, reinforcing loops amplify the reactions of the system leading to exponential growth without the presence of a balancing loop. On the other hand, balancing loops oppose change and growth, so a system with balancing and reinforcing loops may eventually reach dynamic equilibrium (Shepherd 2014).

A simple example of the behavior of population growth is shown in Figure 5. First, the CLD shows a reinforcing loop (left) formed by births and population, where the positive polarities between them mean that an increase in the number of births causes population growth, and an increase in population number, in turn, causes more births years after (thus the delay). Second, the diagram also shows a balancing loop (right), where the negative polarity means that an increase in the number of deaths causes a decrease in the population number, and the positive polarity means that a decrease in population, in turn, causes a decrease in the number of deaths. If we continue iterating on this loop, we can see that fewer deaths mean more population, which in turn means more deaths again.

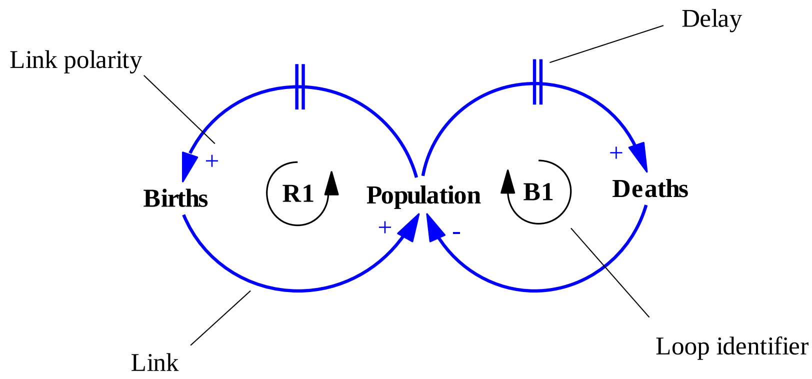

Figure 5. Example and main elements of a CLD (Source: Forrester 1971 and Morecroft 2015)

CLDs show the complete picture of causal relations and feedback loops of a given system, which makes them a useful tool to explore the impact of external influencers, such as policies, in the system.

The CLD analysis can show how policy mechanisms aimed at one part of the system can generate unintended consequences in another part of the system. It is also possible to discover potential sources of policy synergies derived from reinforcing loops, as well as policy resistance derived from balancing feedback loops (Stepp et al. 2009).

Chapter 4: Analysis

4.1 System Scope Definition

4.1.1 Problem Dimensions

According to the research methodology (Section 1.4), the first activity is defining the problem and scope. The objective is to identify the main dimensions of the issue of concern and the level of analysis to define the system and set the boundaries (Morecroft 2015). To achieve this, the Venn Diagram Framework was applied. The framework methodology is explained in detail in Section 3.1.1.

As established in Chapter 1, the subject of study is the installation of charging infrastructure for EVs within existing MURBs. Therefore, the most relevant dimensions are EVs along with their charging infrastructure and existing MURBs. The other relevant dimension identified from the literature review is the role of regulations and policies as tools to enable said installation. These three dimensions were organized into circles to form the Venn diagram as seen in Figure 6. We can also observe the four intersections that result from the overlaps between the dimensions. The three dimensions, along with the intersections between them, form the problem system. Both the dimensions and the intersections will be explained in more detail in the subsections that follow.

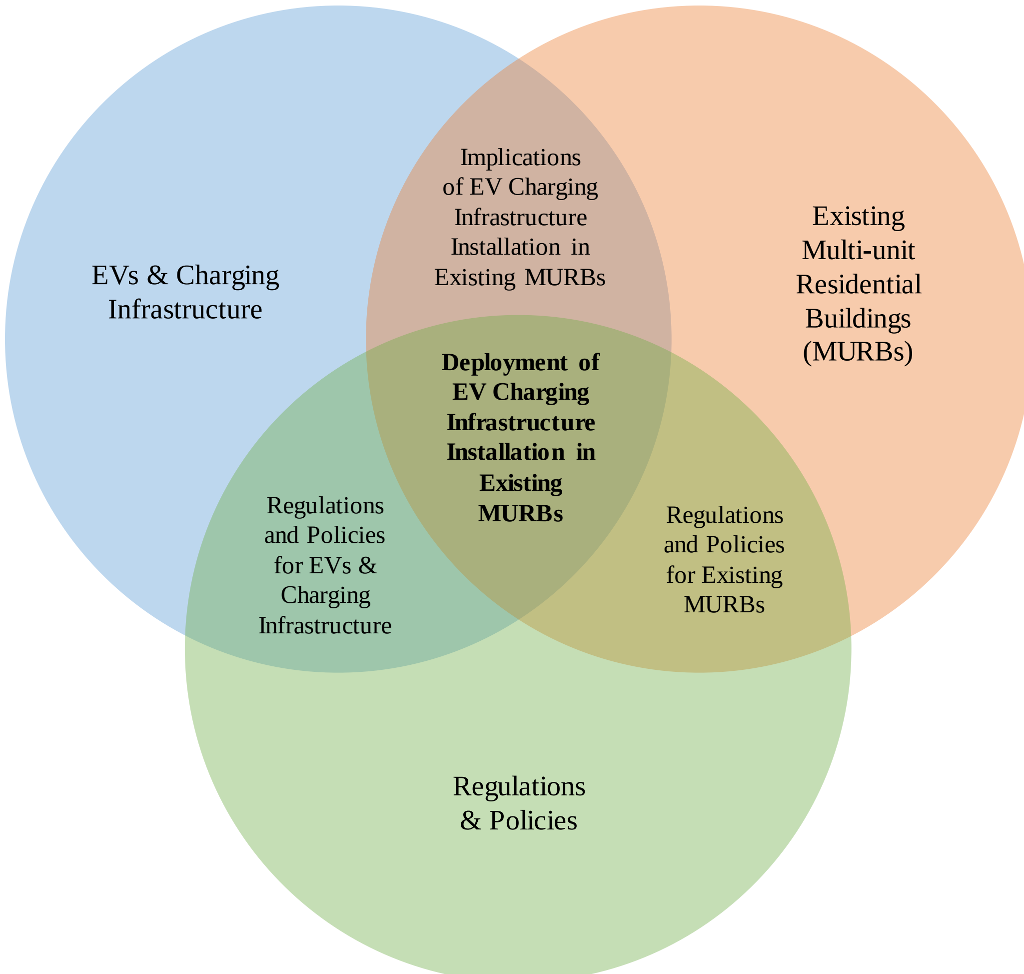

Figure 6. The Venn diagram framework

4.1.1.1 EVs and Charging Infrastructure

The first dimension is EVs and charging infrastructure. The relevant aspects of this dimension with respect to the system being analyzed include the EV adoption in BC, including the types of EVs that are available for purchase, as well as the existing charging infrastructure across the province.

First, as reviewed in Chapter 2, different types of vehicles are encompassed within the "Electric Vehicle" term. The EV types included in the framework are only the Plug-In Electric Vehicles which can be partially or fully fueled by grid electricity (Plug'n Drive and Canadian

Condominium Institute-Toronto n.d.). This includes both PHEVs and BEVs but excludes HEVs because they do not have the capacity to be plugged in and charged with electricity from the grid, and therefore do not need nor benefit from the electric charging stations.

The EV offer in Canada is quite comprehensive. There are currently 15 different models of BEVs and 26 models of PHEVs. Table 2 represents the EV sales by vehicle model in BC since 2010 (when the first EVs were sold in Canada) up until September 2017. As mentioned, BEV sales in BC exceed the PHEV sales by more than double, mainly led by the Tesla models (only available as BEVs) which account for more than 40% of the total BEV sales in the province. EV sales in BC have reached a market share of 1.5% as of September 2017, a percentage that has been rising steadily from under 0.5% in 2013, and that is higher than the national average of 0.8% (R.L. Polk & Company and Stevens 2017).

Table 2. BEV and PHEV sales in BC from 2010 to September 2017 and their electric driving range

EV Brand	Sales in BC (#)	Average range on electric (km)
BEVs	*5,246*	
Tesla S, X and Roadster	2,170	375 – 580
Nissan Leaf	1,623	172
Kia Soul	397	150
Smart Fortwo	231	112
Chevrolet Bolt	200	383
BMW i3	167	183
Ford Focus	139	185
Mitsubishi i-MiEV	135	100
Hyundai Ioniq	78	170
Other models	106	-
PHEVs	*2,523*	
Chevrolet Volt	996	85
BMW I3, I8, X5, 330, 530	579	22 – 46
Volvo XC90	184	22
Audi A3	171	26
Porsche Cayenne	170	22
Ford C-Max	131	32
Toyota Prius	74	40
Ford Fusion	73	34
Others	145	-

Regarding charging levels, there are three levels of EV charging: Level 1 (Opportunity), Level 2 (Primary) and Level 3 (Fast). There are also two types of charging infrastructure, public and private. Public charging infrastructure includes the charging stations that are available for use to the general public and are publicly accessible. Public infrastructure is useful for EV owners that need additional charging during the day or that don’t have access to overnight charging at home. As EV sales increase, so does the network of charging stations. There are currently around 1,000 public charging stations in BC, most them being Level 2.

Private charging infrastructure refers to the charging stations located on private property and not available for use of the general public. Private charging stations are usually located on home or office premises and can only be used by the station owners (in the case of households) or other authorized personnel (such as office employees). As reviewed in Chapter 2, private charging infrastructure is usually Level 1 or Level 2, since Level 3 works on DC and is not currently considered viable and safe for installation within residential buildings. The decision between Level 1 and Level 2 installation depends on several factors, among them the user's charging needs and daily driving range, the EV model they own, the cost they are willing to invest for charging infrastructure, as well as the desired location and existing electrical system where the charging station will be installed.

4.1.1.2 Existing MURBs

The second dimension is the existing Multi-Unit Residential Buildings or MURBs. The term "existing" refers to buildings in the operation phase for which EV charging infrastructure was not installed during the construction phase. As established in Chapter 1, installing charging stations in residential buildings is a more expensive and complex task than in new constructions, hence the importance of focusing on these buildings. The relevant aspects of this dimension regarding the system being analyzed include types of MURB ownership and green MURBs in BC, and the building power distribution system. These concepts were reviewed in detail in Chapter 2 and are summarized here.

In B.C. there are mainly two types of MURB ownership: purpose-built rental buildings and strata or self-owned buildings. Depending on the type of building, the decision of installing charging stations is handled differently. In purpose-built rental buildings, tenants can request the installation of a charging station in their parking stall to the landlord or property manager and the decision relies on them. Strata buildings, on the other hand, have strata councils that can vote on the decision and the majority is achieved usually with 75% of the votes. In both cases, if the request is approved, agreements, bylaws, and rules may need to be put in place.

MURBs can also be classified as either traditional buildings or green buildings. Although green buildings are more likely to have had charging infrastructure installed during construction, this is not necessarily a rule. For instance, the LEED V4 for New Constructions (NC) standard, in its Green Vehicles credit, requires the designation of 5% of all parking spaces as preferred parking to EVs and install EVSE in an additional 2% of all parking spaces (U.S. Green Building Council 2017). However, not all building developers will pursue this credit as it is optional and not a prerequisite, and even if they did, prioritizing only 7% of parking spaces for EVs might not be sufficient in the future. Because there is no requirement to prepare the building for future infrastructure needs, LEED-certified green buildings might face similar challenges as traditional existing buildings.

The electricity produced by the electric utility—in this case, BC Hydro—is fed through a meter, into the building, and is distributed to units and other areas by the building's power distribution system. This system is composed of meters, transformers, panels, wires, and protection devices, among others. The particular characteristics of each system vary among buildings, but the current BC Building Code and other applicable City Bylaws govern the overall design, as reviewed previously.

4.1.1.3 Regulations and Policies

The third dimension is regulations and policies. From the literature review, it was observed that regulations and policies play an important role in the deployment of charging infrastructure in MURBs. The specific interactions between regulations and policies with the EV and MURBs dimensions will be explained in detail in Sections 4.1.2.2, and 4.1.2.3.

As established in Chapter 2, there are two types of regulatory instruments in BC relevant to EV and MURB regulations: codes and standards. First, legislated codes are mandatory and are developed and published by government institutions. They can be prescriptive, containing rigorous requirements and identifying methods of achievement (performance-based, stating expectations to achieve certain results) or outcome-based (which establish target levels and ways to measure and report results) (Vierra 2016). Second, standards are usually non-mandatory guidelines against which something can be measured, and they are created by national or international organizations through consensus processes among subject experts. The most widespread standards eventually become the basis for the evolution of industry norms, as they usually serve as incentives for improved performance (Vierra 2016).

In Chapter 2, policy was defined as *a course or principle of action adopted or proposed by a government, party, business, or individual* (from Oxford Dictionary). It serves as an interface between the government and the rest of society to address needs (policy demand) and incentivize certain conduct patterns (policy outcomes). In this case, policy can address the need for charging infrastructure availability within MURBs by incentivizing charging station installation and addressing the barriers that hinder this action.

Policy analysis is used for designing, implementing and evaluating policies that have been or might be adopted by an entity, generally regarding public problems. As part of the policy analysis, understanding the policy process is important to identify the stages in which it is possible to exert the greatest influence. The policy process is a sequence of activities to transform situations that need addressing (problems) into actions and measures expected to address them (policies) (Campbell and Corley 2012).

4.1.2 Intersections Between Dimensions

4.1.2.1 Intersection 1: EV Charging Infrastructure Installation in Existing MURBs

The interaction of EVs and MURBs is modeled through the installation of charging infrastructure into the building electrical system. This new concept emerged from the commercialization of EVs, and the fact that these vehicles can be charged at home using grid electricity as other appliances do. New buildings are increasingly including the installation of charging infrastructure during construction to be "EV-ready" and provide charging infrastructure to its residents. However, existing buildings don't have the same opportunity and, in turn, should make adaptations to the existing building system. Some of the limitations regarding the implications of installing EV charging infrastructure in MURBs are detailed in Section 4.3.

Regarding the characteristics of the charging infrastructure that can be installed, the levels of charging available for residential building are Levels 1 and 2. Level 3 works on DC and is not currently considered viable and safe for installation within residential buildings.

Level 1 charging can be considered sufficient for PHEVs, which have a shorter electric range (as seen in Table 2) and therefore a smaller onboard battery pack (as seen in Table 1). However, this is not the case for BEVs that rely only on their onboard battery pack to operate, which would take between 11 and 36 hours to fully charge on this charging level. In addition to this limitation, BEV adoption in BC is approximately the same as PHEV adoption (excluding Tesla BEVs that use fast-charging methods). Therefore, it is preferable to install Level 2 charging infrastructure in MURBs to accommodate the needs of both BEV and PHEV users. As reviewed previously, there is also a general preference from all EV users to achieve a full charge faster than what Level 1 can offer. As technology evolves and battery capacity improves, faster charging will be prioritized.

4.1.2.2 Intersection 2: Regulations and Policies for EVs and Charging Infrastructure

As reviewed in Chapter 2, there are standards and codes that regulate charging stations and their installation. The most relevant standard of EV charging stations in BC is the "SAE Surface Vehicle Recommended Practice J1772, SAE Electrical Vehicle Conductive Charge Coupler" standard that covers physical, electrical, communication protocol and performance requirements of EV electrical connectors.

The document that regulates EV charging stations in Canada is the Canadian Electrical Code, specifically the recently added Section 86 – Electric Vehicle Charging Systems. There is also another relevant rule within this code for new equipment installation in apartment buildings: Rule 8- 202(3)(a)(d) of this code, in its Circuit Loading and Demand Factor section. New equipment installed into an existing building creates additional electrical loads to the system. According to this rule, the load of equipment installed in a common area of an apartment building (among them, the parking lot) should be continuous, as if the equipment was operating constantly. This is a conservative approach to ensure that overloading of electrical systems does not occur and the public is protected, but unrealistic since not all vehicles will begin and end charging at the exact same time, neither will all charge stations be continuously charging a vehicle (Impey 2013). Therefore, the calculated load of the new charging stations on the electrical system will be greater than the actual load. This can lead to unnecessary and costly upgrades in the building's power distribution system, given that the parts of this system might need to be changed to allocate for the extra loads as calculated by this rule. In terms of policies, government support is key to overcome obstacles that make EVs not competitive with CVs. The three government levels (federal, provincial and municipal) express and demonstrate their support to widespread EV adoption through principles of action that materialize into public policy. These policies can be classified into financial incentives, non-financial incentives, and others (Ralston and Nigro 2011). Furthermore, these policies can be demand-focused or supply-focused, as mentioned in the Points of Departure. In short, the first seek to directly increase consumer interest in EVs, and the second aim to incentivize vehicle suppliers to improve EV efficiency and diversify the range of available EVs (Wolinetz and Axsen 2017). Table 3 lists and classifies policy examples.

Table 3. EV policy example classification

Policy	Demand-focused	Supply-focused
Financial Incentives		
EV purchase incentives	X	
Parking and tolls reduction/exemption	X	
Fees and taxes reduction/exemption	X	
Electricity charging rates reduction	X	
Public infrastructure incentives	X	
Private infrastructure incentives	X	
Research and development (R&D) funding		X
Manufacturing incentives		X
Non-Financial Incentives		
High Occupancy Vehicle (HOV) lane access	X	
Vehicle emission inspection exemption	X	
Other Initiatives		
Low carbon fuel standard		X
EV selling mandate (automakers)		X
Streamline processes	X	
Gasoline tax	X	
Information sharing and facilitation	X	
Government fleet electrification	X	

4.1.2.3 Intersection 3: Regulations and Policies for Existing MURBs

As reviewed in Chapter 2, residential buildings in BC and their electrical systems are regulated by the 2012 BC Building Code based on the 2010 National Building Code of Canada. Each municipality within BC can also develop their own bylaws that address issues outside of the scope of the BC Building Code. For example, the City of Vancouver has its own building code known as the Vancouver Building Bylaw, which is more stringent than the provincial code. As reviewed, the City of Vancouver has included a provision in their Building Bylaw to provide charging stations for 20% of the parking stalls within MURBs and to make technical considerations to reach 100% in the future. Although this ensures that new buildings in this City will be suitable for charging EVs now and in the future, it does not address existing MURBs.

In terms of green buildings, different standards, codes, and certifications and rating systems focus on mitigating the environmental impact of new and existing buildings. The most popular green building certification in Canada is LEED. Although LEED v4 for New Constructions (NC) does allocate credits to EV charging infrastructure as reviewed previously, there is no such consideration in LEED v4 for Existing Buildings Operations and Maintenance (EBOM). Therefore, there is no incentive for installing charging stations in existing buildings when pursuing a green building certification.

4.1.2.4 Intersection 4: Deployment of EV Charging Infrastructure Installation in Existing MURBs

In the center of the Venn diagram is the intersection of the three dimensions. In the first intersection, the implications of the decision to install EV charging infrastructure in existing MURBs were analyzed. In this intersection, the guiding question is: *What are the policy barriers and incentives to accelerating the installation of charging infrastructure in MURBs?* This question will be answered through the analysis tools chosen for this study. First, the potential barriers will be assessed through the Barrier Categorization Framework; second, the problem domain analysis; and third, the development and analysis of the system CLD. The problem articulation and scoping achieved through the Venn Diagram Framework also serves as the basis for the further analysis, as well as for establishing the boundaries for the CLD. Likewise, developing and analyzing the CLD can give insights that can help inform the question at the center of the Venn Diagram Framework.

4.1.3 Other Scope Considerations

As explained in Section 3.2.1, the Venn diagram is a useful tool to help define the system boundaries and establishing the problem scope. The circle's outside perimeters represent the system boundaries, and the content of circles forms the problem scope. Therefore, any concept or dimension that falls outside of the circles can be out of the scope of the research study.

Other important boundaries of the system are the spatial context, level of analysis and time frame. First, the dimensions are bounded and defined within the spatial context of the province of British Columbia. As mentioned in Chapter 1, this province has favorable conditions for EV adoption and a relevant percentage of the population living in MURBs. Also, due to the scale and specificity of the issue, it is most likely to be addressed by municipalities with support from the provincial government.

Second, the chosen level of analysis for the system is the building level. This level encompasses all the implications of installing charging infrastructure in any given MURB around the province and it is, therefore, more appropriate than municipal or provincial levels of analysis which focus on home charging infrastructure availability at a larger scale.

Third, the issue of installing charging infrastructure in residential buildings is of present concern, and this will continue in the future as EV adoption across the province grows. The exact time frame will depend on factors such as EV market share, provincial targets, average life, and retrofit rate of existing MURBs, availability of other private and public charging infrastructure, etc.; but it is possible to estimate that the order of magnitude of this timescale will be decades.

4.2 Barrier Categorization

The second research activity of the research methodology is to identify and categorize the potential barriers to installing EV charging infrastructure in MURBs. To achieve this, a framework based on Browne, O'Mahony, and Caulfield (2012) was developed (explained in Section 3.2.2).

The comprehensive set of categories assist in the identification and organization of the potential barriers. Both the literature review in Chapter 2 and the information from the Venn Diagram in Section 4.2 served as the basis for the barrier formalization process. As per the Barrier Categorization Framework, the potential barriers were classified into six categories: financial, technical, institutional/administrative, public acceptability, legal/regulatory, and physical.

The characteristics of these potential barriers, as well as the types of policies that could be used to solve them, were also analyzed. The analysis is focused on evaluating characteristics of the barriers (timeline), prioritizing their importance (significance), as well as proposing potential policy actions, their scale and the relevant group that could implement them (level of implementation, type of policy measure and developer).

This information was organized into a table (Table 4) to provide a comprehensive visualization of the barriers assessment.

Table 4. Categorization of barriers to EV charging infrastructure deployment in existing MURBs

Potential barriers	Timeline	Significance	Type of policy measure	Level of implementation	Policy developer
Financial					
Cost of charging infrastructure and installation	Medium-term	Medium	Financial/Fiscal	National	Government/Industry
Cost of building system upgrades	Long-term	High	Financial	Provincial	Government
Technical					
Building system limitations	Long-term	High	N/A	Local	N/A
Institutional and Administrative					
Governance issues	Short-term	Low	Education and awareness/Regulatory	Local	Government/Associations
Public acceptability					
Liability issues associated with EV installation	Short-term	Low	Technical/Regulatory	National	Government/Industry
Lack of support from non-users	Medium-term	Medium	Education and awareness/Financial	Local	Government/Associations
Limited understanding of new technology	Medium-term	Low	Education and awareness	Local	Government/Associations
Legal or Regulatory					
Lack of regulation of rights and obligations of stakeholders	Medium-term	Medium	Regulatory	Provincial	Government/Associations
Limited technical guidance	Short-term	Low	Regulatory/Education and awareness	Local	Associations
Conservative regulatory requirements	Medium-term	Medium	Regulatory/Technical	National	Government/Industry
Planning permission for charging points	Short-term	Low	Regulatory	Local	Government
Physical					
Spatial building constraints	Long-term	Medium	N/A	Local	N/A
Lack of parking within MURB	Medium-term	Low	N/A	Local	Government

According to the timeline and significance criteria, all the barriers that were identified as short-term barriers were also judged to be of low significance. These are: 1) the governance issues that arise from charging infrastructure procurement and installation; 2) potential liability issues associated with EV installation; 3) limited technical guidance throughout the process, and 4) planning permission for charging infrastructure installation.

The medium-term barriers with the most significance (medium) include: 1) the cost of charging infrastructure and installation as an additional investment for users; 2) the lack of support from non-users, especially relevant within strata corporations; 3) the lack of regulation of rights and obligations of users, strata corporations and landlords; and 4) the conservative regulatory requirements, especially referring to the contingency in the Canadian Electrical Code. Other medium-term barriers with less significance are the limited understanding of the new EV charging technology and the lack of parking available for all the residents within their MURB (off-street parking).

The long-term barriers identified are considered of high and medium significance, and although they belong to different categories, they all refer to the implications of accommodating the additional loads and the EVSE in the existing building power distribution system. These barriers are 1) the actual building power distribution system limitations; 2) the cost of the building power distribution system upgrades needed due to the limitations, and 3) the spatial building constraints.

The table also illustrated that the most significant barriers are related to the financial and technical categories. Most of the other categories have a combination of medium and low significance barriers.

The level of implementation is predominantly local, which means that municipal governments can take relevant actions through policy and successfully address most of the barriers. The cost of building power distribution system upgrades is of high importance and it is likely that policies will come from the provincial government level (due to the economic scale of a potential financial incentive). While the government is the most likely to take action, associations can also play an important role in addressing these barriers, especially with regulatory, education and awareness policies that do not require a large financial investment.

The financial barriers naturally require financial and fiscal policies, but most barriers can be addressed through regulatory policies, which, as mentioned, do not necessarily require large investments, unlike the financial or tax incentives.

4.3 Problem Domain Analysis

Based on the literature review from Chapter 2, as well as the system scope definition and potential barrier categorization from Sections 4.1 and 4.2 (respectively), the system was broken down into four main problem domains. A problem domain can be understood as the areas that need examining to solve the problem. In this case, these domains are the main aspects that can impact the potential for charging infrastructure availability in MURBs for residents that require it. The four domains are: charging infrastructure installation, building limitations, governance issues and parking availability within MURBs.

The analysis of these four main domains includes identifying and analyzing the following elements for each one:

- Decision-making stakeholder(s): refers to the relevant stakeholders involved in making the decisions to create a solution strategy in each particular problem domain.

- Decision criteria: the independent factors that the decision-making stakeholder takes into consideration to create a solution strategy.
- External factors: the outside influences that impact the solution strategy as well as the outcome implications.
- Solution strategy: the result of the decisions made about a specific problem domain. It can be formalized in writing or informally agreed upon by the relevant stakeholders.
- Implications: the effect that the solution strategy determined by the stakeholders will have on certain dependent factors.

The following sub-sections include the definition and analysis of the domains, as well as the decision-making diagrams. In the diagrams, the stakeholders determine the decision criteria and observe the external factors; the decision criteria dictate the solution strategy, which is also impacted by the external factors; and the solution strategy has implications that can bring further consequences.

4.3.1 Charging Infrastructure Installation

The first problem domain is the actual installation of the charging infrastructure. The idea or desire of installing the EV charging infrastructure in a MURB can usually come from building residents who are current or potential EV owners and/or from the building owners. In the case of self-owned/strata buildings, the interested residents and the strata council will usually be involved in the installation decisions. The strata council acts like the building owner since it represents the interests of the unit owners, and all major decisions are voted on by the unit owners as well. In the case of the purpose-built rental buildings, most decisions will be made by the building owner, especially if the charging stations will be fixed to the building's electrical system.

The stakeholders can then decide on the number of charging stations they are going to install, the level of charging of each station, and the EVSE model. First, the number of charging stations is determined by the number of residents interested in having access to charging infrastructure, as well as by the number of additional charging stations that the building owner wishes to install to allocate for future demand or for other purposes, such as visitor parking. Second, the level of charging will also be determined by the interested residents according to their charging needs, and it can be either Level 1 or Level 2 charging, or a combination of both. Third, the EVSE model can be chosen as a function of their location, and it should also be decided whether the EVSE will be fixed or portable. These factors might also be determined as a function of the available funds—both from the EV owners and from the building owner—to pay for this investment. This set of decisions will form the charging infrastructure investment plan.

The external factors that need to be considered when creating this plan are the building characteristics and the regulatory demands since both can have an impact on the investment. The building characteristics refer to factors such as the station's proximity to owner's unit, the potential for water damage or interference with maintenance tasks, and required ventilation and rewiring for installation. The regulatory demands refer to the requirements that need to be made to comply with the current regulations.

The total investment refers to the EVSE and installation costs and it will be determined by the charging infrastructure investment plan. In some cases, the investment will be covered partially or totally by the current or potential EV owners. This represents an extra expense that they must consider as part of the total EV investment (in addition to the already more expensive EV compared to a CV). On the other hand, CV buyers do not have to allocate an extra budget for additional fueling infrastructure costs because numerous gas stations already exist across the province.

The underlying cause of additional charging infrastructure costs for EV buyers is that, even though EVs have been sold for several years in Canada, they are still considered a new technology due to their low market share. EV buyers, as early adopters, face challenges that make EVs economically accessible to only a limited sector of the population. MURBs are still not normally equipped with charging stations for overnight charging. The lack of available public or private charging infrastructure means that EV owners need to self-provide charging stations to be able to use their vehicles. Inevitably, the additional investment for charging infrastructure can act as a disincentive to potential EV buyers and owners, who can decide against the technology, at least until charging is available in their MURBs or publicly accessible and convenient. Solving these issues can also make ground for an equal comparison between CVs and EVs, and therefore wider EV purchase consideration of the mainstream market and not just early adopters.

Figure 7 illustrates the analysis of the charging infrastructure installation problem domain.

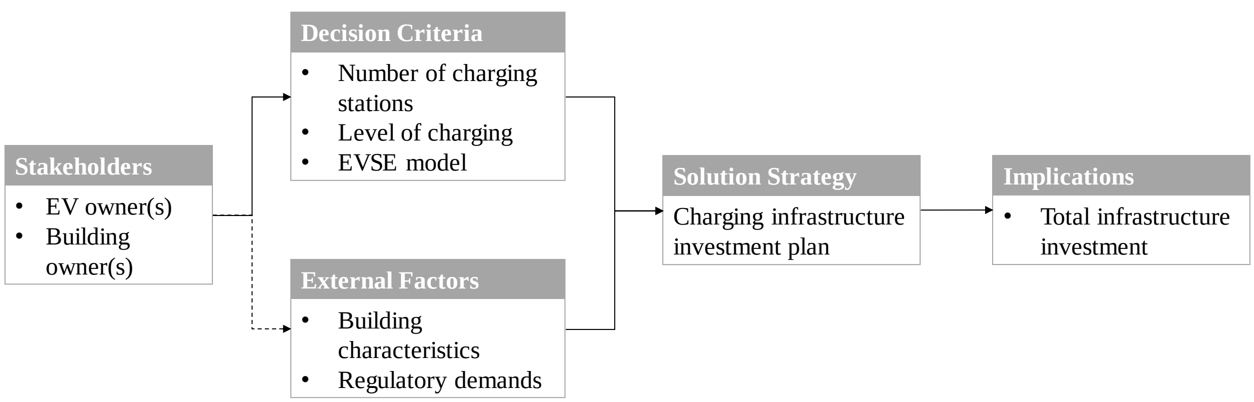

Figure 7. Diagram of the charging infrastructure installation domain

4.3.2 Building Limitations

The second problem domain is the building physical and technical limitations. When implementing the charging infrastructure investment plan, the building electrical systems might present some limitations according to its characteristics. These characteristics include the power-distribution-system-base-demand load, which refers to the degree to which this system is loaded before any new EV loads are added; its configuration in terms of wiring, location (including the available space on the electrical room), and metering configurations; and service type or system voltage (which can be 120V or 240V).

The building's power distribution system is a series of electrical-energy-carrying components that transmit electrical energy in a safe and efficient manner to its point of end use. The building's power distribution system limitations exist when the loads of charging EVs were not included in the design of the building distribution system and, therefore, adding them results in exceeding the system's capacity. The service type can also create limitations if it is not compatible with that of the EVSEs (i.e. 240 V outlets needed for Level 2 charging). Also, additional individual meters might be needed in the parking lot to individually measure and charge the electricity use to each end user. If a building's electrical system is not able to support the additional EV charging loads, connections or voltage, then a system upgrade is needed. The configuration, capacities, and baseload are different for each building and should be evaluated on a case-by-case basis.

The reason why a building distribution system can present limitations is that charging stations were not part of the initial scope of a building project, therefore their loads and location were not considered in the system's design. EVs have only recently been introduced to the mainstream market, therefore building regulations and bylaws did not require allocating for charging stations in buildings' electrical design.

The other factors that should be observed are the regulatory demands, which refer to the requirements that need to be made to comply with the current regulations. This is especially relevant in this domain because, as mentioned in Section 4.1.2.2, some current regulatory demands are conservative, which can lead to an increase in the upgrade project scope, and this should be considered at the early planning stages of the building retrofit investment plan.

The charging infrastructure investment plan, in addition to the reviewed external factors, will shape the building retrofit investment plan, which will, in turn, determine the total retrofit investment and the retrofit project size. As with the charging infrastructure investment, the funds to cover the plan cost can be funded by the building owner, the EV owners, or both. In this case, it would make more sense if it was funded by the building owner, since the benefits of the retrofit will remain on the building, even if the EV owner decides to move or sell their unit. In strata buildings, however, this would mean that retrofit will be funded by the strata budget, which is in turn funded by all the strata members (or unit owners). Strata members that are not EV owners might not agree to spend the strata budget on retrofits required to install charging stations that they are not interested in and that only a few residents will benefit from.

In addition, the cost of upgrading the building's electrical system is usually not marginal and can be out of the investment scope for individual EV owners, even if the cost is to be divided among all the interested residents. The retrofit investment depends on the kind of upgrade to be done and the amount of labor, equipment, and material that requires. Simple additions such as installing outlets on certain parking stalls might not have high costs associated with them, although rewiring can be considered a disruptive activity for building residents. More complex projects that involve upgrading the building's electric panel(s), the switchgear and/or the transformer can be very costly and disruptive, and require the project to be designed, executed and supervised by an experienced electrical contractor.

For example, installing 8 level 2 chargers in an 18-storey condominium tower located in Vancouver, BC requires upgrading three of the building's power distribution system components: a breaker, the parking lot panel, and its feeder, which costs approximately CDN$10,000. Additionally, installing the charging stations requires 8 individual level 2 circuits, which costs CDN$9,600. The level 2 EVSEs (the actual charging equipment) cost an average of CDN$1,300 each, for a total cost of approximately CDN$10,400 (Impey 2013). The total cost comes to CDN$30,000. From this example, the upgrades account for one-third of the total cost, the installation for approximately another third, and the actual charging station for approximately the final third.

In addition to the total retrofit investment, the other implication is the retrofit project scope. The scope of the project will determine the level of attention, management, and expertise that will be required, and the building owners should also account for that. Outsourcing the project management can also add up to the total retrofit investment.

Figure 8 illustrates the analysis of the building limitations problem domain.

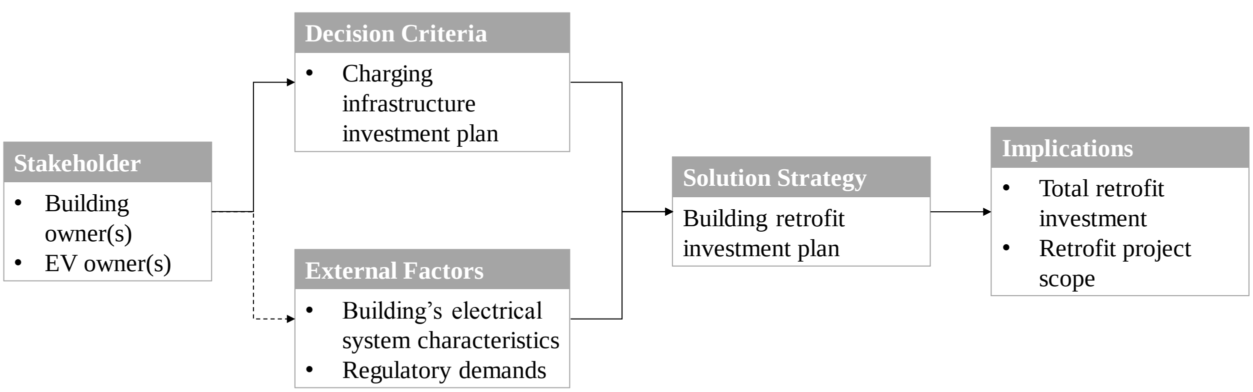

Figure 8. Diagram of the building limitations domain

4.3.3 Governance Issues

The third problem domain is governance issues, and it is most relevant to strata building ownership. The decision of installing charging stations is handled differently depending on the building type. In purpose-built rental buildings, tenants can request the installation of a charging station in their parking stall by the landlord or property manager, and the decision rests entirely with the landlord. The costs of installation should also be covered by the landlord, who will keep the EVSE and the benefit of the upgrades once the tenant moves out. Strata buildings, on the other hand, have a more complex structure and decision-making processes.

Installing charging infrastructure in residential buildings is a new trend, therefore the implications are not well understood by building owners (i.e. strata corporation). MURBs that consider the implementation of EV charging put their decision makers in the position of needing to understand emerging vehicle technology in the context of their building electrical design constraints plus any existing governance issues. Given the varying level of technical knowledge and the fact that the strata budget must be spent in common areas for installation, there can be confusion and hesitancy on the part of the MURB decision makers in deciding when, and to what degree, to act on requests for EV charging in their buildings. The local government is also identified as a stakeholder because it can inform and make recommendations on governance issues.

The governance decision criteria consist of infrastructure and retrofit investment allocation, EVSE ownership, energy costs responsibility and management, and security considerations. As discussed, the infrastructure and retrofit investment allocations determine who should pay for the infrastructure and the building retrofit, which is either the building owner, the EV user(s), or divided between both. This will have an impact on the decision to pursue the installation or not, according to the investment the stakeholders are willing to make. Once it’s determined who will pay for the infrastructure, it is easier to determine their ownership and the details of what would happen should the EV owner leave the residence.

The energy cost allocation should also be discussed and whether it is feasible to install individual meters on the EVSEs to bill each unit separately. If it is not feasible, the energy use can be estimated or calculated by the EV owner or another involved party, but this energy management plan should be discussed as well. Regarding the security considerations, the main ones have to do with lighting, insurance, liability and vandalism concerns. It is also not clear who should address these potential issues and the procedure that should be followed in case an issue regarding these considerations occurs.

The governance policies are the result of how the strata council or landlord deals with these issues and the solutions they give to each one of them. There might also be additional issues in a particular MURB that might not have been included here, and these issues might not be applicable to all MURBs.

It is expected that knowledge is imperfect or incomplete among mainstream EV buyers, even years after their introduction to the market. When it comes to charging installation, this lack of knowledge can also act as a disincentive. Giving each individual strata corporation the freedom to establish their governance policies on a topic that they might not have the sufficient knowledge and experience about could result in future issues among residents, especially if this is done without a long-term charging infrastructure deployment plan. Although local government agencies can inform and make recommendations on governance issues, the lack of regulations and guidelines for charging infrastructure installation in MURBs leaves EV owners without any alternatives to install charging infrastructure if their strata council refuses to allow it. There should be more clarity on the policies and procedures that should be followed by strata councils when faced with the task of adding charging infrastructure to their MURBs.

Figure 9 illustrates the analysis of the governance issues problem domain.

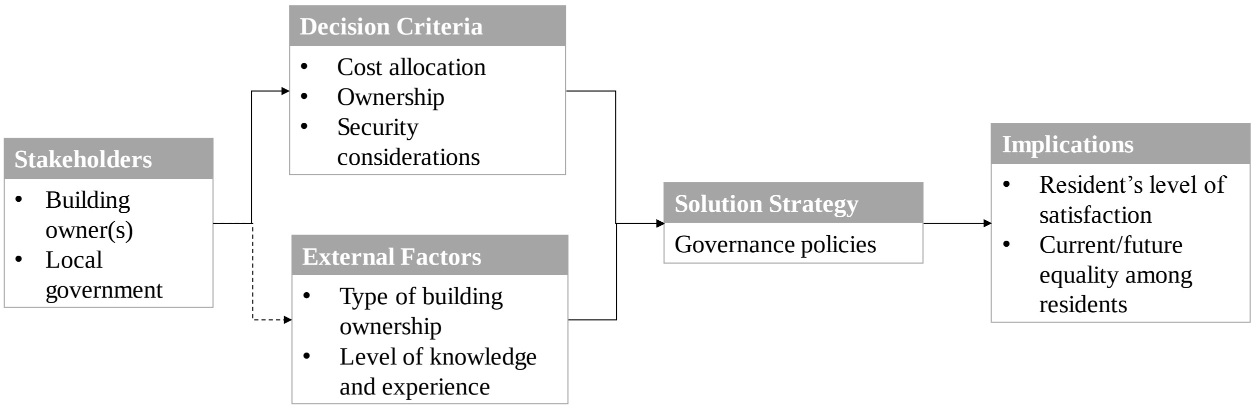

Figure 9. Diagram of governance issues domain

4.3.4 Parking Availability Within MURBs

The fourth problem dimension is the parking availability within MURBs. As stated previously, the majority of EV adopters and potential adopters have expressed interest in the convenience of having access to overnight home charging. Having access to home charging infrastructure is most likely to happen where there is also access to a home private parking lot. Although it is common for MURB residents to have access to off-street parking within their building, not all residents have this privilege.

Building developers, when planning and constructing each building, decide on the type of parking lot it will have, whether it is underground or on ground level, covered or uncovered, and other criteria. The number of parking stalls provided in MURBs can also be determined by the building developer. However, there are minimum parking requirements established by municipal bylaws and provincial codes, as well as parking limitations suggested by the green building rating system used (if any). The rating system can also be chosen by the building developer, or it could also be dictated by city bylaws where green certification is mandatory for new buildings.

First, the level of government that determines parking provisions in BC is the municipal authorities and (while it varies between municipalities) they are not likely to require the provision of parking stalls for 100% of MURB residents.

Second, LEED is the most popular certification of green buildings in Canada and the province, and even some cities are moving towards making a certain level of LEED certification mandatory (e.g. LEED Gold in City of Vancouver) (U.S. Green Building Council, World Green Building Council, and C40 Cities 2015). LEED V4 for New Constructions (NC) standard, through the Reduced Parking Footprint credit, suggests reducing the building's parking footprint by not exceeding the minimum local code requirements for parking capacity, with the intent of minimizing environmental harms associated with parking facilities, including automobile dependence. Limiting and reducing the amount of available parking space within the MURB might be counterproductive because it limits the possibility of overnight charging availability for residents without access to off-street parking, which will gain relevance as the EV market share increases.

The type of building ownership is also an external factor that can influence the parking allocations since it is more likely that high-end apartments for sale will include parking within the building for all their residents, while economic purpose-rental units might not.

All these criteria and factors form the MURB parking plan, which is usually determined in the planning phase of the building project. This plan has implications for the parking arrangements for the building residents and therefore influence the availability of charging infrastructure within the MURB. The lack of parking stalls in MURBs means that some residents would not be able to have access to home charging infrastructure. This could act as a disincentive for adopters or potential adopters as it, in turn, means that they should make other provisions to charge their vehicles. If providing all EV owners or potential buyers with a parking space within the MURB is not viable, then other charging options must be convenient and inexpensive if they are to be considered as real alternatives.

Figure 10 illustrates the analysis of the parking availability within MURBs problem domain.

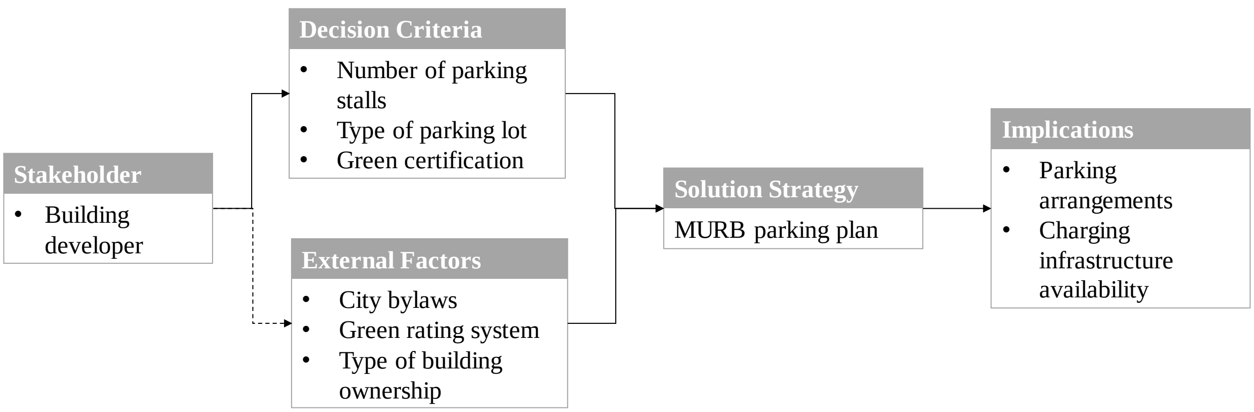

Figure 10. Diagram of the parking availability within MURBs domain

4.4 System Interdependencies Mapping

The third activity in the research methodology is mapping the system using the Causal Loop Diagram (CLD) method, outlined in Section 3.3. The diagram is based on the concepts outlined in the literature review (Chapter 2), as well as in the problem and scope definition and the barrier analysis conducted previously (Sections 4.2 and 4.3). To build the CLD, all the information, analyses and assessments come together to form the network of the system. This network is a set of entities connected to each other using causal links and forming feedback loops. The software used to build the CLD was Vensim PLE 7.1 (Student Version). The complete CLD is shown in Figure 11.

The following sections explain the CLD in terms of the feedback loops that were identified (which were four) and the interdependency and causality between entities. The loops were numbered and identified based on whether they are balancing or reinforcing loops.

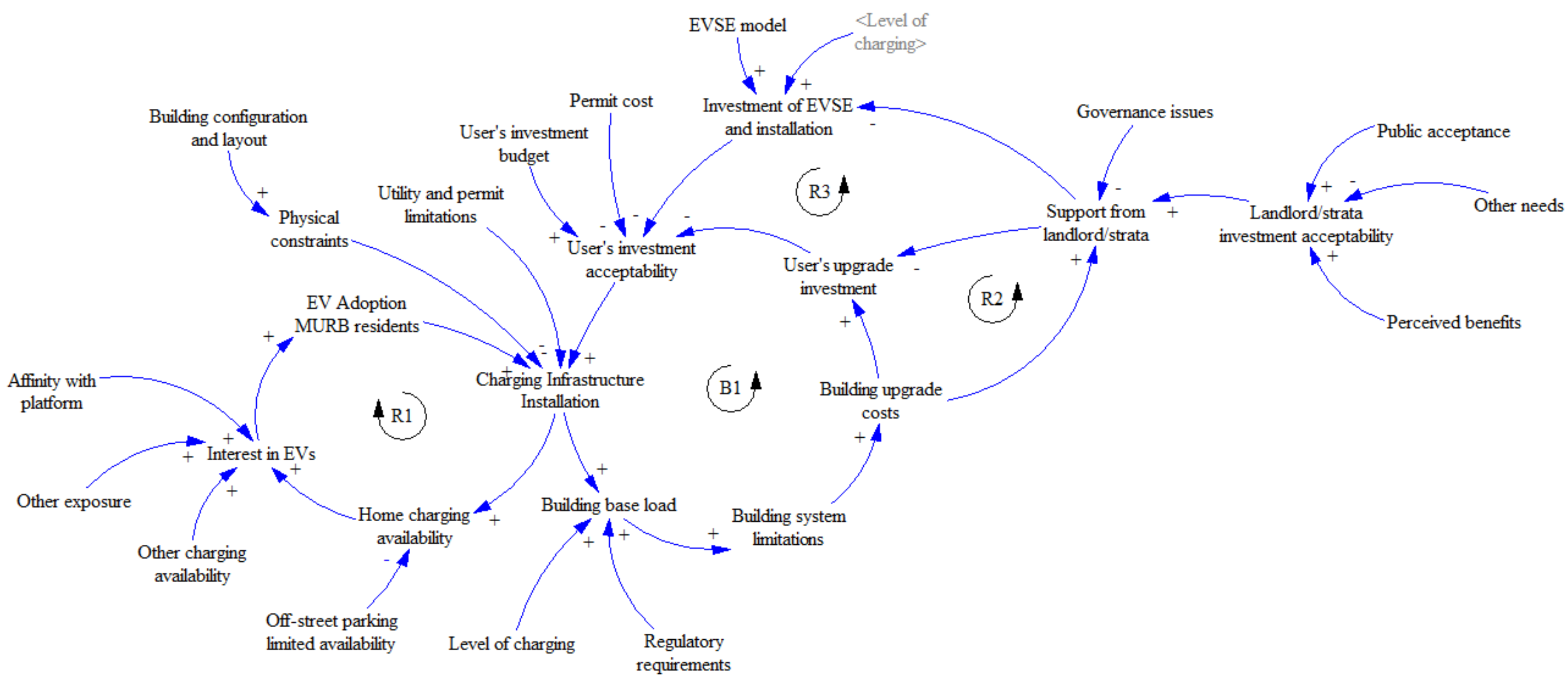

Figure 11. CLD of the system

4.4.1 Loop R1: Infrastructure and EV Adoption

The first reinforcing loop (Figure 12) describes the positive tendency of EV adoption and infrastructure installation in MURBs. The analysis starts with the entity of charging infrastructure installation.

If the charging infrastructure in MURBs increases, the home charging availability increases as well. This, in addition to numerous other factors, increases the interest in EVs and the public willingness to consider EVs. Examples of other factors included in the model are: 1) other public and private charging availability; 2) other types of exposure to EVs, such as marketing campaigns and word of mouth from other users and non-users (Struben and Sterman 2008); and 3) perceived affinity with the EV platform (Struben and Sterman 2008); among others. The interest in EVs drives up the EV adoption among MURB residents. The MURB residents that now own an EV will most likely be interested in installing charging infrastructure to be able to charge their EVs at home, therefore increasing the charging infrastructure installation and, thus, closing the reinforcing loop. All the causal links in this loop have a positive polarity. The home charging availability depends on the amount of charging infrastructure installed within the MURB (as mentioned previously), but also on the off-street parking availability of the building. If a number of residents do not have access to parking spaces within the MURB or in its close proximity, they would not have access to home charging, which can reduce their interest in EVs.

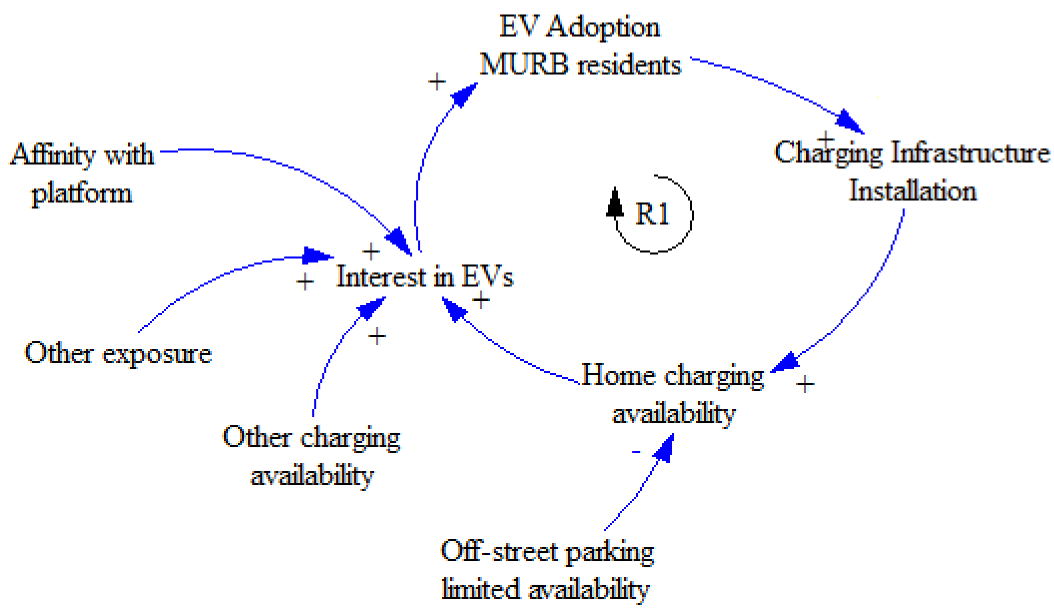

Figure 12. Loop R1 from the CLD

4.4.2 Loop B1: Building Limitation Implications

The first and only balancing loop describes the negative effects of the building's power distribution system limitations, as well as the financial implications of these. Figure 13 shows the elements that form this loop.

Charging station unit cost will almost always go down with higher quantity because of economies of scale. The main exception is when larger quantities change the work into a different class of work. This is the case for infrastructure installation in existing MURBs, and it is represented by this loop. The addition of a relatively small amount of charging infrastructure can be done with few, if any, upgrades to the building distribution system, but the more infrastructure installed, the greater the changes needed to the building's distribution system, causing the unit cost of charging infrastructure to increase.

Charging infrastructure installation in existing buildings is more likely to be done in steps, meaning that only a number of charging stations will be installed simultaneously (or even one by one), rather than adding EVSEs to all the parking stalls within the MURB at the same time. As the demand keeps growing, more charging stations will be gradually installed (Impey 2013). With each installation step (i.e. with each new EVSE added), the building baseload increases, which means more components will require upgrades to allow for more EVSEs to be installed without overloading the building's electrical system. Therefore, the more numerous and larger the charging stations are, the more frequent and expensive the changes to the building power system needed to accommodate them will be.

The variables in the loop and their interactions are explained as follows. As with loop R1, the analysis starts with the entity of charging infrastructure installation. If a number of charging stations are installed within the MURB, the building baseload will increase because installing charging infrastructure loads the building power distribution system even further. The building baseload increment not only depends on the number of charging stations installed, but also depends on the level of charging of these stations, and the regulatory requirements that establish how to allocate the new loads in the existing power system. The higher the level of charging and the code stringency, the higher the building baseload will be (positive polarity).

Increasing the building base loads increases the building system limitations as well. This limitation refers to the available capacity in each of the building's carrying components of the power distribution system. If the amount of carrying components that need upgrade increases, the building upgrade costs also increases and so does the user's upgrade investment. This last entity has other causal links that will be analyzed as part of other feedback loops within the next sub-sections.

The next entity is the user's investment acceptability, which can be calculated as the difference between the user's investments needed to upgrade the building system, and their investment budget. Therefore, if the needed investment increases, the user's investment acceptability decreases. This investment acceptability also depends on the cost of the permits to install the charging infrastructure and the investment needed for the EVSE and its proper installation.

So, if the upgrade investment increases, the investment acceptability decreases. Although the investment acceptability decreases, if it is still within the range that the user is willing to pay, then the charging infrastructure is likely to be installed anyway. However, this acceptability has a limit, and as the upgrade costs keep increasing, they will reach a point where the needed investment is no longer acceptable, therefore the installation of new charging infrastructure will stop. This entity would not decrease because that would mean charging stations are being removed from the building, but it simply means that it would not keep increasing.

All the causal links in this loop have a positive polarity, except the link that joins user's upgrade investment with user's investment acceptability. This negative polarity turns the loop into a balancing loop.

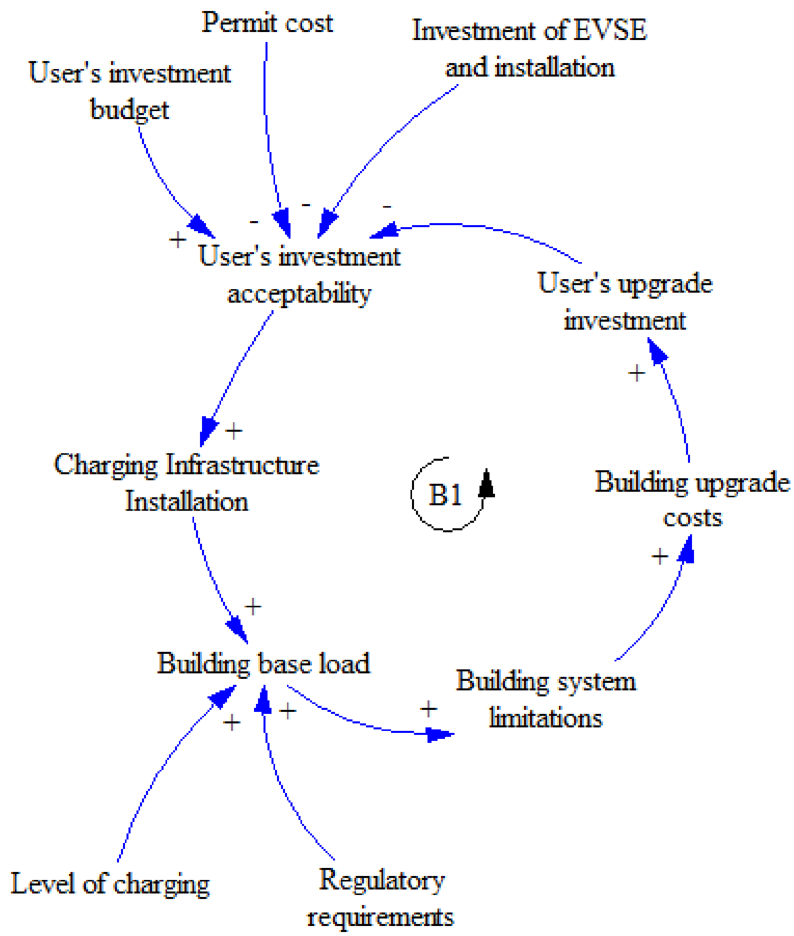

Figure 13. Loop B1 from the CLD

4.4.3 Interaction Between Loops R1 and B1

Loops R1 and B1 are connected by the charging infrastructure installation entity (see Figure 14). On one hand, the reinforcing loop drives the EV market adoption up, which therefore increases the amount of charging infrastructure so that all users can charge their EVs at home overnight. The increase in home charging availability, in turn, drives the interest of more residents to adopt EVs as they see that it is now feasible for them to install a charging station at their parking stall, as their neighbors did.

On the other hand, as the interest from more building residents increases and more charging stations get installed, the building will face more and more limitations of the power distribution system. This drives the upgrade costs up, and the investment needed for every new installation increases. The investment needed will eventually become unacceptable and the installation of new charging stations will stop. This is where the system will reach its limit, even if there is still a percentage of parking stalls without charging stations available.

The limit, in this case, was forced by the building limitations, which means a portion of the interested residents might not have access to overnight charging at home, as their neighbors do. This can create an unfair situation among building residents. The ideal situation would be for the system to reach its limit by means of saturation, in other words, that 100% of the parking stalls become EV ready, or that all the residents interested in having access to overnight home charging do.

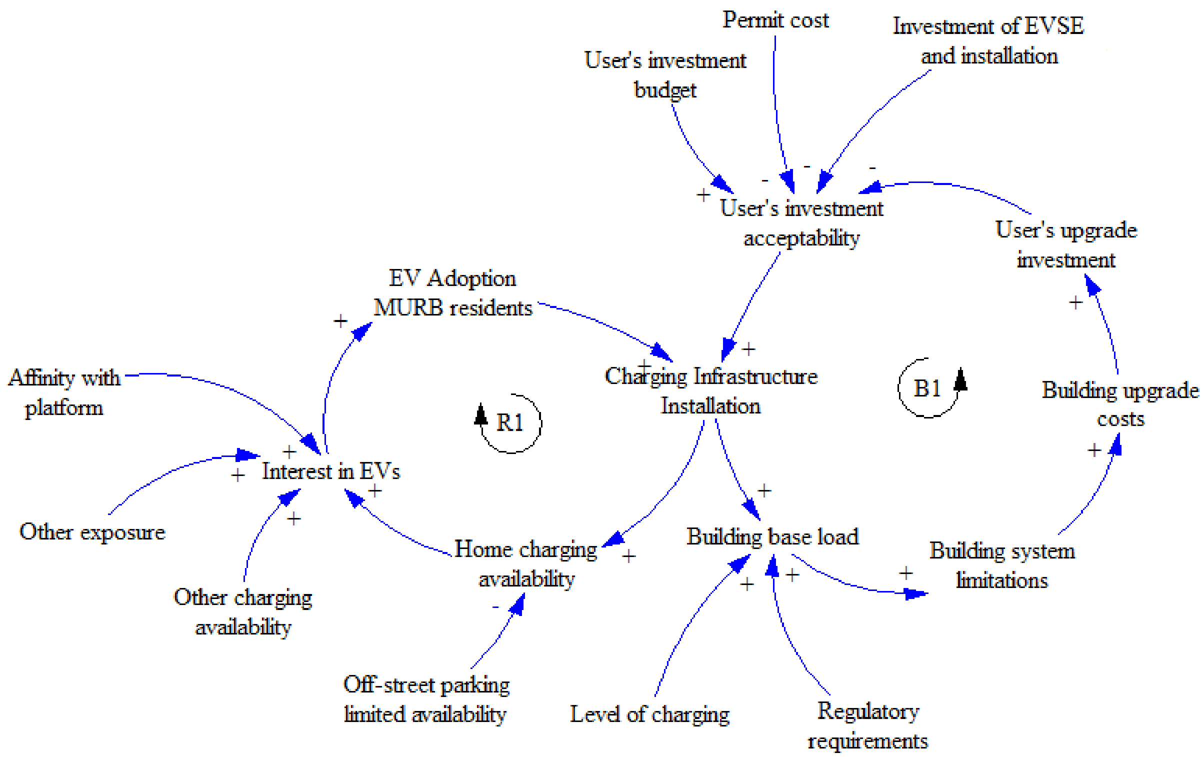

Figure 14. Loops R1 and B1 from the CLD

4.4.4 Loops R2 and R3: Financial Support from Building Owners

The second and third reinforcing loops (Figure 15) refer to the support that the building owner(s), landlord or strata council can provide to the user by partially or fully paying for the building upgrade costs and/or the EVSE and installation costs. In both purpose-built rental and strata corporation buildings, the landlord or strata council might agree to pay for the upgrades and the charging station since the benefits from these investments remain with the building, even if the current tenant moves or the apartment owner sell their unit.

The analysis starts with the entity of support from landlord/strata. In this case, the more the financial support from the landlord or strata, for both the building upgrades and the cost of the EVSE and installation, the less the user must invest from their own funds. The decrease in user investment increases their investment acceptability, which in turn leads them to install a charging station in their parking stalls. As mentioned previously, the installation of new charging stations increases the building base load, which in turn increases the upgrade costs. An increase in the upgrade costs also means an increase in the financial support that the strata will have to give to the users to maintain the same user investment acceptability. In other words, the fact that the landlord or strata provide support to install charging infrastructure will generate the need for higher support as the number of charging stations within the MURB keeps increasing. This illustrates that an expense that the landlord or strata council thought to be a one-time support can eventually turn into a repeating and increasing pattern of financial support that they were not anticipating.

The support that the landlord or strata are willing and able to provide depends on two factors: the landlord or strata investment acceptability and governance issues. A high investment acceptability increases the support, but a high number of governance issues can decrease it. This is because, if the strata find that the installation will cause numerous governance issues, it might influence their decision to not install or give permission to install charging infrastructure within the MURBs. The landlord/strata investment acceptability increases if the public acceptance and perceived benefits of installing charging stations increase, but it decreases with any other financial needs that the building might have that are perceived as a higher priority, such as building maintenance, administrative and insurance costs, etc.

Finally, the landlord or strata might agree to also finance or pay for the EVSE and installation. The cost depends on the EVSE model and the level of charging. The higher the level of charging and the sophistication of the EVSE model, the more investment they require to get installed. Also, in the case that landlord/strata support is provided, they might require that the

EVSE be fixed so that it can remain building property if the user decides to move to another residence.

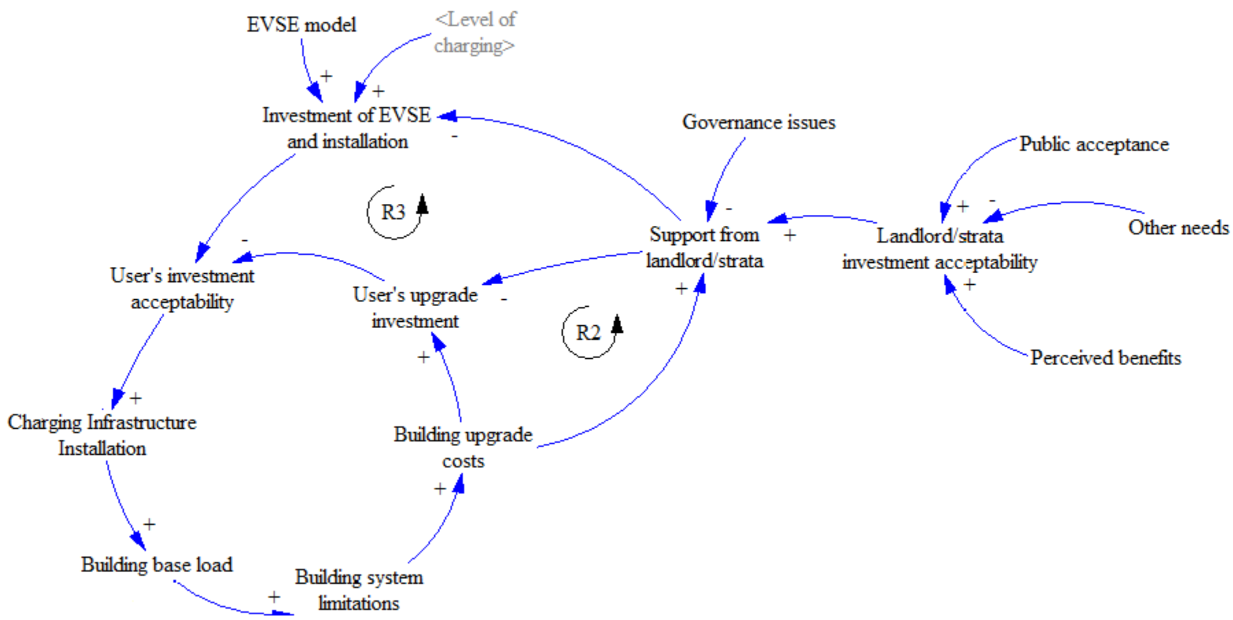

Figure 15. Loops R2 and R3 from the CLD

4.4.5 Other Influencing Factors

It has been established that the charging infrastructure installation in MURBs is driven by EV adoption among MURB residents (from loop R1), as well as the user's acceptance range of the investment they would need to put in (if any) to install a new charging station (from loop B1). There are two other factors that influence this decision: potential utility and permit limitations and other building physical constraints. The first one refers to any obstacles that the user runs into regarding permit requirements from the utility or the municipality. These obstacles might complicate the process and therefore the user might decide against pursuing it.

The second one refers to the physical and spatial constraints that a building might present because of the configuration and layout of the systems and areas in the building. Situations that could increase physical constraints could be the location of the parking stalls or their distance to the main electrical room, for example. If the complexity of the building configuration increases, the physical constraints increase as well, and this decreases the charging infrastructure installation. These constraints are independent of the other technical constraints, as these cannot be easily solved with a building upgrade and would represent a fundamental change in the building configuration.

4.5 Policy Recommendations

The analysis conducted on the previous research activities brought light to a number of potential issues and barriers regarding the installation of charging infrastructure for EVs in existing MURBs, as well as the main stakeholders, decision-making factors, and causal relations between all these elements. Having all this as a basis, a number recommendations can be made regarding policies and actions that could be implemented to overcome or mitigate the barriers and their impacts.

The recommendations are categorized by type of policy measure according to the barrier classification explained in Section 3.2.2 and defined in terms of the obstacles or issues they can potentially solve and the type of policy measure, along with examples of possible policy actions.

4.5.1 Financial and Fiscal Policy Measures

Financial barriers and implications have a high importance in the system. Financial barriers mainly refer to the additional investment that EV users or other stakeholders (strata councils or landlords) must pay to cover the costs of purchasing EVSEs and installing them, as well as upgrading the building's power distribution system in case the system capacity is surpassed by the new charging stations. As seen on the CLD, these barriers directly influence the decision of whether to pursue the installation or not, which in turn can have repercussions on the decision to acquire an EV over a CV. Naturally, the type of policy measure that is most compatible with financial barriers is fiscal and financial instruments, such as subsidies, cash rebates, capital grants, tax incentives, discounted loans (Browne, O'Mahony, and Caulfield 2012).

In this case, a cash rebate or discounted loan from the government is the logical response to help EV users cover the costs of the EVSE and its installation. A policy measure like this was actually implemented in BC in 2013, and then again in 2017, through the "Multi-Unit Residential Building Charging Program", where MURB residents could apply to receive a rebate of 75% of the total cost of acquisition and installation of one Level 2 charging station (PlugIn BC 2017).

Although this incentive helps EV users with part of the necessary investment, the other part (building upgrades) can be even more costly in some cases, which means the rebate offered might not be sufficiently attractive to potential EV adopters. For this reason, governments should consider extending the rebate, incentive or loan to also cover a percentage of the upgrade costs needed for the installation.

Another important aspect to consider is the beneficiary of said financial aid. As mentioned, the installation of charging infrastructure in MURBs usually happens gradually in steps, either one by one as the users request them, grouping several requests and installing a few stations at the same time, or anticipating future needs and installing a few stations even if only one station is required. Installing only one charging station at a time increases the cost per station, given that each new station is a new project while installing several stations at once will likely reduce the cost per station. Directing the financial aid to single EV users in the case of MURBs promotes the installation on a case to case basis, thus reducing the effectiveness of the incentive. By making the financial aid accessible to strata councils and landlords as well, and restricting the minimum number of charging stations, the effectiveness of the policy measure per station installed increases, as does the number of stations, which promotes EV adoption among other residents.

A long-term effect is that incentivizing the installation of charging stations within existing MURBs gets more expensive as it grows, as observed from the CLD (Section 4.4). For this reason, governments should consider programs and policy actions geared towards incentivizing and financially helping strata councils and landlords to upgrade the building's power distribution system sufficiently to accommodate future charging needs from the residents. Preparing the grounds for future charging station installations is important because: 1) it is possible to do it as part of one planned and well-thought project; and 2) it avoids just patching the system as installation grows without further planning and replacing recently added equipment because it is no longer sufficient to sustain more charging stations. Education and awareness policy measures also become applicable in this case, by anticipating strata councils and landlords of this potential future situation and guiding them through the planning process. Further detail on this policy will be given in sub-section 4.5.3.

It is understood that financial and fiscal policy measures have the highest cost to the institution that implements them, in this case, the government. Nevertheless, they address high significance barriers that directly impact the decisions of potential EV buyers.

4.5.2 Regulatory Policy Measures

Several barriers and implications relevant to this problem can be addressed through regulatory policy measures, mainly related to legal or regulatory barriers, but also institutional and public acceptability. Regulatory policy instruments include technology-forcing mandates and standards, mandatory codes and bylaws, and voluntary certifications (Browne, O'Mahony, and Caulfield 2012).

One of the most relevant barriers identified as having medium significance is the conservative regulatory requirements of codes and standards when dealing with the installation of charging stations in existing buildings. The specific case is the Canadian Electrical Code which, as mentioned, mandates that EV charging has to be included at 100% in demand calculations to avoid overloading of the electrical system (Impey 2013). This rule can lead to unnecessary and expensive upgrades, especially when the design building baseload somewhat differs from the actual base load. As observed in the CLD, this has direct and indirect implications and repercussions in the whole installation and EV adoption process. This code should be revised as more information on EV charging patterns and actual building loads become available, as well as charging technology and alternative advances.

The other medium significance barrier that can be addressed through regulatory policy measures is the lack of regulation of rights and obligations of EV users, building residents, strata councils, and landlords, regarding the installation and use of charging stations within MURBs. This is necessary to avoid future situations that can be unfair to some residents and favor some residents over others. Several examples of these situations are illustrated as follows.

First, as established previously, building upgrades are likely to become more expensive and comprehensive as more charging stations are installed. If EV users are expected to pay for the building upgrades when wanting to install a new charging station, the cost of the upgrade will vary, and some residents might end up having to cover much higher costs than other residents to receive the same benefit.

Second, if the strata council or landlord financially supports a group of EV users to install charging stations in their parking stalls at any given moment, other future EV users might expect the same support, or an even higher support given that the building upgrades might even be higher.

Third, if at some point it becomes unfeasible to keep installing charging infrastructure within the building, the existing infrastructure would have to be shared to ensure all residents can receive the same benefits, which might create further complications among the building residents.

Finally, in the case of apartment owners, it might seem unreasonable to prohibit them to install charging infrastructure to charge their EVs if they are willing to pay all the costs that this might represent. EV owners in this position should be provided with other charging options or arrangements, which should also be outlined as part of the governance policies. They should also have access to information on other available charging alternatives within or outside of the MURB.

Also related to these situations are the governance issues that EV users and building owners face when considering charging station installation. Although these issues have been addressed with education and awareness policy instruments, such as guidelines, these measures might be insufficient to deal with future issues in a generalized manner. Strata councils and landlords should be given freedom to decide on issues such as these, yet it is important to foresee these situations and provide the relevant regulatory frameworks to avoid unfair situations among building residents in the future, especially as EV adoption level increase.

In preparation for this future, it becomes quite relevant that municipalities and the provincial government consider mandating that all new MURBs provide a percentage of “EV ready” parking stalls, as well as provisions in the electrical system to install the full capacity in the future, such as the City of Vancouver Building Bylaw mandate. This mandate prepares the building for the present and future interactions and reduces the number of buildings that present all the discussed limitations.

4.5.3 Education and Awareness Policy Measures

Several of the identified barriers from different categories can be addressed with education and awareness policy measures. These include governance issues, public acceptability barriers like lack of support and understanding, and regulatory barriers that refer to limited technical guidance.

As mentioned, there are numerous governance issues that can have a negative indirect influence on the decision of new charging station installation in existing MURBs. Such governance issues, as well as other technical considerations, can be addressed through guidelines developed by the government and relevant associations that help close the knowledge gap and provide guidance throughout the whole process.

Within the BC context, there are some available resources that deal with some of the issues and raise awareness of others.

- The Condominium Home Owners Association of BC (CHOA) published the guide "Installation of Electric Vehicle Charging Stations on Strata Properties in British Columbia" in 2014 with the purpose of identifying options and procedures for strata corporations installing charging stations on common property and within the strata lot. It provides guidance on technical and non-technical aspects to be taken into account when considering the installation of charging infrastructure in new or existing MURBs.
- The Building Owners and Managers Association of British Columbia (BOMA BC) created a guide of EV charging stations for MURBs that covers aspects such as charging levels, the installation process for new charging stations, parking space considerations, power and transformer requirements, metering, cost, maintenance, and safety. Although it serves well as a guide and in raising awareness on potential problems that can be encountered, it lacks on providing guidance towards achieving solutions to these problems.

- Metro Vancouver has an online guide for EV Charging in Condos, Apartments, and Townhomes in which they provide relevant information for homeowners and tenants and strata councils, as well as key information, challenges and solutions, and tools and resources. They also have an EV friendly strata registry for public consultation.
- The "Canadian Electric Vehicle Infrastructure Deployment Guidelines 2014" document provides technical guidance for residential charging, including a section for multi-family dwellings additional considerations such as siting requirements and the installation process.

These resources provide valuable information to guide different stakeholders, they are publicly available for consultation, and they have helped close the knowledge gap. However, there is still uncertainty about how to deal with some governance issues, especially the ones referring to cost responsibility and ownership.

There is also a lack of guidance on the need and process to develop long-term EV charging infrastructure plans that will guide and dictate present and future charging infrastructure deployment in the building, the infrastructure upgrade needs, governance and ownership considerations, among others.

Chapter 5: Conclusions

5.1 Summary

As EVs become a viable and clean alternative to light-duty conventional vehicles and the EV market in BC grows, new opportunities and challenges emerge due to the different fueling mode of EVs. Because they are charged with grid electricity, which can be sourced from households, the majority of EV owners want to charge their vehicles overnight at home for convenience. Making charging infrastructure available in MURBs is a new and complex process that has numerous technical, financial, social and regulatory implications. Therefore, the goal of this thesis was to analyze the implications of installing charging infrastructure for EVs in Multi-Unit Residential Buildings in BC to uncover present and future issues that can emerge throughout the process and to identify the actions that can be taken to address them.

To achieve this, four research activities were conducted. First, the problem and scope were defined with the help of a conceptual framework, and the implications of the installation process were analyzed. Three main dimensions were identified: EVs and charging infrastructure, existing MURBs, and regulations and policies. Likewise, four major implications were identified and analyzed: technical building implications, additional infrastructure investment, governance and knowledge implications, and off-street parking availability implications. The analysis determined their definitions, dependency factors, causes, and effects.

Based on the results of this analysis, a list of barriers was identified using another conceptual framework. The identified barriers were categorized into financial, technical, institutional and administrative, public acceptability, legal or regulatory, and physical barriers. The barriers were then assessed in terms of their timeline, significance and the applicable policy measures that could be applied to address them.

Having defined the problem system and having a comprehensive visualization of the implications and barriers, a causal loop diagram was developed to map the causal relations that exist among its main entities. Four causal loops were identified, three that reinforce EV uptake and the infrastructure installation process, and one that balances the growth given the technical limitations of the building and the investment implications it would have to address them.

Finally, based on the implications, barriers and causalities, a set of policy recommendations were developed in terms of potential policies and actions that could be implemented to address the challenges of charging infrastructure installation. These recommendations are categorized by policy measure and summarized in Table 5.

Table 5. Summary table of policy recommendations

Type of policy measure	No.	Recommendations
Financial & Fiscal	1	Financial or fiscal 2-5 year incentives such as cash rebates or discounted loan offered by the provincial government, to aid EV users in partially covering the costs of the EVSE and its installation, as well as the required building upgrade costs.
	2	Extend the financial aid to strata councils and landlords, and condition it to a minimum number of charging stations, which will increase the effectiveness of the incentive measured in dollar/charging station.
	3	Within the following decade, municipal and provincial governments should plan and implement a program to incentivize and financially aid strata councils and landlords to develop a retrofit plan and to upgrade their building's power distribution system sufficiently to accommodate future charging needs of their residents.
Regulatory	1	Revise and constantly update the regulatory requirements from codes and standards to reflect the current technological advances and avoid being over conservative, which can lead to unnecessary oversizing of electrical equipment.
	2	Regulate the rights and obligations of EV users, building residents, strata councils, and landlords, regarding the installation and use of charging stations within MURBs to avoid future situations of unfairness and inequality among them.
	3	Make it mandatory at a provincial level for new MURBs to provide charging stations for a percentage of the parking stalls, as well as being technically prepared to accommodate charging stations in all parking stalls in the future. This will avoid having more non-ready existing MURBs in the near future.
Information and awareness	1	Expand the existing guidelines to provide clear guidance and solutions on technical and governance issues, such as charging infrastructure cost responsibility and ownership.
	2	Develop a program or guideline to inform and guide strata councils and landlords on how to develop a long-term EV charging infrastructure plan that will guide and dictate present and future charging infrastructure deployment in their building, the infrastructure upgrade needs, and governance and ownership considerations.

5.2 Contributions of Work

This thesis contributes to the body of knowledge by outlining key insights and policy recommendations based on an in-depth analysis and assessment of the problem of EV charging infrastructure installation in BC MURBs. Important barriers and problematic situations were identified by applying systems thinking principles, as opposed to traditional event-oriented thinking. The insights outlined in this thesis can be of relevance to different stakeholders such as EV users, strata councils, landlords, and building residents. The policy recommendations have the potential to inform the decisions and policy programs of the municipal and provincial government of BC, as well as other governmental and non-governmental agencies and associations.

5.3 Limitations and Future Work

The research methodology for this thesis is based only on qualitative analysis, which is vulnerable to subjective evaluation, even when supported and based on other empirical studies. Future studies based on quantitative methods, such as the system dynamics simulation process, could be conducted to validate the qualitative results. In the case of this thesis, this qualitative study was not conducted because it was not possible, within the scope for this thesis, to have access to accurate quantitative data, nor to conduct the model development and validation with input from different stakeholders.

The barriers, implications, and recommendations made by the author, although based on previous studies, cannot be considered as exhaustive. The objectives and research methodology were only directed towards the development of an in-depth analysis, but they were not designed to achieve exhaustive lists, and some aspects could have been overlooked. Likewise, the methodology and results of the thesis were designed to be applicable to the province of BC in a general sense, and not to every specific case. Therefore, discrepancies might exist if being applied or compared to particular cases.

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