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Putting electric vehicles on the map: A policy agenda for residential charging infrastructure in Canada

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ABSTRACT

Electric vehicles (EVs), when powered with sustainable sources of electricity, can contribute to the mitigation of climate change through reduced greenhouse gas emissions. The Canadian province of British Columbia (BC) is an attractive location for EV deployment because ~85% of its electricity is sourced from large hydropower. The driving ranges of EVs and their potential to reduce local emissions mean they are well suited to urban contexts, where most residential buildings in BC are located. The challenges associated with installing new charging stations, particularly in Multi-Unit Residential Buildings (MURBs), can become barriers to uptake of EVs. In this study, we develop a conceptual framework to identify the challenges, potential barriers and stakeholders involved in the process of charging infrastructure installation in MURBs. We establish four main domains to this problem, each of which involves specific stakeholders: charging infrastructure installation, building limitations, governance issues and parking availability. Mapping out these problem domains using decision-making flow diagrams allows us to characterize their internal dynamics and the relationships between stakeholders. As EV markets continue to grow both in Canada and across the world, a better understanding of barriers to stakeholders in these residential settings is essential for informing policy interventions.

1. Introduction

Electric vehicles (EVs) are rapidly becoming viable alternatives to traditional fossil fuel vehicles. Over 735,000 EVs were sold worldwide in 2016, representing a 40% year-on-year increase [1]. EVs contribute to the reduction of fossil fuel dependency of the transportation sector [2,3], as well as the improvement of air quality and mitigation of climate change through reduced greenhouse gas emissions [3–6]. In this paper, we define EVs as light-duty vehicles that use one or more electric motors, which can be partially or fully fueled by grid electricity, or independent of the grid using other self-generated or off-vehicle energy sources. Although the energy-saving potential of EVs has been demonstrated in a variety of contexts (e.g [7,1].), many uncertainties remain in the scale and timing of market diffusion [6,8,9].

In Canada, where the transportation sector accounted for 24% of emissions in 2015 and is the second largest source of carbon pollution [10], EV sales have been growing as manufacturers release new models and consumer understanding and trust in the technology improves (Fig. 1). Canadian federal, provincial and territorial governments are jointly developing a national Zero-Emissions Vehicle Strategy with an unbinding target to achieve 30% EV sales by 2030 [11]. Studies have shown that commercially available EVs meet 90% of Canadians' daily driving needs [7], particularly in urban contexts where driving ranges are generally shorter and there is greater capacity to reduce emissions [5]. In the City of Vancouver, for example, 70% of trips do not exceed 10 km and 95% do not exceed 30 km [12], which falls well under the average driving range of an EV [13]. However, despite purchasing incentives being offered in three provinces, EVs accounted for only 0.6% of car sales in Canada in 2016 [14]. This proportion is similar to the US (0.9%) but lower than many European countries such as the UK (1.4%), Sweden (3.41%), the Netherlands (6.4%) and Norway (28.8%).

An important aspect of boosting EV adoption across Canada is investment in charging infrastructure [15]. Goldthau [16] has pointed to the inherent co-evolution of physical energy infrastructure with socio-economic institutions and social norms as a potential source of inertia when attempting to address the energy challenge. Goldthau [16]

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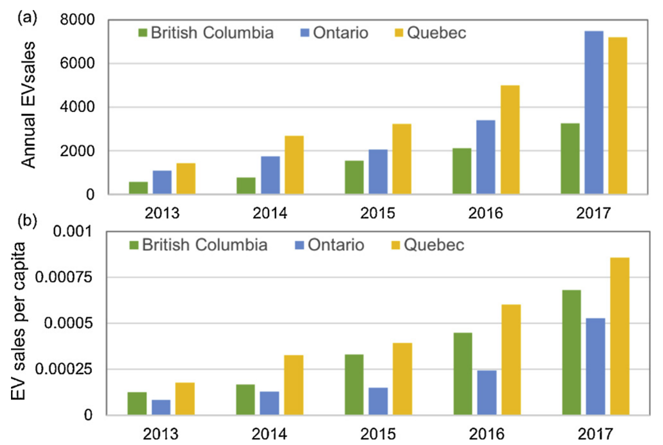

Fig. 1. Annual EV sales (excluding HEV) in the three top Canadian provinces for 2013–2017: (a) absolute sales; (b) per capita sales (data from [25]).

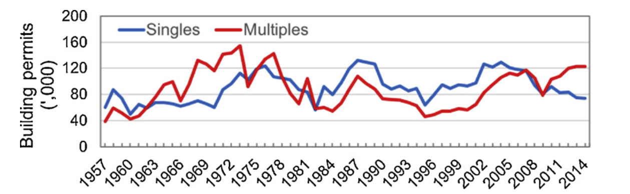

Fig. 2. Building permits for single-family and multi-family dwelling units in Canada, 1957–2014 (data from [40]).

therefore recommends polycentric, multi-scale governance systems to be developed for energy infrastructure, to allow for contextualization, experimentation and innovation. Although high rates of EV deployment may require a high-density public charging network to reduce range anxiety among users and potential buyers, home-charging capabilities will be key to encouraging adoption [15,17,18]. Indeed, research suggests that 80–90% of charging takes place at home, where it is most convenient for drivers [19]. Increasing home-charging availability can also help to solve the classic 'chicken-and-egg' problem that besets alternative fuel vehicles (AFVs) in general: fuel providers will not invest in fueling infrastructure until a critical mass of AFVs are in circulation, and people will avoid purchasing an AFV until adequate infrastructure exists [20].

In this paper, we concentrate on EVs that must be plugged into grid electricity to charge the vehicle's battery pack. This includes Battery Electric Vehicles (BEVs), which are powered exclusively by electricity, and Plug-in Hybrid Electric Vehicles (PHEVs), which have both a gas and electric motor as well as an onboard battery, giving them longer driving ranges than BEVs [21]. Other EV types, such as Hybrid Electric Vehicles (HEVs), use electricity that is sourced from recaptured kinetic energy rather than from the grid and HEV's are thus not reliant on electric charging stations. For most EVs, a full daily battery charge is usually enough for city commuting, and residential settings allow charging to be performed overnight and for the longest times [22].

The Canadian province of British Columbia (BC) provides an interesting case study for EV home charging. BC is considered an attractive location for EV deployment because 85% of its electricity is sourced from large hydropower, a clean renewable energy source [23]; EV diffusion could be ineffective for reducing carbon emissions if it occurs in regions with high-carbon electricity [6]. Additionally, current residential electricity rates in BC are low enough that charging a vehicle at home is less expensive than fueling a conventional gasoline vehicle [24]. These factors, together with BC's provision of generous EV subsidies, resulted in sales of hybrid vehicles and battery EVs reaching 4% of total car sales in 2017 – a 48.6% increase over 2016 figures [25]. In efforts to further incentivize EV uptake across BC, the provincial government and a number of municipal governments have highlighted the major strategic importance of expanding access to home charging (e.g. [12,26]).

A core part of this strategy involves the deployment of charging infrastructure in Multi-Unit Residential Buildings (MURBs), defined as buildings with residential occupancy with three or more dwelling units and common interior and exterior spaces shared among residents. Across Canada, construction rates for MURBs have surpassed those of single-family dwellings ever since the 2008 recession, as cities increase urban densification to house their growing populations (Fig. 2). In BC, MURBs account for 28.6% of households [19], and are forecast to make up 66–69% of all new residential constructions in the province over the period 2018–2020 [27].

Many MURB households are interested in becoming EV owners but ensuring access to charging infrastructure in MURBs is generally more complex than in detached homes. Most MURBs are not equipped with EV charging infrastructure in their parking lots, and access to power outlets within reach of parking stalls is usually limited [28]. Even for those with power outlets located in common areas, difficulties in allocating electricity consumption to single occupants outside their private suites means that all residents are billed for power used solely by the EV owner(s). Other challenges include limitations to the additional power capacity available from a building's electrical distribution system for EV charging. As a result, building modifications and dedicated charging infrastructure provisions are often required to enable EV home charging in MURBs. This is a complex task with numerous potential barriers that serve to hinder EV uptake among MURB residents [29]. Whilst much of the literature has focused on examining the potential benefits of EVs and designing policy interventions that rest on motivating users to act on monetary savings or prioritizing contributing to the global good (e.g. [30]), there has generally been a lack of in-depth research that considers actual and perceived barriers for different stakeholders.

In this study, we develop a conceptual framework for assessing stakeholder dynamics around EV charging in MURBs within BC. Our approach is framed by calls from scholars such as Sovacool [31] and [30] for energy research to account for intricate social contexts, in order to better capture the human dimensions of energy usage and technology uptake. The framework we develop allows us to map out the challenges and opportunities from the perspective of each major stakeholder in the system. We focus our analysis on the main metropolitan areas of BC, since they are home to the majority of MURBs in the province and concentrate 70% of the light-duty vehicle fleet that could be replaced by EVs [29]. EV markets are set to continue growing both in Canada and across the world; given the major importance of charging infrastructure to the EV system, it is essential to inform policy interventions by identifying the nature of the barriers related to residential charging and the stakeholders affected. As an example of a steadily growing EV market in a region with a permissive clean energy mix, BC is a useful case study for drawing wider conclusions about stakeholder dynamics when promotion EV uptake in cities where MURBs are prevalent.

The remainder of this paper is presented in three parts. The next section introduces our methodology for categorizing potential barriers and analyzing stakeholder dynamics. Section 3 presents the results of our analysis, discusses its implications and identifies future avenues of research. Section 4 summarizes the main conclusions of this paper.

2. Methods

We conducted a three-part analysis of stakeholder dynamics in the installation of EV charging in MURBs. We first outlined our system boundary using a Venn diagram framework, in order to identify key drivers of change and potential barriers for EV adoption in MURBs. Finally, we used our framework to disaggregate the system into four main problem domains, for which we mapped the main stakeholders, decision-making criteria and potential outcomes using decision-making flow diagrams.

In this study, we focused on EVs that can be partially or fully fueled by grid electricity (BEVs and PHEVs) and did not consider EVs whose electricity is sourced from recaptured kinetic energy (e.g. HEVs). We also chose to concentrate our analysis on existing MURBs (i.e. buildings in the operation phase for which EV charging infrastructure was not installed during the construction phase). This is because there are a multitude of MURBs already in place in BC and stakeholder dynamics in these situations are particularly complex. We excluded new-build MURBs with pre-installed charging infrastructure from the scope of this study because EV owners with existing access to overnight charging in their parking stall will not be faced with the problems under consideration.

2.1. Venn diagram framework

We developed a conceptual framework based on a Venn diagram to analyze the issues surrounding the installation of EV charging infrastructure in MURBs. Venn diagrams help to outline the boundaries of a system and to visualize the interactions between several concepts or dimensions. Based on a comprehensive review of the literature, we identified three main dimensions to our system and the issues arising in their overlapping spheres.

2.2. Barrier categorization framework

We identified and categorized the potential barriers to installing EV charging infrastructure in MURBs by modifying the methodological framework of Browne et al. [32]. In their study, Browne et al. [32] qualitatively evaluated the barriers to widespread AFV deployment. Not all their categories and criteria applied to our problem system, so we adapted their methodology to classify potential barriers into six categories: financial, technical, institutional/administrative, public acceptability, legal/regulatory and physical (Table 1). The potential barriers were analyzed in terms of five overarching criteria: timeline, significance, required policy type, implementation scale and policy developers (Table 2).

This barrier categorization framework allowed us to contextualize how barriers can hinder the deployment of EV charging infrastructure in residential buildings. Results from this analysis were then used to map out the problem domain (see Section 2.3).

2.3. Problem domain analysis

The Venn diagram and barrier categorization frameworks were used to break the system down into its main component domains. In our context, problem domains can be understood as the areas that must be examined and acted upon to improve charging infrastructure availability in MURBs for residents that require it. We analyzed each problem domain in relation to five elements: (i) decision-making stakeholders (the stakeholders involved in making decisions to create a solution strategy in the domain); (ii) decision criteria (the independent factors that decision-making stakeholders take into consideration to create a solution strategy); (iii) external factors (the outside influences that impact the solution strategy as well as the outcome implications); (iv) solution strategy (the result of the decisions made about a specific problem domain); and (v) implications (the effect that the solution strategy will have on certain dependent factors).

We present our problem domain analysis in the form of decision-making flow diagrams, wherein 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.

3. Results and discussion

The framework we used to outline and analyze the problem dimensions of EV charging infrastructure installation in MURBs is illustrated as a Venn diagram in Fig. 3. We identified three main dimensions: (i) EVs and charging infrastructure, (ii) existing MURBs, and (iii) regulation and policies. We analyzed these dimensions and their intersections in the context of BC.

3.1. Problem dimensions analysis

3.1.1. Problem dimensions

In Canada, 15 BEV models and 26 PHEV models are currently available for purchase [25]. In BC, BEV sales amounted to more than double the PHEV sales in 2017, mainly owing to Tesla models, which are only available as BEVs and account for > 40% of all BEV sales in the province. There are currently around 1000 public charging stations in BC, most of which are categorized as 'Level 2 (Primary)', with 'Level 1 (Opportunity)' and 'Level 3 (Fast)' also available (see Table 3). Public stations are useful for EV owners that have no access to overnight charging at home or those requiring additional daytime charging. Private charging infrastructure is usually set at Level 1 or Level 2 because Level 3 requires Direct Current that is often unavailable in residential settings. The decision to install a Level 1 or Level 2 charger depends on several factors, including the user's charging needs and daily driving range, the EV model they own, the cost they are willing to invest for charging infrastructure and the pre-existing electrical system in the chosen charging site.

Although different types of EV connectors exist for different vehicle models and charging levels, the standard connector in Canada and the United States for Level 2 charging is the SAE J1772 EV plug, which can be used to charge all EVs. Tesla EVs can be charged with Level 3 stations in the home, and these use a different connector than the Level 2 J1772 EV plug. Level 3 connectors vary by model and region of origin and are incompatible with each other.

Two principal types of MURB ownership exist in BC: (i) purpose-built rental buildings, which are in most cases entirely owned by a single organization and administered by property managers; and (ii) strata buildings, where owners own individual strata lots and together own the common property and assets as a strata corporation. Decisions regarding charging station installations are handled differently depending on the building type. In purpose-built rental buildings, tenants can request installation in their parking stall from the landlord or property manager, and the decision relies on the latter. Strata buildings

Table 1
Descriptions of categories used in the barrier categorization framework (adapted from [32]).

Barrier category	Description
Financial	Additional or increased monetary costs of charging infrastructure
Technical	Technological barriers referring to charging infrastructure installation feasibility
Institutional / administrative	Resistance from stakeholders due to an aversion to new technologies or established administrative procedures
Public acceptability	Acceptance from the public of charging infrastructure installation as a new technology
Legal / regulatory	Regulatory and policy gaps, potential legal challenges and planning restrictions
Physical	Spatial constraints for charging infrastructure installation and availability

Table 2
Descriptions and classifications of the criteria used to analyze potential barriers.

Analysis criteria	Description	Classifications
Timeline	The timeframe in which the barrier could be eliminated or mitigated through policy actions	Short-term (1-2 years), medium term (2-5 years) or long-term (5-10 years)
Significance	Subjective evaluation of the likelihood of the barrier being an obstacle	High, medium or low significance
Required policy type	The policy tool that is most appropriate to address the barrier	Fiscal incentives or taxes, Financial incentives such as rebates or discounts, regulatory, technical improvements, institutional, and education and awareness campaigns
Implementation scale	The appropriate scale for policy implementation	National, provincial or local
Policy developers	The stakeholders or actors that are most likely to take action to overcome or mitigate a barrier	Government, associations and organizations, the industry and the public

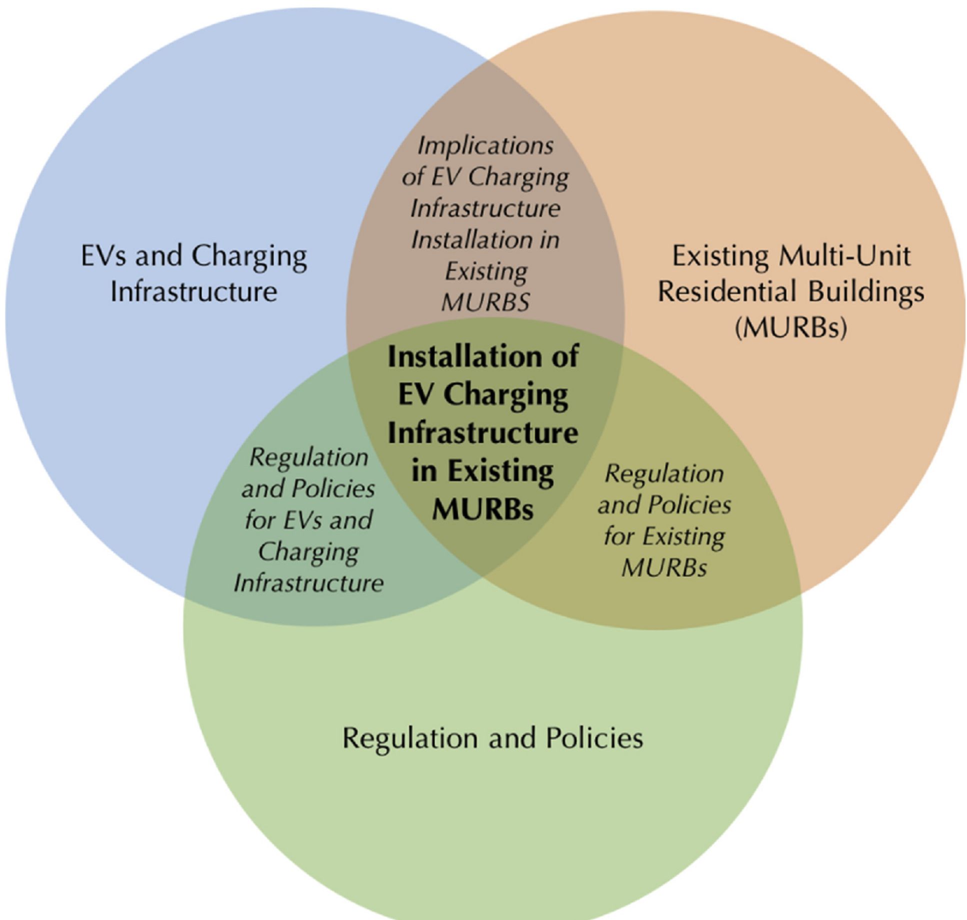

Fig. 3. Venn diagram framework for analyzing the installation of charging infrastructure for EVs in existing Multi-Unit Residential Buildings (MURBs).

have strata councils that can vote on the decision. In both cases, the approval of an installation request will likely require the amendment or creation of agreements, bylaws, and rules for the building.

Regulation and policies play an important role in the deployment of charging infrastructure, and external support from the public sector will evidently be key for achieving widespread EV adoption [6,9]. Governments shape EV markets through policy instruments such as regulation, taxation, subsidies, and incentives, as well as through setting long-term goals and providing R&D funding for technical development of infrastructure [33]. Two types of regulatory instruments exist in BC that are relevant to EV and MURB regulations: codes and standards. Legislated codes are mandatory and are developed and

Table 3
Available charging levels, voltage, power levels and charging times.

Charging Levels	Voltage (V) and Power	Battery capacity (kWh)	Power Level (kW)	Charging Time (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

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

Potential barriers	Timeline	Significance	Type of policy measure	Implementation scale	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	Medium	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

published by government institutions. They can either be performance-based, by prescriptively stating expectations to achieve certain results, or outcome-based, by establishing target levels and ways to measure and report results [34]. In contrast, standards are usually non-mandatory measurable guidelines and 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 [35]. We now analyze the intersections between each problem dimension, as shown in Fig. 3.

3.1.2. Problem dimension intersections

First, the interaction between EVs and MURBs concerns primarily the installation of charging infrastructure into a building's electrical system. New buildings increasingly install charging infrastructure as part of their construction, in order to be 'EV-ready' for residents. In contrast, existing buildings require adaptations for charging infrastructure to be installed. Level 1 charging is considered sufficient for PHEVs because they have small onboard battery packs and relatively short electric ranges. However, fully charging a BEV battery pack takes much longer (11–36 h) at Level 1 [15]. Given the significant uptake of BEVs in BC [25], and faster charging will increasingly be prioritized by consumers as battery capacity improves, it is preferable to install Level 2 charging infrastructure in existing MURBs where possible.

Second, the installation of charging stations in Canada is regulated using the Canadian Electric Code, through its Electric Vehicle Charging Systems section (Section 86) and its Circuit Loading and Demand Factors section (Section 8). New equipment installed in an existing building creates additional electrical loads to the electrical system; according to rule 8-202(3)(a)(d), any additional load in a common area of an apartment building (including parking lots) should be continuous, as if the equipment was operating constantly. This conservative approach prevents overloading of electrical systems for safety purposes, but it is unrealistic since not all vehicles will begin and end charging at the exact same time, nor will all stations be continuously charging a vehicle [29]. This requirement can, therefore, result in unnecessary and costly upgrades in the building's power distribution system. Standards for EV charging stations themselves, which differ among world regions but are increasingly designed to unify and guide the industry, address issues such as compatibility, power management, communication and safety. For instance, the Society of Automotive Engineers publishes a constantly reviewed standard covering physical, electrical and performance requirements for EV electric connectors [36], which is endorsed by the leading EV manufacturers in North America.

Third, any building alterations, repairs, and demolitions conducted in existing MURBs are regulated by the 2012 BC Building Code (based on the 2010 National Building Code of Canada). Each municipality within BC can also develop its own bylaws to address issues outside the scope of the BC Building Code. For example, the City of Vancouver's Building Bylaw builds on the provincial code by including a provision to provide charging stations for 20% of all parking stalls in new (not existing) MURBs and to reach 100% in the future. The push to create 'green(er) buildings' with reduced environmental impact has also led to the development of various standards, codes, certifications and rating systems [34]. For instance, the New Constructions (NC) standard of the Leadership in Energy and Environmental Design (LEED) requires the designation of 7% of parking spaces as EV-ready for its Green Vehicles credit [37]. However, this credit is optional for new constructions and does not apply to existing buildings, so there are few incentives for installing charging stations in existing buildings when pursuing LEED certification. Mandatory green codes are sometimes used by governments to prompt more rapid sustainability and performance improvements compared to voluntary certification and rating systems. For instance, the City of Vancouver has adopted green building and energy codes to reduce GHG emissions of private sector buildings, as part of the C40 Cities Climate Leadership Group [38].

The central node of the Venn diagram (Fig. 3), where all the dimensions interact, is representative of the potential barriers that can hinder (or opportunities that can enable) the installation of charging infrastructure in MURBs. The characteristics of these barriers were analyzed using the modified framework of Browne et al. [32], and the results are presented in section 3.2.

3.2. Categorizing potential barriers

Using information from our review of the literature and the Venn diagram framework, we ascribed potential barriers to six categories (financial, technical, institutional/administrative, public acceptability, legal/regulatory and physical) and evaluated each barrier according to five overarching criteria (timeline, significance, implementation scale, policy type and policy developer). The results of this analysis are presented in Table 4.

We found that the most significant barriers are related to financial and technical issues arising from the imposition of additional loads onto the existing building power distribution system. The cost of charging infrastructure as an additional investment for users, the technical limitations of existing building systems, and the associated costs of upgrading those systems, are all barriers that could strongly hinder EV charging installation in MURBs in the medium- to long-term. Other significant medium-term barriers include the lack of support from non-users, the lack of regulation of rights and obligations of users, strata corporations and landlords, and conservative regulatory requirements (e.g. the contingency of the Canadian Electrical Code discussed in section 3.1.2). All the barriers identified as short-term were deemed to be of low significance, meaning that they can be overcome or significantly mitigated through policy actions within 1–2 years, but are also not considered essential to prioritize. Short-term barriers include limited technical guidance provided throughout the installation process and the planning permission required for charging infrastructure installation. Governance issues that arise from charging infrastructure procurement and installation are of medium significance, so should be prioritized over other barriers.

Whilst the financial barriers will require dedicated financial and fiscal policies, most other barriers can be addressed through incentive-free regulatory policies. The scale of policy implementation is predominantly local, meaning that municipal governments can take regulatory action in many cases. The cost of upgrading a building power distribution system is of high importance, and it is likely that policies will need to be imposed at the provincial government level owing to the economic scale required for appropriate financial incentives. Outside the governmental sphere, associations can also play an important role in addressing some barriers, especially with education and awareness policies that do not require as large financial investments as providing monetary subsidies or incentives.

3.3. Mapping the problem domains

Based on our problem dimensions analysis and our barrier categorization framework, we established four main problem domains that can impact the potential for charging infrastructure availability in MURBs. We analyzed each domain in relation to the five elements outlined in section 2.3 (decision-making stakeholders, decision criteria, external factors, solution strategy and implications), and visualize the stakeholder dynamics using decision-making diagrams (Fig. 4).

3.3.1. Charging infrastructure installation

The motivation to install EV charging infrastructure in a MURB can come from building residents who are current or potential EV owners and/or from the building owners (Fig. 4a). In the case of self-owned/strata buildings, the interested residents and the strata council will usually be involved in the installation decisions. 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 or its electrical system.

The stakeholders decide on the number of charging stations to be installed, the charging level of each station, and the Electrical Vehicle Supply Equipment (EVSE) of each model (the equipment that serves as an intermediary between the power source and the vehicle's charging port). The number of charging stations is determined by the number of interested residents and the number of additional charging stations the building owner allocates for future demand or for other purposes such as visitor parking. The charging level is determined by charging needs (Level 1 and/or Level 2 charging). The EVSE model can be chosen as a function of location, and the requirement for fixed or portable EVSEs. These factors may be shaped by fund availability, which can be provided by EV owners and/or the building owner.

Together, this set of decisions will form the charging infrastructure investment plan. When creating the plan, external factors will also have to be considered: building characteristics and regulatory demands. Building characteristics include the station's proximity to the EV owner's unit, the potential for water damage or interference with maintenance tasks, and the ventilation and rewiring required for installation. The regulatory demands refer to the requirements for complying with currently imposed regulations.

As discussed in section 3.2, the additional investment of installing charging infrastructure for owners could be a strong disincentive for EV adoption among MURB residents. In these early stages of market development, many potential EV buyers in MURBs will wait to invest in the technology until charging is available in their buildings or is publicly accessible and convenient. Addressing issues at the heart of the 'chicken-and-egg problem' [20] will help to make investment decisions between EVs and conventional vehicles more comparable, and eventually, drive a larger market share for EVs.

3.3.2. Building limitations

A building's electrical systems can present limitations that must be considered during the design and implementation of upgrade plans (Fig. 4b). An existing building's power distribution system, which is composed of a series of electrical-energy-carrying components that transmit electrical energy in a safe and efficient manner, is usually not designed to cope with additional EV loads. Impey [29] reported that the addition of four Level 2 charging circuits (6.6 KW each) to an existing MURB's electrical system resulted in full use and overload of two of the system's principal components. A building's wiring and metering configuration must be assessed on a case-by-case basis; for instance, individual meters might be required in parking lots to measure and bill electricity usage to each end user. The service type or system voltage can create other problems, with some voltages not being compatible with certain EVSEs (e.g. 240 V outlets are needed for Level 2 charging, although most existing MURBs should be able to accommodate this). Regulatory requirements must also be considered early in the planning stages of a building retrofit investment plan because the conservative nature of some regulation (e.g. the Canadian Electrical Code) can increase the scope of the upgrade project.

These external factors, together with the charging infrastructure investment plan, shape the building retrofit investment plan, including the retrofit monetary investment and the retrofit project scope. As with investments for charging infrastructure, funding for the building retrofit investment plan can be provided by the building owner, the EV owners, or both. In strata buildings, the use of the strata budget – which is funded by all strata members – for retrofit investments can be complex, as non-EV owners may not agree to spend the budget on charging stations that do not directly benefit them. In this case, the cost of upgrading a building's electrical system is usually out of the investment scope for individual (or small groups of) EV owners.

As for the retrofit projects, they can vary greatly in scope. While installing outlets on certain parking stalls can be relatively affordable, rewiring work is often disruptive for 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 eight Level 2 chargers in a condominium tower in Vancouver costs a total of ~C$30,000 [29]. The scope of the project will also determine the level of management and expertise that will be required; outsourcing project management can substantially increase the total retrofit investment.

3.3.3. Governance issues

Once the infrastructure and retrofit investment allocations determine who should pay for the infrastructure and the building retrofit, governance issues dictate whether relevant stakeholders pursue the installation (Fig. 4c). These issues vary depending on the building type. In purpose-built rental buildings, the governance process may be relatively simple: tenants can request the installation of charging stations but the ultimate decision rests entirely with the landlord, as the building owner usually covers the installation and maintenance costs –

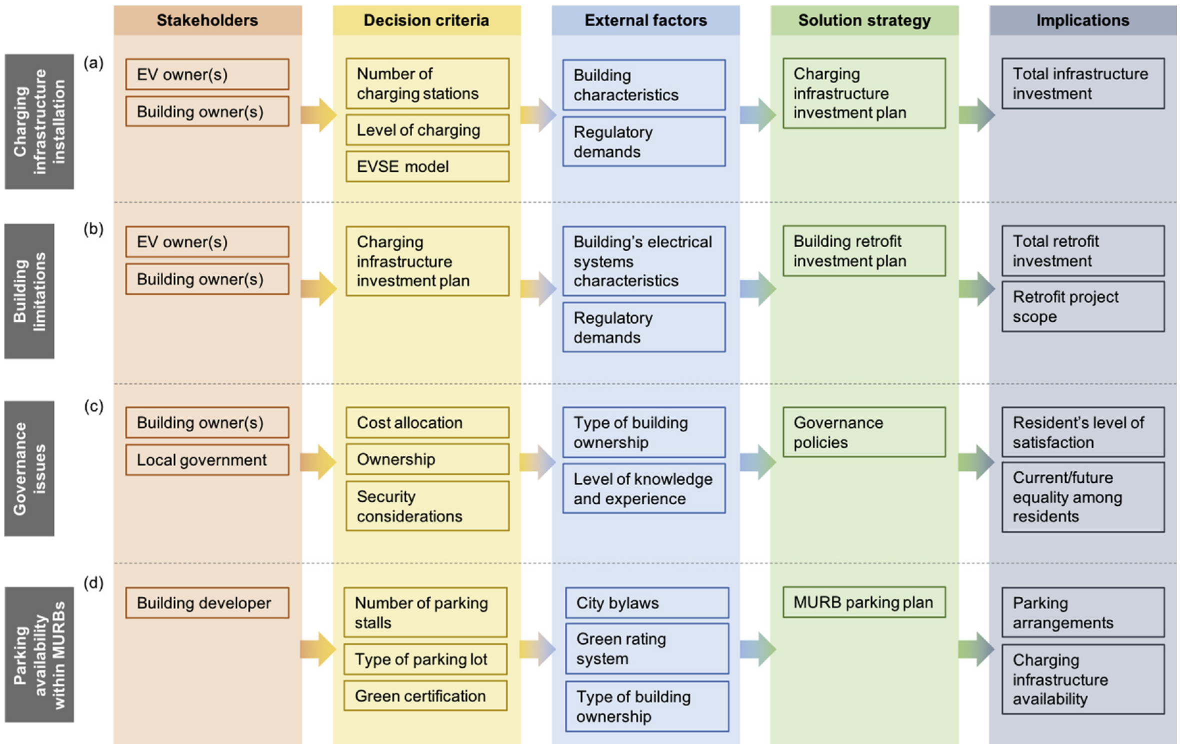

Fig. 4. Stakeholder decision-making diagrams of the four main problem domains: (a) charging infrastructure installation; (ii) building limitations; (iii) governance issues; (iv) parking availability within MURBs. In the diagrams, the stakeholders determine the decision criteria and observe the external 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.

and then keeps the EVSE and the benefit of the upgrades once the tenant moves out. Strata buildings, on the other hand, have more complex structures and decision-making processes. In these cases, it is essential to agree on ownership and maintenance structures and outline procedures for when EV owners leave the residence. Energy cost allocation must also be discussed: if individual meters cannot be installed on EVSEs to bill each unit separately, additional energy use may be estimated by EV owners or another involved party, although this can complicate energy management plans. Lighting, insurance, liability and vandalism concerns may add further complexity to EV governance in strata buildings.

The installation of EV charging infrastructure puts a significant burden on the decision-makers of MURBs to understand emerging vehicle technology, electrical design constraints of the building, and the regulatory environment. Given the varying level of technical knowledge amongst EV owners, let alone building owners or strata member residents who do not use EVs, confusion and hesitancy can arise on the part of MURB decision-makers in deciding whether to act on requests for EV charging in their building. Giving each individual strata corporation the freedom to establish their governance policies on such a complex topic without sufficient knowledge and experience about could result in future issues among residents, especially if a long-term charging infrastructure deployment plan is not developed. Local government can play a role in better informing MURB decision-makers and making recommendations on governance issues. Currently, the lack of regulations and guidelines for charging infrastructure installation in MURBs leaves EV owners without any alternatives if their strata council refuses to allow installation. More clarity is therefore needed from local government on the policies and procedures that building owners should follow when faced with requests to install charging infrastructure in their MURBs.

3.3.4. Parking availability within MURBs

Having access to overnight home-charging is an important convenience for the majority of (potential) EV adopters, and this is most feasible when there is also access to a private parking lot. Although MURB residents commonly have access to off-street parking, this is not always the case. Building developers are responsible for deciding the characteristics and to some extent the number, of parking lots in the buildings they design and construct. There are minimum parking requirements established by municipal bylaws and provincial codes in BC, but these rarely require the provision of parking stalls for 100% of MURB residents. At the same time, many green building rating systems also suggest maximum parking footprints for buildings to minimize automobile dependence among residents (e.g. [37]). While the rating system can sometimes be chosen by the building developer, the adoption of a specific system may be dictated by bylaws. The type of building ownership can also influence parking allocations: high-end apartments for sale are likely to include parking for most, if not all, their residents, while economic purpose-rental units may not.

These factors feed into a MURB parking plan, which is usually determined in the planning phase of the building project. Limiting the amount of available parking space within MURBs, as some green building rating systems seek to do, might be counterproductive with respect to EV uptake because it could limit the possibility of overnight charging availability for residents. If providing all potential EV owners with a parking space within a MURB is unviable, the alternative charging options must be convenient and inexpensive enough to encourage further adoption.

3.4. Limitations and future research

Our research methodology was based in large part on a qualitative analysis of empirical literature. This allowed us to collate data and findings from a variety of existing sources, in order to provide a comprehensive overview of the challenges, potential barriers and stakeholder dynamics involved in the installation of EV charging infrastructure in MURBs. The methodology and scope of this study did not include primary data collection such as stakeholder interviews or surveys with MURB residents and EV owners. Future studies in this field should aim to develop and test our findings and frameworks through the use of primary data collection and quantitative analysis.

Having identified important barriers and problematic situations, the next step in this research will be to fully map the causal relations that exist between the system's main entities. This will highlight important negative and positive feedbacks that could serve to accelerate or hinder, EV uptake among MURB residents. A related study by Lopez-Behar et al. [39] seeks to fully map the stakeholder dynamics and feedbacks involved. Lopez-Behar et al. [39] use the framework presented in this paper to develop a set of policy recommendations to address current and future challenges of EV charging infrastructure installation. This work builds on calls by Sovacool [31] and others to use human-centered methods that can capture the human dimensions of energy use, and provides insights that are relevant to EV users, building residents, strata councils, landlords and government at multiple scales.

4. Conclusions

New opportunities and challenges are emerging as EVs become a viable and clean alternative to conventional vehicles in British Columbia and around the world. At the same time, cities are pursuing urban densification policies to meet growing housing demand, including increased MURB construction. The reliance of EVs on grid electricity, which can be sourced from households, means the majority of EV owners prioritize the convenience of overnight home charging. Making charging infrastructure available in MURBs is an evolving problem with numerous technical, financial, social and regulatory facets.

In this paper, we conducted a three-part analysis to define the key stakeholders, identify barriers, and potential interventions to support EV charging infrastructure investment in MURBs. Three main dimensions were outlined using a Venn diagram framework: EVs and charging infrastructure, existing MURBs, and regulations and policies. Potential barriers were categorized as either financial, technical, institutional and administrative, public acceptability, legal and regulatory, or physical barriers. We found that the most significant barriers are related to financial and technical issues arising from the imposition of additional loads onto the existing building power distribution system. Other significant barriers include the lack of support from non-users, the lack of regulation of rights and obligations of users, strata corporations and landlords, and conservative regulatory requirements for buildings.

Based on this analysis, we identified four main problem domains: charging infrastructure installation, building limitations, governance issues and parking availability within MURBs. We mapped the main stakeholders and the decision-making criteria and outcomes for each domain using decision-making diagrams. We showed that communication between EV owners, other MURB residents and building owners (including strata councils) will be key for developing comprehensive, future-proof infrastructure and retrofit investment plans. The number and level type of charging stations will have to be negotiated between building owners and EV users according to cost and disruption potential, and the financing of installations may prove complex, especially in the case of strata buildings.

Governance issues abound, because of varying levels of technical knowledge and confidence about EV technology, and the lack of clarity surrounding the policies and procedures relevant to building owners. Local government can play a role in informing MURB decision-makers and making governance recommendations. Better dialogue is needed between building developers and government to ascertain optimal strategies for parking provision, as limiting parking space availability in MURBs could be counterproductive for increased EV uptake.

Although our categorization of barriers and problem domain analysis were focused on the case of British Columbia, both the methodology and results are relevant outside the province and Canada. While the results presented in this paper are somewhat predicated on BC's significant renewable energy component, the methodology can be applied to analyze key barriers and opportunities for EV uptake around the world. This is especially the case for cities where much of the population lives in shared residential buildings. However, adapting our framework to different geographical contexts will require accounting for regional specificities, particularly relating to EV markets, building structure and governance, and regulation and policies.

Cities are responsible for ~70% of CO_2 emissions [38] and generate ~80% of global GDP [41], so are critical arenas for addressing the sources and effects of climate change. The obstacles and opportunities associated with providing adequate charging infrastructure will crystallize as vehicle electrification gains pace in urban areas. Future research should now focus on mapping out the implications of current EV-relevant policies, as well as potential policies that could be deployed to encourage investment in charging infrastructure in MURBs. Informing policies in this way would likely help to accelerate EV adoption among urban residents.

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