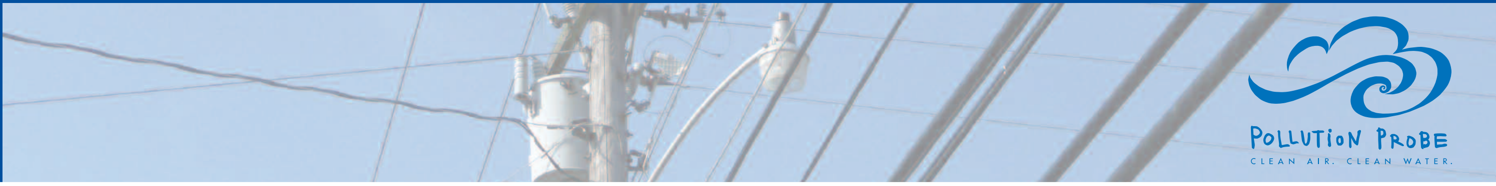

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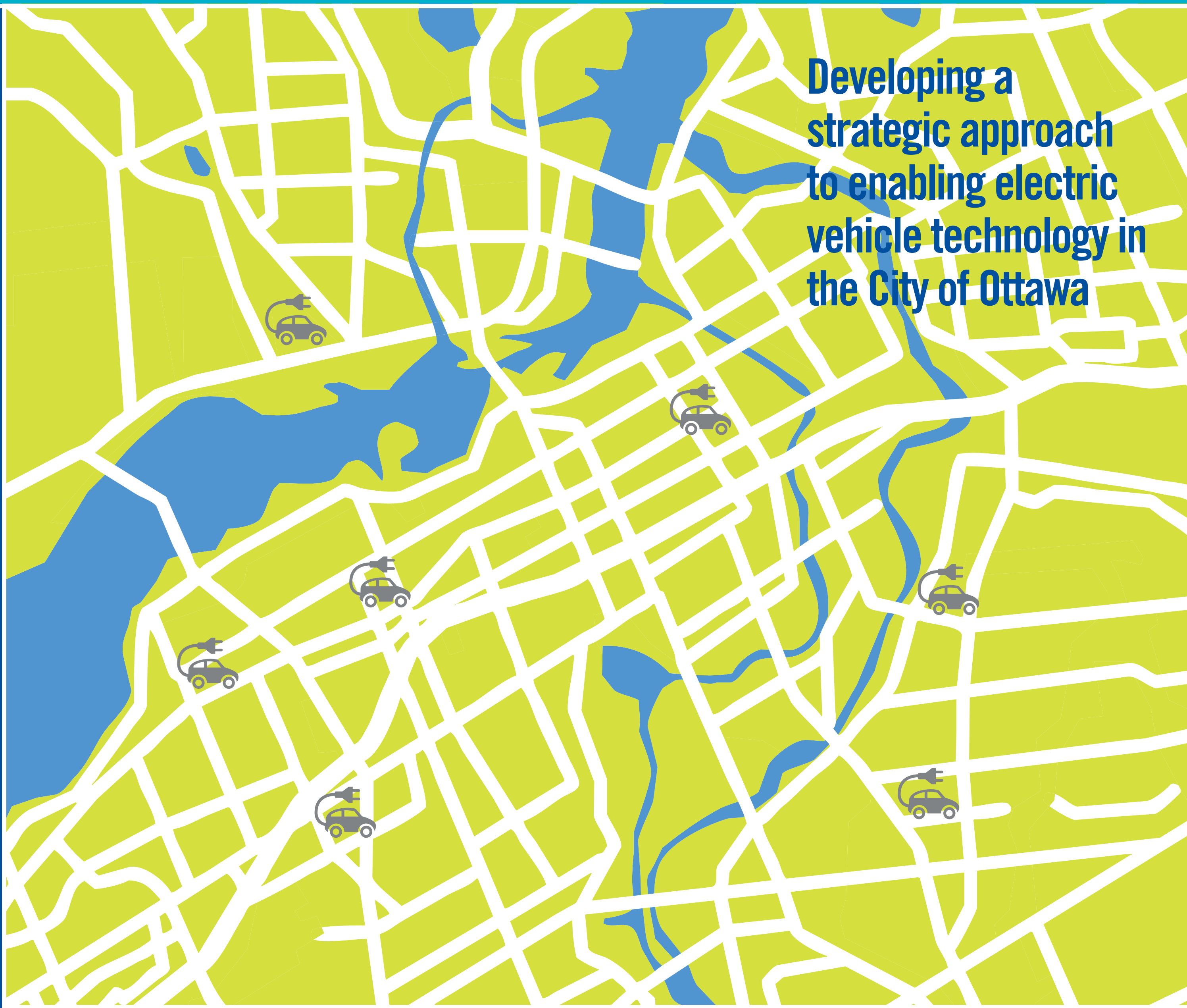
EMAP OTTAWA

ELECTRIC MOBILITY ADOPTION AND PREDICTION



Developing a strategic approach to enabling electric vehicle technology in the City of Ottawa

ABOUT POLLUTION PROBE

Pollution Probe is a national, not-for-profit, charitable organization that exists to improve the health and well-being of Canadians by advancing policy that achieves positive, tangible environmental change. Pollution Probe has a proven track record of working in successful partnership with industry and government to develop practical solutions for shared environmental challenges.

ABOUT ELECTRIC MOBILITY CANADA

Electric Mobility Canada (EMC) is a national, not-for-profit industry association advocating for electric transportation as the primary solution to Canada's transportation sector issues. Established in 2006, EMC members include the automotive industry, infrastructure and battery suppliers, electricity providers, end-user fleets, research and development institutions, and others who strive to maximize Canada's green potential.

ABOUT HYDRO OTTAWA

Hydro Ottawa Limited is a regulated electricity distribution company operating in the City of Ottawa and the Village of Casselman. As the third-largest municipally owned electrical utility in Ontario, Hydro Ottawa maintains one of the safest, most reliable and cost-effective electricity distribution systems in the province, serving 309,000 residential and commercial customers across a service area of 1,104 square kilometres. Hydro Ottawa receives power from the provincial electricity grid and transports it across a distribution network consisting of 85 distribution stations, 2,700 kilometres of underground cable, 2,900 kilometres of overhead lines, 43,000 transformers and 48,400 hydro poles.

ABOUT THE DEPARTMENT OF ELECTRONICS AT CARLETON UNIVERSITY

Carleton University is a dynamic research and teaching institution dedicated to achieving the highest standards of scholarship. Carleton offers 65 programs of study in areas as diverse as public affairs, journalism, film studies, engineering, high technology and international studies. More than 2,000 professors and staff members constitute a diverse and dedicated team serving 26,000 students. The Department of Electronics is a leader in advanced components for communications, computing and sensing applications.

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About This Report

Electric Mobility Adoption and Prediction (EMAP) combines sophisticated market research methodologies with detailed grid integration and impact analyses. The EMAP methodology is a tool of predictive analysis, capable of improving the efficiency of capital investments in electricity distribution system assets and electric vehicle (EV) charging infrastructure by ensuring that they align with the needs of early adopter markets.

In 2011, Pollution Probe collaborated with the Centre for Urban Energy (CUE) at Ryerson University on a pilot EMAP study for the City of Toronto. Building on the Toronto study, Pollution Probe partnered with the utilities in five other Canadian municipalities – Ottawa, Hamilton/St. Catharines, London, Markham/Richmond Hill/Vaughan and Calgary – to conduct further EMAP studies with support from the five utilities and the ecoENERGY Innovation Initiative led by Natural Resources Canada. This report summarizes the application of the EMAP methodology to the City of Ottawa and the implications of the EMAP analysis for Hydro Ottawa, the local distribution company (LDC).

Representatives of stakeholder organizations integral to the future of electrified transportation in Ottawa met regularly as an advisory group for the study, contributing to the overall project scope, sharing technical expertise and providing guidance for all milestones and deliverables. The participation of these expert advisory group members helped to ensure that a local perspective informed the project, thus providing further credibility and enhancing the value and relevance of the outputs. This study also led to the production of a number of complementary reports, including an in-depth investigation undertaken by Hydro Ottawa of the electricity distribution system at the systems level and full-length reports on the EMAP market research and the electricity distribution system assessment produced by Environics Research Group and the Department of Electronics at Carleton University, respectively. Taken together, these resources provide a comprehensive look at the implications of EV technology uptake for Ottawa and served as the basis for this report.

This report summarizes the process, findings and implications emerging from the Ottawa EMAP study.

This report summarizes the process, findings and implications emerging from the Ottawa EMAP study. It also proposes a set of strategic objectives and recommendations intended to prepare Hydro Ottawa to manage and support the use of EVs in its service area.

Report Outline

This report is divided into three sections describing the process, findings and implications of the EMAP study and exploring options for a strategic path forward.

Section One provides a brief description of the EV as an emerging technology and proposes a three-point strategy for enabling EV use in Ottawa, based on key findings from the EMAP market research and electricity distribution system assessment.

Section Two describes the specific process, outputs and assumptions made in the development and application of the market research. This section builds a detailed picture of the characteristics of potential early adopters, including a broad demographic profile, typical personal mobility patterns, and the barriers to and opportunities for the uptake of EVs. It also summarizes the outputs from a focus group held with current EV owners in the Ottawa area.

Section Three describes the methodology and results of simulation work conducted by the Department of Electronics at Carleton University, using data provided by Hydro Ottawa. The simulations address the capacity of the electrical distribution system at the neighourhood level to support additional loading resulting from EV charging under a number of conditions. This section also provides an overview of Hydro Ottawa's examination of its capacity to accommodate EV charging at the system-wide level.

A Strategic Approach to Enabling EV Use in Ottawa

The Electric Vehicle as an Emerging Technology

For EVs to become a viable part of a successful sustainable transportation system in the City of Ottawa, the social, environmental and financial needs of the user must be met. If early users of the technology are unable to experience and appreciate its full value, a broader market will not emerge. These early users will play a key role in expanding and developing the EV market and, for this reason, it is important to better understand exactly how to address their needs and incorporate the technology into their lives.

While the results of the EMAP study identify barriers and opportunities specific to EVs, the technology's adoption cycle also shares a number of characteristics with other emerging technologies. The process of technology adoption tends to follow a classical bell curve. The first users are known as innovators, followed closely by an early adopter group. Innovators are generally a very small number of risk takers who thrive on the challenge of a new technology and are willing to buy into a product even though the technology may ultimately fail. Early adopters, on the other hand, are generally more cautious in their adoption of a new technology and are not as willing to form new routines or behaviours to incorporate it into their lives. This observation is supported by the early adopter profile generated through the EMAP market research, which suggests that, in the City of Ottawa, this group is unaccustomed to inconvenience and perhaps reluctant to make the sacrifices they perceive to be necessary to transition to an EV, given current market and technological considerations.

Support or endorsement of a technology from the early adopter group is one of the most important factors contributing to its adoption by a broader market. Whereas innovators may be perceived as extravagant or in a better position to take risks than the general public, early adopters demonstrate a high degree of opinion leadership capable of generating confidence in the usefulness of a technology among the broader public. The early majority of the mass market tends to take its cues and base its decisions on the experiences of and feedback from early adopters because their choices are perceived to be more discerning. It is for this reason that the EMAP study focuses on this influential consumer group.

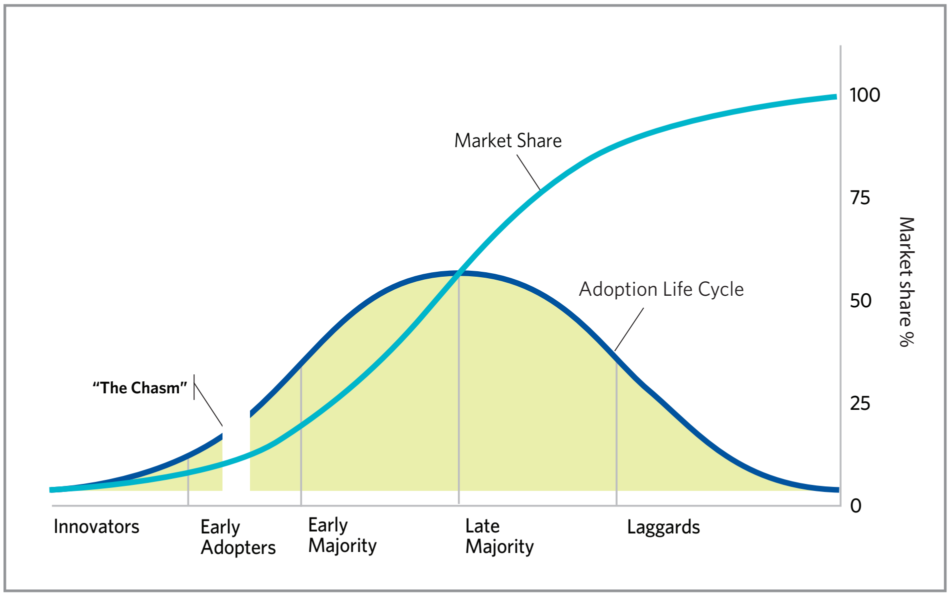
While the traditional bell curve has long been the typical visual representation of market development for an emerging technology, more recently, Geoffrey Moore* has introduced the notion of a "chasm." Moore argues that there is a gap (or chasm) between the early adopter group and the early majority because the latter not only wants a useful product but also a well-established infrastructure to support it. Moore believes that, during the chasm phase, an emerging technology experiences a pause in market development. The length of this pause depends entirely on how disruptive the technology is to "business as usual."

**Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers*. HarperCollins, 1991.

The actual market share held by an emerging technology does not follow the traditional bell curve for market development. Market share shows an upward trend before reaching full market saturation. This is because each adoption group is made up of a different number of people. For example, innovators and early adopters are relatively small groups and, as such, their interest in a technology translates into a relatively small percentage of the overall market. By the time the late majority and laggards adopt a technology, the market share is close to approaching saturation because these groups make up a much larger proportion of the population. See Figure 1.

There have been many attempts to forecast the rate at which the adoption of EVs will occur – whether it will move quickly, like the Internet or the radio, or whether it will resemble the slower adoption curve of the washing machine, considered a luxury item for many years. Radically new or different technologies may have a difficult time breaking through, not because of the merits of the technology itself, but because

Figure 1: Technology Adoption Life Cycle and Market Share



regulations, infrastructure, maintenance networks and user practices are aligned to an existing technology. This is certainly a major consideration in the case of EVs. The current automotive marketplace revolves primarily around gasoline-powered vehicles. In addition to automakers themselves, there is an entire aftermarket involved in manufacturing, distributing, retailing and installing vehicle parts, equipment and accessories for gasoline-powered vehicles. This is not to say, however, that emerging technologies are unable to overcome these challenges. (See Appendix A for a brief overview of the current EV market in Canada.)

While technological advances will go a long way to overcoming barriers to EV adoption, these alone may not be enough to appeal to the broader market. EVs will not succeed in the market if perceptions about their usefulness are not positive. For example, Consumer Reports, an independent organization that tests consumer products and services, awarded the Tesla Model S a rating of 99 out of 100 in 2013. This matches the best score earned by any vehicle, not just an EV, in the history of Consumer Reports. Yet many were quick to point out that, because of the lack of infrastructure to support its use, particularly infrastructure for fast charging, the Model S is hardly just one point shy of perfect.

The electricity distribution system's ability to respond to the power demand for EV charging will play a critical role in the adoption of the technology, particularly in the broader market.

The electricity distribution system's ability to respond to the power demand for EV charging will play a critical role in the adoption of the technology, particularly in the broader market. One of the key factors affecting the ability of the electricity distribution system to accommodate EV-related loading is the capacity of the vehicle's on-board charger. The charging process for an EV involves components both on and off the vehicle. Electricity delivered through an external device such as a household outlet or an EV charging station is converted to battery power by a small charger on board the vehicle. The charging level determines the rate at which electrical energy is drawn when an EV battery is being charged. Most of the first wave of mass-produced EVs on the market contain an on-board charger rated at 3.3 kW or 6.6 kW when charging at 240 V – similar to the power delivered through a clothes dryer receptacle. This is known as Level 2 charging. Most EVs can also be charged using a standard 120 V household outlet; this is known as Level 1 charging. A vehicle charging at Level 1 draws power at a lower rate, between 1.0 kW and 1.9 kW – similar to a typical hair dryer.

With advances in technology, some newer EVs have significantly more powerful on-board chargers – in some models, rated up to 20 kW. Some models have the capacity to use Level 3 charging (also known as DC fast charging). Level 3 chargers use greater amounts of power, operating at up to 500 V, to provide a fast charge – in minutes rather than hours. The amount of power required to supply a fast charge is so great that, without significant upgrades, very few homes would be able to support a Level 3 charging station; as such, Level 3 charging is primarily found at public charging stations. Because these fast chargers can address concerns about the limiting range of EVs ("range anxiety") and the amount of time required to charge the vehicle away from home, implementing them will likely be a key factor influencing EV adoption and will require careful planning on the part of the LDC.

The Potential Impacts of EV Use in Ottawa

Current patterns of EV charging in Hydro Ottawa's service area do not represent a risk to the utility's capacity to maintain a safe and reliable supply of power to all its customers. Nor is the demand for power to charge EVs at home expected to exceed the rated capacities of Hydro Ottawa's current infrastructure assets, either at the neighbourhood level or system wide, in the near future. But in the coming years, EV charging will increasingly put the integrity of the utility's service at risk. The EMAP market research suggests that the population of Ottawa is characterized by an above-average propensity to consider adopting EV technology, with potential early adopters identified in both established neighbourhoods and in new community developments alike. At the same time, the prevailing trend in new EV technology is towards larger batteries and faster charging, as automakers respond to market demand for greater driving range, convenience and overall utility. The compounding effect of these two factors means that, in the absence of proactive measures, Hydro Ottawa's capacity to accommodate the demand for electricity could be exceeded.

The good news is that the EMAP grid assessment shows that, provided the demand for power to charge EVs is actively managed, such risks can be effectively mitigated – indeed, the risks could actually be turned into cost advantages for the utility and its customers. For example, if just a handful of neighbouring households charge EVs with greater on-board charger ratings at the same time, the electricity infrastructure on some streets could be overloaded; however, by staging and sequencing the power supplied to each EV, a full charge could be provided to as many EVs as there are households on the street – with no changes to the existing electricity distribution assets. Taking proactive approaches such as this to manage EV charging could, in the long term, help the LDC to level the overall load on the system, which currently fluctuates over a 24-hour period between daytime "peaks" and evening "valleys." Load levelling can help to optimize asset utilization, ultimately leading to cost savings for customers, regardless of whether or not they own an EV.

Using electricity to replace the combustion of gasoline and diesel to power transportation in the City of Ottawa also offers broader social benefits, such as cleaner air and reduced emissions of greenhouse gases. Because EV adoption will, in the long term, pose challenges for the electricity distribution system and at the same time deliver significant consumer and environmental benefits, it makes sense for Hydro Ottawa to respond pre-emptively to address the risks and proactively to capitalize on the benefits associated with EV charging. Such a strategy is consistent with Hydro Ottawa's mandate to ensure a safe and reliable supply of power for its customers and with its long-standing commitment to routinely assessing the capacity of the electricity distribution system on an ongoing basis, identifying and addressing issues before they become a problem.

Enabling Electric Vehicle Use in Ottawa – A Strategy to Manage the Risks and Optimize the Benefits

By developing a strategy for enabling EV use in its service area, Hydro Ottawa can enhance its current organizational capacities to be responsive to consumers' basic needs and to the evolving state of EV technology; to be proactive in encouraging EV charging patterns that optimize benefits for all customers; and to be progressive in promoting public awareness of EV technology, informing customers' decisions about becoming EV drivers and supporting their transition. Flexibility will be key to ensuring the success of this strategy for enabling EV adoption as it evolves within the broader electricity utility landscape of smart grid technologies, distributed generation and demand response programming.

Key stakeholders internal and external to Hydro Ottawa must be engaged in the development of this strategy because the successful deployment of EV technology in Ottawa depends on actions and decisions taken by a range of individuals and organizations. Stakeholders internal to Hydro Ottawa include its Executive Management Team as well as those responsible for asset management, communications, customer service, and conservation and demand management. Stakeholders external to Hydro Ottawa include

- the Ontario Energy Board (OEB)
- the Independent Electricity System Operator (IESO)
- the Ontario Ministry of Energy
- the Ontario Ministry of Transportation
- Hydro Ottawa customers, including current and future EV owners and users
- the City of Ottawa
- academia, including local colleges and universities
- automotive sales professionals (e.g., the Ottawa New Car Dealers Association)

A strategic approach to enabling successful EV use in Ottawa can be built on the following recommendations, drawn from the EMAP market research and electricity distribution system assessment:

1 Enhance responsiveness to evolving patterns of EV charging.

- Monitor the progression of the EV market in the Hydro Ottawa service area. This means maintaining knowledge and awareness of changes in EV products and technologies, operating standards, regulations and general market adoption. It also includes monitoring and evaluating the evolving impacts of EV charging on the local distribution system.
- Implement a program through which Hydro Ottawa customers can voluntarily share information about their intention to purchase an EV, the technology they choose to purchase (e.g., vehicle model and charging services), or their experience driving an EV. With this information, Hydro Ottawa can conduct predictive assessments of the infrastructure that will be affected and ensure that quality of service is maintained.
- Equip Hydro Ottawa's communications and customer service groups with the necessary information, including sample scripting where appropriate, to respond to general customer inquiries about EV technology, including the EV charger installation process and charging station locations.
- Continue to ensure that the secondary drop leads that deliver power at the neighbourhood level conform to the new minimum 325 A rating not only in new installations but also in scheduled replacement of existing assets. This will ensure that overcurrent conditions on secondary drop leads are less likely to occur as a result of EV charging loads in residential areas.
- Collaborate with key stakeholders to identify optimal locations for public charging stations. The EMAP study identifies range anxiety among potential early adopters of EVs as a barrier that can be addressed by providing fast-charging services away from home. This report points to some desirable locations for charging stations, but further planning and coordination among Hydro Ottawa and other stakeholders (e.g., the municipal government, property managers and employers) will be necessary.

Key stakeholders internal and external to Hydro Ottawa must be engaged in the development of this strategy because the successful deployment of EV technology in Ottawa depends on actions and decisions taken by a range of individuals and organizations.

2 Encourage EV charging during optimal time frames.

- Promote and facilitate EV charging habits that reduce daily peaks in demand for power and that optimize use of the distribution system's existing assets. For example, encouraging EV charging between the hours of 11:00 p.m. and 5:00 a.m. would help to ensure that EVs do not contribute to peak demand on the distribution system. Managing optimal EV charging will mean that the prevailing 50 kVA design standard for pole-top and pad-mounted transformers can be maintained, which can help to control infrastructure costs. Even very high levels of demand for charging services (i.e., every house charging an EV at night) can be accommodated if the load is actively managed (e.g., by way of smart grid automation or user-programmable charging parameters, such as level of charge or timing of charge).
- Engage the system regulator and other key stakeholders in dialogue about super off-peak electricity service rates for EV owners. This would constitute a financial reward for customers who charge their EVs in a time frame that helps to optimize system utilization.
- Engage the system regulator and other key stakeholders in dialogue about the opportunities for and benefits of responsive, automated EV charging. Establishing a program in which EV owners can volunteer to share control of charging times and levels with Hydro Ottawa could be a productive first step.

3 Establish an active engagement with customers on EV technology.

- Contribute to the creation of targeted communications to address the concerns identified in the analysis of the early adopter community, as summarized in this report. The EMAP study also shows that Hydro Ottawa is considered a trusted source of information about EV technology and a trusted provider of services for EV charging. This provides a solid foundation for effective communication with customers – both early adopters and the general public.
- Contribute to building understanding of the benefits and limitations of EV technology, particularly from a social perspective. For example, the EMAP study shows that early adopter interest in EV technology is more strongly linked to environmental performance (e.g., mitigating air pollution and climate change) than it is to the financial advantages of reduced fuel and maintenance expenses.
- Help to educate customers about the benefits of optimal charging behaviours and how they can improve the reliability and performance of existing distribution system assets and help to keep rates low.
- Help to identify opportunities to educate businesses and workplaces on EV charging so that they can directly support EV deployment across Ottawa. The EMAP study indicates that employers are not aware that the lack of workplace charging facilities represents a very real barrier for employees who want to drive EVs to work. Employers are also not well informed about how appropriate charging services are installed and the costs involved in doing so.
- Help automotive dealers and their associations to explore opportunities to respond to customers' questions about EV technology and to provide them with the information they need to drive electric.

SECTION TWO:
Market Research

Purpose of Surveying the City of Ottawa

Understanding the perceptions of EVs – both positive and negative – among the early adopter community in the City of Ottawa will make it possible to develop effective and targeted information and awareness campaigns and to provide a framework to facilitate local policy implementation. Market research can generate critical information on the needs and views of the early adopter population, using demographic and psychographic analyses to understand the barriers that must be addressed to encourage the uptake of EV technology.

Much can also be learned from drivers in Ottawa who are already successfully using the technology. A better understanding of the usage patterns of current EV owners, related to personal mobility and charging behaviours, can supplement the information drawn from the analyses of the early adopter community, many of whom have little or no direct experience with EVs. It is important to understand how EVs can be used in order to ensure that their deployment in communities is a successful experience for owners, and that the range of potential benefits associated with the technology can be fully realized.

Methodology

The market research process involved three separate but related sets of investigations:

- secondary research to identify the geographic distribution of potential early adopters of EV technology
- primary research to characterize early adopters and identify potential opportunities and barriers to EV adoption
- an informal focus group with EV owners to better understand real-life experiences related to driving electric

The specific process, outputs and assumptions made in the development and application of the research are described below.

Secondary Research to Identify the Geographic Distribution of Potential Early Adopters

The secondary research sought to identify the behavioural and attitudinal characteristics of likely early adopters of EV technology and to map the neighbourhoods in which they may tend to cluster. This research was the basis for the primary research that followed, allowing for a more efficient and targeted household survey of the characteristics and preferences of likely early adopters of EV technology.

The secondary research was undertaken in collaboration with Environics Analytics, using its proprietary PRIZM$_{c2}$ segmentation system database. The PRIZM$_{c2}$ system classifies every neighbourhood and postal code throughout Canada into one of 66 segments based on the most important drivers of consumer behaviour, including demographics, lifestyles and social values. It assumes that neighbourhoods that are classified similarly have comparable demographic, behavioural and attitudinal characteristics regardless of where they are located. As such, the PRIZM$_{c2}$ segments are an effective means of estimating behaviours and attitudes at a very local level, based on data collected at a very high level.

For the purpose of creating a profile of a potential early adopter of EV technology, data from a number of different surveys as well as national and regional vehicle purchase information were linked to the PRIZM$_{c2}$ segments. These databases included the Environics Analytics DemoStats database, the Environics Research Group Social Values nationwide survey, and IHS Automotive's New Vehicle Registrations (NVR) and Total Vehicles in Operation (TVIO) databases.

Because EVs currently account for only a small portion of total vehicles in the marketplace, EV purchase data in surveys and databases are limited. Therefore, the following key variables were selected as indicators of the propensity to purchase an EV:

- demographic characteristics
- social values
- vehicle purchase data

These variables were developed using analogous products and services, appropriate demographics and relevant social values. The key variables are described in further detail below.

KEY VARIABLES USED AS INDICATORS OF THE PROPENSITY TO PURCHASE AN ELECTRIC VEHICLE

Demographic Characteristics

Early adopters were assumed to be those who met a set of demographic criteria based on an understanding of the current characteristics of the EV market and technology. These demographic criteria are as follows:

- **Average household size of not less than two people:** Because of the potentially limiting vehicle range, it was assumed that early adopters of EV technology would at least initially see the vehicle as a second, rather than the sole, household vehicle. While EVs easily suit urban transportation needs, longer trips could require a second, conventional gasoline-powered or hybrid vehicle. If the EV were bought as a second vehicle, it was assumed that the current purchase price of an EV would be prohibitive for such purposes for a single household resident.
- **Smaller average household size:** Many EV models currently on the market tend to be small and, therefore, more suitable for small households than for large families. However, consideration was given to the increasing size and range of EV models being introduced as the market evolves.
- **Greater than average household income:** Based on the high purchase price of EVs at the time the research was done, it was assumed that the household income of early adopters would be high compared to the general population in Ottawa. Special consideration was, therefore, given to the types of neighbourhoods with high disposable incomes.

Social Values

Potential early adopters of EV technology were assumed to be those who exhibited one or more of the following three attitudes:

- **Ecological lifestyle:** This indicator characterizes those individuals who value the integration of environmental concerns with purchasing decisions. Because of the potential environmental benefits and emissions reductions promised by EV technology, early adopters were assumed to be environmentally conscious.
- **Enthusiasm for technology:** This indicator reflects a favourable bias towards technology. People with an enthusiasm for technology tend to believe that it is the best tool for adapting and responding to the demands of daily life. Because EVs are not yet part of the mainstream marketplace, early adopters of EVs were assumed to have an enthusiasm for technology.
- **Consumptivity:** This indicator represents an enthusiasm for purchasing products or services in an area of particular interest (e.g., music, electronics) about which consumers make an effort to stay informed. Because information about EVs is not yet widely available in the mainstream media, particularly in Canada where the market is still small, it was assumed that early adopters of the technology would have to be particularly enthusiastic or have made an effort to become informed about the topic.

Vehicle Purchase Data

For the purposes of the market research, EV purchase data, including both new vehicle registrations between January 2012 and June 2013 and total vehicles in operation in 2012, were used to identify early adopters of EV technology. Because EV purchases are low, potential early adopters of EV technology were assumed to share psychographic and demographic characteristics with early adopters of hybrid vehicle technology. Accordingly, hybrid vehicle purchases for the same periods were also used to help estimate potential EV demand.

SECONDARY RESEARCH RESULTS

The variables identified as indicators of the propensity to purchase an EV were used to create profiles that were compared with the $PRIZM_{c2}$ system to identify a set of early adopter target segments. This section documents the findings from the secondary research, including a description of the target segments and their distribution within the City of Ottawa.

Target Segments

Eight psychographic segments of the Ottawa population were identified based on the selected demographics, social values and vehicle purchasing data. These segments include the types of individuals and households considered the most likely to be early adopters of EV technology in Ottawa.

In two of the eight segments identified based on the strength of their alignment with the characteristics of potential early adopters, there were not enough households located within the boundaries of the City of Ottawa to be included in the household survey. These two segments (Nouveaux Riches and Mini Van & Vin Rouge) are heavily concentrated on the Québec side of the Ottawa River, which does not fall within the Hydro Ottawa service area. The following are the six segments selected:

Cosmopolitan Elite: This group represents Canada's wealthiest people, including new-money entrepreneurs and heirs to old-money fortunes. The Cosmopolitan Elite are urban, middle-aged families and older couples. With household incomes five times the national average, this segment is concentrated in only a handful of established neighbourhoods throughout the country.

Urbane Villagers: Located in Canada's largest urban centres, this segment is a prosperous world of stately homes and high-end cars, charity auctions and golf club memberships. The nation's second wealthiest segment, it is characterized by married couples with university degrees and university-aged children, and includes a significant percentage of European, Asian and Middle Eastern immigrants.

Suburban Gentry: This segment is made up of Canada's up-and-coming business class, with a high percentage of managers, scientists, government workers, and other professionals. Suburban Gentry residents rank near the top for operating a small business, owning business software and taking business trips. They include dual-income couples with university degrees and large families, are big spenders, particularly on entertainment, and take pride in their healthy lifestyle.

Young Digerati: This segment consists of the nation's tech-savvy singles and couples living in fashionable neighbourhoods in a handful of big cities. Affluent, highly educated and ethnically mixed, Young Digerati communities are typically filled with high-rise apartments and expensive condos located near fitness clubs, clothing boutiques and bars. Because many residents in this segment have yet to start families, they have the time and discretionary income to pursue active social lives.

Money & Brains: The residents in this segment have high incomes, advanced degrees and sophisticated tastes. Many of them are empty nesters or married couples with university-aged children, who live in older, fashionable homes in both urban and suburban neighbourhoods.

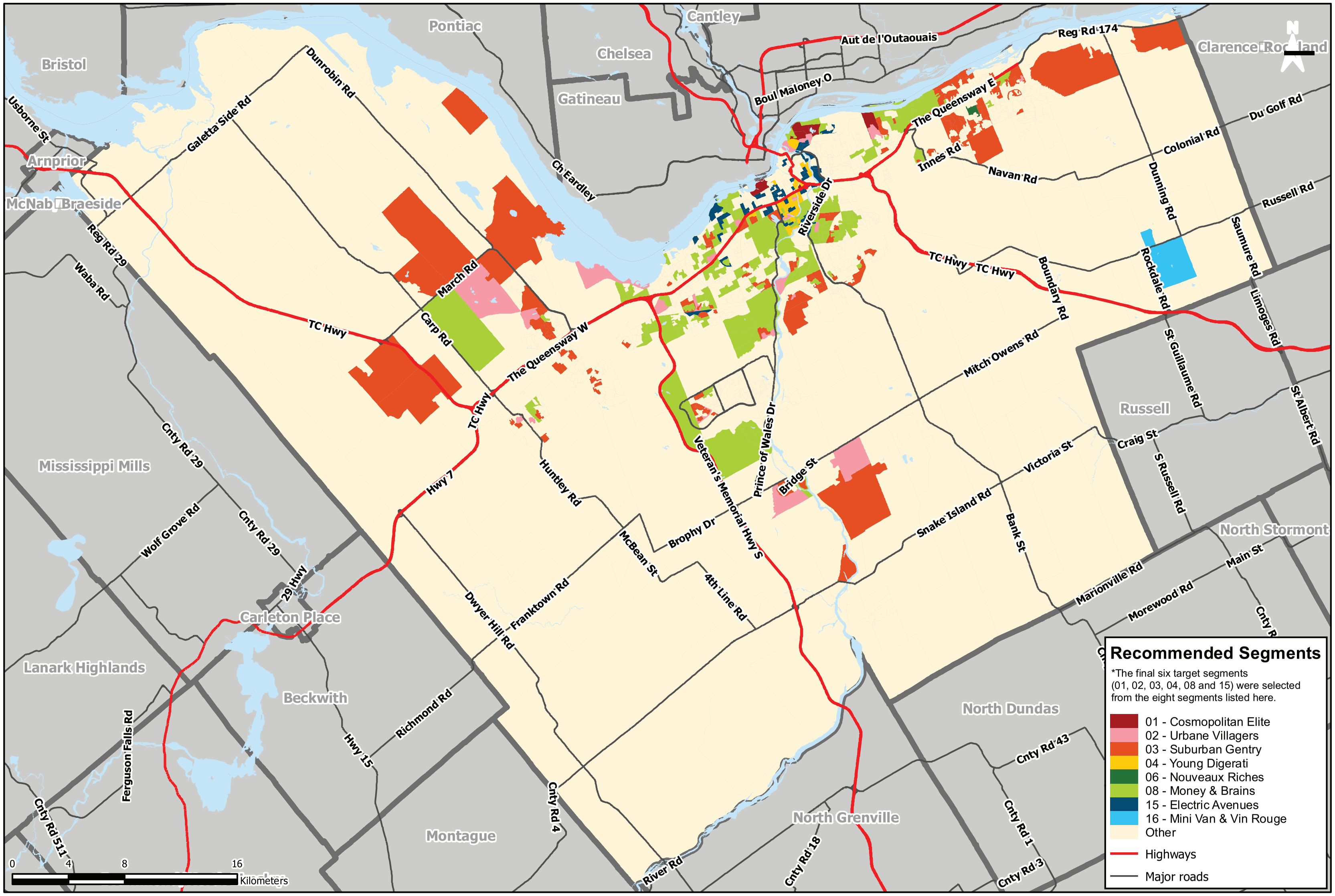
Electric Avenues: This group represents young singles and couples pursuing lively urban lifestyles. Concentrated in Canada's largest urban centres, these older, crowded neighbourhoods are known as havens for university graduates who rent apartments, have mid-level jobs and enjoy active leisure lives. While residents here have above-average household incomes, their spending power appears even greater because many of these households are childless.

Geographic Distribution

A map was created, indicating the geographic distribution of each of the six target segments within the City of Ottawa, based on postal codes (see Figure 2). Each area identified on the neighbourhood map represents a postal code area of potential early adopters, providing a visual representation of where they may be clustered throughout the city (the size of each area is determined by the boundaries of the postal code and is not a representation of the concentration of potential early adopters). These areas became the focus of the primary research described below.

Figure 2: Distribution of Target Segments in the City of Ottawa

Electric Mobility Adoption and Prediction Plan
Recommended Segments Map
Ottawa – By Dissemination Area (Based on Postal Codes)



Primary Research to Validate and Characterize Early Adopter Neighbourhoods

In addition to estimating the demand for EVs in the Ottawa area using $PRIZM_{c2}$-based tools, the secondary research informed the primary research that followed. A questionnaire was designed for use in a household telephone survey conducted by Environics Research Group. The survey was conducted in key locations containing high proportions of segments with behavioural and attitudinal characteristics linked to the early adoption of EV technology. A total of 750 Ottawa residents participated in the survey, which took place between August 27, 2013, and September 15, 2013, and averaged approximately 16 minutes in length. The use of a telephone survey rather than an online survey allowed for a targeted focus on residents in the geographic areas identified; it would have been difficult to screen for this online. In addition, the telephone survey allowed for a greater opportunity to test scenarios with survey respondents to build an understanding of how best to position EVs in a deployment strategy.

Respondents were screened to ensure that they were licensed drivers, aged 18 or over, and involved in household vehicle purchase decisions. They also had to have bought or leased a 2011 or newer vehicle within the past two years or be intending to buy or lease a late-model vehicle in the following two years. Respondents who met these criteria were deemed to have an understanding of or experience with the factors contributing to purchasing decisions for a new vehicle.

The household survey was designed to gain insight into motivations for and interest in EV use, the personal mobility patterns of the respondent, the expectations of EV technology, and the barriers to address and opportunities to leverage in relation to EV use. The survey was divided into the following four sections:

- vehicle ownership and use
- awareness and perceptions of EVs
- charging capabilities
- market segmentation and respondent profile

KEY FINDINGS FROM THE PRIMARY RESEARCH

This section presents key findings and insights from the household telephone survey. It begins with a profile of potential early adopters and is followed by a discussion of their awareness and perceptions of EV technology and their expectations for residential charging.

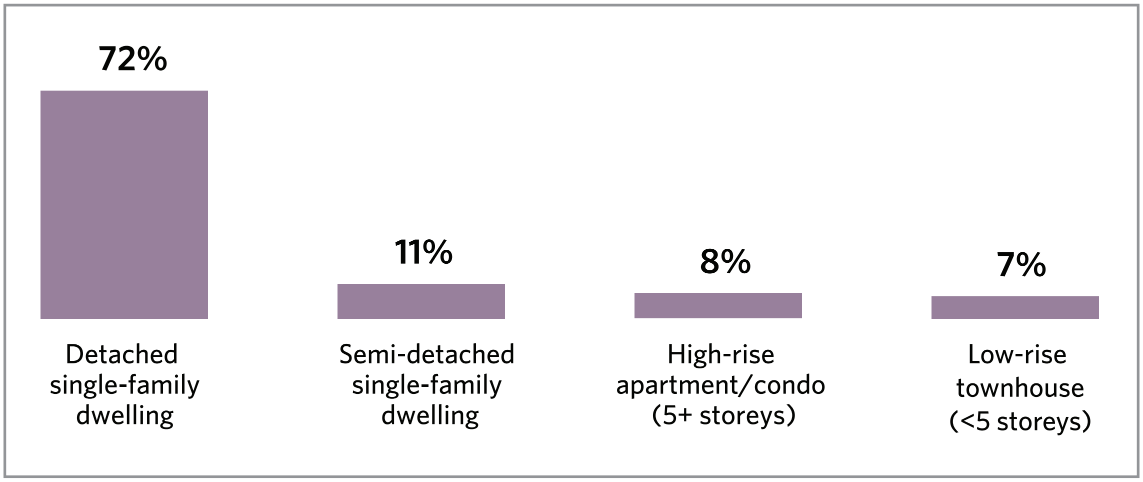
Profile of the Potential Early Adopter

Demographic Profile

Potential early adopters are older, better educated and more affluent than the general population. The majority live in detached, single-family homes.

Potential early adopters are considerably more likely to be over the age of 45 than the general adult population in Ottawa. They are better educated, with close to three-quarters of those surveyed holding a university degree (bachelor or post-graduate), compared to only 42 per cent of the general population. Potential early adopters are also twice as likely as the average city resident to have a household income of $150,000 or more, and a strong majority live in detached single-family homes and have no children currently living with them.

Figure 3: Dwelling Type



Around eighty per cent of potential early adopters consider themselves to be "opinion leaders," which means that they enjoy sharing their opinions with others, are sought out for their opinions or actively seek out new information sources. Three in ten use social media to distribute or follow information on subjects of interest to them.

Vehicle Purchasing Preferences

Personal experience with an EV is linked to greater interest in owning one.

Of the 750 participants in the household telephone survey, one in ten indicated that they currently own a hybrid vehicle (not a plug-in), and four people reported owning an EV. Among potential early adopters who do not currently own an EV, personal experience with EVs is limited. Only 3 per cent have driven one, while one in ten has been a passenger, and fewer than one in five reported knowing someone who drives one. A strong majority (eight in ten) have not had any of these experiences with EVs. Those with personal experience with an EV were more likely than those without to indicate that they would either likely or definitely consider the purchase of an EV in the near future. Personal experience and exposure to EVs is likely to increase and, as it does, it is expected that interest in purchasing them will likely also increase.

Figure 4: Experience with an Electric Vehicle

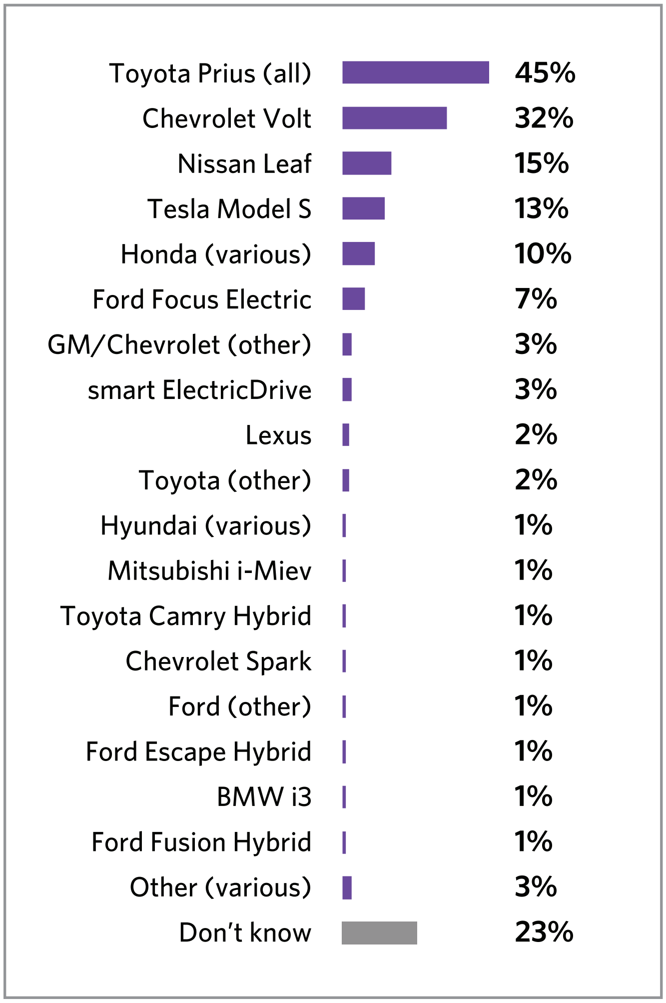
Experience with electric vehicles in terms of	(n=746) %
Having previously owned or driven one	3
Knowing someone else who owns/drives one	17
Riding in one as a passenger	11
None of the above	78

Subsample: Intending to purchase a new vehicle and recent purchasers who do not currently own an EV.

Note: adds up to more than 100% due to multiple mentions

Despite the limited incidence of personal experience with an EV, three-quarters of those who do not currently own an electric or hybrid vehicle and who indicated that they were not considering one were able to name at least one make or model on the road today. Those who could name a specific model almost always mentioned a hybrid. The Toyota Prius and the Chevrolet Volt were the most commonly mentioned models, followed by the Nissan LEAF and the Tesla Model S. The ability to name an electric or hybrid vehicle increases with the likelihood of considering the purchase of an EV.

Figure 5: Most Mentioned Hybrid or Electric Vehicles on the Road Today



Subsample: Drivers who do not own an electric or hybrid vehicle and are not considering one (N=704)

Reliability and fuel efficiency are the main considerations for potential early adopters when they are purchasing a vehicle.

Reliability and fuel efficiency were the top responses for both recent and prospective buyers when they were asked why they chose their current vehicle or would choose their next vehicle. Prospective buyers were almost twice as likely (39 per cent) as recent purchasers (24 per cent) to cite fuel efficiency as the main consideration. While recent purchasers were more likely to note positive experience with a make or model of vehicle as a factor in their purchase decision, prospective buyers were more likely to mention fuel efficiency, safety ratings or environmental friendliness.

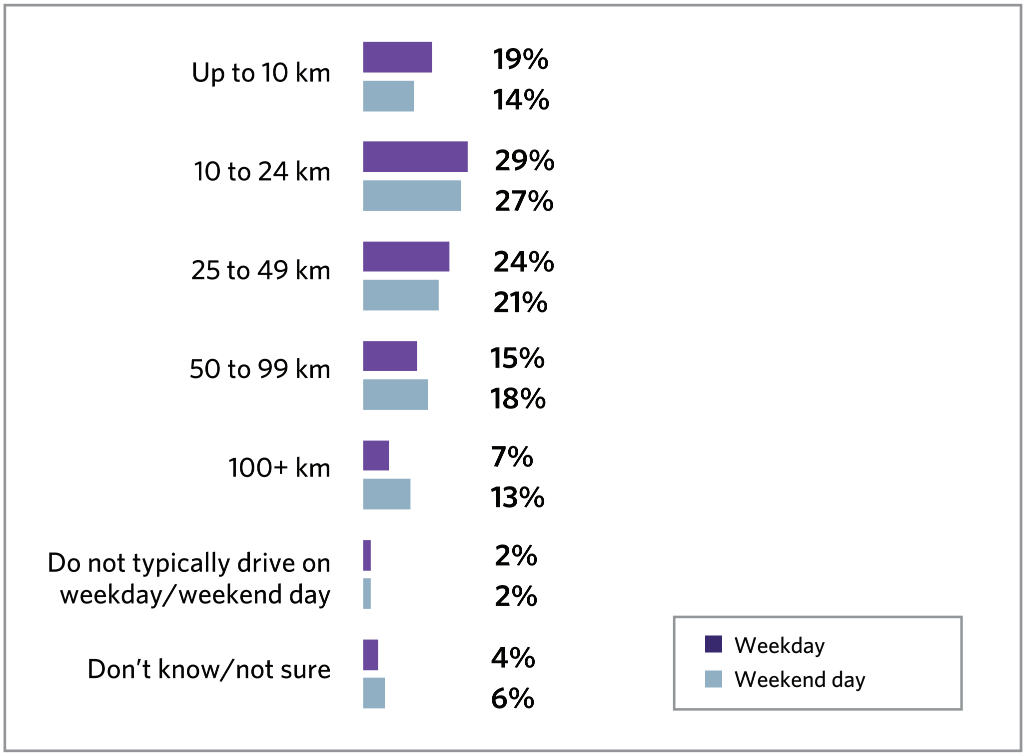
Personal Mobility Patterns

Close to half of all potential early adopters use their vehicles every day.

About half of potential early adopters (46 per cent) indicated that they use their vehicles seven days a week. Driving every day increases proportionally with the number of vehicles in the household and with the distance driven on a typical weekday. It is also higher among those with a child in the home (54 per cent). Driving seven days a week, however, does not appear to have any relationship to the level of interest in purchasing an EV in the next couple of years.

Close to half of potential early adopters travel more than 25 kilometres on a typical weekday, while 52 per cent drive the same distance on a typical weekend day. Driving 50 kilometres or more on the weekends was highest among those who would definitely not consider purchasing an EV. The four EV owners in the survey reported driving a range of distances on both weekdays and weekend days.

Figure 6: Kilometres/Day Typically Driven



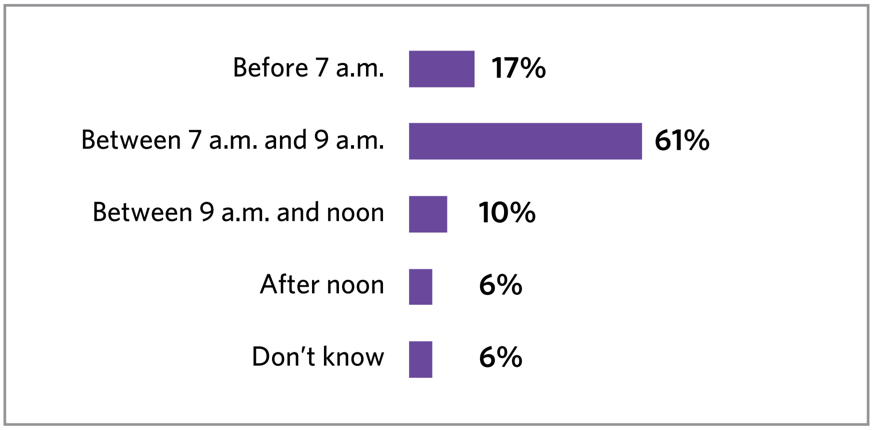
Four in ten potential early adopters are considered vehicle commuters.

Four in ten potential early adopters (41 per cent) said that there is a specific location that they typically drive to at least three days per week and where they leave their vehicle for three or more hours (the selected proxy for vehicle commuting). Vehicle commuting increases with household income and is highest among those with incomes of $150,000 or more.

The majority of vehicle commuters leave home between 7 a.m. and 9 a.m. and return home between 5 p.m. and 7 p.m.

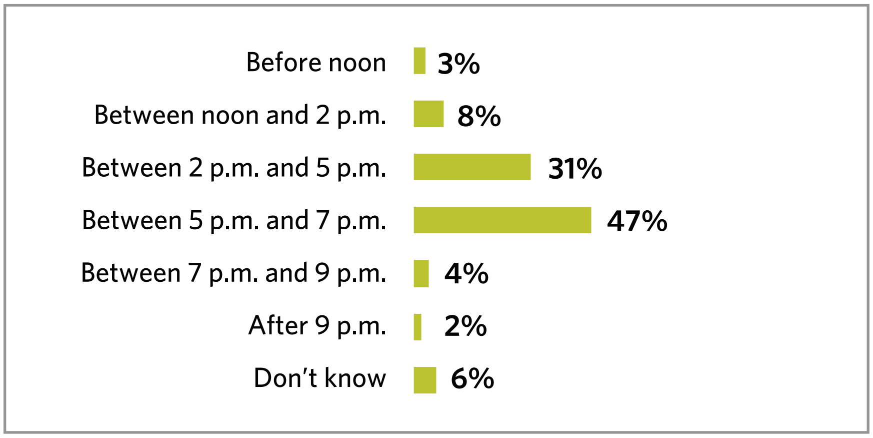
Most vehicle commuters described a typical workday as one on which they leave home between 7 a.m. and 9 a.m. (61 per cent) and return home between 5 p.m. and 7 p.m. (47 per cent). Vehicle commuters who indicated that they typically drive 50 or more kilometres on a weekday were more likely to say that they leave home before 7 a.m. Vehicle commuters were also asked to indicate how many hours they park at the location where they typically leave their vehicle. The most common response was eight hours (39 per cent). Close to six in ten spend at least eight or more hours parked at this location, while 41 per cent spend seven or fewer hours.

Figure 7: Time of Day When Vehicle Commuters Typically Leave Home



Subsample: Those who leave their vehicle at a specific location at least 3 days per week for at least 3 hours (N=310)

Figure 8: Time of Day When Vehicle Commuters Typically Arrive Home



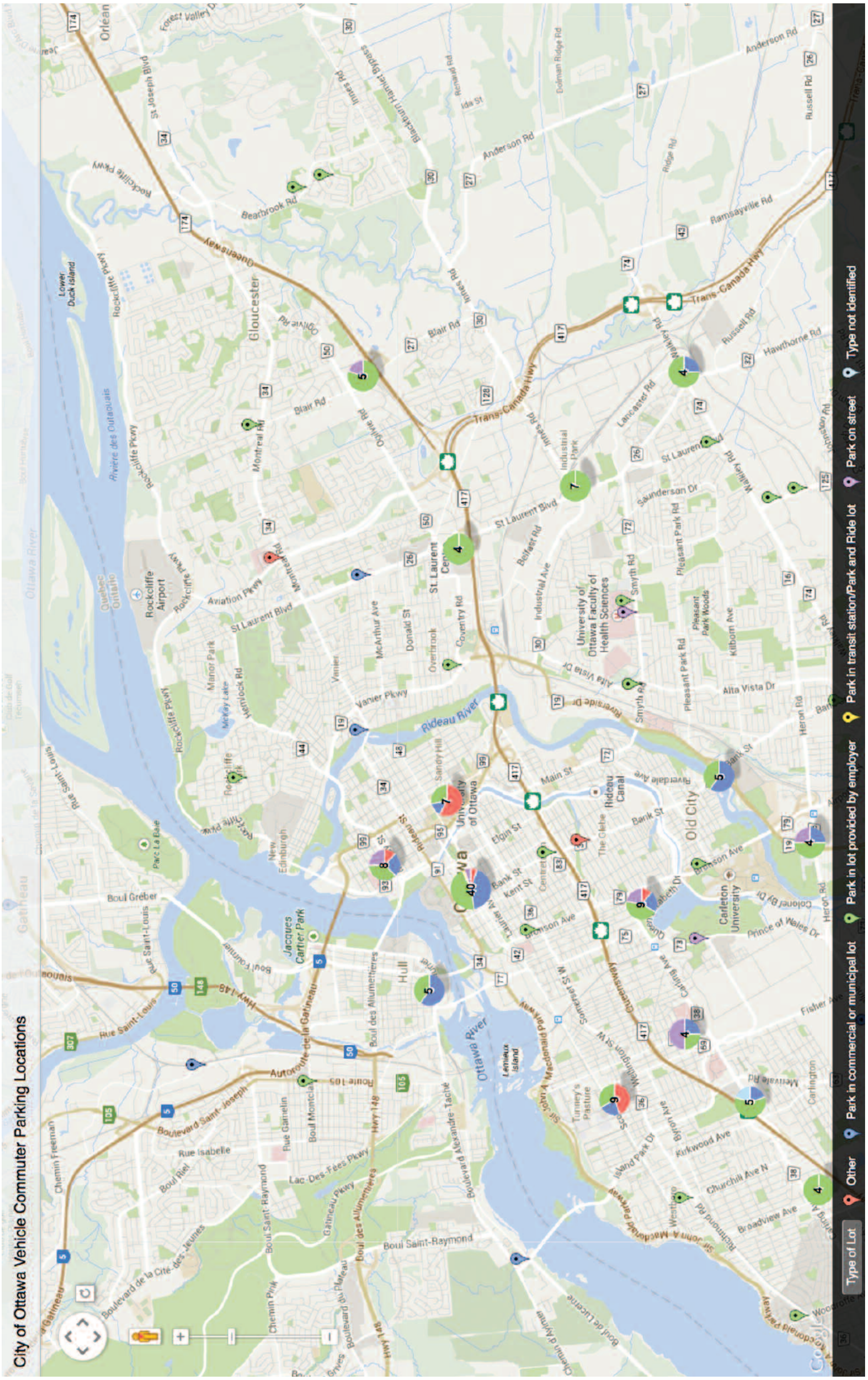
Subsample: Those who leave their vehicle at a specific location at least 3 days per week for at least 3 hours (N=310)

The majority of vehicle commuters park in an employer-provided lot

When asked which of several options describes their typical parking arrangements at the location where they park at least three days per week, the majority of vehicle commuters indicated that they park in an employer-provided lot.

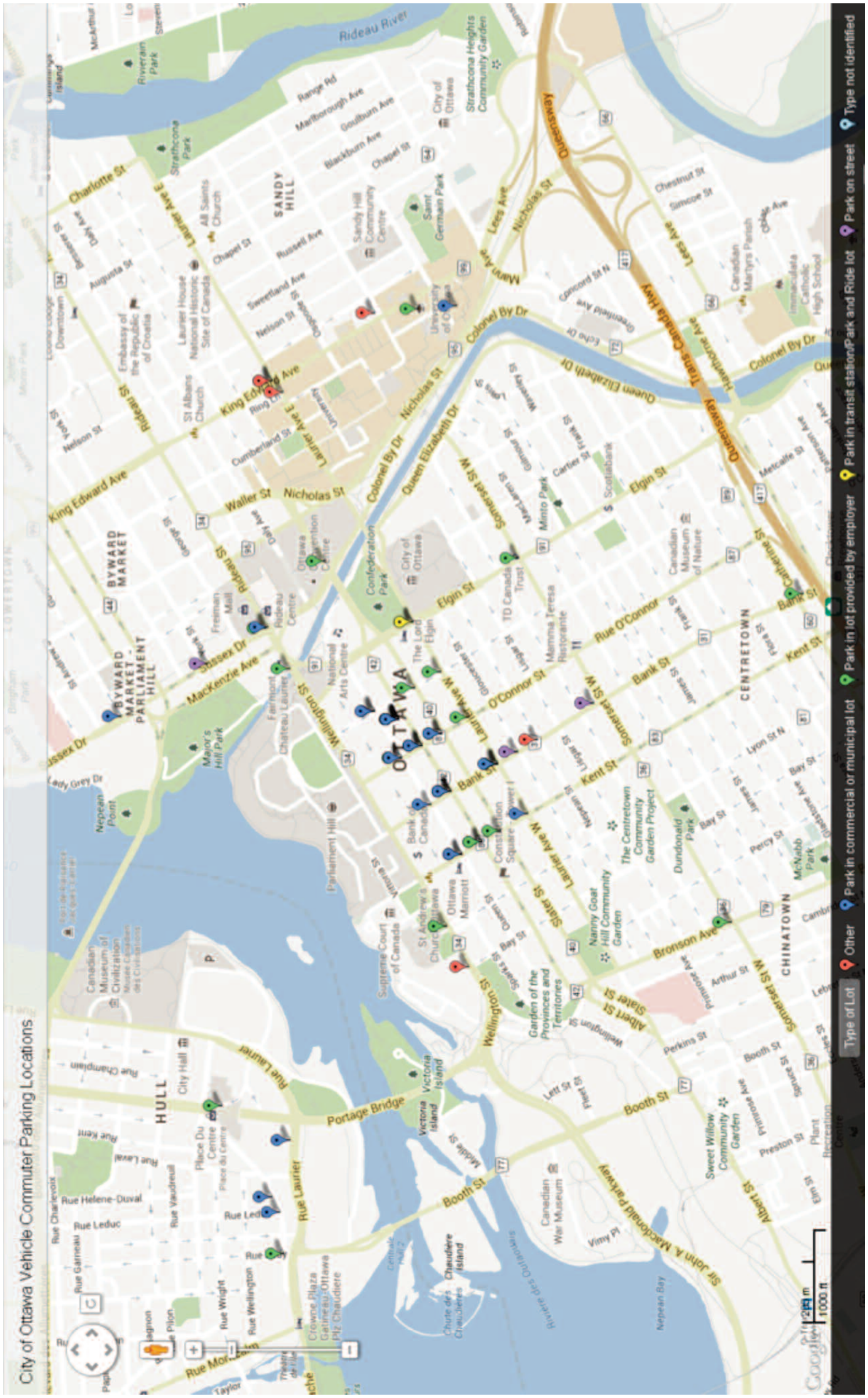
When asked to name the major intersection nearest the location where they typically leave their vehicle, vehicle commuters reported locations throughout the region (see Figure 9). Many of the vehicle commuters reported that they commute to downtown Ottawa (see Figure 10). Some of the vehicle commuters commute to the Québec side of the Ottawa River and park there during the day; these people could be looking to charge their EVs outside Ottawa during the day even though they reside in Ottawa.

Figure 9: Vehicle Commuter Parking Locations in the City of Ottawa by Lot Type



Note: The numbers in the circles indicate the number of respondents.

Figure 10: Vehicle Commuter Parking Locations in Downtown Ottawa by Lot Type



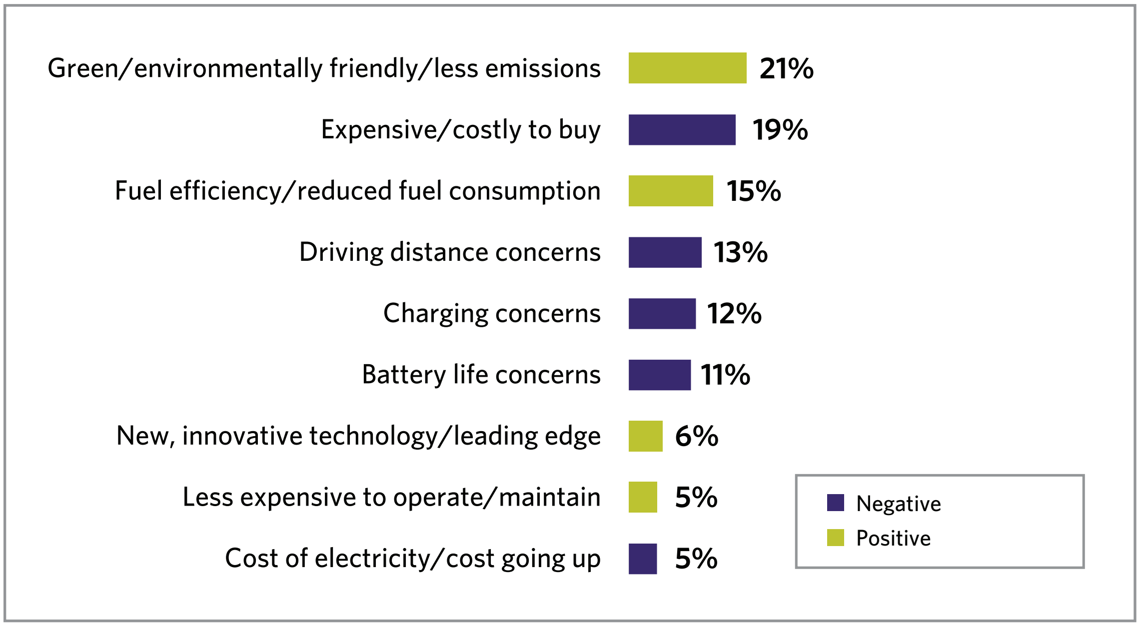
Awareness and Perceptions of Electric Vehicles

Familiarity with Electric Vehicles

Potential early adopter impressions of EVs reflect both barriers and opportunities.

When asked to provide their top-of-mind impressions of EVs, potential early adopters gave a range of responses, covering both the advantages and the disadvantages. The most common response was the green or environmentally friendly potential of the vehicle, but a majority of six in ten made some negative mention. The most common negative responses were related to purchase price or range anxiety, including battery life, charging concerns or the potentially limiting range of the vehicle. Purchase price was mentioned more by those who said that they would definitely not consider an EV.

Figure 11: Most Mentioned Top-of-Mind Impressions of Electric Vehicles



Note: adds up to more than 100% due to multiple mentions

The majority of potential early adopters are most familiar with the environmental impact of EVs.

All potential early adopters were asked to indicate their level of familiarity with five specific aspects of EVs:

- their impact on the environment
- how they compare with conventional gasoline-powered vehicles
- the technology, or how EVs work
- government incentives for purchasing EVs or installing home charging stations
- the public charging station at Ottawa City Hall

While few respondents claimed to be very familiar with any aspect of EVs, eight in ten said that they were at least somewhat familiar with their environmental impact. Approximately six in ten expressed the same level of familiarity with how EVs compare with conventional vehicles, and half indicated some familiarity with the technology, or how EVs work. Awareness of current government incentives was relatively low, and a strong majority of potential early adopters indicated that they were not at all familiar with the public charging station located at Ottawa City Hall. Strong familiarity with any of the five aspects of EVs was linked to a definite willingness to consider buying an EV.

Likelihood of Considering an Electric Vehicle

Less than one-third of potential early adopters would consider purchasing an EV in the next couple of years.

Only 32 per cent of potential early adopters said that they would likely (23 per cent) or definitely (9 per cent) consider an EV if they were purchasing or leasing a vehicle in the next couple of years. A majority of 63 per cent felt that they would likely not or definitely not consider an EV within the next two years. Age is an important factor in the potential purchase of an EV, with the likelihood of considering one lowest among those aged 60 and older (23 per cent versus 42 per cent of younger drivers).

As previously noted, some experience with an EV is higher among those who would likely or definitely consider purchasing one in the next couple of years. However, it should be noted that, even among those who would consider an EV in the near future, seven in ten have had no experience with one.

Those early adopters who might consider an EV would use it as a primary vehicle.

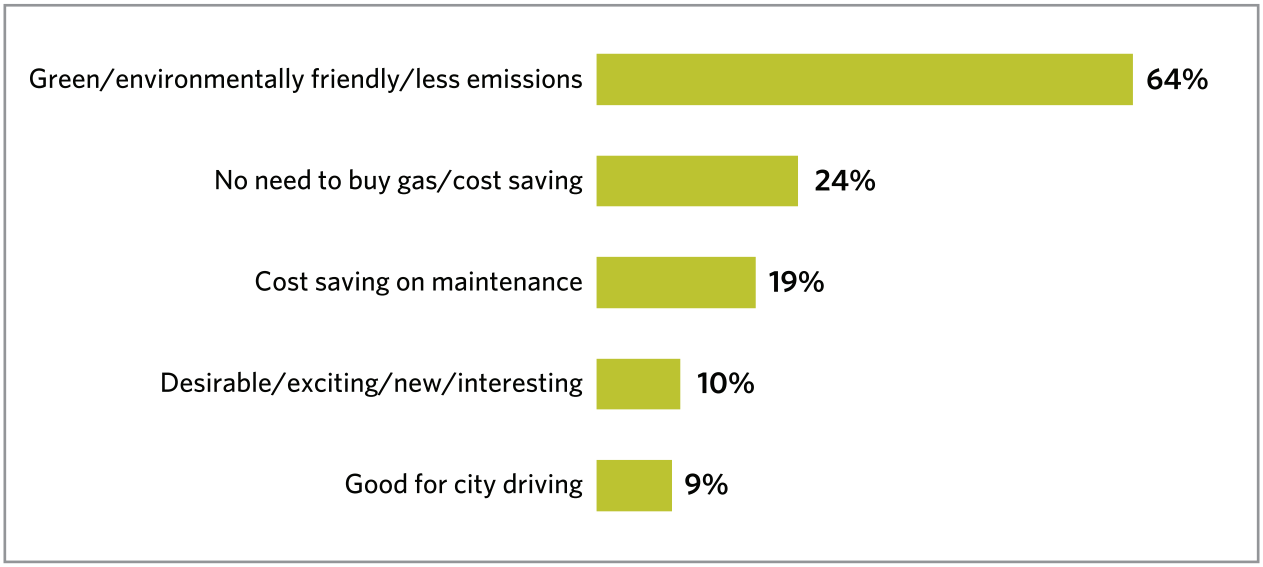
The majority of those who would at least marginally consider an EV indicated that they would use it to replace an existing primary vehicle. The remainder are divided as to whether it would be an additional, secondary vehicle, the sole household vehicle or a replacement for an existing secondary vehicle.

Perceived Barriers and Opportunities

Potential environmental benefits are the most mentioned advantage of EVs. Purchase price and limited range are the most mentioned barriers.

Around two-thirds (64 per cent) of those who would likely or definitely consider purchasing an EV mention that the main advantages of the vehicle are the potential environmental benefits and the opportunity to reduce vehicle emissions. Twenty-three per cent mention not having to purchase gas and 19 per cent note the cost savings related to vehicle maintenance. A smaller number report an interest in EVs as an emerging technology and the suitability of the vehicle for city driving. Fewer than one in ten mentioned other benefits, such as the quiet ride or government purchase incentives.

Figure 12: Top Reasons for Considering an Electric Vehicle



Subsample: Would definitely/likely consider an EV (N=235)

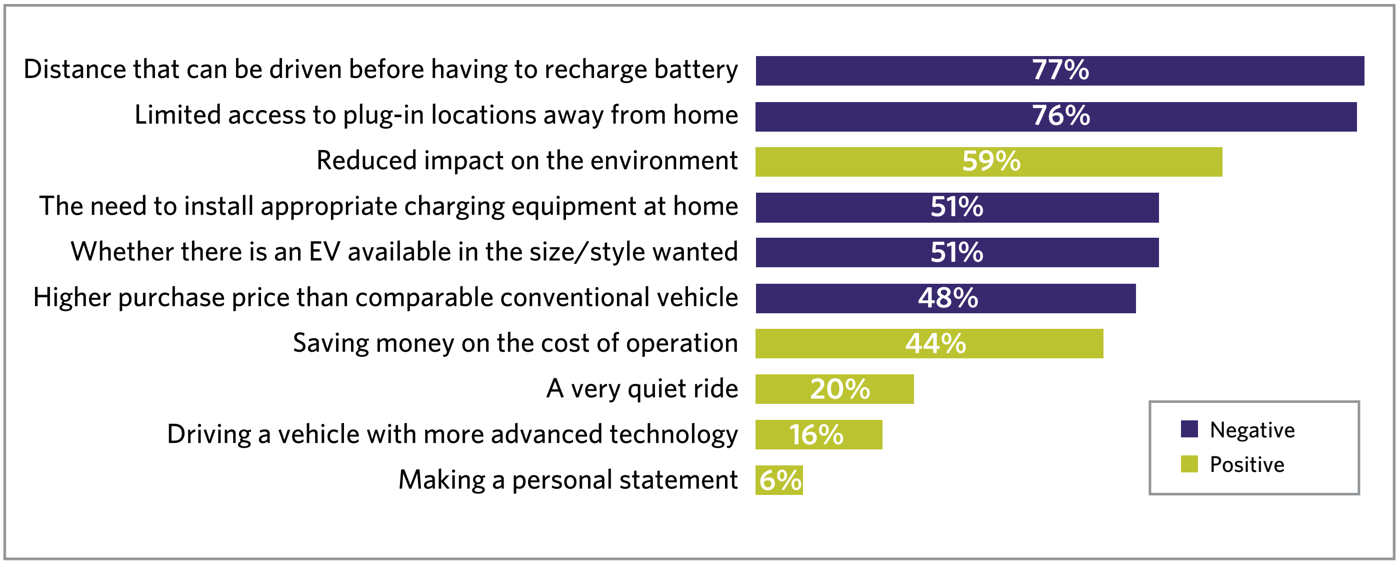
Three in ten of those who indicated that they would definitely not or likely not consider an EV felt that the most important reason for not doing so was the potentially limiting range of the vehicle. A further 23 per cent mentioned the high purchase price of the vehicle, and 18 per cent noted a lack of charging locations away from home as a barrier. Equal numbers (13 per cent) felt that vehicle size was an issue or that the technology was not yet ready, while a smaller number mentioned battery life, environmental concerns about battery disposal or the cost of electricity.

Charging concerns are the most important consideration in deciding whether to purchase an EV.

Those potential early adopters who would at least marginally consider purchasing an EV were asked to rank several positive and negative aspects of the vehicle in terms of their importance in the consideration of a future purchase or lease. The aspects rated as the most important once again reflect concerns related to range anxiety, including the distance that can be driven before the vehicle needs to be charged and the currently limited access to public charging stations. The potential for reduced impact on the environment as a result of driving an EV, the need to install appropriate charging equipment, available sizes or styles, and cost or status aspects are of less importance than the concerns about range anxiety. It should be noted, however, that purchase price may end up being more of a deciding factor when an actual retail scenario is being considered.

Those who indicated that they would definitely consider an EV were more likely than others to mention that the positive aspects would be important, while those who would likely not consider an EV were the most likely to say that barriers related to range anxiety would be very important.

Figure 13: Electric Vehicle Aspects Considered *Very Important* in Purchase Decision



Subsample: Would definitely/likely/likely not consider an EV (N=514)

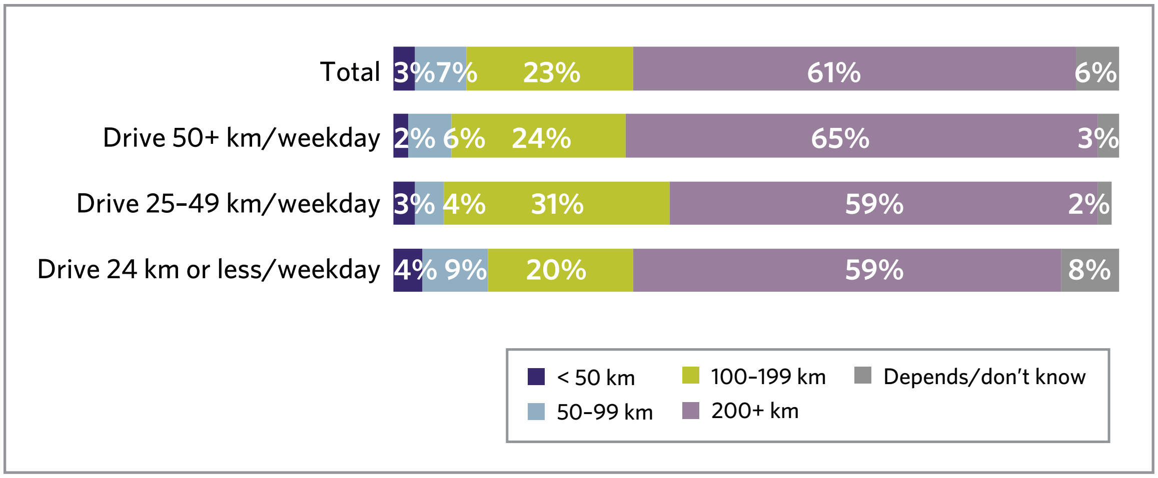
Charging Expectations

An EV would have to have a range of at least 200 kilometres on a single charge for most potential early adopters to feel comfortable.

Six in ten potential early adopters (61 per cent) said that an EV would have to be able to travel more than 200 kilometres on a single charge for them to feel comfortable that they would not get stuck somewhere without access to charging facilities. Less than one-quarter would be comfortable with a charge that lasted between 100 and 200 kilometres, and only one in ten would find a range of less than 100 kilometres acceptable.

Potential early adopters who drive less than 25 kilometres on a typical weekday were just as likely as those driving longer distances to say that a 200 kilometre range would be required. This suggests that these drivers were thinking about a worst-case scenario or basing their expectations on the topping up of a gasoline-powered vehicle rather than on their actual typical personal mobility patterns.

Figure 14: Acceptable Distance for Travel on a Single Charge

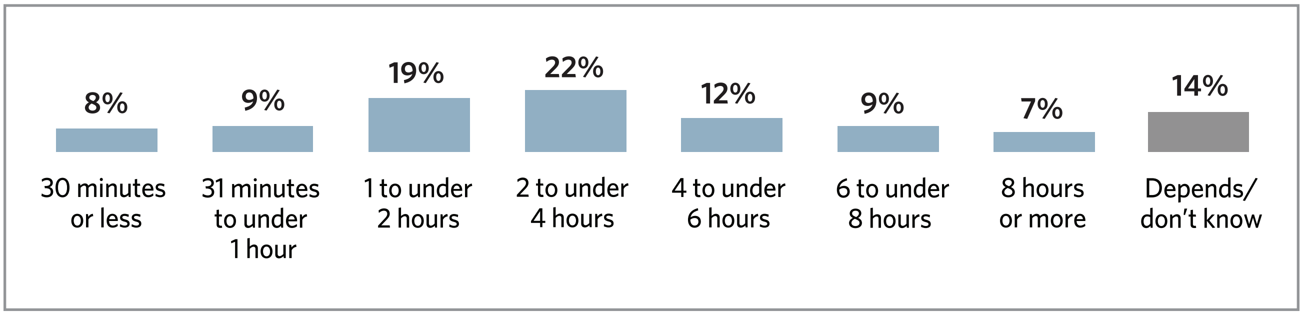


Subsample: Would definitely/likely/likely not consider an EV and do not own an EV (N=514)

The majority of those who would consider purchasing an EV think that it should take less than four hours to fully charge.

A range of opinions were expressed when those who would be at least marginally likely to consider an EV purchase in the next couple of years were asked what they felt would be an acceptable length of time to fully charge the vehicle. Six in ten (58 per cent) think that it should take less than four hours to charge, with the most common response being between two and four hours, followed closely by one to two hours. A small number of those who would consider purchasing an EV felt that it should take 30 minutes or less.

Figure 15: Acceptable Length of Time to Fully Charge an Electric Vehicle



Subsample: Would definitely/likely/likely not consider an EV and do not own an EV (N=514)

Access to faster home charging is considered very important.

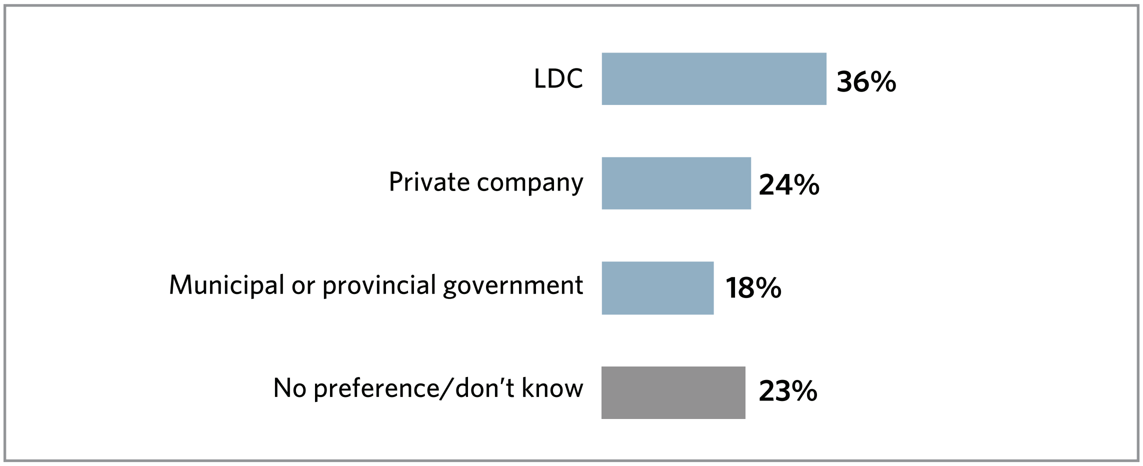
Potential early adopters understand that EVs need time to charge, unlike a gasoline-powered vehicle with a gas tank that can be filled quickly. However, close to half think that it should take less than four hours (similar to the length of time it takes to charge an iPod) to fully charge the vehicle. When told that, depending on how depleted the battery is, charging the vehicle could take 12 hours or more using a standard household outlet, an overwhelming majority said that it would be very (76 per cent) or somewhat (20 per cent) important to be able to charge faster – for example, with a more powerful Level 2 charger installed at home. This is consistent with more than half of those who would consider purchasing an EV indicating that an acceptable length of time to fully charge the vehicle would be less than four hours.

The number of respondents who said that faster charging would be very important increased proportionally with an increase in the distance driven on a typical weekday and was higher among vehicle commuters. The importance attached to faster charging also increased as the level of consideration for buying an EV decreased and was highest among those who would likely not consider this type of vehicle.

Most potential early adopters would prefer the LDC to install and maintain a home charging station.

Those who said that it would be at least somewhat important to charge an EV faster were asked which of three potential service providers they would prefer to have install and maintain a Level 2 charging station at their home. Approximately one-third said that they would prefer this to be done by the LDC, while 24 per cent would prefer a private company and 18 per cent would prefer the government to act as the primary service provider.

Figure 16: Preferred Service Provider for Installing and Maintaining an At-Home Charging Station

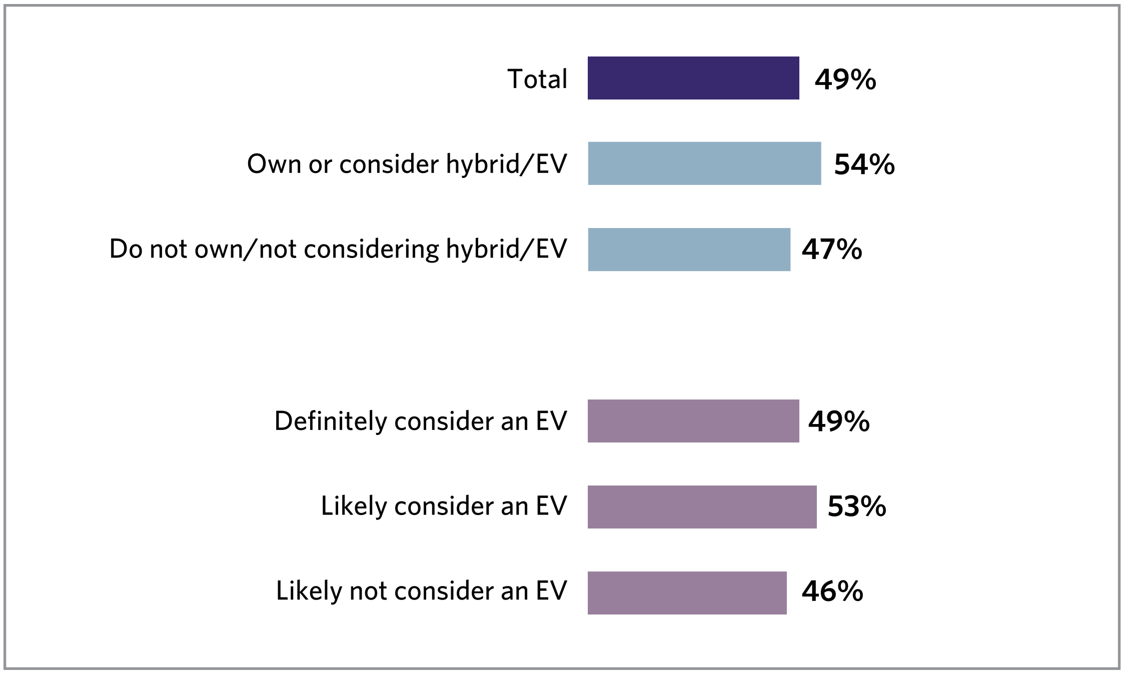


Subsample: Important to charge EV faster (N=496)

Almost half of potential early adopters would be willing to wait 30 minutes for a top-up charge at a public charging station.

When those who own an EV or would at least marginally consider one were asked if they would be willing to wait 30 minutes at a public charging station to top up their charge, approximately half said that they would be willing to do so. The proportion of those willing to wait did not vary significantly based on the likelihood of considering an EV in future; however, none of the four current EV owners surveyed said that they would be willing to wait – possibly because they know they would be able to make it home to recharge.

Figure 17: Willingness to Wait 30 Minutes for a Top-Up Charge at a Public Charging Station

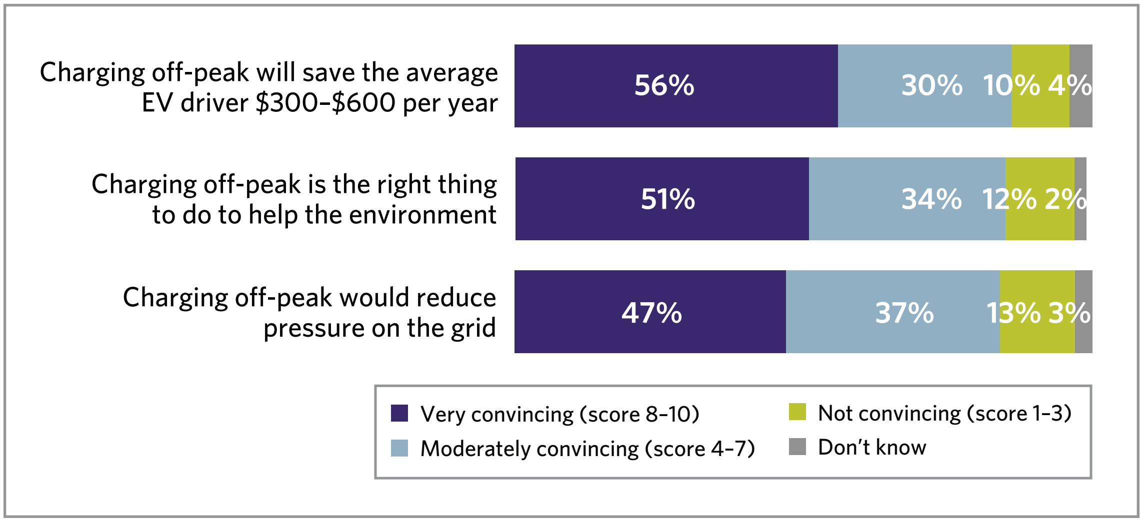


Subsample: Own or would definitely/likely/likely not consider an EV (N=518)

Potential early adopters think that providing opportunities for personal savings would be the best way to encourage off-peak charging.

Potential early adopters were asked to rate three statements, based on how convincing an argument they would be for encouraging others to charge an EV during off-peak hours (in Ontario, off-peak hours are between 7 p.m. and 7 a.m.). About half indicated that all three statements would be very convincing. The most convincing statement was found to be the one about saving money by charging off-peak. All three statements were considered very convincing by higher proportions of those who would definitely consider an EV in future while those who would definitely not consider an EV were the most likely to think that none of the statements were very convincing.

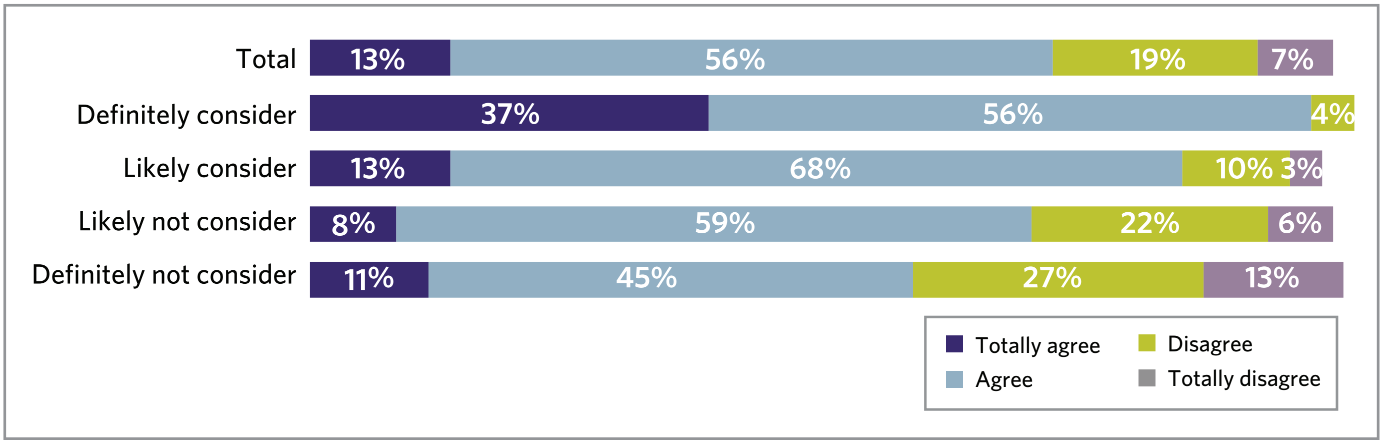
Figure 18: Statements for Encouraging Off-Peak Charging



Validation of Preliminary Assumptions

Potential early adopters who said that they would definitely consider an EV expressed greater agreement with statements about ecological consciousness, interest in technology and consumptivity than those less likely to consider an EV. This helps to validate the initial assumptions and criteria used to profile early adopters during the secondary research. In particular, potential early adopters felt strongly about their ecological consciousness and interest in technology.

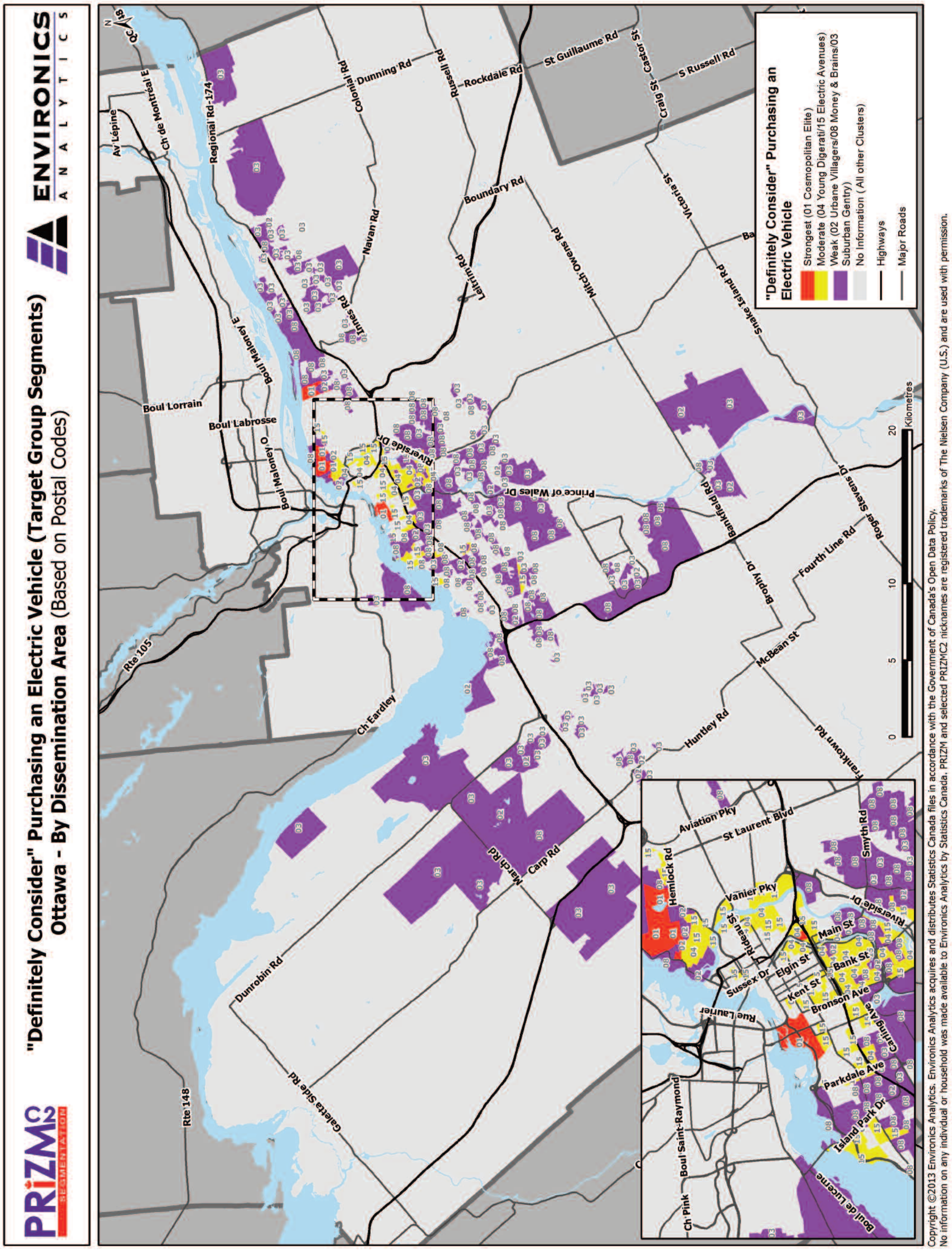
Figure 19: Responses to the Statement "I am prepared to pay more for an environmentally friendly product" by Likelihood of Considering an Electric Vehicle in the Next Two Years



Note: does not include "don't know" and "neither agree nor disagree."

Each of the six early adopter segments was cross-referenced with the number of "definitely consider" responses about a potential EV purchase and rated according to strong, moderate or weak interest. The original segment map was then recalibrated to reflect the relative strength of interest in acquiring an EV. The recalibrated map (see Figure 20) details the areas in the City of Ottawa where the adoption of EVs will likely take place.

Figure 20: Strength of Interest in Purchasing an Electric Vehicle by Dissemination Area in the City of Ottawa



Focus Group with Electric Vehicle Owners in the City of Ottawa

On November 6, 2013, an informal focus group with six current EV owners residing in the Ottawa area was held at the Hydro Ottawa offices. The purpose of the discussion was to better understand the experience of owning an EV and the extent to which the perceived barriers and opportunities for EV adoption are, in fact, a reality.

Some of the EV owners who participated in the discussion had met previously through membership in a local EV council in the City of Ottawa, highlighting their enthusiasm for the technology. All of the EV owners are male and were invited to participate through their connection with this local EV council. These EV owners drive different vehicle makes and models, including the Nissan LEAF, Tesla Model S, Tesla Roadster, Chevrolet Volt and a Ford Ranger electric conversion (converted in 2001). The length of ownership of these EVs ranged from several months to over 30 years. The variety of vehicles ensured that the discussion captured a full range of experiences related to ownership of an EV, rather than just those associated with any one make or model. Comparisons between vehicle types served to further enrich the discussion. For example, range anxiety is experienced differently by the owner of a Tesla because Teslas have a greater range than the Nissan LEAF or a conversion

The focus group followed a loose discussion guide, and participants were also encouraged to introduce ideas and topics of interest to them. It is important to note that the objectives of this qualitative research were exploratory. Qualitative research provides insight into the range of opinions held within a population rather than the weights of the opinions as measured in a quantitative study (e.g., a household telephone survey).

The informal discussion augmented the findings from the market research survey related to charging behaviours, personal mobility patterns and public infrastructure. For example, the discussion provided specifics about where, for how long and to what extent EV owners are charging their vehicles, none of which could be captured by the household telephone survey because the respondents did not have the same familiarity with the technology. It is important that the EV owners participating in the focus group not be confused with the potential early adopters targeted during the household survey. These EV owners were some of the first adopters of the technology and, as such, should be considered innovators rather than early adopters.

KEY FINDINGS FROM THE FOCUS GROUP WITH ELECTRIC VEHICLE OWNERS

This section presents key findings and insights from the focus group with current EV owners. It begins with a profile of the participants, including their vehicle purchasing preferences and personal mobility patterns, and is followed by a discussion about vehicle charging patterns and potential barriers and opportunities for EVs.

Profile of the Electric Vehicle Owner

EV owners live in different neighbourhoods and have a relatively short commute to work.

The participating EV owners reside in neighbourhoods located in and around the City of Ottawa, including suburbs fairly close to the downtown core (Barrhaven, Bells Corners, Hunt Club), a suburb somewhat farther outside the city (Kanata), and a rural location (Embrun, which is outside the Hydro Ottawa service area). These EV owners are employed in various sectors, including a home-based business, the federal government, records management, engineering and technology. None of the EV owners reported a long commute and, with the exception of the owner of the home-based business, they all indicated that they travel to work by car.

As previously noted, all the participating EV owners were male. The group discussed whether they felt that the technology is currently an attractive option for female drivers. Several participants reported having seen female EV drivers in Ottawa or knowing women (in some cases, their wives) who drive an EV, indicating at least anecdotally that the technology is, in fact, of interest to women. Participants also noted that they have recently observed an increasing number of both younger and older EV drivers.

The most common questions others have for EV owners are related to vehicle range and charging.

When the EV owners were asked about the type of questions and feedback they receive from friends and family about their vehicle, they reported that people express interest in owning an EV, but with reservations. Purchase price was noted as a contributing factor in the hesitation to switch to an EV. One participant felt that this could be the result of failing to factor the significant reductions in maintenance costs into the overall cost of ownership of an EV. Although the upfront purchase price of an EV may be higher than for a conventional gasoline-powered vehicle, these costs are recovered over the life of the vehicle through reduced maintenance and fuel costs.

EV drivers noted that the main questions people have about their vehicle are related to range anxiety, including how far they are able to drive on a single charge, the length of time required to recharge the vehicle and where they go to charge.

EV drivers noted that the main questions people have about their vehicle are related to range anxiety, including how far they are able to drive on a single charge, the length of time required to recharge the vehicle and where they go to charge. One EV owner indicated that he has spoken to people who are under the impression that it is necessary to stay with the vehicle during charging, as one does when filling up a conventional gasoline-powered vehicle at a gas station. Another owner reported regularly making the comparison to charging a cell phone to explain how charging the vehicle works.

EV owners believe that putting people behind the wheel of an EV would be an effective way to interest them in purchasing one.

When asked how best to convince others to purchase an EV, current owners felt that getting someone behind the wheel would be an effective way to overcome many of the misconceptions about EVs. Several EV owners reported that they have taken people who have shown an interest in or had questions about EVs for a ride in their vehicle. Participants felt that once people have first-hand experience with an EV, they realize that they would not need to make compromises in terms of vehicle handling and driving habits – and that EVs are, in fact, a lot of fun to drive.

Vehicle Purchasing Preferences

Economic and environmental considerations as well as an interest in new technology were key factors in the decision to purchase an EV.

The EV owners reported that technological, economic and environmental factors influenced their decision to purchase an EV. One noted that, when he did the math, the lease for his EV was not much different than it would be for a gasoline-powered vehicle, making his decision an easy one. For other participants, it was factoring in the potential savings over the lifetime of the vehicle (no longer needing to purchase gasoline, change the oil or spend as much on maintenance) that convinced them that the EV was competitively priced. One participating owner recalled that, while it was the rising cost of gasoline that initially led him to investigate alternatives to a conventional gasoline-powered vehicle, it was the oil spill in the Gulf of Mexico that sealed his decision to purchase an EV. He decided that he preferred to support the local utility by buying electricity to power a vehicle rather than an international oil company by buying gasoline.

Another EV owner indicated that his initial interest in driving electric was based on the potential for reducing vehicle-related emissions and pollution. He used to walk across a busy bridge to get to work and found the pollution from the traffic on the road below unbearable. When he later moved further out of the city, he did not want his commute to contribute to vehicle-related emissions. Other participants noted the need to move away from a carbon-based economy for long-term sustainability and an interest in new technology as factors in their decision to purchase an EV.

Cost savings, convenience and useful vehicle features are some of the most enjoyable benefits of driving an EV.

The EV owners were asked to describe the most enjoyable aspect of driving their vehicle. The advantages most noted were the savings on fuel, servicing and maintenance costs that help to make EVs affordable. The EV owners also noted that they enjoy features such as quick acceleration and response time, and how quietly the vehicle operates. The eco mode available with many EVs, which allows the driver to optimize the vehicle's charge, was also noted for its contribution to better management of the vehicle's state of charge.

The convenience of driving an EV was also mentioned by a number of participants. Being able to charge the vehicle at home, rather than having to stop at a gas station, particularly in poor weather, was noted as one of the most attractive features of the vehicle. One EV owner indicated that his vehicle provides him with an independence or self-sufficiency not possible with a conventional gasoline-powered vehicle. Should electricity become prohibitively expensive, he could install a solar panel or pursue other means of generating electricity, whereas drivers of gasoline-powered vehicles have no control over the cost of gasoline and are entirely dependent on oil companies for supply.

Economic and environmental considerations as well as an interest in new technology were key factors in the decision to purchase an EV.

Personal Mobility Patterns

EV owners adapted quickly to driving electric and the characteristics specific to their EVs.

Participating EV owners reported a number of features specific to EVs, including quick acceleration and regenerative braking. EV owners also noted that their vehicles do not idle, making stop-and-go traffic easier to tolerate.

EV owners reported that they quickly adapted their driving patterns to maximize efficiency while at the same time addressing traffic conditions around them. For example, a number of participants indicated that some drivers of conventional gasoline-powered vehicles become impatient when an EV is driving below the speed limit to preserve the vehicle's charge. Following behind buses or trucks, which tend to move more slowly, is a strategy some EV owners use to avoid this. One participant reported driving the speed limit or slightly above in traffic and slowing down when he is alone on the road. It was noted that an increase in the number of public charging stations, particularly those offering a fast charge, would help EV drivers better manage typical traffic conditions because they would be less concerned about driving slowly to maximize range.

Some EV owners noted that they have to be careful not to exceed the speed limit because the vehicle is so quiet when accelerating, providing little indication of how fast it is going.

When maintaining the vehicle's charge is not a concern, some EV owners noted that they have to be careful not to exceed the speed limit because the vehicle is so quiet when accelerating, providing little indication of how fast it is going. One EV owner reported that on one occasion when he and his wife were in a hurry, she became concerned that he was driving too slowly when, in fact, he was driving over the speed limit. Other participants shared stories about EV drivers being pulled over for speeding without even realizing that they were driving above the speed limit.

Learning to drive an EV efficiently has also helped EV owners when they have to drive a gasoline-powered vehicle. Some participants noted that the driving habits acquired through use of their EV have contributed to fuel savings and lower maintenance costs for their non-electric vehicle.

EV owners drive more now than when their primary vehicle was gasoline powered.

Several of the participating EV owners reported purchasing their vehicle with the idea that it would be used as a second vehicle for city driving but quickly found that it was able to meet almost all of their driving needs for a typical day. In fact, EV owners reported that, since acquiring their vehicles, they tend to drive more because they enjoy the experience more. Almost all of the participants still own a second vehicle (hybrid or gasoline powered) that they sometimes use for longer trips, but the EV has become their primary vehicle and, in some cases, the preferred vehicle among household drivers.

Driving an EV does not prohibit longer trips but requires more planning and a better understanding of distances between stops.

EV owners reported that it was uncommon for them to drive more than 100 kilometres on an average day, with between 60 and 80 kilometres being the distance most often travelled. Interestingly, all EV owners had attempted a trip out of the city at some point, and none felt that, with appropriate planning, vehicle range was a major barrier. When they first acquired their vehicle, longer trips might have been limited to a distance that could be driven without recharging because there were no public charging stations available. However, recent installations of public charging infrastructure on particular routes allow them to stop along the way to top up their charge. More than one of the EV owners noted that being able to charge at hotels was important for long-distance trips and that if a hotel does not have a public charging station available for guests, they will not stay there.

EV owners reported trips from Ottawa to Kingston on a single charge and to Toronto with a number of stops to charge along the way. One EV owner indicated that with a Level 2 charger installed at his cottage and public charging stations en route, he often drives 300 kilometres over the course of a weekend. EV owners also indicated that the navigation system in some models is useful in planning long trips. The system has a feature that allows drivers to program in arrival at their destination with a small amount of charge left. For example, a driver can program in arrival with a surplus of 30 kilometres to account for unexpected construction or detours.

Not surprisingly, the Tesla owner had a different experience with longer trips because the Tesla has a much greater range than other EVs. However, although he does not have to stop as often, his vehicle has a larger battery, requiring a charging capacity that is much greater than what is available at most public charging locations (while there are now some public Level 3 charging stations, they are still quite uncommon). The group discussed how this barrier would likely be addressed with the introduction of the Tesla supercharger network (providing 50 per cent charge in just 20 minutes).

Barriers and Opportunities for Electric Vehicle Adoption

Common Misconceptions about Electric Vehicles

Range anxiety is perceived to be a barrier to EV adoption but is not a typical experience for EV owners.

EV owners were asked if the range anxiety often associated with EV technology is, in fact, a problem. Because of range anxiety, EVs are sometimes thought to be appropriate only as a second vehicle, mainly for city driving. As previously noted, the EV owners participating in the discussion found themselves using their EV as their primary vehicle, only occasionally driving their second, gasoline-powered vehicle. One participant even got rid of his gasoline-powered vehicle a few days after purchasing his EV because he felt he no longer needed it.

The EV owners participating in the discussion found themselves using their EV as their primary vehicle, only occasionally driving their second, gasoline-powered vehicle.

While the market research survey indicates that range anxiety factors heavily into decisions about purchasing an EV, current EV owners indicated that they do not experience range anxiety very often, if at all. The EV owners mentioned that they were unsure about the range of their vehicle when they were first driving it, and most of them had at least one story about running out of charge. However, they did not feel that this warranted range anxiety. One participant pointed out that range anxiety is not limited to EVs, as he also experiences anxiety when driving a gasoline-powered vehicle with its tank nearly empty.

EV owners also reported that, in reality, it is quite difficult to run out of charge in an EV when following predictable, routine driving patterns. The vehicle clearly shows the driver how much range it has left – just as the fuel gauge in a gasoline-powered car shows how much gas is left – and appropriate planning is all that is required to ensure an uninterrupted drive. Range limitations come into play primarily when there is an unexpected event, such as an unanticipated detour. Most of the participating EV owners felt that fears about vehicle range are likely related to worst-case scenarios or the rare day when a driver may be required to make a longer trip on short notice.

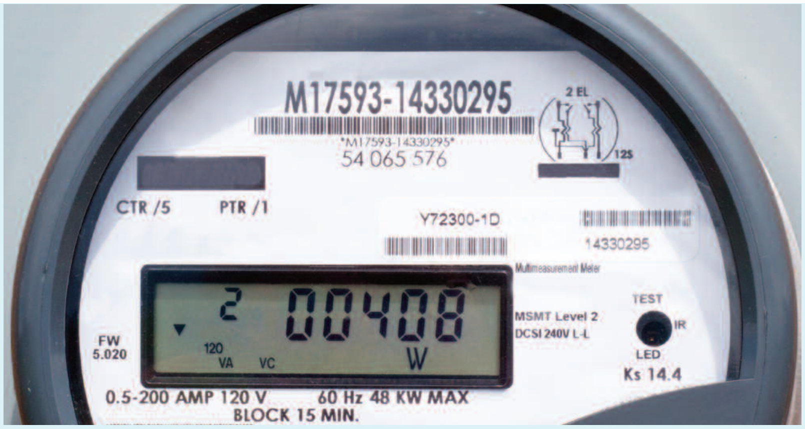
Common misconceptions about EVs include those related to the amount of electricity used and their environmentally friendly status.

EV owners discussed some of the common misconceptions that the general public has about the technology. For example, participants noted that there is often misinformation about the amount of electricity required to power the vehicle. One participant commented that many people do not realize that, in fact, the use of gasoline-powered vehicles depends heavily on electricity because of the power required to refine oil for use as gasoline. Similarly, the group observed that some emissions comparisons between electric and gasoline-powered vehicles factor in only the carbon associated with what goes into the gas tank while ignoring the carbon used to produce gasoline and ship it to gas stations.

The group also discussed the perception that the batteries in EVs are not environmentally friendly and may pose recycling issues. The EV owners noted that the lithium-ion batteries used in EVs include valuable and recyclable materials, including cobalt and nickel. In addition, one participant noted that the lead-acid batteries found in gasoline-powered vehicles contain toxic heavy metals such as lead.

EV owners contribute to informing the general public about the benefits of driving electric.

Some of the EV owners noted that, particularly after first acquiring their vehicle, they tried to come up with ways to inform the general public about the reality of driving electric. For example, one EV owner put ecologos on his vehicle, along with a breakdown of the average cost of electricity to power the vehicle for a week, so that passersby could better understand the true cost of operating an EV. He felt it was important to try to correct misconceptions about the cost of EV ownership. Because it can be difficult to tell the difference between a gasoline-powered vehicle and an electric vehicle, one of the other EV owners put a sign on the back of his vehicle that read “Sparky the Electric Vehicle” so that other drivers could see that there are EVs on the road. One EV owner even maintains a blog detailing his experiences with his vehicle.



Participants noted that there is often misinformation about the amount of electricity required to power the vehicle.

Barriers to Electric Vehicle Adoption

EV owners identify purchase price, potentially limiting vehicle range and length of time required to charge as key barriers to EV adoption.

The EV owners discussed what they felt were the current barriers facing the broader adoption of EVs. One participant noted that there are three main barriers that, once addressed, would eliminate any compelling reason to consider a gasoline-powered vehicle. At that point, it would not be a question of *if* EV deployment will be successful, but simply *when*. The three barriers are as follows:

- purchase price
- potentially limiting range
- length of time required to charge the vehicle

The participating EV owners felt that, of these three barriers, the length of time required to charge the vehicle is the biggest obstacle to broader public interest in EVs. Even if the initial purchase price comes down and the range is improved, interest will not likely increase if it takes, for example, 10 hours to recharge an EV.

Increasing the range of vehicles on the market to include trucks, vans and SUVs would address the needs of a much broader market.

The group also identified additional barriers to EV adoption. Increasing the range of vehicles on the market to include trucks, vans and SUVs would address the needs of a much broader market. The absence of a Level 3 charging network that would allow for a 20-minute top-up charge was also seen as a key barrier, particularly for interurban travel. One EV owner pointed to the confusion about the comparative costs of an EV and a gasoline-powered vehicle as another barrier. He viewed the battery in an EV to be the consumable, comparable to gasoline for a conventional vehicle. As such, he felt that if the cost of the battery were to be clearly separated from the vehicle cost when EVs are being marketed, it would ensure an “apples to apples” comparison that would make the financial benefits of driving an EV more evident.

The group also discussed government incentives for EVs in Ontario, and some of the current restrictions for qualification were identified as potential barriers to EV adoption. For example, one participant noted that because he purchased a demonstration vehicle from the dealership, he did not qualify for the vehicle purchase incentive (the dealership received the incentive instead). Another EV owner reported that he had licensed his vehicle before the Electric Vehicle Charging Incentive Program was in effect. While the incentive applied retroactively to the day he licensed the vehicle, he had installed his home charging station before acquiring the vehicle so he did not qualify. Participants were in agreement, however, that government incentives are an important factor in ensuring that EVs make the transition from the early adopter to the broader mass market.

The cost of installing residential charging stations was also mentioned as a potential barrier to EV adoption. One EV owner noted that some electrical panels have to be upgraded to accommodate a Level 2 charger, which can be expensive. Another EV owner identified hydro inspections as a potential barrier because they can result in additional upgrades and costs to meet legislated requirements for electrical safety.

Another EV owner reported that when he recently put in an offer on a condominium in the downtown area, the building owners told him that he would have to pay for a charging station to plug in his vehicle and that his condominium fees would increase to cover the cost of the electricity used to charge the vehicle. He felt that, if the costs were too high, he would rather give up the condominium than his EV. EV owners felt that further education about charging EVs was necessary for condo boards and building operators.

EV owners believe incentives will be helpful in the future deployment of EVs.

EV owners discussed the future for EVs and what steps need to be taken for the technology to move beyond the early adopter market. One participant noted that incentives that are carefully thought out and developed in the context of what is happening worldwide would be necessary. As an example, the group pointed to the current regulatory environment and market for EVs in Norway, where a significant tax on gasoline-powered vehicles is thought to be a major contributing factor to EVs being among the top-selling vehicles in the country. The EV owners felt that, while details such as the level of tax incentives might differ in Canada, looking closely at what Norway has accomplished in terms of the deployment of EVs could be beneficial.

Vehicle Charging Patterns

Residential Charging

Most EV owners have a Level 2 charging station at home, but they do not always charge at the full rated capacity available.

Most of the EV owners reported having a Level 2 charging station installed at home. One participant said that when he first acquired his EV, he charged it using a typical 120 V outlet (Level 1); when he found that this was not enough to keep up with his charging needs, he had a Level 2 charger installed. Another member of the group, however, stated that Level 1 charging at home does meet his charging needs.

The group discussed an aftermarket add-on upgrade for the Nissan LEAF on-board charger. Currently available only as a do-it-yourself kit, the upgrade enables the vehicle to charge at 10 kW rather than the standard 3.3 kW. A number of participants hoped that this would become a standard feature to enable faster charging when overnight charging is not sufficient. However, one EV owner indicated that he does not always charge his vehicle at the full capacity available, preferring at times to charge it at a lower rate over a longer period of time.

EV owners usually charge their vehicle overnight and use the timer onboard their vehicle to program the timing of the charge.

The majority of participating EV owners said that they usually charge their vehicles overnight, during off-peak hours, with the exception of those occasions when they need a quick charge. A number of participants noted that their preferred time to charge is between 2 a.m. and 5 a.m., when the demand for electricity is generally lowest.

Some of the EV owners indicated that they make regular use of the vehicle timer to pre-program when the vehicle will charge. This feature allows them to plug their EV in as soon as they arrive home for the day and program it to begin charging later on. Participants felt that residential charging was convenient, and the use of the timer made it possible for them to take advantage of off-peak rates, charging when the overall load on the electricity distribution system is low. One EV owner noted that there are programs in the United States that allow drivers to program in when they would like the vehicle to finish charging, ensuring that their vehicle is ready to drive when they need it.

EV owners would be willing to allow the LDC to manage the flow of electricity to their vehicle when charging.

The EV owners were asked whether they would be open to allowing the LDC to manage the flow of electricity to their vehicle so that the overall load on the electricity distribution system could be better managed. They were in general agreement that this would be acceptable, provided that they had a means of overriding this option as necessary (e.g., if they needed to use their vehicle sooner than anticipated).

Most EV owners think that financial incentives are important for encouraging off-peak charging.

EV owners identified financial incentives as an obvious means of encouraging off-peak charging. However, some of the EV owners noted that time-of-use rates were not a major factor in their decisions about when to charge their vehicle because the difference between mid-peak and off-peak rates is relatively small. This led to a discussion of a super off-peak rate as an effective strategy for motivating EV owners to charge their vehicles when it would have the least impact on the electricity distribution system. A number of participants mentioned that off-peak charging helps the LDC manage the electricity distribution system by ensuring a more evenly distributed load over a 24-hour period, and that a super off-peak rate would recognize the contribution that EV owners can make to conservation and effective energy management. One EV owner noted that at least one program in the United States provides free residential charging during off-peak times.

EV owners feel that there is a need for better information about residential charging station installation.

The majority of EV owners reported that their home charger was installed by an electrician. They noted that quotes for installation range in price, and that many electricians charge a lot for this service. One EV owner mentioned that he had to get a recommendation for an electrician to install his home charger from another driver in the group because the salesperson at the automotive dealership provided no information.

EV owners would be open to providing personal information to the LDC so that it would know where EVs are charging within its service area.

The EV owners were asked whether they would be willing to provide their personal information to the LDC at the point of purchase so that the LDC could better monitor the demand for EV charging. A number of the EV owners were surprised that this was not already in place. The group discussed the need for this information to be available to the LDC so that it has clear and accurate data about charging patterns and, as a result, is better able to manage the electricity distribution system to accommodate EV charging.

A number of participants mentioned that off-peak charging helps the LDC manage the electricity distribution system by ensuring a more evenly distributed load over a 24-hour period.

Workplace Charging

Education and engagement of employers regarding workplace charging is necessary to encourage EV adoption.

The EV owners felt that employer education and engagement regarding workplace charging would be key to the future deployment of EVs. EV owners reported usually charging at home, but those who do not already charge at work would like the option to do so. In fact, one participant indicated that if there were only one thing that the LDC could do to help promote EV adoption, it would be to educate employers about the importance and value of workplace charging and charging station installation.

One EV owner reported that when he approached his employer about charging his vehicle at work using a standard 120 V outlet, he was told he would have to pay $1000 for installation of the charging station and a monthly charge of $50 to cover what the employer thought the cost of charging the vehicle would be (despite the EV owner's estimate of $5 to $10 a month). The EV owner felt that it was a lack of awareness of the actual cost of EV charging that prevented his employer from taking up this important opportunity to support the adoption of EVs. One of the other EV owners had the opposite experience: his employer allowed him to begin charging immediately, using a standard 120 V outlet, and agreed to charge him for the electricity used only if and when he saw a spike in the electricity bill (which did not happened).

It was acknowledged that employers were not likely to be open-minded about allowing workplace charging without a clear understanding of the actual costs associated with it. As such, EV owners felt that it could be beneficial to provide employers with incentives or assistance in offsetting any initial costs for the installation of charging stations. They also noted that further education about the actual costs associated with workplace charging was important.

Public charging

The location of public charging stations plays a role in the personal mobility patterns of EV owners.

EV owners were asked whether there are enough public charging stations located throughout the City of Ottawa. The group agreed that the number of public stations has increased, but they felt that there is still a long way to go to ensure that there are enough to accommodate increasing EV ownership throughout the city. EV owners also felt that an increase in the number of public charging stations would be beneficial for the economy because it would encourage EV drivers to make Ottawa a travel destination. Locations suggested for charging station installation included the airport and places where people often park for several hours at a time, such as movie theatres or shopping malls.

All the EV owners noted that the location of public charging stations plays a role in their personal mobility patterns, such as the routes they travel, where they choose to shop or which hotel they select for longer trips.

All the EV owners noted that the location of public charging stations plays a role in their personal mobility patterns, such as the routes they travel, where they choose to shop or which hotel they select for longer trips. One EV owner noted that he gravitates to areas where there are multiple charging stations available to ensure that he will have a spot to charge. Most EV owners indicated that they seek out Level 2 public charging stations whenever possible so that they do not have to wait several hours to top up their charge.

EV owners feel that Level 3 public charging stations would contribute to getting more EVs on the road.

EV owners felt that locating Level 3 stations at the perimeter of most cities and at strategic locations in between would enable EVs to become an effective means of interurban transportation. The group agreed that making Level 3 charging stations available would be a turning point for the deployment of EVs and encourage those in the broader mass market to consider driving one.

Summary

The results of the household telephone survey build a better picture of the characteristics of potential early adopters, including a broad demographic profile, typical personal mobility patterns and clearly articulated perceptions of the barriers to and opportunities for the uptake of EVs. At the same time, the informal focus group with current EV owners provided important insights into the real-life experience of owning and operating an EV. Current EV owners can provide a clear picture of vehicle usage patterns, particularly those related to charging. Taken together, the findings from the household telephone survey and the focus group provide a robust foundation for determining strategies to facilitate the successful uptake and integration of the technology in the City of Ottawa.

Potential early adopters in the City of Ottawa are more likely to be over the age of 45, more affluent and better educated than the general population. The majority of this group live in detached, single-family homes with on-property parking and easy access to an electrical outlet. Early adopters consider themselves to be opinion leaders and enjoy sharing their opinions with others or actively seeking out new information sources. This suggests that early adopters could play a key role in communication strategies aimed at informing the broader market about EV technology. As the focus group demonstrated, current EV owners are already promoting EVs to friends and family.

Potential early adopters in the City of Ottawa are more likely to be over the age of 45, more affluent and better educated than the general population.

Few potential early adopters report having personal experience driving or riding in an EV, but there is evidence of a broadening general knowledge about EVs. A majority of the early adopter group are able to name at least one hybrid or fully electric vehicle (usually the Toyota Prius). However, this does not necessarily mean that a deeper understanding of the technology has developed; potential early adopters are generally not very familiar with the impact of EVs on the environment, how they compare with conventional vehicles, how the technology works or current government incentives designed to encourage their use. This lack of knowledge about EVs may underlie much of the resistance to the technology and points to opportunities for further education.

The survey results suggest that even among potential early adopters, purchasing or leasing an EV is not imminent. Concerns about the purchase price and current lack of infrastructure, as well as the potentially limiting range of the vehicle, are perceived as major barriers to the adoption of EVs. Interestingly, some of these perceived barriers do not align with the typical needs of the user. For example, while close to half of early adopters regularly drive less than 25 kilometres a day, the majority think that an EV would need to be capable of a range of more than 200 kilometres for them to feel confident that they would not be stuck somewhere without access to charging facilities. This finding suggests that range anxiety may be related to planning for worst-case scenarios as opposed to the respondents' typical driving patterns.

The survey findings also identified important opportunities for the promotion of EV uptake. For example, the majority of potential early adopters felt that access to faster home charging would be very important. This points to an opportunity to promote technology that enables faster home charging as a means of overcoming a perceived barrier. The survey also shows that the LDC is the proponent most trusted to install and maintain a Level 2 residential charging station and to act as a facilitator of EV adoption for the early adopter group. The LDC already has a clear stake in preparing for EV deployment because of the need to meet the demand for additional electricity. Given that the survey results showed a high level of trust in the LDC among potential early adopters, there is also an opportunity for it to play a vital role in the promotion and success of EV deployment.

The focus group with current EV owners also provided key insights into the opportunities and potential role of the LDC in the success of EV adoption. The EV owners were willing to provide personal information to the LDC so that it can better manage the load associated with EV charging on the electricity distribution system. They were also open to providing the LDC with the ability to manage the flow of electricity to charge their vehicle provided that they could override this option when required. EV owners also identified a need to provide workplaces and businesses with better information and support for facilitating workplace charging. These insights can help the LDC tailor its marketing of and communications about EVs.

The market research can be used to determine methods for advancing awareness of the value proposition of EV use among potential end-users, establishing a solid foundation for the growth of the EV industry.

The market research can be used to determine methods for advancing awareness of the value proposition of EV use among potential end-users, establishing a solid foundation for the growth of the EV industry. The results can inform a comprehensive understanding of the knowledge and information required to plan and prepare for the continued deployment of EVs in the City of Ottawa. Unless the barriers identified in this report are addressed, scarce and valuable resources may be misallocated or misaligned with the needs of the emerging market for EVs, thus decreasing the efficiency of these investments and increasing the cost of enabling EV use in Ottawa.

Section Two of the EMAP report has described the methodology and results of three separate but interrelated market research investigations. Section Three of the report describes the process of assessing the capacity of the electricity distribution system to accommodate the additional loading predicted as a result of the uptake of EVs.

SECTION THREE: Electricity Distribution System Assessment

Purpose of Assessing the Electricity Distribution System

The electrical power generation and transmission systems serving the City of Ottawa are capable of supporting a robust market for EV charging and use. However, the capacity of the local distribution system to deliver power to EV end-users may be constrained under certain conditions. The EMAP market research survey showed that potential early adopters of EV technology may exhibit consumer values that are shared by others in their communities. This could lead to "clustering" of early EV adopters, which, in turn, could create conditions in which the electricity distribution system might be constrained in its capacity to support EV-related loads.

The EMAP market research survey generated a body of evidence that richly characterizes the market for EVs in Ottawa. It also provides a better understanding of the nature of the charging services required to support EV deployment (i.e., when vehicles would be plugged in, for how long, and the importance of fast charging to the end-user). The findings from this market research were the basis for an assessment of the capacity of the electricity distribution system to accommodate the predicted patterns of demand for power to charge EVs.

Understanding how EVs are likely to change the profile of power demand at the neighbourhood level is critical to making informed, strategic and effective investments in technology and infrastructure to maintain and improve quality of service. At the same time, it is important for the LDC to clearly understand the impact of EV penetration across the entire electricity distribution system. The findings in this report identify the needs of the early adopter market, defined by location and mobility patterns, and the key barriers to EV charging and use that must be addressed. As such, this report can provide a foundation for developing strategies to enable the use of EVs in the Hydro Ottawa service area.

Terms and Definitions

The following section provides an overview of a number of key terms related to the basic units of electricity as well as power system configurations, with examples drawn from the City of Ottawa and the Hydro Ottawa service area. The definitions and descriptions are provided solely for the purpose of supporting the discussion of the EMAP electricity distribution system assessment and are not intended to reflect the intricacies of either the basic units of electricity or electrical power systems in general.

Basic Units of Electricity

The following basic units of electricity are used throughout this report in relation to potential constraints on the electricity distribution system:

Current (I) is the flow of electric charge through a conductor, such as a copper wire. Current is measured in amperes (A), often referred to as amps.

Voltage (V) is a measure of electromotive force between two points in an electrical circuit. Voltage is measured in volts (V). Volts are also used to express the voltage applied to a circuit by an energy source, such as a battery or an electrical generator.

Resistance (R) is a measure of a material's tendency to oppose the flow of electrical current. Resistance is expressed as the ratio of voltage to current and is measured in ohms (Ω). The greater the resistance, the less electrical current flows through a conductor. Increased resistance results in more of the electrical energy in the conductor being converted to heat energy that dissipates into the immediate surroundings. Keeping current levels low in an electric wire is one way to minimize the amount of electrical energy that is converted and lost as heat. Such losses are known as line losses.

This report also makes frequent references to three other terms related to electricity: **power**, **load** and **energy**.

What is the difference between a watt and a volt-ampere?

Both watts and volt-amperes can be used to express power when direct current (DC) circuits are being measured. In alternating current (AC) circuitry, which is a more common design in transmission and distribution systems, volt-amperes are used to accurately express more complex power characteristics.

Power is the time rate at which energy (e.g., the energy a conducting wire carries to charge a battery) is transferred or converted. Power is expressed as the product of voltage and current, and is measured in watts (W). For example, a wire carrying a current of 15 A at 110 V is transferring energy at a rate of 1,650 W. A watt is a per-second measure of energy transfer or conversion. A kilowatt (kW) is equal to 1,000 W and is one of the units typically used to express the maximum power characteristics of an electric motor or a transformer. For example, the charging systems built into new EVs (i.e., the on-board chargers) referenced in this report are rated in kilowatts. Power is also measured in kilovolt-amperes (kVA). The rated power capacities of the transformers investigated in this report are expressed in kilovolt-amperes, which include active power (the power consumed by the customer load) and reactive power (the energy exchanging within inductors and capacitors in the grid).

A **load** is any device that uses electrical energy or changes it into other forms of energy (e.g., heat, light, mechanical energy). An EV plugged in to charge its battery is an example of an electrical load. If the EV is plugged into a socket that supplies electricity at 15 A and 110 V, power flows at 1,650 W – similar to a typical hair dryer.

Energy, measured in kilowatt-hours (kWh), is the product of the power (i.e., the rate at which energy is transferred) and the time over which it is supplied (Energy = Power x Time). An EV battery charging at 1,650 W for eight hours stores approximately 13 kWh of energy.

The Electrical Power System

The primary focus of the electricity distribution system assessment is the distribution system at the secondary, or neighbourhood, level. To better understand the implications of EV charging for the distribution system, it is important first to explore the functions of some of the electrical power system components. The following section provides a simplified description of these functions; it is not intended to reflect the intricacies of any particular system.

The purpose of the electrical power system is to connect the centres of demand for electricity (i.e., the end-users) with the sources of supply (i.e., the power plant). Because the capacity to store electricity once it is generated is limited, the balance of supply and demand in Ontario is delicately managed on an instant-by-instant basis by the Independent Electricity System Operator (IESO). If customers generated their own electricity to meet their individual needs, no system of transmitting or distributing power would be needed. In reality, however, because the centres of demand are usually located far from the sources of supply, transmission and distribution are essential elements of today's power system.

In general, the power system involves electricity being generated at a power plant, where it is converted, or "stepped up," to very high voltages for transmission over long distances and then "stepped down" to lower voltages for distribution to end-users.

GENERATION

At the core of almost all generating stations is a series of turbines that are driven by water, steam or combustion gases. Connected by a driveshaft, the turbines cause an electromagnet inside the generator to rotate. The movement of the magnetic field induces a current in the surrounding coils of wire within the generator, producing a voltage that can feed the transmission system. The voltage levels generated are directly related to how quickly and with how much force the generator spins. Some generating stations in Ontario are privately owned and operated, while some are publicly owned. The largest power generator in the province is a Crown corporation, Ontario Power Generation (OPG).

At the core of almost all generating stations is a series of turbines that are driven by water, steam or combustion gases.

TRANSMISSION

A **transmission substation** is located at or near the generating station. The transmission substation contains a large **step-up transformer**, which increases the voltage produced by the generator to the high levels required for long-distance transmission. Electrical power systems generally use a series of transformers to convert electricity to different voltage levels appropriate for each stage of the system.

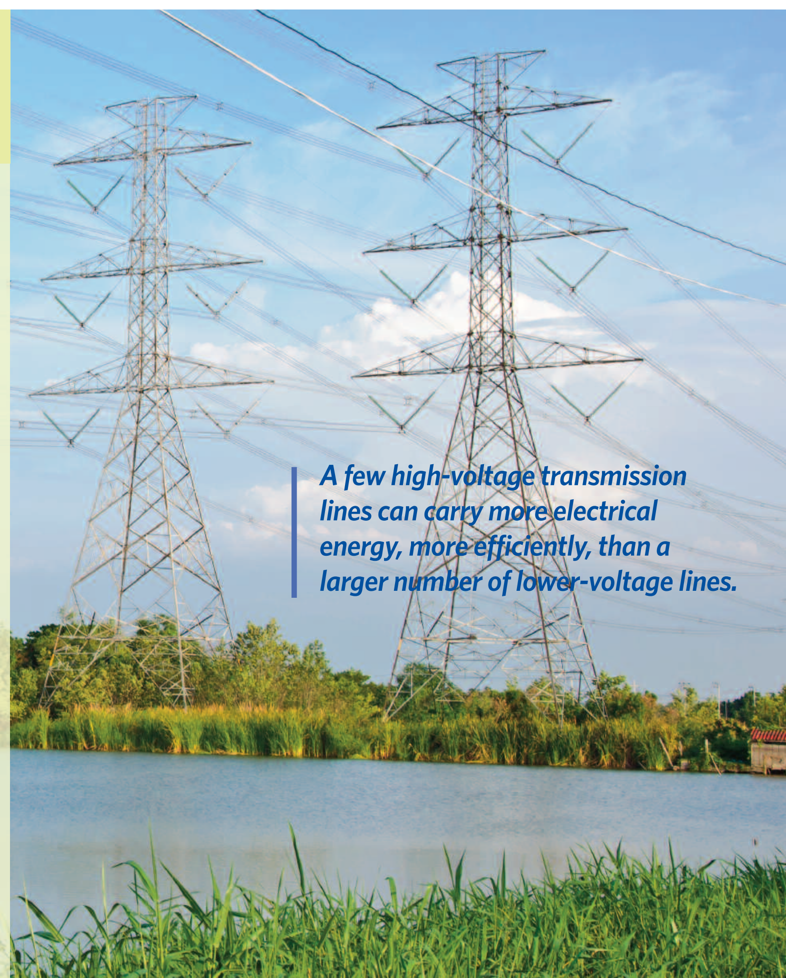
Individual households are usually located far from the generation station. To reach the consumer, the electricity generated must be conducted by wires spanning long distances. High-voltage **transmission lines** are used for this purpose. A few high-voltage transmission lines can carry more electrical energy, more efficiently, than a larger number of lower-voltage lines. Also, the transmission of electrical power at high voltage keeps current levels low, and this minimizes resistance and line losses. While for the majority of end-users, these high voltages need to be reduced (stepped down) to a lower level for household or small business use, some industrial facilities with high electrical loads (e.g., high-power motors) may be connected directly to the transmission system. The transmission company responsible for transmitting electricity to the City of Ottawa is Hydro One Networks, Inc. The transmission lines servicing the city operate at voltages of 500 kV, 230 kV or 115 kV.

Step-down transformers are found at transmission stations located close to or in the city. These transformers convert the high voltages from the transmission lines to lower voltages for distribution. These transmission stations and lower-voltage transmission lines are sometimes referred to as the **subtransmission system**.

How does a transformer "step down" or "step up" voltage?

Transformers neither produce nor consume power or energy. But, by regulating power to the right levels, they make it possible for devices of all types and purposes to operate on just a few levels of power supply.

At their most essential level, transformers consist of parallel but separate coils of wire wound around a magnetic core. When voltage is applied to one coil (usually called the primary or input), it magnetizes the iron core, which induces a voltage in the other coil (usually called the secondary or output). If the secondary coil has fewer loops than the primary coil, less voltage and more current is induced in the secondary coil. This is the case with a "step-down" transformer. A "step-up" transformer works in the opposite way. With more loops in the secondary coil than in the primary coil, it increases voltage and reduces current. The turns ratio (the ratio of the number of turns on the primary coil of an electrical transformer to the number on the secondary) of the two sets of windings determines the amount of voltage transformation.



A few high-voltage transmission lines can carry more electrical energy, more efficiently, than a larger number of lower-voltage lines.

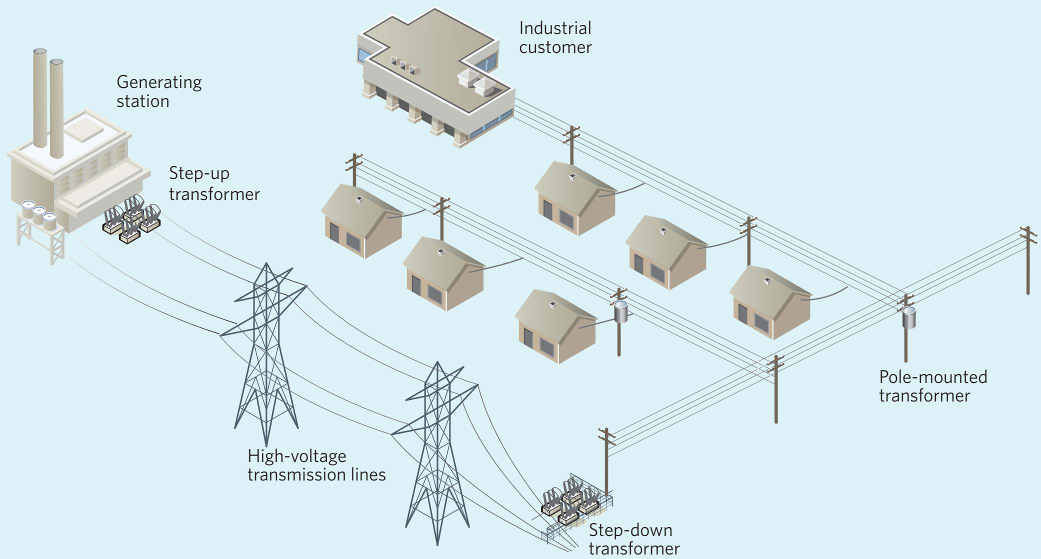
DISTRIBUTION

Electricity distribution is the final step in the delivery of electricity to end-users. The distribution system takes the electricity carried along the high-voltage transmission lines and, through a series of step-down transformers, lowers the voltage to levels appropriate for use by individual households and businesses. The distribution system is owned and operated by LDCs. As previously mentioned, Hydro Ottawa is the LDC for the City of Ottawa.

The **distribution transformer station** is the point where the conversion from transmission to distribution occurs. In the Hydro Ottawa service area, these transformers step down power to one of six voltage levels – 44 kV, 27.6 kV, 13.2 kV, 12.43 kV, 8.32 kV or 4.16 kV. **Distribution feeders** are electrical cables or conductors that originate at the distribution transformer station and distribute electrical power to one or more secondary transformers. The voltage level of these distribution feeders may vary geographically within a service area. For the Hydro Ottawa service area, there are two broad geographic areas that represent different distribution system configurations: the east, south and west of the city (the region surrounding downtown Ottawa) and the downtown core.

East, south and west of the city: Both 230 kV and 115 kV transmission lines supply electrical power to distribution transformer stations that step down the voltage to 44 kV, 27.6 kV, 13.2 kV or 8.32 kV and provide electrical power to the areas of the city located outside the downtown core.

Electricity distribution is the final step in the delivery of electricity to end-users.



Electricity Generation, Transmission and Distribution

Each of these voltage classes directly serves end-users (residential, commercial and industrial) with the exception of the 44 kV distribution feeders, which serve the following:

- Smaller **municipal substations** where step-down transformers convert voltage to either 27.6 kV or 12.43 kV (only a small pocket in the west of the city is served by 12.43 kV substations). Feeders running from the 27.6 kV or 12.43 kV municipal substations provide electrical power directly to end-users.
- Smaller **municipal substations** where step-down transformers convert voltage to 8.32 kV for end-users.

In addition, the 13.2 kV system of distribution transformer stations also serves smaller **municipal substations** where step-down transformers convert voltage to 4.16 kV and provide electrical power directly to end-users.

Downtown core: Nine of the twelve distribution transformer stations located in the downtown core of Ottawa convert 115 kV transmission lines to 13.2 kV feeders. The feeders from these 13.2 kV distribution transformer stations serve the following:

- residential and commercial end-users as well as the very small number of industrial loads in downtown Ottawa
- municipal substations that convert the voltage from 13.2 kV to 4.16 kV for downtown residential and commercial end-users.

LOCAL TRANSFORMERS

Pole- or pad-mounted transformers or transformers in underground vaults provide the final voltage transformation in the electrical power system. These transformers step down the voltage from distribution feeders to the level appropriate for use by individual households (typically 120 V or 240 V).

When distribution feeders are located overhead, the transformer is usually mounted on a utility pole and is referred to as pole-mounted. When the distribution feeders run underground, the transformer is mounted on a concrete pad (pad-mounted) or installed in an underground vault.

SECONDARY CONNECTION SYSTEM – SECONDARY DROP LEAD, SECONDARY BUS AND SERVICE CABLES

The secondary connection system supplies power from the local transformer to the end-user and consists of the following:

- The **secondary drop lead** is a conductor connecting the transformer to a secondary bus. A bus provides a common electrical connection between multiple electrical devices.
- The **secondary bus** is a common connection point for the individual service cables running directly to each household serviced by the transformer.
- **Service cables** connect the secondary bus to the end-user. Service cables are the last stage of the distribution system.

For the purposes of this report, the neighbourhood-level distribution system is defined as either the pole- or pad-mounted transformer and anything beyond it (i.e., the secondary connection system).

Methodology

To better understand the implications of the anticipated uptake of EVs in the context of electricity demand in Ottawa, scenario development and simulation were undertaken to assess the electricity distribution system's capacity to support additional loading resulting from EV charging. The process involved two separate but related investigations:

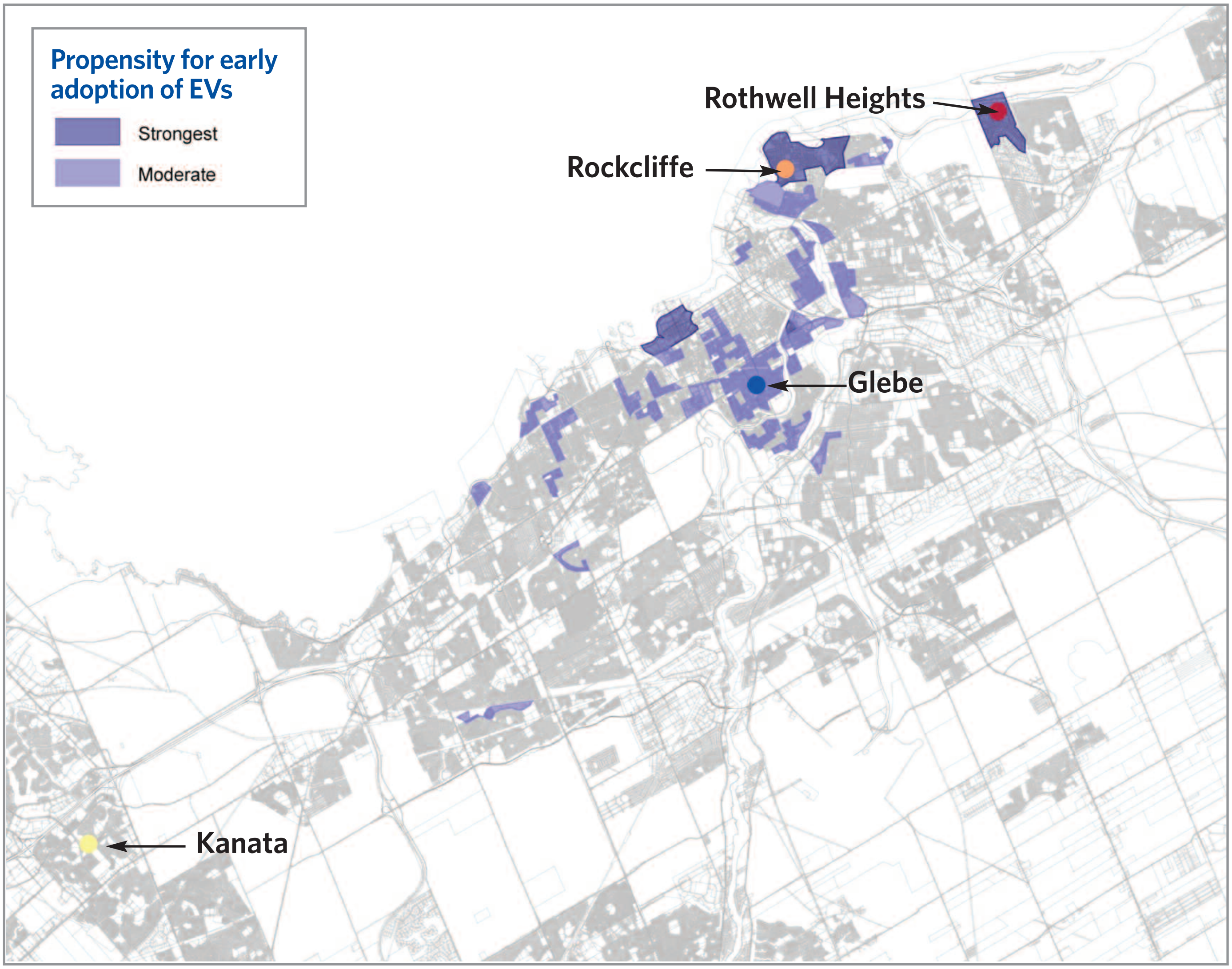
- A neighbourhood-level assessment of the distribution system, beginning with the pole- or pad-mounted transformer and ending with the secondary cables responsible for running electrical power to individual households. The impacts of EV charging on the distribution system were simulated by Dr. Xiaoyu Wang of the Department of Electronics at Carleton University, using relevant feeder and transformer data provided by Hydro Ottawa.
- A system-wide examination of the potential impact of EVs on the distribution system for the City of Ottawa as a whole was conducted by Hydro Ottawa.

The specific process, outputs and assumptions made in the development and application of the assessment are described below. Each of the scenarios modelled reflects a steady-state analysis as opposed to real-time dynamic simulations, which were beyond the scope of this study.

Assessment of the Electricity Distribution System at the Neighbourhood Level

Transformers in three postal codes corresponding to areas identified through the market research survey as having a high propensity for early adoption of EVs and in one postal code (Kanata) representative of Hydro Ottawa's new planning standards were selected as test cases for the investigation of the neighbourhood-level distribution system (see Figure 21). Relevant feeder and transformer data were used as inputs to an electrical distribution system modelling and simulation software tool to estimate the additional load on the selected transformers resulting from a number of variables associated with EV charging.

Figure 21: Location of Transformers Investigated in the City of Ottawa



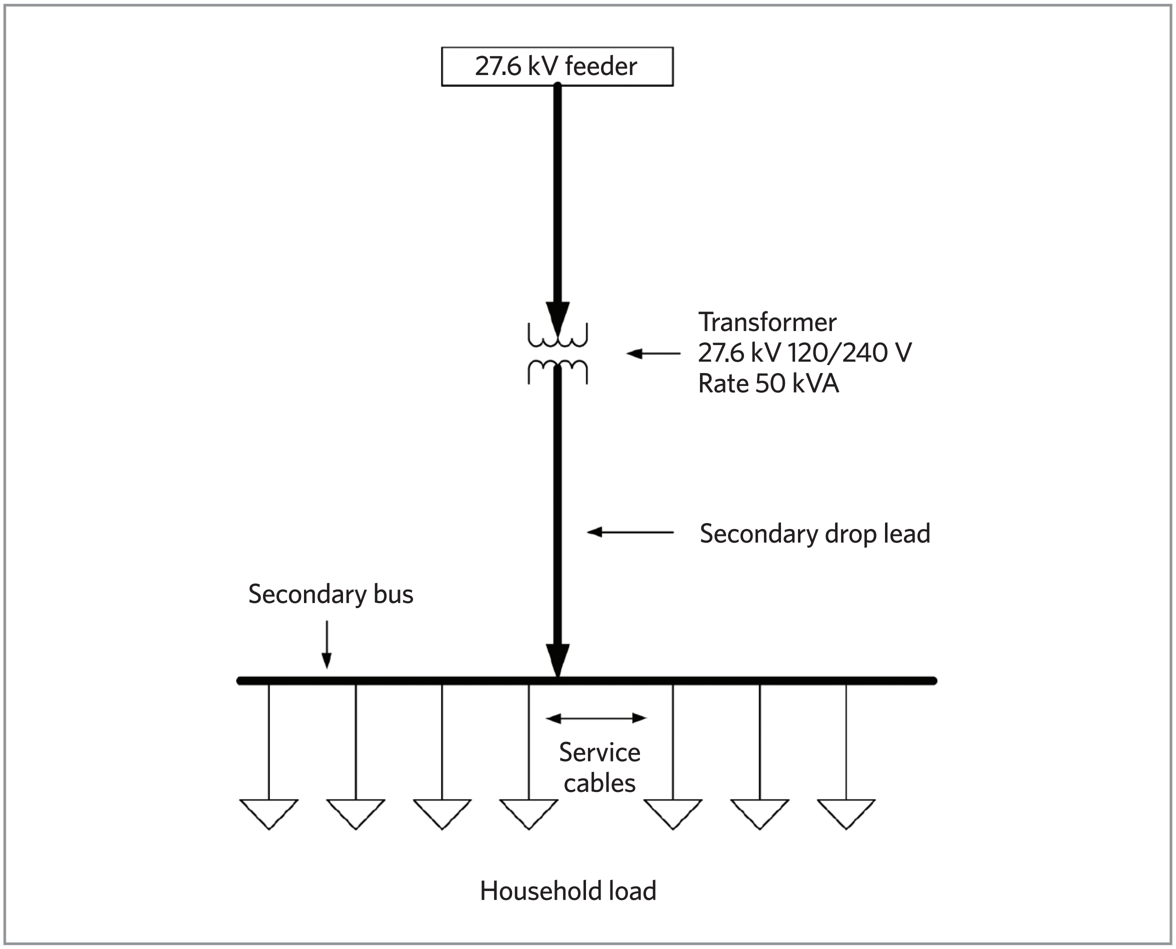
The postal code areas selected are supplied by 120/240 V local transformers, with a 50 kVA capacity. This is a fairly common transformer size for the City of Ottawa, but it should be noted that the distribution system is made up of a range of transformers with different capacities, each of which would experience the impacts related to EV penetration differently.

The current capacity for the secondary cables in the Hydro Ottawa service area varies primarily based on when they were installed, with older installations having a secondary drop lead rated at 185 A to meet the design standard required in the past. As a result of changes to the design criteria, there is now a new standard requiring that any upgrades or new installations have a secondary drop lead rated at 325 A. The scenarios in this report investigate both planning standards to gain a better understanding of the implications of EV charging under existing conditions and under those that will result from future equipment upgrades.

Further details specific to each of the transformers investigated are described below.

Rothwell Heights: The transformer selected in Rothwell Heights is pole-mounted and supplied by a 27.6 kV feeder. It provides power to seven households. The current capacity of the secondary drop lead is 185 A. See Figure 22 for a representation of the model of the distribution system at the neighbourhood level for the Rothwell Heights transformer.

Figure 22: Model of the Distribution System at the Neighbourhood Level for Rothwell Heights

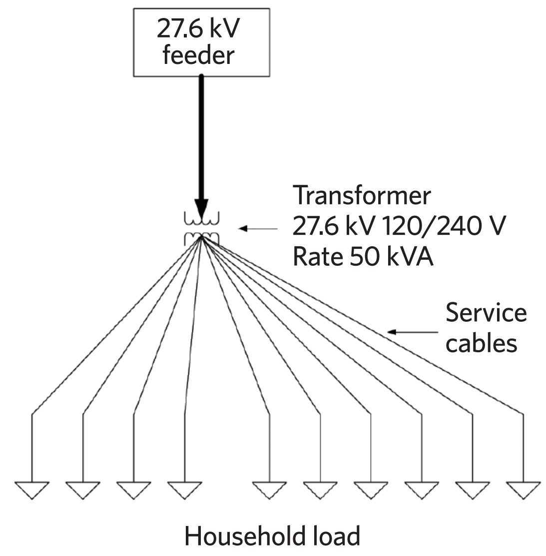


Rockcliffe: Five households are served by the transformer selected in Rockcliffe. It is pole-mounted and supplied by a feeder with a rated primary voltage of 4.16 kV, and the secondary drop lead has a capacity of 185 A.

Glebe: The transformer selected in the Glebe is pole-mounted and supplied by a feeder with a rated primary voltage of 4.16 kV. It provides power to 12 households. The secondary drop lead has a capacity of 185 A.

Kanata: The transformer selected in Kanata provides power to 10 households and is supplied by a 27.6 kV feeder. The transformer is pad-mounted, and its secondary cables connect directly to end-users without a secondary drop lead or secondary bus. See Figure 23 for a representation of the model of the distribution system at the neighbourhood level for the Kanata transformer.

Figure 23: Model of the Distribution System at the Neighbourhood Level for Kanata



SCENARIO DEVELOPMENT AND RESULTS

By offering a means of investigating hypothetical situations, scenario development and simulation can inform the development of strategies to produce desired outcomes. A range of scenarios were investigated to better understand the extent to which a number of key variables could impact the capacity of the electricity distribution system at the neighbourhood level to accommodate EV charging at home. In the interests of brevity, this report focuses on the findings for the Rothwell Heights transformer. For a summary of the findings for the other three transformers investigated, see Appendix B.

The scenario development consisted of

- investigating key variables
- establishing the effects of EV charging on transformer aging
- determining an optimal EV charging strategy

The following section outlines both the process and the key findings of the electricity distribution system assessment, beginning with a discussion of the key variables predicted to have an effect on the capacity of the neighbourhood-level distribution system to support EV-related loads. This is followed by an investigation of the effects of EV charging on the lifespan of transformer equipment and discussion of a strategy for maximizing the number of EVs that can be charged on a single transformer.

Investigating Key Variables

The first set of scenarios tested the capacity of the electricity distribution system at the neighbourhood level to accommodate the potential loading from EV charging. These scenarios were developed based on the predicted home charging patterns of early adopters of EV technology, four on-board charger capacities and the assumption that ambient temperature can create additional stress for the neighbourhood-level distribution system. While these conditions are not likely to occur simultaneously, this investigation allows for a better understanding of possible worst-case scenarios and key factors that could limit the number of EVs that can be accommodated by the electricity distribution system.

In any given scenario, if the sum of the household load and the EV-related load is less than the available capacity of the transformer and the secondary cables, the system is deemed to be equipped to accommodate the load. If the household load plus the additional EV-related load exceeds the available capacity, overloading of either the transformer or the secondary cables, or both, will occur.

The results for each scenario are documented in the tables in this section of the report. Results highlighted in light turquoise in the tables indicate that loading exceeds the rated capacity of the transformer (i.e., 50 kVA) or the secondary drop lead (results are given for both 185 A and 325 A).

Scenarios were developed and tested based on a number of key variables predicted to have the greatest potential for impacts on the capacity of the system to support EV-related loading.

The variables tested were

- EV penetration rate
- EV on-board charger capacity
- ambient temperature
- time of charge

The key variables investigated are described in greater detail below.

Electric Vehicle Penetration Rate

As the results of the market research show, the rate of EV penetration is influenced by several factors, including demographics, consumer attitudes and the availability of charging infrastructure. At the same time, the number of EVs that can be charged simultaneously is limited by the capacity of the transformer and secondary cables to meet the demand for power. The scenarios in this report explore the impact on the transformer and secondary cables resulting from the incremental load from each additional EV charging. Unless otherwise noted, the EV penetration rate is calculated by using the total load profile for the transformer and adding the additional load for one EV per household served by the transformer.

Electric Vehicle On-Board Charger Capacity

As previously noted, most EVs can be charged using a standard 120 V household outlet (Level 1 charging). If a vehicle is charging at Level 1, power flows through the on-board charger at a lower rate than when charging at 240 V (Level 2 charging). For example, the 2013 Fiat 500e can charge at 6.6 kW at 240 V, but power flows at 1.0 kW when the vehicle is charging at 120 V. For the purposes of this report, the 2013 Fiat 500e will be used to illustrate the effects of Level 1 charging on the electricity distribution system.

A number of EVs on the market have an on-board charger rated at 3.3 kW (e.g., the 2013 Nissan LEAF base model) or 6.6 kW (e.g., Ford Focus Electric or Honda Fit EV) when charging at 240 V. Compared to a 3.3 kW charger, a 6.6 kW charger significantly reduces the length of time required to charge the vehicle, but it also doubles the demand for power from the electricity distribution system. Even more powerful on-board chargers are also available, such as the 20 kW rated charger on board the Tesla Model S.

Table 1 summarizes the specifications for the different vehicles used to illustrate the charger capacities investigated in this section of the report. Looking at a range of charger capacities allows for more in-depth analysis of the extent to which conditions such as time of charge or ambient temperature can affect the capacity of the electricity distribution system to meet the additional demand for power for EV charging.

Table 1: Charger and Battery Specifications for Various Electric Vehicle Models

EV model	2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
Charging level	120 V	240 V	240 V	240 V
On-board charger capacity	1.0 kW	3.3 kW	6.6 kW	20 kW
Battery size	24 kWh	24 kWh	20 kWh	85 kWh
Hours to fully charge vehicle	22 hours	8 hours	3 hours	5 hours
Distance vehicle can travel per hour of charge	7 km	14 km	43 km	100 km

Notes:

(1) The Fiat 500e can also draw power at 6.6 kW when charging at 240 V.

(2) The Fiat 500e and Honda Fit EV are not currently available for purchase in Canada.

Ambient Temperature

In summer, there is an increase in the demand for electricity to power air conditioners to cool houses. There is also a higher demand for power during the winter months; people tend to be inside longer, with the lights on and furnace fans and heaters running. These seasonal factors increase the load on the transformer. This means that the electricity distribution system could reach capacity during the summer and winter months at a lower EV penetration rate than it would during the times of the year with less extreme temperatures. The scenarios investigated, therefore, used the warmest day from the previous year, July 17, 2013, with a high of 33.2 °C, to illustrate the worst case for summer and the coldest day, January 23, 2013, with a low of –28.5 °C, to represent the worst case for winter.

Time of Charge

Because the demand for electricity fluctuates over the course of a day, the time at which EVs are plugged in has significant implications for electricity distribution system capacity. Before any additional loading from EV charging was considered, the load profiles for the warmest day in summer and the coldest day in winter were generated to determine the maximum (i.e., peak) and minimum (i.e., valley) loads and the time of day when they occurred.

Figures 24 and 25 show the overall load profiles for the transformer and the individual load profiles for each of the seven households serviced by it over a 24-hour period. Figure 24 shows that the peak load for the warmest day was 18.48 kW, and the valley load was 7.69 kW. This indicates that the transformer would not have been close to its rated capacity on the warmest day, even at peak load. Similarly, Figure 25 shows that on the coldest day, the system would have operated well below capacity and easily accommodated any additional loading related to winter conditions (e.g., people remaining indoors more, using more lights or electric heaters). The peak load for the coldest day was 14.9 kW, and the valley load was 6.73 kW.

Figure 24: Transformer Load Profile by Hour on the Warmest Day (July 17, 2013)

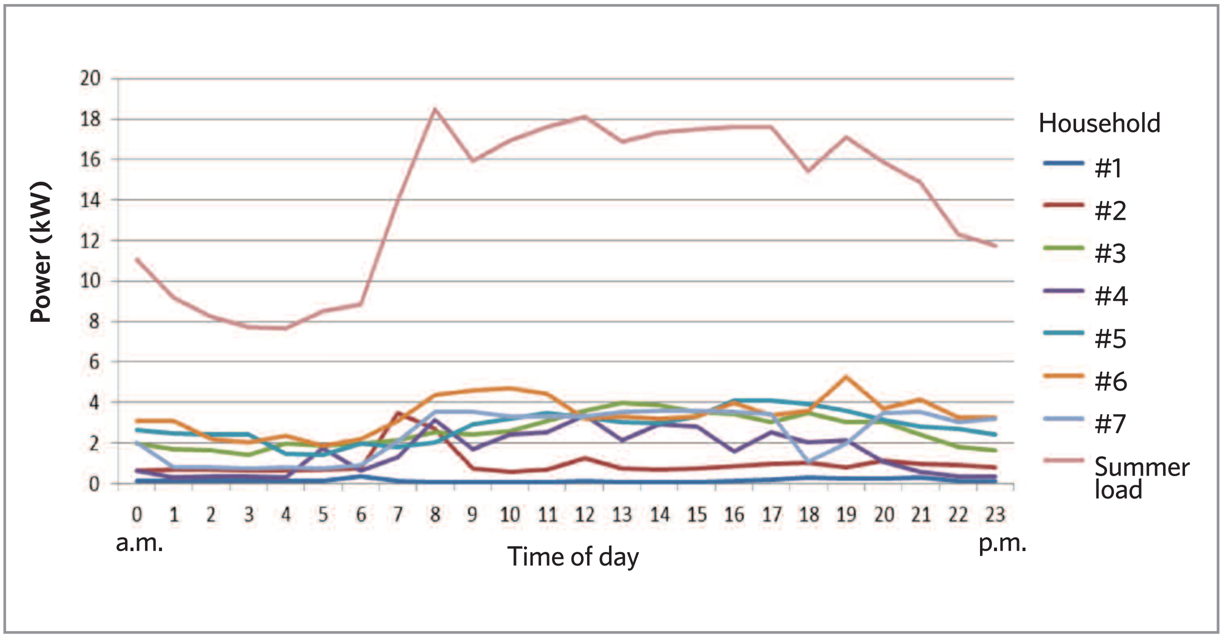
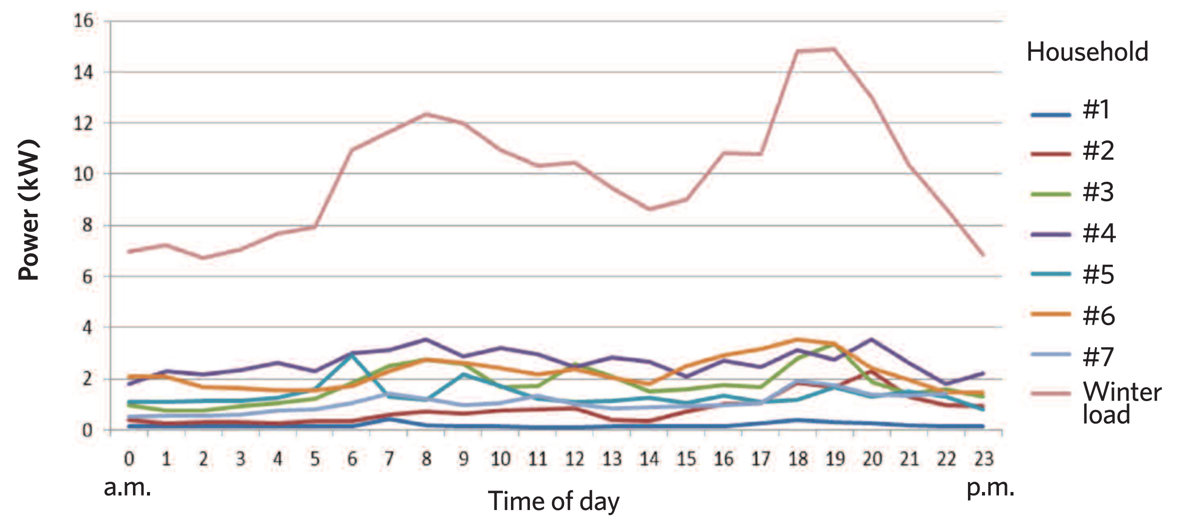


Figure 25: Transformer Load Profile by Hour on the Coldest Day (January 23, 2013)



Based on the load profiles for the days in question, the following periods were selected for further analysis:

- valley load time (4 a.m. on the warmest day and 2 a.m. on the coldest day)
- peak load time (8 a.m. on the warmest day and 7 p.m. on the coldest day)

The following scenarios were used to investigate the effect of EV penetration and different types of chargers on the electricity distribution system at these times of day in summer and winter.

Warmest Day in Summer (July 17, 2013)

Valley Load Time (4 a.m.)

Table 2 shows that the transformer could accommodate 100 per cent EV penetration (assuming one EV per household) with a 1.0 kW or 3.3 kW charger at valley load time. However, if all seven households were charging an EV with a 6.6 kW charger simultaneously, the transformer would be overloaded. As few as three vehicles with a 20 kW charger would exceed the rated capacity of the transformer.

Table 3 shows that the 185 A secondary drop lead would be overloaded at relatively high penetration levels of vehicles with a 6.6 kW charger. Vehicles with a 20 kW charger would have a more significant effect, with just two vehicles causing overload. As Table 4 shows, the 325 A secondary drop lead could accommodate greater numbers of vehicles across the range of charger sizes. Only vehicles with a 20 kW charger would cause overloading, and the secondary drop lead could accommodate three such vehicles before overloading.

Table 2: Transformer Load on the Warmest Day at Valley Load Time

Number of EVs in addition to household load	Transformer load (kW) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	8.69	10.99	14.29	27.69
2	9.69	14.29	20.89	47.69
3	10.69	17.59	27.49	67.69
4	11.69	20.89	34.09	87.69
5	12.69	24.19	40.69	107.69
6	13.69	27.49	47.29	127.69
7	14.69	30.79	53.89	147.69

Table 3: Current on the Secondary Drop Lead (185 A) on the Warmest Day at Valley Load Time

Number of EVs in addition to household load	Current on 185 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	36.21	45.79	59.54	115.38
2	40.38	59.54	87.04	198.71
3	44.54	73.29	114.54	282.04
4	48.71	87.04	142.04	365.38
5	52.88	100.79	169.54	448.71
6	57.04	114.54	197.04	532.04
7	61.21	128.29	224.54	615.38

Table 4: Current on the Secondary Drop Lead (325 A) on the Warmest Day at Valley Load Time

Number of EVs in addition to household load	Current on 325 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	36.21	45.79	59.54	115.38
2	40.38	59.54	87.04	198.71
3	44.54	73.29	114.54	282.04
4	48.71	87.04	142.04	365.38
5	52.88	100.79	169.54	448.71
6	57.04	114.54	197.04	532.04
7	61.21	128.29	224.54	615.38

Peak Load Time (8 a.m.)

Table 5 shows that the transformer would be overloaded if five EVs with a 6.6 kW charger were plugged in simultaneously at peak load time. It would take just two vehicles charging with a 20 kW charger to exceed the capacity of the transformer. The transformer would be severely over capacity (over three times the rated capacity) if all seven vehicles were charging with a 20 kW charger.

Table 6 shows that the 185 A secondary drop lead would be overloaded if four vehicles with a 6.6 kW charger were charging simultaneously and by just one vehicle with a 20 kW charger. As Table 7 shows, the 325 A secondary drop lead would be overloaded by three vehicles with a 20 kW charger.

Table 5: Transformer Load on the Warmest Day at Peak Load Time

Number of EVs in addition to household load	Transformer load (kW)			
	EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	19.48	21.78	25.08	38.48
2	20.48	25.08	31.68	58.48
3	21.48	28.38	38.28	78.48
4	22.48	31.68	44.88	98.48
5	23.48	34.98	51.48	118.48
6	24.48	38.28	58.08	138.48
7	25.48	41.58	64.68	158.48

Table 6: Current on the Secondary Drop Lead (185 A) on the Warmest Day at Peak Load Time

Number of EVs in addition to household load	Current on 185 A secondary drop lead (A)			
	EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	81.17	90.75	104.50	160.33
2	85.33	104.50	132.00	243.67
3	89.50	118.25	159.50	327.00
4	93.67	132.00	187.00	410.33
5	97.83	145.75	214.50	493.67
6	102.00	159.50	242.00	577.00
7	106.17	173.25	269.50	660.33

Table 7: Current on the Secondary Drop Lead (325 A) on the Warmest Day at Peak Load Time

Number of EVs in addition to household load	Current on 325 A secondary drop lead (A)			
	EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	81.17	90.75	104.50	160.33
2	85.33	104.50	132.00	243.67
3	89.50	118.25	159.50	327.00
4	93.67	132.00	187.00	410.33
5	97.83	145.75	214.50	493.67
6	102.00	159.50	242.00	577.00
7	106.17	173.25	269.50	660.33

Coldest Day in Winter (January 23, 2013)

Valley Load Time (2 a.m.)

The results of EV charging for the coldest day in winter at valley load time closely resemble those from the warmest day in summer. Table 8 shows that the transformer could accommodate 100 per cent penetration of EVs with a 1.0 kW or 3.3 kW charger. If all seven households were charging an EV with a 6.6 kW charger simultaneously, the transformer would be overloaded, and just three vehicles with a 20 kW charger would create similar conditions.

Table 9 shows that the 185 A secondary drop lead would be overloaded if six vehicles with a 6.6 kW charger or two vehicles with a 20 kW charger were plugged in simultaneously. As Table 10 shows, four vehicles with a 20 kW charger would cause the 325 A secondary drop lead to overload.

Table 8: Transformer Load on the Coldest Day at Valley Load Time

Number of EVs in addition to household load	Transformer load (kW)			
	EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	7.73	10.03	13.33	26.73
2	8.73	13.33	19.93	46.73
3	9.73	16.63	26.53	66.73
4	10.73	19.93	33.13	86.73
5	11.73	23.23	39.73	106.73
6	12.73	26.53	46.33	126.73
7	13.73	29.83	52.93	146.73

Table 9: Current on the Secondary Drop Lead (185 A) on the Coldest Day at Valley Load Time

Number of EVs in addition to household load	Current on 185 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	32.21	41.79	55.54	111.38
2	36.38	55.54	83.04	194.71
3	40.54	69.29	110.54	278.04
4	44.71	83.04	138.04	361.38
5	48.88	96.79	165.54	444.71
6	53.04	110.54	193.04	528.04
7	57.21	124.29	220.54	611.38

Table 10: Current on the Secondary Drop Lead (325 A) on the Coldest Day at Valley Load Time

Number of EVs in addition to household load	Current on 325 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	32.21	41.79	55.54	111.38
2	36.38	55.54	83.04	194.71
3	40.54	69.29	110.54	278.04
4	44.71	83.04	138.04	361.38
5	48.88	96.79	165.54	444.71
6	53.04	110.54	193.04	528.04
7	57.21	124.29	220.54	611.38

Peak Load Time (7 p.m.)

As Table 11 shows, at peak load time on the coldest day in winter, six EVs with a 6.6 kW charger charging simultaneously would cause the transformer to overload. As on the warmest day in summer, it would take only two vehicles with a 20 kW charger to exceed the rated capacity of the transformer.

Table 12 shows that the 185 A secondary drop lead would be overloaded with five vehicles with a 6.6 kW charger and two vehicles with a 20 kW charger. Table 13 shows that the 325 A secondary drop lead could accommodate 100 per cent EV penetration of vehicles with a 6.6 kW charger and three vehicles with a 20 kW charger.

Table 11: Transformer Load on the Coldest Day at Peak Load

Number of EVs in addition to household load	Transformer load (kW) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	15.9	18.2	21.5	34.9
2	16.9	21.5	28.1	54.9
3	17.9	24.8	34.7	74.9
4	18.9	28.1	41.3	94.9
5	19.9	31.4	47.9	114.9
6	20.9	34.7	54.5	134.9
7	21.9	38	61.1	154.9

Table 12: Current on the Secondary Drop Lead (185 A) on the Coldest Day at Peak Load

Number of EVs in addition to household load	Current on 185 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	66.25	75.83	89.58	145.42
2	70.42	89.58	117.08	228.75
3	74.58	103.33	144.58	312.08
4	78.75	117.08	172.08	395.42
5	82.92	130.83	199.58	478.75
6	87.08	144.58	227.08	562.08
7	91.25	158.33	254.58	645.42

Table 13: Current on the Secondary Drop Lead (325 A) on the Warmest Day at Peak Load

Number of EVs in addition to household load	Current on 325 A secondary drop lead (A) EV charger capacity			
	1.0 kW	3.3 kW	6.6 kW	20 kW
1	66.25	75.83	89.58	145.42
2	70.42	89.58	117.08	228.75
3	74.58	103.33	144.58	312.08
4	78.75	117.08	172.08	395.42
5	82.92	130.83	199.58	478.75
6	87.08	144.58	227.08	562.08
7	91.25	158.33	254.58	645.42

Summary – Key Variables

The results of the investigation of key variables show that there are several factors that contribute to determining the number of EVs that the electricity distribution system at the neighbourhood level can support. For example, the number of vehicles that would cause the transformer or secondary drop lead to overload decreases proportionally as the size of the on-board charger increases. Vehicles with a 6.6 kW or 20 kW charger would have a more significant effect on the electricity distribution system, with just two vehicles with a 20 kW charger causing transformer overload at periods of peak load and just three at valley load in both summer and winter.

The findings also show that seasonal ambient temperature is a key factor in determining the number of EVs that can charge simultaneously; the electricity distribution system carries an additional load from air conditioning in summer and from heating and lighting in winter, reducing its capacity to accommodate EV charging. For most of the scenarios tested, the Rothwell Heights transformer could accommodate fewer EVs charging in the summer than the winter. The relationship between the winter and summer results was not the same for all four transformers investigated; for the results for Rockcliffe, the Glebe and Kanata, see Appendix B.

EV charging during periods of peak electricity demand poses a greater risk of system overload and potential power outages than charging during valley load times. The market research showed that early adopters are likely to return home to charge their vehicles at periods of peak demand, particularly in winter. Time of charge is thus a critical variable and will be explored more fully later in this section.

With regard to Hydro Ottawa's old and new standards for secondary drop leads, the investigation of key variables showed, unsurprisingly, that in all cases the 185 A secondary drop lead could accommodate fewer EVs than the 325 A secondary drop lead. However, even the 325 A secondary drop lead would be overloaded if vehicles with a 20 kW charger were charged at either peak or valley load in summer or winter.

Establishing the Effects of Electric Vehicle Charging on Transformer Aging

The degree to which EV charging could contribute to a reduction in the lifespan of a transformer is an important consideration, given the costs associated with upgrading or replacing such equipment. A transformer's rate of aging and overall lifespan are determined by the condition of its internal insulation materials because they typically fail before other components. The temperature of the transformer – more specifically, the hottest spot within its windings (known as the winding hot spot) – impacts the rate at which the insulation materials deteriorate. The temperature of the winding hot spot depends on factors such as ambient temperature and the load the transformer is carrying. The transformer's insulation materials deteriorate more rapidly the hotter the transformer gets and the longer it stays hot.

Because the load on the transformer impacts the temperature of its internal components, the increased load from EV charging could contribute to accelerated aging of the transformer. Moreover, EV charging is likely to occur at night, cutting into the transformer's cooling cycle (reduced loads during off-peak hours typically allow transformers to cool down). For these reasons, it is important to better understand the extent to which EV charging could impact transformer aging.

For the purposes of assessing the effect of EV charging on transformer aging, the method outlined in IEEE C57.91-1995, *Guide for Loading Mineral-Oil-Immersed Power Transformers*, was used, taking temperature as the principal variable affecting insulation degradation. This method consists of the following two-step process:

1. Calculating the **Factor of Aging Acceleration (*F_{AA}*)**: The winding hot spot temperature is determined based on transformer load and ambient temperature and is fed into an equation that estimates the instantaneous accelerated aging of the transformer (i.e., the F_{AA}). The following is a condensed version of the algorithm for F_{AA}:

$$F_{AA} = e^{\left[\frac{15000}{T_{HR}+273} - \frac{15000}{T_{HS}+273}\right]}$$

where

T_{HR} is the reference temperature of 110 °C
T_{HS} is the transformer winding hot spot temperature in degrees Celsius
273 is the conversion from degrees Celsius to Kelvin

An F_{AA} value of 1.0 corresponds to the reference temperature (i.e., 110 °C); above this threshold, accelerated transformer aging occurs. Where the winding hot spot temperature is greater than 110 °C, the F_{AA} value will be greater than 1.0, indicating accelerated transformer aging.

2. Calculating the **Factor of Equivalent Aging (*F_{EQA}*)**: Once the F_{AA} is determined, it is fed into an equation that estimates the rate of accelerated aging averaged over a given period of time (i.e., the F_{EQA}). The condensed algorithm for F_{EQA} is as follows:

$$F_{EQA} = \frac{\sum_{n=1}^{N} F_{AAn} \Delta t_n}{\sum_{n=1}^{N} \Delta t_n}$$

where

n is the index of time interval, t
N is the total number of time intervals
F_{AAn} is the F_{AA} for the temperature during the time interval Δt_n
Δt_n is the time interval in hours

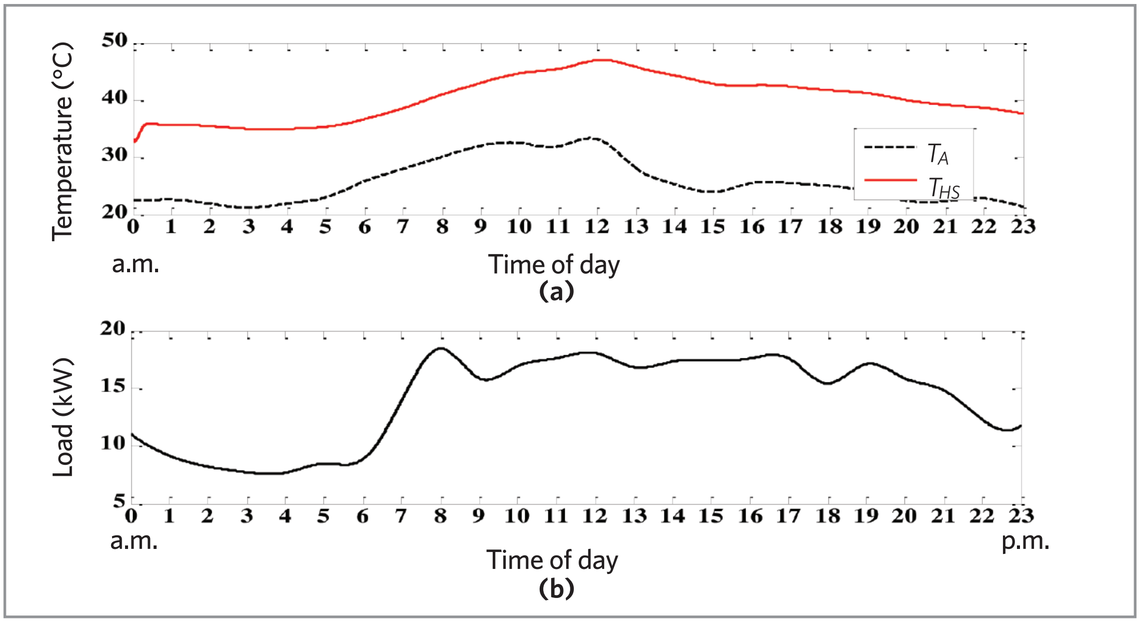
For the purposes of this study, the F_{EQA} is determined over a 24-hour period. As with the F_{AA}, when the F_{EQA} is greater than 1.0, transformer aging is accelerated. While the F_{AA} denotes the instantaneous rate of accelerated aging, the F_{EQA} provides the average rate for the total number of time intervals over a 24-hour period. As such, the F_{EQA} value can be used to determine the level of EV penetration that would contribute to the accelerated deterioration of the insulation materials and, as a result, the reduced lifespan of the transformer.

Warmest Day at Peak Load

Because ambient temperature and transformer load affect transformer temperature, the key determinant of transformer aging, this set of scenarios looked at the worst case for the Rothwell Heights transformer: EV charging at peak load time on the warmest day in summer. For information about the effects on the Rothwell Heights transformer of EV charging on the coldest day in winter, see Table 15; for the results for the other three transformers investigated, see Appendix B.

Ambient temperature and the temperature of the winding hot spot for the transformer were determined over a 24-hour period on the warmest day in summer (see Figure 26a), and a load profile excluding any additional load from EV charging was generated (see Figure 26b). These figures show that the load on the transformer was well below its rated capacity, and the temperature of the winding hot spot was below 110 °C.

Figure 26: Ambient Temperature, Temperature of the Winding Hot Spot and Load Profile for the Warmest Day



T_A is ambient temperature
T_{HS} is temperature of the winding hot spot

Figure 27 shows that the maximum F_{AA} value for the day in question remains well below the 1.0 threshold without the additional loading from EV charging. The F_{AA} curve for various penetration levels of EVs with a 6.6 kW charger is shown in Figure 28. The results show that six EVs with a 6.6 kW on-board charger could charge simultaneously without exceeding the threshold for instantaneous accelerated aging of the transformer.

Figure 29 illustrates the F_{EQA}, showing that when the rate of accelerated aging is averaged out across a 24-hour period, all seven EVs with a 6.6 kW charger could charge simultaneously without exceeding the threshold. This is likely because the lower ambient temperatures and transformer load at night bring down the temperature of the winding hot spot when it is averaged over the course of the day. Figure 30 shows that EVs with more powerful on-board chargers could contribute to accelerated transformer aging at much lower penetration levels. Just two vehicles with a 20 kW charger would exceed the F_{EQA} threshold.

Figure 27: F_{AA} for the Warmest Day in Summer without Electric Vehicle Charging

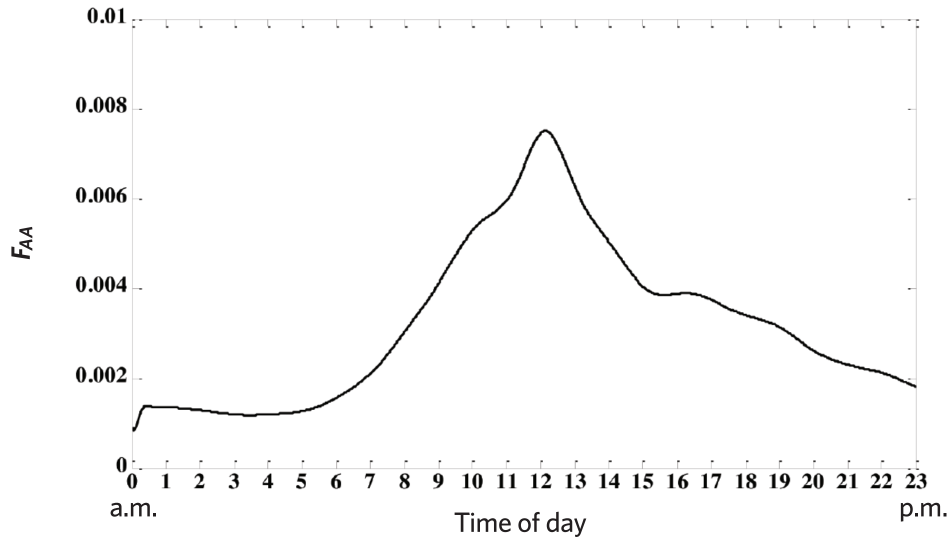


Figure 28: F_{AA} for the Warmest Day, Including Electric Vehicle Charging at 6.6 kW

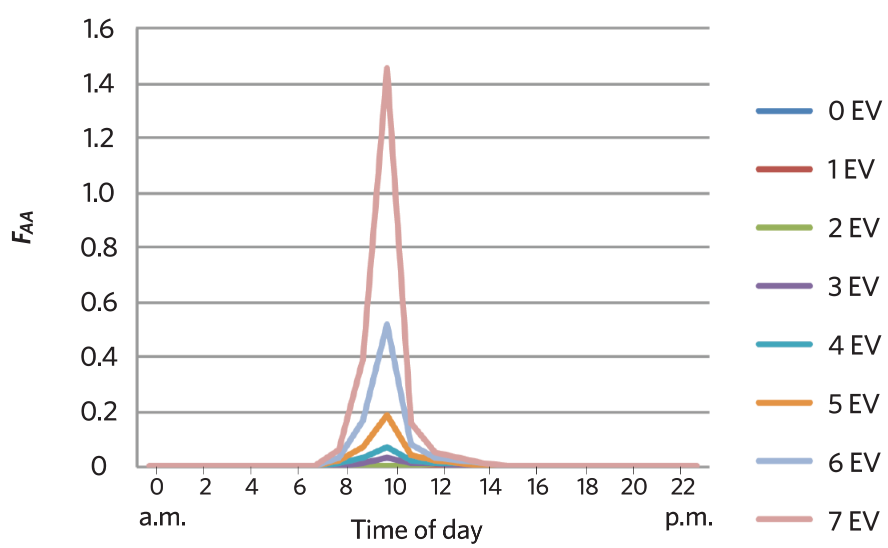


Figure 29: F_{EQA} for the Warmest Day, Including Electric Vehicle Charging at 6.6 kW

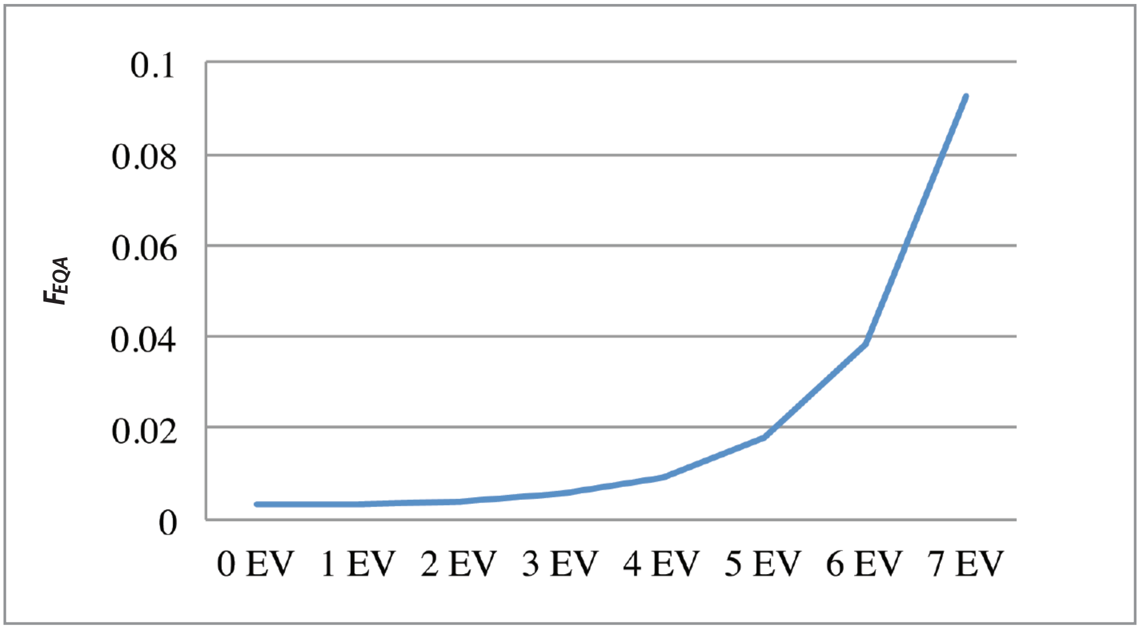
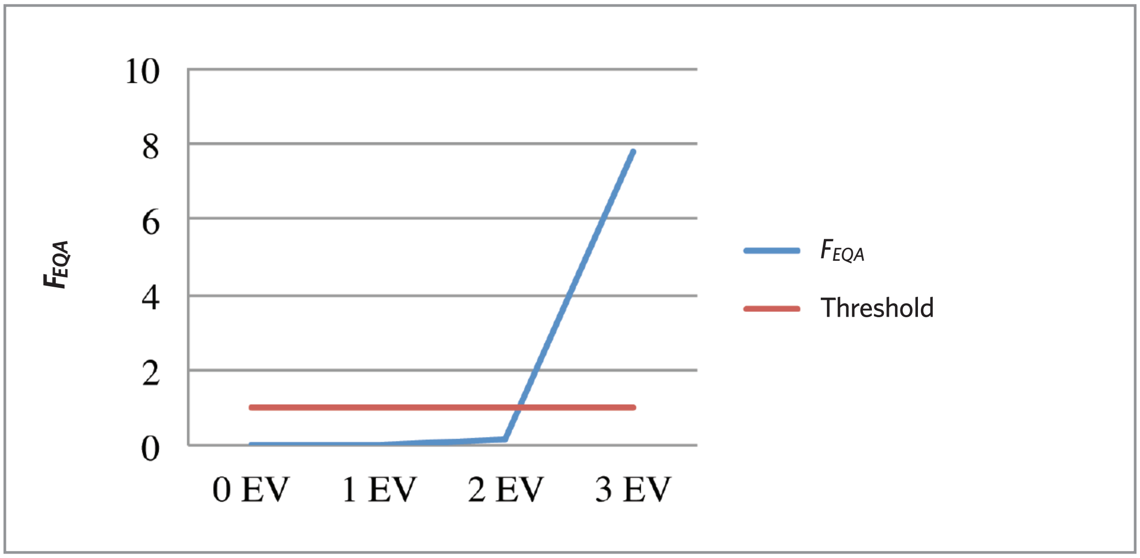


Figure 30: F_{EQA} for the Warmest Day, Including Electric Vehicle Charging at 20 kW



Summary – Rate of Transformer Aging

The scenarios used to investigate the effects of EV charging on transformer aging show that low penetration rates of vehicles with a 6.6 kW charger would not accelerate the degradation of the transformer insulation materials. Even at peak load time in summer, all seven EVs could charge simultaneously at 6.6 kW without accelerating transformer aging. At much lower penetration levels, vehicles with more powerful on-board chargers could impact the rate at which the transformer ages. Just two vehicles with a 20 kW charger would significantly exceed the F_{EQA} threshold and, as a result, greatly reduce the lifespan of the transformer. These findings support the idea that an effective strategy for enabling EV use should include efforts to encourage EV charging when ambient temperature and the demand for power are low.

Determining an Optimal Electric Vehicle Charging Strategy

Following the investigation of key variables and of the impact of EV charging on transformer aging, two additional scenarios were developed with a view to understanding how to maximize the number of EVs charging while at the same time creating the least possible burden for the transformer. In contrast to most of the previous scenarios, which looked at the worst case, these scenarios were designed to investigate the best case – conditions under which key variables such as time of charge could be managed. These scenarios assume some element of control, likely by the LDC, over the flow of electricity so that EVs would be charged when it would least impact the electricity distribution system.

Both of the scenarios assumed that each EV has a charger rated at 6.6 kW and that charging would occur only between the hours of 7 p.m. and 7 a.m. (i.e., off peak). While the figures in the following section highlight the results for the warmest day in summer, the coldest day in winter was also modelled and the results are noted.

Scenario A

Scenario A first investigated the effect of EV charging if all seven households served by the transformer owned a single EV with a 6.6 kW onboard charger. Once the results based on seven EVs were determined, the maximum number of vehicles each household could charge without exceeding the rated capacity of the transformer was investigated. It was assumed that power to charge the vehicle could be drawn at any rate between 0 and 6.6 kW and that charging would occur only at randomly assigned intervals beginning and ending on the hour between 7 p.m. and 7 a.m.

Each vehicle was randomly assigned a different state of charge (SOC) – the percentage of charge left in the battery – at the point when it returned home (EVs rarely require a full recharge). As such, a different number of hours and percentage of charge would be required for the vehicle to reach exactly 90 per cent SOC before leaving home again the following morning. An SOC of 90 per cent was chosen to represent an optimal charge because a full charge of 100 per cent reduces the life of the battery. Figure 31 shows the randomly assigned SOC for each of the seven vehicles and the amount of charge required to reach 90 per cent. For example, the first EV returned home with an SOC of 5 per cent and would require an 85 per cent charge overnight.

Figure 31: Vehicle Charge Required to Reach 90 Per Cent State of Charge

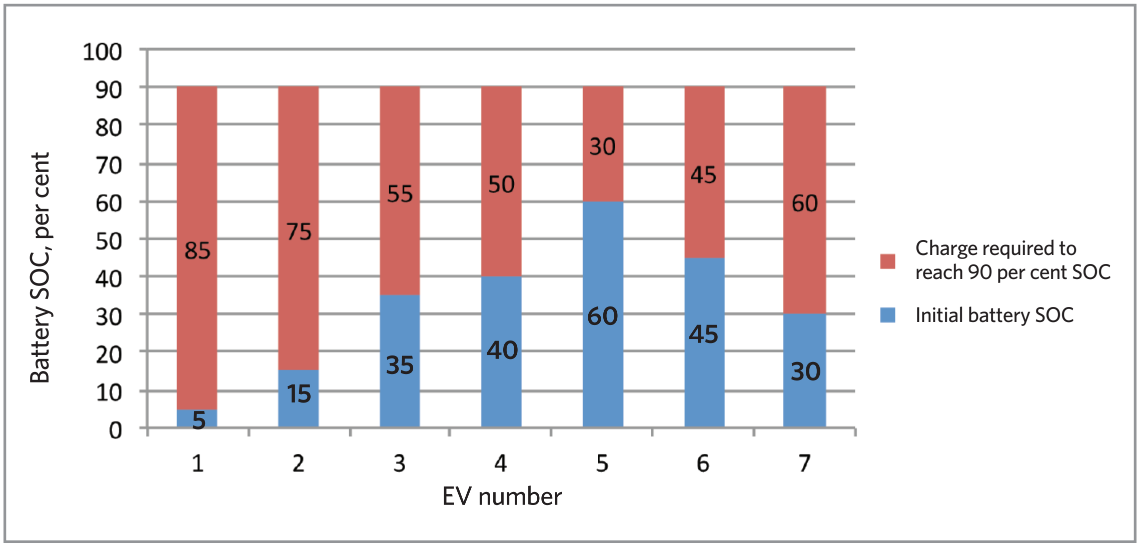
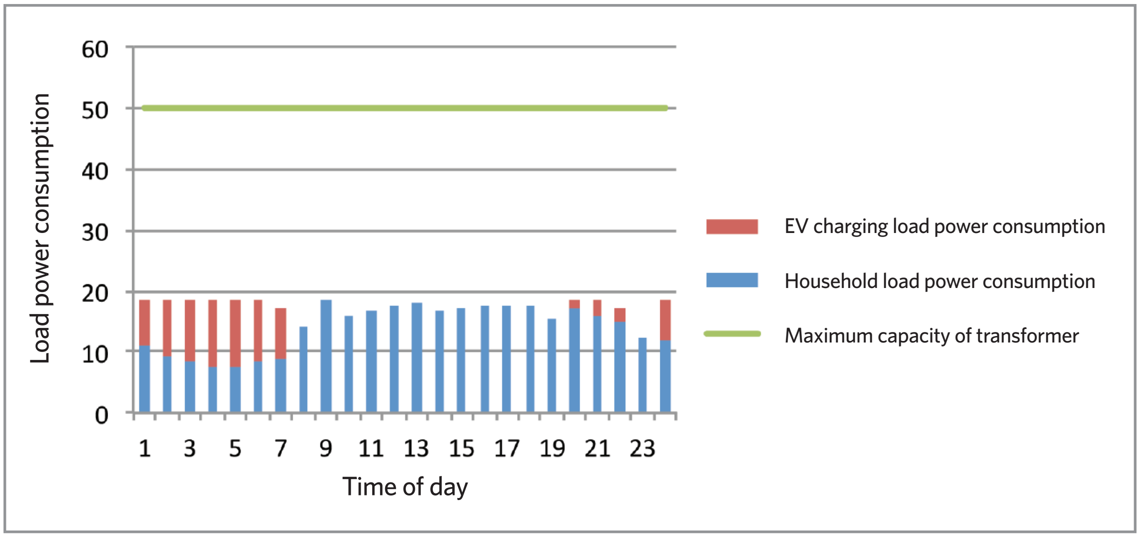


Figure 32 shows that the maximum load for the transformer, including both household and EV load, under the conditions tested for the warmest day in summer, i.e., July 17, 2013, would be 18.48 kW. The maximum load for the transformer on the coldest day in winter, i.e., January 23, 2013, was 15.7 kW.

Once the results were determined for the maximum load with each household charging a single EV, additional EVs were added to determine the number the transformer could accommodate before exceeding its rated capacity of 50 kVA. The results indicated that the transformer could accommodate 35 EVs (i.e., 5 per household) in summer without overloading if the EVs were charging at staggered one-hour intervals and drawing power at different rates. The transformer could accommodate 42 vehicles in winter (i.e., 6 per household) under the same conditions.

Figure 32: Transformer Load Profile for the Warmest Day by One-Hour Intervals, Including Electric Vehicle Charging



Scenario B

Because it is highly unlikely that EVs would draw power to charge at a randomly selected rate or that they would plug in and finish charging on the hour, the second scenario assumed that power to charge the vehicle could be drawn only at 6.6 kW and further staggered the charging intervals from one hour to every 15 minutes. This means that each vehicle would begin charging at a randomly assigned 15-minute interval (e.g., 8:15 p.m. or 10:45 p.m.) and continue charging until it reached its target SOC. Each of the seven EVs was assumed to return home with the same SOC as in Scenario A (i.e., 5, 15, 35, 40, 60, 45, and 30). Optimization software was used to randomly assign a target SOC greater than 90 per cent but less than 100 per cent for each vehicle (see Figure 33).

Figure 33: Vehicle Charge Required to Reach Greater than 90 Per Cent State of Charge

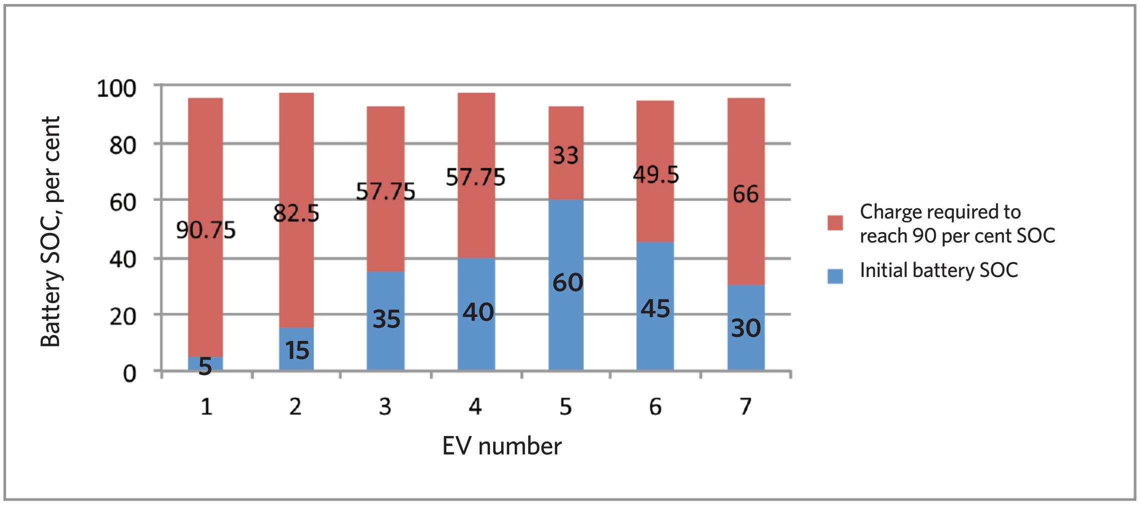


Figure 34 illustrates the staggered start times for one EV per household modelled for Scenario B, while Figure 35 shows the load profile on the warmest day in summer under the conditions tested. The results show that the lowest load possible (including both household and EV load), assuming one EV charging per household, would be 21.69 kW. The lowest load on the transformer on the coldest day would be 21.27 kW. It is important to note that Figure 35 also shows that when the additional load associated with charging EVs is added to the base load, it fills in the valley times and creates a more even load profile across a 24-hour period. This could prove beneficial for the electricity distribution system in that it would level power demand by reducing the distribution losses that occur at night as well as avoiding demands for increased power during the day.

After the results for one EV charging per household were assessed, the load from additional EVs was added up to the maximum number possible without exceeding the rated capacity of the transformer. Under the conditions outlined for Scenario B, 21 vehicles (i.e., three per household) could charge at staggered start times between 7 p.m. and 7 a.m. on both the warmest and the coldest day without exceeding the transformer's rated capacity. It should be noted that the total number of EVs that could be accommodated under Scenario B is lower than under Scenario A because they are charging at 6.6 kW, not at a lower rate.

Figure 34: Electric Vehicle Charging Times for Scenario B

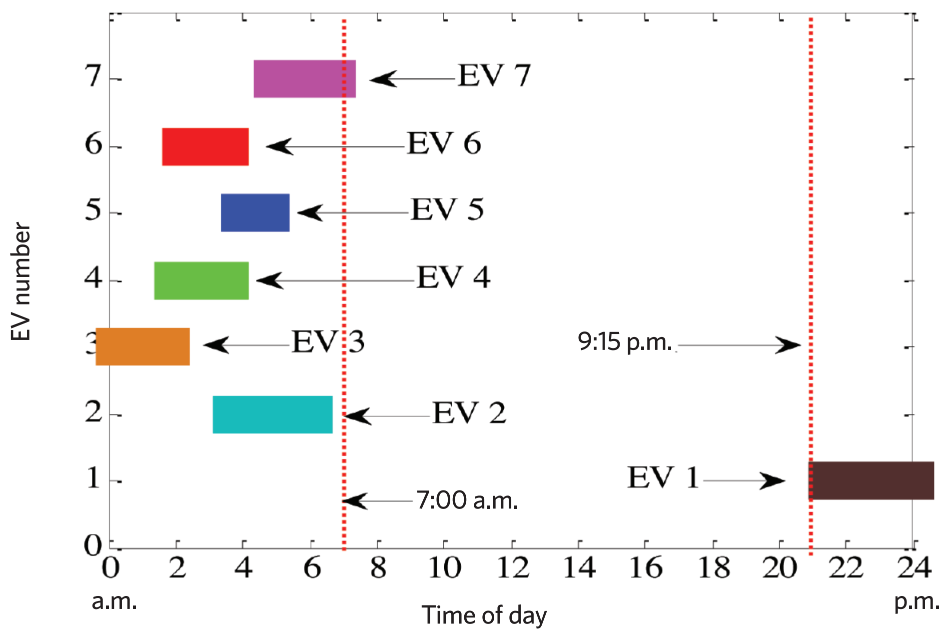
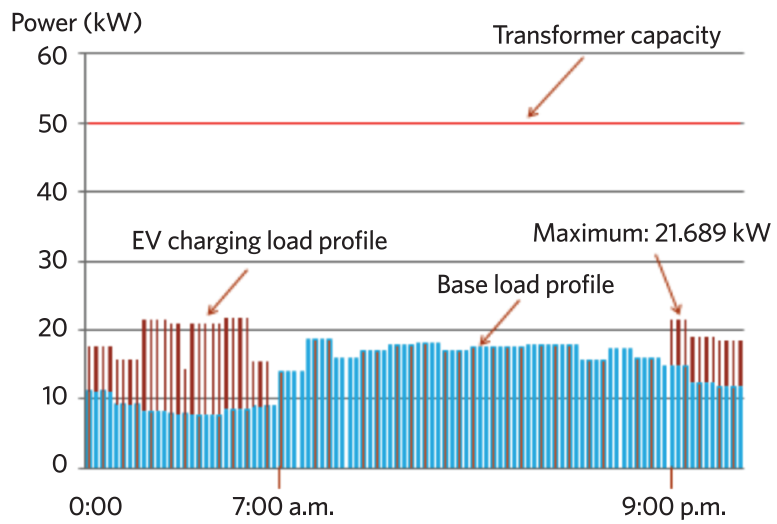


Figure 35: Load Profile for the Warmest Day for Electric Vehicle Charging Starting at 15-Minute Intervals



Summary – Electric Vehicle Optimization Strategy

The scenarios designed to determine a strategy for maximizing the number of EVs that can be accommodated by a single transformer without exceeding its rated capacity showed that the number could be dramatically increased if charging were to occur at staggered start times rather than simultaneously. As previously noted, the conditions modelled in these scenarios would be possible only if there were some means of controlling the flow of power to the vehicle, determining when it begins and finishes charging. A staggered approach to EV charging would effectively allow the existing distribution assets to reliably service any reasonable number of EVs at home while also levelling the demand for power throughout the day. This shows that EV charging could actually increase asset utilization, which would help to keep prices low for all LDC customers.

SUMMARY – ASSESSMENT OF THE ELECTRICITY DISTRIBUTION SYSTEM AT THE NEIGHBOURHOOD LEVEL

The results of the assessment of the electricity distribution system at the neighbourhood level, using the Rothwell Heights transformer as an example, are summarized in Tables 14 and 15. These tables show how many EVs across a variety of charger sizes can be accommodated, based on the rated capacity of the transformer, the old and new standards for the secondary drop lead and transformer aging (F_{AA} and F_{EQA}). Results highlighted in light turquoise in the tables indicate that loading would exceed the rated capacity of the transformer (50 kVA) or the current limit on the secondary drop lead (185 A or 325 A) or that transformer aging would be accelerated (F_{AA} and F_{EQA}). Results highlighted in light blue identify the limiting factor for each charger size – in other words, for each charger size, which of the constraints (transformer overload, secondary drop lead overload or accelerated transformer aging) would come into play first. These results can be used to prioritize the concerns that need to be addressed in relation to the impact of EVs on the electricity distribution system at the neighbourhood level.

The results show that, under all conditions, 100 per cent EV penetration of vehicles with a charger rated at 1.0 kW or 3.3 kW could be accommodated. The electricity distribution system could support a much lower EV penetration rate for vehicles with 6.6 kW or 20 kW chargers. Current capacity on the 185 A secondary drop lead is the key constraint in terms of the number of EVs with chargers rated at 6.6 kW or 20 kW that could charge simultaneously in both summer and winter. While Hydro Ottawa's new 325 A standard would increase this number, the secondary drop lead would still be unable to accommodate 100 per cent EV penetration of vehicles with a 20 kW charger. Exceeding the rated capacity of the transformer is also a limiting factor, particularly for vehicles with a 20 kW charger, with just two vehicles causing overload in both summer and winter.

Because each transformer has a particular load profile and serves a different number of households, the effects of EV charging would differ across the four transformers investigated. Comparing the four transformers helps to clarify the effects of key variables and transformer aging on a broader scale and what limiting factors would govern the number of EVs that could charge. For results for the Rockcliffe, Glebe and Kanata transformers, see Appendix B.

Table 14: Number of Electric Vehicles That Could Be Charged at Peak Load on the Warmest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		7	7	4	1
Current limit	Old standard (185 A)	7	7	3	1
	New standard (325 A)	7	7	7	2
F_{AA}		7	7	6	1
F_{EQA}		7	7	7	2

Table 15: Number of Electric Vehicles That Could Be Charged at Peak Load on the Coldest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		7	7	5	1
Current limit	Old standard (185 A)	7	7	4	1
	New standard (325 A)	7	7	7	3
F_{AA}		7	7	7	3
F_{EQA}		7	7	7	4

Assessment of the Electricity Distribution System at the System-Wide Level

The scenarios developed by Carleton University provide a framework for understanding the potential effects of EVs on the electricity distribution system at the neighbourhood level, but it is also important for the LDC to understand the impact of EV penetration across the entire distribution system. To this end, Hydro Ottawa undertook a system-wide examination of electricity distribution in the city. The impact of EVs on Ottawa's distribution system as a whole was examined through analysis of distribution transformer stations, with a view to better understanding the current and future capacity of the system to accommodate EV charging. The assessment underscores the need to address system-wide limitations on the distribution of electricity in the city in relation to EV deployment.

The following section outlines the process and key findings of the system-wide assessment, including a discussion of current capacity, five- and ten-year capacity predictions, and an investigation of the number of EVs that the system could accommodate over this time frame. This section summarizes a more detailed analysis and findings that are not included in this report.

ASSESSMENT CRITERIA

Hydro Ottawa routinely assesses the capacity of the electricity distribution system in an effort to maintain a safe and reliable power supply for its customers. When potential capacity issues are identified, appropriate measures (new installations and/or modifications to existing equipment) are planned and implemented, consistent with the appropriate regulatory requirements and with due consideration for safety, the environment, cost and supply system reliability.

The system-wide assessment focused on the neighbourhoods that were identified by the market research survey as having either a strong or moderate interest in the adoption of EVs. Because the neighbourhoods located in the east, south and west of the city showed weaker interest in comparison to the neighbourhoods in the residential downtown core, most of the stations investigated are part of the 13 kV and 4 kV systems.

CURRENT STATION CAPACITY

To assess the current station capacity, the system-wide summer peak load values from 2012 for each of the stations were compiled. While system loading has remained relatively constant over the past five years, many of the areas identified as having a strong or moderate interest in EVs align with communities that have seen intensified growth and in which this growth is expected to continue. It is predicted that, even without EV deployment, investment in the capacity of the electricity distribution system will be required to keep pace with demand in these areas. The 28 kV and 8 kV stations, along with three of the nine 13 kV stations, are currently operating at the planning rated capacity and, as such, would be unable to accommodate additional loading. Although the 4 kV stations investigated still have capacity (albeit limited) to accommodate additional loading, these stations are constrained by the capacity of the 13 kV stations that support them.

FIVE-YEAR FORECAST OF STATION CAPACITY

A forecast of station capacity over the next five years was developed, based on projected population and load growth, planned infrastructure development and station upgrades. Load growth over the next five years is predicted for the 28 kV station assessed, based on planned development in the area and the introduction of the Ottawa Light Rail Transit (LRT) system. As previously noted, this distribution transformer station is currently operating at planning rated capacity, and there are currently no plans for upgrade because strong interconnection ties allow for a load transfer to nearby 28 kV stations if necessary. As such, this station is predicted to continue to operate at planning capacity for the next five years.

The areas supplied by the 13 kV stations are also expected to grow over the next five years, with continued intensification in mature, established neighbourhoods throughout the city where older homes are being replaced by high-density housing. These areas are also expected to be impacted by the development of the Ottawa LRT. Over the next five years, it is predicted that three of the nine 13 kV stations investigated will be operating at the planning rated capacity. Two of the stations identified as operating at capacity have upgrades planned within the next five years to bring their load within the planning capacity limits.

Growth in the 8 kV supply areas has been relatively slow over the last couple of years, and this trend is expected to continue as no major projects for the area have been identified for the next five years. The 8 kV stations are currently operating at capacity and, with no current plans for upgrade, it is predicted that they will continue to operate at this capacity over the next five years. These 8 kV stations have strong interconnection ties that allow for the transfer of their load to other stations nearby if necessary.

Because no significant load increase is expected during the next five-year period for any of the 4 kV substations assessed in this study, the remainder of the assessment focuses only on the 28 kV, 13 kV and 8 kV stations.

TEN-YEAR FORECAST OF STATION CAPACITY

The capacity of the 28 kV and 8 kV stations studied is expected to remain at the planning rated capacity over the next ten years. There are no major developments planned for these areas and, as such, no plans for capacity upgrades. The load from these stations can be transferred to others nearby if necessary.

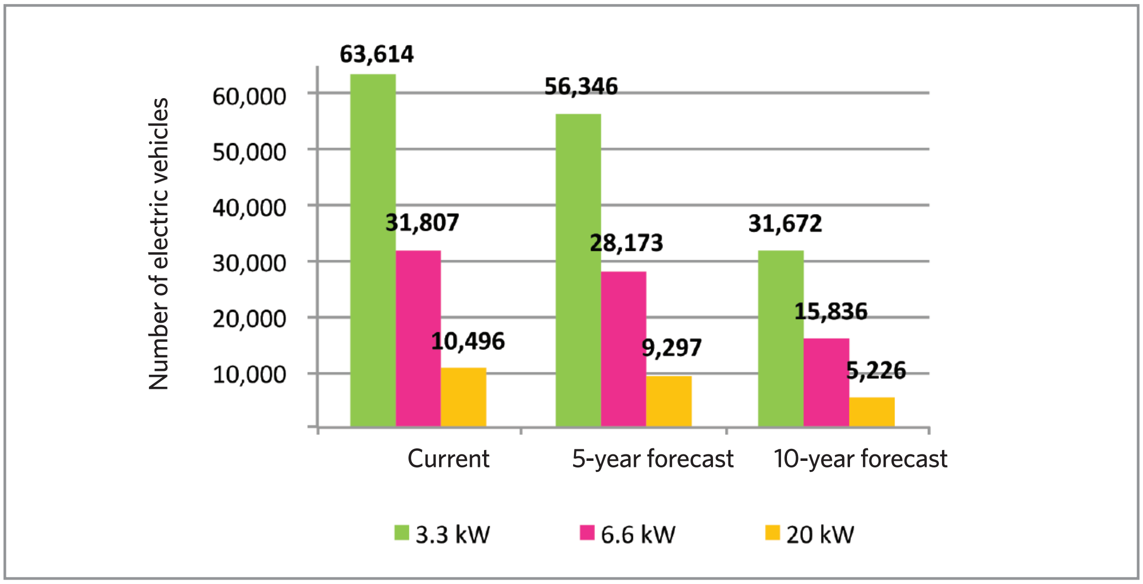
Growth in the areas served by the 13 kV stations is expected to continue primarily because of population intensification and the introduction of the Ottawa LRT. It is predicted that four of the nine 13 kV stations studied will be at the planning rated capacity in the next ten years. In the five-year forecast, one station was identified as being at capacity; an upgrade planned for completion by 2021 will increase its capacity.

CAPACITY TO ACCOMMODATE EVs AT THE SYSTEM-WIDE LEVEL

Taking into account the current, five- and ten-year capacity of the stations serving the areas where EV adoption is expected to occur, the number of vehicles that the electricity distribution system could accommodate at the system-wide level was predicted. The assessment looked at the available capacity at summer peak load for vehicles with a 3.3 kW, 6.6 kW or 20 kW charger. This section of the report focuses only on the 13 kV stations that have additional capacity to support EV charging. The 28 kV and 8 kV stations are predicted to be overcapacity for each of the time frames investigated, and the 4 kV stations are limited by the 13 kV stations that supply them.

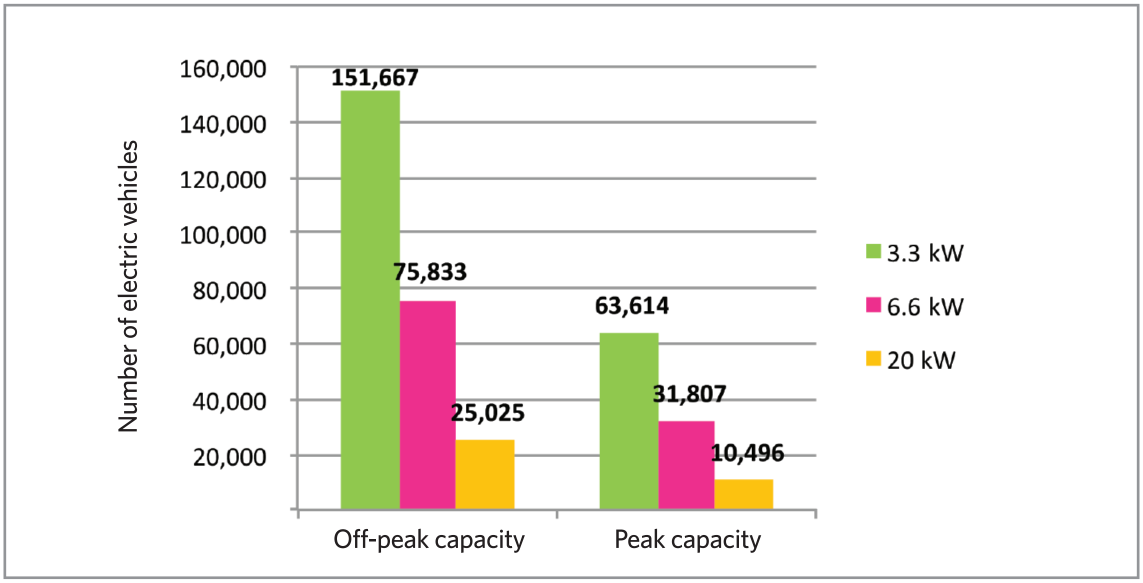
Figure 36 shows that there is currently capacity to accommodate 63,614 vehicles with a 3.3 kW charger, 31,807 with a 6.6 kW charger and 10,496 with a 20 kW charger. The numbers are slightly lower for the five-year forecast and approximately half for the ten-year forecast.

Figure 36: Capacity of 13 kV System to Accommodate Electric Vehicles at Summer Peak Load



Because EV owners will likely choose to charge their vehicle overnight, during off-peak hours, it is also important to understand the difference between capacity at the system-wide level during peak and off-peak hours. The current average load of the distribution transformer stations for valley load time was estimated, and the results show that the number of vehicles that the system can accommodate during off-peak hours more than doubles from peak hours (see Figure 37).

Figure 37: Current 13 kV System Capacity to Accommodate Electric Vehicle Charging During Peak and Off-Peak Hours



SUMMARY – ASSESSMENT OF THE ELECTRICITY DISTRIBUTION SYSTEM AT THE SYSTEM-WIDE LEVEL

The assessment of the electricity distribution system at the system-wide level showed that areas identified by the EMAP market research as those in which the adoption of EVs will likely take place align with areas identified by Hydro Ottawa as those predicted to experience continued population growth and intensification over the next ten years. It is expected that investment in the capacity of the system at the distribution transformer station level will be required to keep pace with the demand for power in these areas. The neighbourhoods serviced by the 28 kV, 8 kV and three of the nine 13 kV stations are currently operating at the station planning rated capacity and have no capacity for additional loading. The downtown core, supplied by 4 kV stations, has some capacity for additional loading, but these stations are limited by the capacity of the 13 kV stations that support them.

The projected load growth over the next five and ten years reduces the capacity of the electricity distribution system to accommodate the loads predicted as a result of EV uptake. In ten years, it is predicted that the 28 kV, 8 kV and four of the nine 13 kV stations will be at the planning rated capacity because of continued intensification in these areas and development associated with the Ottawa LRT. Because these neighbourhoods align with those where the adoption of EVs is likely to occur, the need to monitor these areas in order to ensure that potential EV-related risks are mitigated is evident. The assessment also showed that if EV charging occurred during off-peak hours, the number of EVs that the system could accommodate would be greatly increased, pointing to the importance of strategies aimed at encouraging off-peak charging.

Summary

The assessment of the electricity distribution system points to some of the key factors that will affect its capacity to accommodate anticipated EV-related loads at the neighbourhood level. At the same time, this report provides a better understanding of both the current and future capacity at the system-wide level to accommodate EV charging in Ottawa. The majority of the scenarios investigated show that the system is currently able to support EV-related loading. Variables such as the capacity of the on-board charger, ambient temperature and time of charge all have the potential to significantly impact the system. While the likelihood that the conditions simulated will occur, particularly in combination, is not high, planning and asset management will nonetheless require consideration of these factors.

The potential reduction in the life of distribution equipment as a result of EV charging is also an important consideration. While vehicles with common on-board charger capacities would not have a significant effect on the degradation of transformer equipment, those with more powerful chargers could contribute to accelerated aging at very low penetration rates. This consideration becomes even more critical when combined with other conditions, such as charging at peak load and during the summer months when temperatures are higher.

The assessment also indicates that there are strategies that could reduce the effects of EV charging on the electricity distribution system while at the same time maximizing the number of vehicles that can be accommodated. For example, in comparison to simultaneous charging, staggering charging start times can dramatically increase the number of vehicles that can charge over a 24-hour period. In addition, a staggered approach to EV charging could help to level the demand for power over the course of a day by filling in valley loads and reducing the need to adjust power generation up or down to meet demand.

The results of the assessment demonstrate that, while there are no immediate issues related to the capacity of the distribution system to accommodate EV charging by early adopters, there are conditions under which overloading will occur. These risks can be mitigated and even substantial EV penetration levels accommodated if charging occurs at optimal times. This means that encouraging charging when it will least affect the electricity distribution system must be a key element of an effective strategy for enabling EV use in Ottawa. Proactively managing EV charging can help to avoid expensive investment in new neighbourhood-level distribution infrastructure, including transformers and secondary cables. At the same time, it is clear that system-wide upgrades and investments in infrastructure will in any case be needed to accommodate predicted population growth. The implications of EV charging at the system-wide level should also be taken into consideration when these upgrades are being planned.

Appendix A

The EV Market

This Appendix provides a brief overview of the EV market in Canada. It provides information about sales and production, incentive programs, charging infrastructure and home energy management as well as an introduction to some of the regulatory issues that could affect the pace of EV adoption. This overview is intended only to provide context for the EMAP report and, as such, does not constitute an exhaustive exploration of the EV market in Canada.

SALES AND PRODUCTION

More than 24,000 of the approximately 764,382 passenger cars sold in Canada in 2013 were electric and hybrid electric vehicles.[1] EVs alone (including battery and plug-in hybrid electric) accounted for a very small part of this total – around 2,650 (see Table A.1). Although this represents a relatively small percentage of the overall market for new vehicles in Canada, significant increases in sales have been made year-over-year since EVs entered the market in 2010. For example, in 2013, EV sales increased by 50 per cent from the previous year, with more units sold than in the previous three years combined.[2] Battery electric vehicle sales alone increased by 165 per cent from 2012 to 2013.

Table A.1: Electric Vehicle Sales in Canada from 2008 to November 2013*

Type of vehicle	2008	2009	2010	2011	2012	2013	Total
Hybrid electric vehicle	19,963	16,904	11,845	10,524	21,674	21,476	102,386
Plug-in hybrid electric vehicle	—	—	—	317	1,336	1,009	2,662
Battery electric vehicle	—	—	4	269	620	1,641	2,534
TOTAL	19,963	16,904	11,849	11,110	23,630	24,126	107,582

* R.L. Polk Canada, Electric Mobility Canada

The range of EVs available continues to grow, with most major automakers currently offering at least one hybrid or electric model. Two SUVs (Mitsubishi Outlander Plug-in Hybrid SUV and Tesla Model X) are expected to hit the market in 2015, which will provide electric options for those looking for a larger vehicle. BMW will also introduce an electric model this year (BMW i3), appealing to segments of the market interested in additional vehicle features. Most new models are introduced in the U.S. before they are introduced in Canada. There were 24 models available in the U.S. by the end of 2013 and a smaller number in Canada, although availability in this country is likely to improve over the next few years. The variety of makes and models signals a commitment to EV technology on the part of automakers and addresses a key barrier to adoption as identified by the EMAP findings: the limited sizes and styles available.

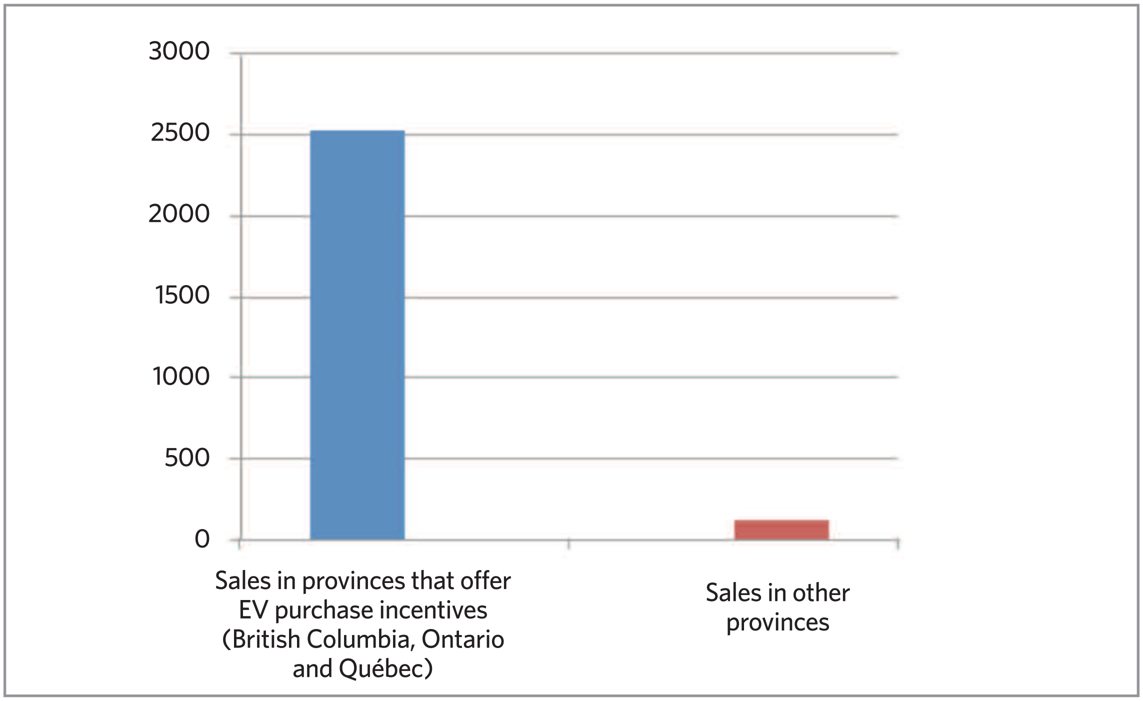
The market is beginning to offer alternatives to traditional vehicle sales business models. Opinion polls have shown that consumers may, in fact, prefer direct sales and, as a result, some automakers, including Tesla Motors, are already using business models that allow consumers to purchase EVs direct from the manufacturer, bypassing the dealership. This business model uses a variety of strategies, such as locating retail operations in shopping malls or offering the option to purchase from the company's website, to appeal to consumers looking for a more customized experience. This new business model has not been without controversy in some jurisdictions, however, because of the threat it represents to the existing dealership model.

INCENTIVE PROGRAMS

EV market share depends on a number of factors, such as production capacity and supply, battery technology, policy and regulations, the upfront cost of the vehicle and the price of fuel (the more expensive fuel is, the more people start looking for cheaper ways to drive – an EV is one of the options). A shift in any one of these factors can dramatically influence adoption of the technology and its share of the overall passenger vehicle market. For example, as the initial EV purchase price comes down, it will become a more economical and viable option for a greater proportion of the population. In addition to automakers offering more affordable EVs, many jurisdictions, including Ontario and Québec, offset the upfront costs through purchase and charging infrastructure installation incentives. In 2013, Québec renewed its incentive program for another three years as part of its Transportation Electrification Strategy 2013–2017, a comprehensive set of policies to encourage the sale and use of EVs in the province. The Government of British Columbia also offered EV incentives for the past three years; the program recently ended, and a new program is now being designed.

When sales in provinces that offer incentives are compared with sales in provinces that do not, it is apparent that such incentives play a role in EV deployment. Reducing the cost of the vehicle is likely the primary factor, but it is also important to note that the provinces offering incentives have a greater number of large, urban centres where, because of range anxiety, driving electric may more readily be perceived as an option. Moreover, such incentives in these provinces are often part of a more robust EV policy framework. Figure A.1 shows that the three provinces offering purchase incentives accounted for a much greater number of EV passenger vehicle sales from January to September of 2013 than those without incentives. It is also worth noting that while financial incentives may be contributing to sales, increasing consumer awareness and understanding of the full life-cycle costs of EV technology is also necessary. For example, comparisons with conventional, gasoline-powered vehicles often do not take into consideration the fact that the upfront cost of an EV includes the vehicle and the most expensive element of the fuel (i.e., the battery).

Figure A.1: Total EV Sales from January to September, 2013, in Provinces with and without Purchase Incentives*



* Electric Mobility Canada.

CHARGING INFRASTRUCTURE

Residential charging station technology has improved considerably over the past few years. Charging units that are smaller, more powerful and more affordable are now available. Some electric vehicle supply equipment (EVSE) manufacturers have introduced portable charging units that can be plugged into any 240 V socket, providing charging options for renters and those not wishing to hardwire a charging station at home. These portable units also help to reduce range anxiety by providing more options for Level 2 charging away from home.

Time-of-use pricing in Ontario has proven to be a successful means of shifting demand for power. In the U.S., some jurisdictions are using aggressive time-of-use structures to encourage EV charging at optimal times. For example, the LDC in Dallas, Texas, is providing power for free between the hours of 10 p.m. and 6 a.m. as a means of addressing the surplus power from wind generation during that period. While the program was not originally conceived with EVs in mind, it provides an opportunity for EV owners to charge at low cost while at the same time putting to use power that would otherwise be surplus. Similar programs may be introduced in Canada in the near future, motivating EV owners to charge at times that make optimal use of the electricity distribution system. There is smart-grid-enabled EVSE technology that allows for control over the time of day when an EV charges so that the impact on the electricity distribution system is minimized.

Various means of addressing consumer concerns related to vehicle range have already been introduced, with varying degrees of success. These include battery swapping stations and DC fast charging (i.e., Level 3) public charging stations. Collaboration among a number of stakeholders is essential to the success of such initiatives. Where collaboration fails (e.g., for battery-swapping to work, automakers would have to incorporate a replaceable battery in the design of the vehicle), these approaches have faltered.

Several initiatives to address range anxiety are currently in the planning stages. Some automakers in Ontario are planning to install Level 3 fast charging stations over the next year. For example, Nissan Canada will install its first Level 3 charger in Toronto while Tesla has plans for a supercharger route along the Windsor-Toronto-Montréal-Québec City corridor.[3] The specific locations of the stations have yet to be announced, but these superchargers will provide EV owners with half a charge in 20 minutes or less. A Level 3 fast charging station network is being implemented in British Columbia, and another is in the planning stage in Nova Scotia. The Canadian Council of the Ministers of the Environment (CCME) is also considering conducting a study on the need for such a network across Canada.

Québec's Transportation Electrification Strategy committed the province to installing 5,000 public charging stations across the province, including Level 3 stations along major highways (such as Highway 50 between Gatineau and Montréal). This will add to the more than 250 charging stations already located throughout Québec as part of the Electric Circuit charging network, powered by Hydro-Québec. The Electric Circuit offers Level 2 charging for a flat rate in the parking lots of its partners (one of the Electric Circuit charging stations is a Level 3 station).

HOME ENERGY MANAGEMENT

Tesla Motors recently announced plans to construct the world's largest battery factory in the southwestern U.S. The factory, also known as the gigafactory, would enable the company to produce finished batteries at a significantly lower cost by manufacturing them directly from metal ore instead of from its processed components. The company indicated that sales of its Model S have been constrained by a battery shortage and that more batteries will be needed in three years for production of its Model E, which will target the broader mass market. The production of batteries on this scale and at its own factory will allow Tesla to reduce the vehicle's price point.[4]

The company is also looking at the long-term opportunities battery packs offer for home energy storage, as a complement to home solar systems. Battery storage, either at home or as part of an EV, will enable the storage of solar power produced during the day for use at night after the sun goes down. This could have a profound effect on LDCs in that it provides customers with opportunities to reduce their dependence on the electricity distribution system for power. Other automakers have also been pursuing similar opportunities. Ford Motor Company has partnered with SunPower and Whirlpool to demonstrate how households can achieve electricity savings by integrating EVs, solar panels and energy-efficient home appliances. Nissan is working on the development of a system capable of powering a home with the battery in the LEAF.

The EV Regulatory Environment

It has often been argued that the successful establishment of innovative technologies that have a high social return, but perhaps a lower private return, during the early adopter phase requires a strong policy framework to support the transition. Uncertainty and a limited understanding of long-term benefits often plague innovation, making engagement of the general public a challenge. As such, a successful technology uptake is one that is able to align private interests and the public good, most often through support from a positive, proactive policy framework.

Because of the potential benefits of EV technology, governments across Canada are setting ambitious goals to support EV production and use. The following section outlines some of the policies and regulations related to EVs in Canada.

EMISSIONS TARGETS

The Government of Canada has committed to reducing GHG emissions levels to 17 per cent below 2005 levels by 2020. Given that transportation-related emissions make up more than 30 per cent of the country's total GHG emissions, reductions in this sector will be needed if Canada is to achieve its objective. While the development of more effective pollution control devices on new cars and improved fuel formulations are bringing emissions down, improvements in air quality have, to some extent, been offset by the overall increase in the number of vehicles on the road. In other initiatives, Company Average Fuel Consumption (CAFC) standards in Canada set aggressive fuel efficiency targets for vehicle manufacturers. The deployment of vehicles partly or fully powered by electricity reduces the demand for gasoline and diesel, thus helping to meet GHG emissions reduction targets.

The Government of Ontario has targeted a 15 per cent reduction of GHG emissions below 1990 levels by 2020 and, as part of this initiative, is working to ensure that one in 20 vehicles driven in Ontario will be powered by electricity in the same time frame. Many municipalities have also taken steps to promote emissions reductions. For example, the City of Ottawa is currently working on an update to its Air Quality and Climate Change Management Plan from 2004, which targets a 20 per cent reduction of GHG emissions from 1990 levels.

GOVERNMENT INITIATIVES

In addition to providing vehicle purchase and charging station incentives, the Government of Ontario has set targets for transitioning 20 per cent of the public service fleet to electric by 2020. Fleet procurements are seen as a means of providing an initial market for the technology while encouraging municipalities and other fleets to follow suit. Ontario's high-occupancy vehicle (HOV) lanes are also open to EV owners even when they are driving alone, with a green vehicle licence plate issued to identify the vehicle as an EV. The province also has plans to integrate more EV charging in designated parking facilities owned by the government and GO Transit.

Under its Transportation Electrification Strategy, the Government of Québec has committed to several major initiatives aimed at rapidly increasing the use of electric transportation in the province and has set goals for deploying 12,500 more EVs by 2017. Québec offers both vehicle purchase and residential charging infrastructure installation incentives and has directed additional funding to the development of charging stations, the purchase of electric taxis, the electrification of the provincial government fleet and EV promotion among consumers and businesses. The province has also committed to supporting municipalities in their efforts to electrify transportation.

INFRASTRUCTURE COST RECOVERY

Recognition of the LDC as an essential component of the energy infrastructure for transportation is a key element in reshaping the EV regulatory framework. For the most part, regulated utilities cannot move pre-emptively to manage the grid system to accommodate EV charging; to plan effectively for the deployment of EVs, they require clear understanding and support on the part of a number of stakeholders. The role of the utility in relation to EV deployment is being investigated in many jurisdictions worldwide, with some permitting the LDC to build and maintain charging infrastructure and recoup costs through the utility rate base and others opting to minimize the role of LDCs in the charging infrastructure market.

REGULATIONS FOR MULTI-RESIDENTIAL BUILDINGS

The majority of early adopters of EV technology live in single-family homes and generally charge their vehicles at home. As EV adoption rates increase, a greater number of people living in multi-residential buildings, such as apartments and condominiums, are likely to want to drive an EV. EV owners in multi-residential buildings currently face barriers to the installation of charging infrastructure, primarily related to building codes and the metering and management of such multi-residential buildings. In Ontario, amendments have been proposed to the *Condominium Act*, 1998, to address some of these issues.

Building Codes

Ontario addresses the safety of EV charging infrastructure in homes and other buildings in the *Ontario Building Code* and the *Ontario Electrical Safety Code*, but there is currently no requirement that charging equipment be routinely included in new construction. The installation of EV charging infrastructure can benefit developers by counting towards Leadership in Energy and Environmental Design (LEED) points and increasing the desirability of the building for prospective tenants or buyers who own an EV. However, the widespread lack of knowledge and understanding about installation costs means that voluntary measures alone are unlikely to result in any significant uptake of the technology in the short term.

Installing a charging station at an existing building requires condo boards, residents and building owners to agree on who is responsible for the costs associated with installation and maintenance of EV charging infrastructure. Pre-wiring new developments is more cost-effective than having to retrofit a building to accommodate EV charging. The City of Vancouver has amended its municipal building code to require new buildings to have a percentage of parking spaces equipped with EV charging infrastructure.

Sub-metering

The most common method of metering a multi-residential building, particularly an older one, is bulk metering, where electricity costs are equally distributed among residents based on the total electricity consumption for the entire building. The implications of charging an EV in a building with bulk metering have been the source of much discussion over the past few years. Many residents feel that the provision of electricity to power an EV in such buildings is comparable to providing gasoline to residents to power a conventional vehicle.

The Government of Ontario allows unit sub-metering (also known as suite-metering) in multi-residential buildings under the *Energy Consumer Protection Act,* 2010, and the *Residential Tenancies Act,* 2006. Sub-metering means that each unit has its own meter, and charges for electricity consumption are based on consumption per unit, not shared among the tenants or occupants of the entire building. However, even buildings that are already sub-metered often do not have meters in parking areas, and installing a new meter can be expensive. Under Ontario law, only LDCs can resell electricity, which prevents building owners and condominium boards from charging for electricity. As a result, EV owners often pay a flat rate instead for use of a parking spot equipped for EV charging; such flat rates may not in any way accurately reflect the actual cost of the electricity needed for EV charging. At the same time, building owners and condominium boards are not required to collaborate with new residents to enable EV charging. Providing for sub-metering for EV parking in multi-residential buildings could help to ensure a more equitable distribution of costs while at the same time addressing a potential barrier to EV adoption for people living in such buildings.

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Appendix B

Assessment of the Electricity Distribution System at the Neighbourhood Level – Summary of Results for Rockcliffe, the Glebe and Kanata

ROCKCLIFFE (5 HOUSEHOLDS)

Table B.1: Number of Electric Vehicles That Can Be Charged at Peak Load on the Warmest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		5	5	4	1
Current limit	Old standard (185 A)	5	5	4	1
	New standard (325 A)	5	5	5	3
F_{AA}		5	5	5	2
F_{EQA}		5	5	5	2

Table B.2: Number of Electric Vehicles That Can Be Charged at Peak Load on the Coldest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		5	5	3	1
Current limit	Old standard (185 A)	5	5	3	1
	New standard (325 A)	5	5	5	2
F_{AA}		5	5	5	3
F_{EQA}		5	5	5	3

GLEBE (12 HOUSEHOLDS)

Table B.3: Number of Electric Vehicles That Can Be Charged at Peak Load on the Warmest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		12	9	4	1
Current limit	Old standard (185 A)	12	7	3	1
	New standard (325 A)	12	12	8	2
F_{AA}		12	10	7	2
F_{EQA}		12	12	9	2

Table B.4: Number of Electric Vehicles That Can Be Charged at Peak Load on the Coldest Day Based on Transformer Capacity, Secondary Drop Lead Standards, and Transformer Aging (Maximum One Vehicle per Household)

EV model		2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger		1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)		12	9	4	1
Current limit	Old standard (185 A)	12	7	3	1
	New standard (325 A)	12	12	8	2
F_{AA}		12	12	12	3
F_{EQA}		12	12	12	4

KANATA (10 HOUSEHOLDS)

Table B.5: Number of Electric Vehicles That Can Be Charged at Peak Load on the Warmest Day Based on Transformer Capacity and Transformer Aging (Maximum One Vehicle per Household)

EV model	2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger	1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)	10	7	3	1
F_{AA}	10	10	5	1
F_{EQA}	10	10	8	2

Table B.6: Number of Electric Vehicles That Can Be Charged at Peak Load on the Coldest Day Based on Transformer Capacity and Transformer Aging (Maximum One Vehicle per Household)

EV model	2013 Fiat 500e	2013 Nissan Leaf	2014 Honda Fit EV	2014 Tesla Model S
EV charger	1.0 kW	3.3 kW	6.6 kW	20 kW
Rated transformer capacity (50 kVA)	10	9	4	1
F_{AA}	10	10	10	2
F_{EQA}	10	10	10	2

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