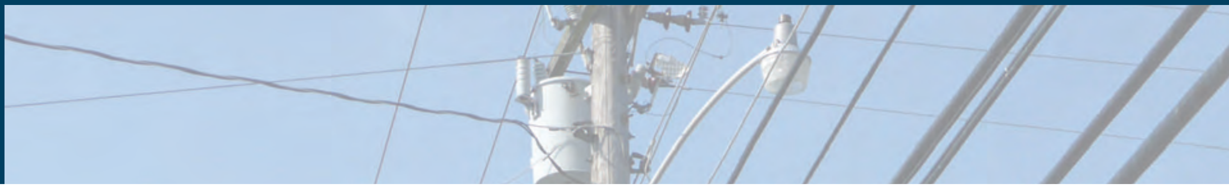
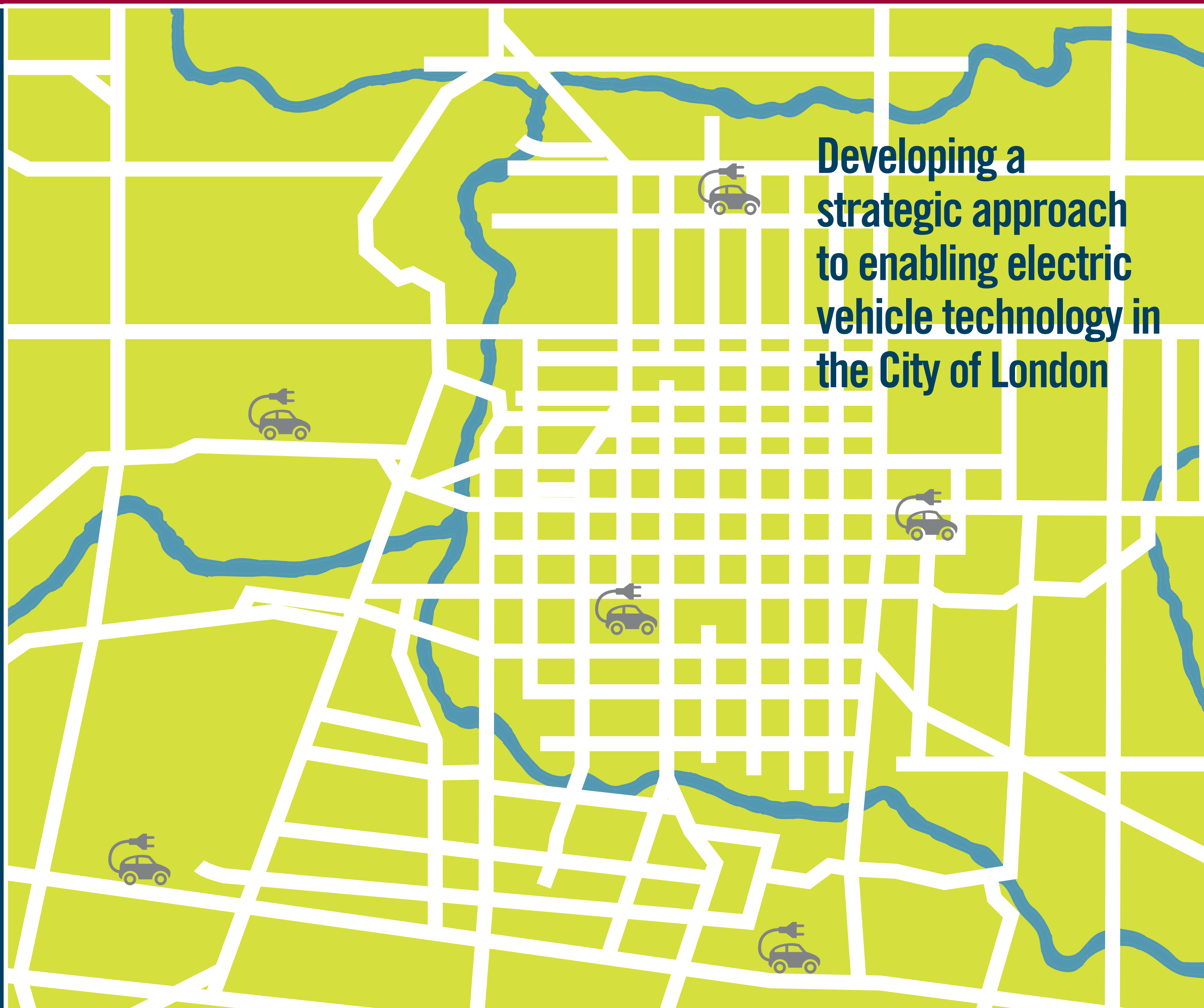


POLLUTION PROBE
CLEAN AIR. CLEAN WATER.

# EMAP LONDON

## ELECTRIC MOBILITY ADOPTION AND PREDICTION



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

## 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 LONDON HYDRO

London Hydro is an electricity distribution company serving the City of London, providing residents and business owners with a safe, efficient and reliable supply of electricity. The City of London is the sole shareholder of London Hydro. Electricity is delivered to the diverse customer base through an extensive network of overhead and underground power lines. This network is fully owned, operated and maintained by London Hydro. London Hydro is a progressive organization that has participated with local institutions of higher education in a number of joint projects, including investigating new technology and programs that may provide alternative energy sources and environmental benefits for the current and future generations.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Pollution Probe is solely liable and responsible for the contents of this report. Inclusion of the names of individuals is for acknowledgement purposes only and does not constitute an endorsement of the material.





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# Contents

# Contents

# 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 Electric Mobility Canada and utilities in other Canadian municipalities (Ottawa; Hamilton and St. Catharines; London; Markham, Richmond Hill and Vaughan; and Calgary and Edmonton) to conduct further EMAP studies with support from the utilities and the ecoENERGY Innovation Initiative led by Natural Resources Canada. This report summarizes the application of the EMAP methodology to the City of London and the implications of the EMAP analysis for London Hydro, the local distribution company (LDC).

Representatives of stakeholder organizations integral to the future of electrified transportation in London 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 full-length reports on the EMAP market research and the electricity distribution system assessment produced by Environics Research Group and London Hydro, respectively. Taken together, these resources provide a comprehensive look at the implications of EV technology uptake for London and served as the basis for this report.

***This report proposes a set of strategic objectives and recommendations intended to prepare London Hydro to manage and support the use of EVs in its service area.***

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

# Report Outline

This report describes the process, findings and implications of the EMAP study and explores options for a strategic path forward. The report is divided into three sections:

**Section One** provides a brief description of the EV as an emerging technology and proposes a three-point strategy for enabling EV use in London, 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.

**Section Three** describes the methodology and results of simulation work conducted by London Hydro. The simulations address the capacity of the electrical distribution system at the neighbourhood level to support additional loading resulting from EV charging under a number of conditions.

# The Electric Vehicle as an Emerging Technology

For EVs to become a viable part of a successful sustainable transportation system in the City of London, 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 London, this group is unaccustomed to inconvenience and perhaps somewhat 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.***

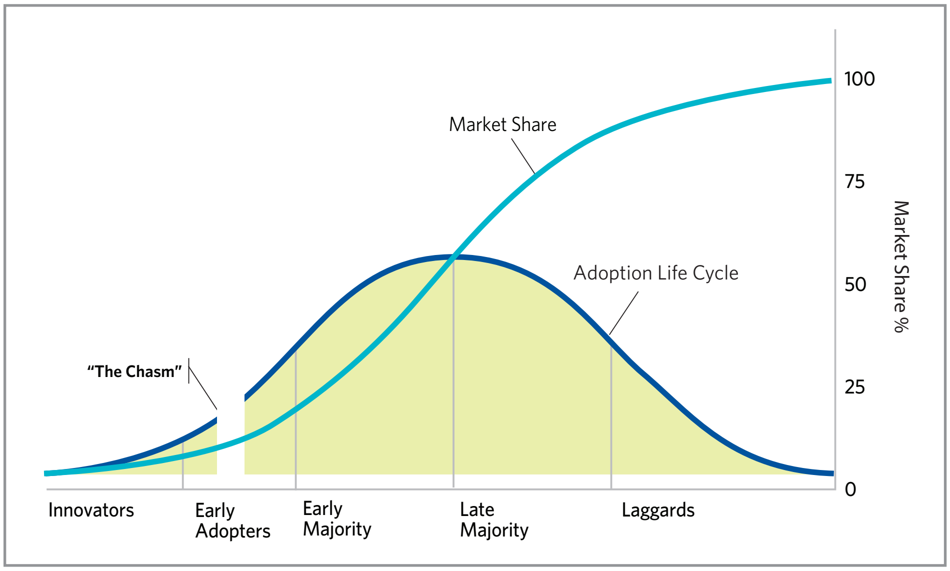
Support or endorsement of a technology from the early adopter group is one of the most important factors contributing to its adoption by a broader market. Whereas innovators may be perceived as extravagant or in a better position to take risks than the general public, early adopters demonstrate a high 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.

**Figure 1: Technology Adoption Life Cycle and Market Share**




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 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.

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. 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.

***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.***

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 London

Current patterns of EV charging in the London Hydro 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, in the short term, to exceed the rated capacities of London Hydro's current infrastructure assets at the neighbourhood level. However, 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 performance. The compounding effect of these factors means that London Hydro will have to continue to monitor the potential effects of EV charging on the electricity distribution system.

***Current patterns of EV charging in the London Hydro 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.***

This report shows that, if just a handful of neighbouring households charge EVs with greater on-board charger ratings at the same time during periods of peak demand, the electricity infrastructure on some streets could be overloaded; however, encouraging charging when demand for power is otherwise at its lowest would allow greater numbers of EVs to charge without necessitating changes to the existing electricity distribution assets. Additional transformer and secondary distribution system capacity may eventually be necessary to accommodate greater numbers of EVs charging; taking EV use into consideration in the process of scheduled upgrades will help mitigate risks.

As the EV market evolves, it makes sense for London Hydro to continue to monitor the potential effects of EV charging, using information systems already in place. Such an EV strategy is consistent with the mandate of London Hydro 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 London – A Strategy to Manage the Risks and Optimize the Benefits

By developing a strategy for enabling EV use in its service area, London Hydro can enhance its current organizational capacities to be responsive to consumers' basic needs and to the evolving state of EV technology. Such a strategy will also allow London Hydro to leverage opportunities associated with EV use and to be progressive in promoting EV technology within the current regulatory framework, 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 London Hydro must be engaged in the development of this strategy because the successful deployment of EV technology in London depends on actions and decisions taken by a range of individuals and organizations. Stakeholders internal to London Hydro include its Executive Management Team as well as those responsible for asset management, communications, customer service, and conservation and demand management. Stakeholders external to London Hydro include

- the Ontario Energy Board (OEB)
- the Independent Electricity System Operator (IESO)
- the Ontario Ministry of Transportation
- the Ontario Ministry of Energy
- London Hydro customers, including current and future EV owners and users
- the City of London, including planners and developers
- academia, including local colleges and universities
- Electric vehicle supply equipment (EVSE) providers

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

### 1 Enhance utility responsiveness to evolving patterns of EV charging.

- Monitor the development of the EV market in the London Hydro service area. This means keeping apprised of changes in EV products and technologies, operating standards, regulations and general market adoption; requesting notification from automotive dealerships or the provincial government when an EV is sold within the service area could also be helpful. Ongoing analysis of load profile data is also an important element in responding to the evolving impacts of EV charging on the local distribution system.
- 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. The EMAP assessment shows that EV charging has the potential to affect the electricity distribution system if early adopters charge their vehicles during periods of peak demand. Encouraging EV charging during off-peak hours will help to ensure that EVs do not add to peak demand on the distribution system.
- Consider implementing a program through which London Hydro customers can volunteer information about their purchase of EV technology (e.g., vehicle model, charging services) or their intention to purchase an EV. With this information, London Hydro can conduct predictive infrastructure assessments to determine if service upgrades will be required to maintain quality of service. This will also ensure that London Hydro is aware of any residential service upgrades that could be required to accommodate the installation of Level 2 or 3 residential charging stations.

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

- Take into consideration the impacts of EV charging when infrastructure design criteria are being developed to ensure that they do not present barriers to EV use. Accounting for anticipated levels of EV uptake in the course of scheduled asset replacement will ensure sufficient capacity for EV charging without compromising the reliability of the power supply. Investigate the effects of EV charging on the electricity distribution system when 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). Building on the analysis in the EMAP grid assessment, determine the degree to which greater levels of demand for charging services could be accommodated if the timing and duration of EV charging were actively managed.

## 2 Build partnerships to address barriers and leverage opportunities for EV deployment, consistent with the needs of early adopters.

- Foster dialogue among electricity utilities on best practices related to EV technology. As the EV market continues to evolve, utilities across Canada will face some common challenges and opportunities related to EV use within their service areas. Shared strategies and lessons learned can contribute to better understanding and, in turn, to enhanced opportunities to successfully enable and promote EV use across the country.
- Collaborate with other organizations with a stake in the future of EV technology (e.g., the London Electric Vehicle Acceleration Group, the City of London) to actively promote and encourage EV use within the current regulatory framework.

## 3 Educate customers about EV technology.

- Create targeted communications to address the concerns identified in the analysis of the early adopter community, as summarized in this report. The EMAP study shows that London Hydro 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.
- Actively promote and encourage EV use within the service area by building an understanding of the implications of EV technology, particularly from a social perspective. This could include educating customers about optimal charging behaviours and how they can help to maintain the reliability of existing distribution system assets, thereby helping to keep rates low.
- Equip London Hydro's communications and customer service groups with the necessary information, including sample scripting where appropriate, to respond to general customer inquiries about

EV technology. This should include information about electrical safety in relation to EV deployment (e.g., the importance of hiring a qualified electrical contractor and complying with inspection requirements when installing residential charging stations).

- Provide information and links to resources related to EV charging on the London Hydro website. This could include tips for deciding whether an EV might be a good fit, the location of public charging infrastructure within the service area, or details about residential charging station installation. For example, installation costs may be higher for residential charging stations capable of drawing power at more than 7 kW than for those that provide a charge at a lower rate (e.g., 3.3 kW or 6.6 kW) because the household service may need to be upgraded to support higher charging levels. Directing customers to London Hydro for information about installing a charging station will help them to make more informed decisions and avoid unnecessary costs.
- Work with 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 make an informed decision about driving electric. The EMAP study indicates that the EV option was mentioned to only a few potential early adopters who had recently visited a dealership. This points to an opportunity to provide information at the point of purchase to actively support EV deployment.
- Identify opportunities to educate businesses and workplaces about EV charging so that they can directly support EV deployment in London. The EMAP study indicates that an overwhelming majority of early adopters currently park in employer-provided lots but that employers are not, on the whole, well informed about how appropriate charging services are installed, the costs involved in doing so, and the potential economic opportunities and benefits associated with offering workplace and/or public charging. Making such information available to employers can help to encourage them to support EV owners.

# SECTION TWO:
# Market Research

## Purpose of Surveying the City of London

Understanding the perceptions of EVs – both positive and negative – among the early adopter community in London will make it possible to develop effective and targeted information and awareness campaigns and to provide a framework to facilitate local policy implementation. 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. 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.

## Methodology

The market research process involved two 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

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 $\text{PRIZM}_{c2}$ 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 London. 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 London.

### Target Segments

Eight psychographic segments of the London 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 London.

The following are the eight 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.

**Winner's Circle:** This segment is made up of large families living in bedroom communities and a few metropolitan areas in Canada. The average household income for this group is high and, while they express concerns about saving enough money for the future, they do not mind spending. Winner's Circle residents live in newer homes surrounded by recreational parks, ball fields, golf courses and malls filled with big-box stores.

**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.

**Pets & PCs:** Scattered around Canada's larger cities, this group is made up of younger, multi-ethnic families with pre-school-aged children. Residing primarily in single-family homes and row house subdivisions, Pets & PCs lead active, child-centred lives, including participation in team sports and visiting kid-friendly destinations.

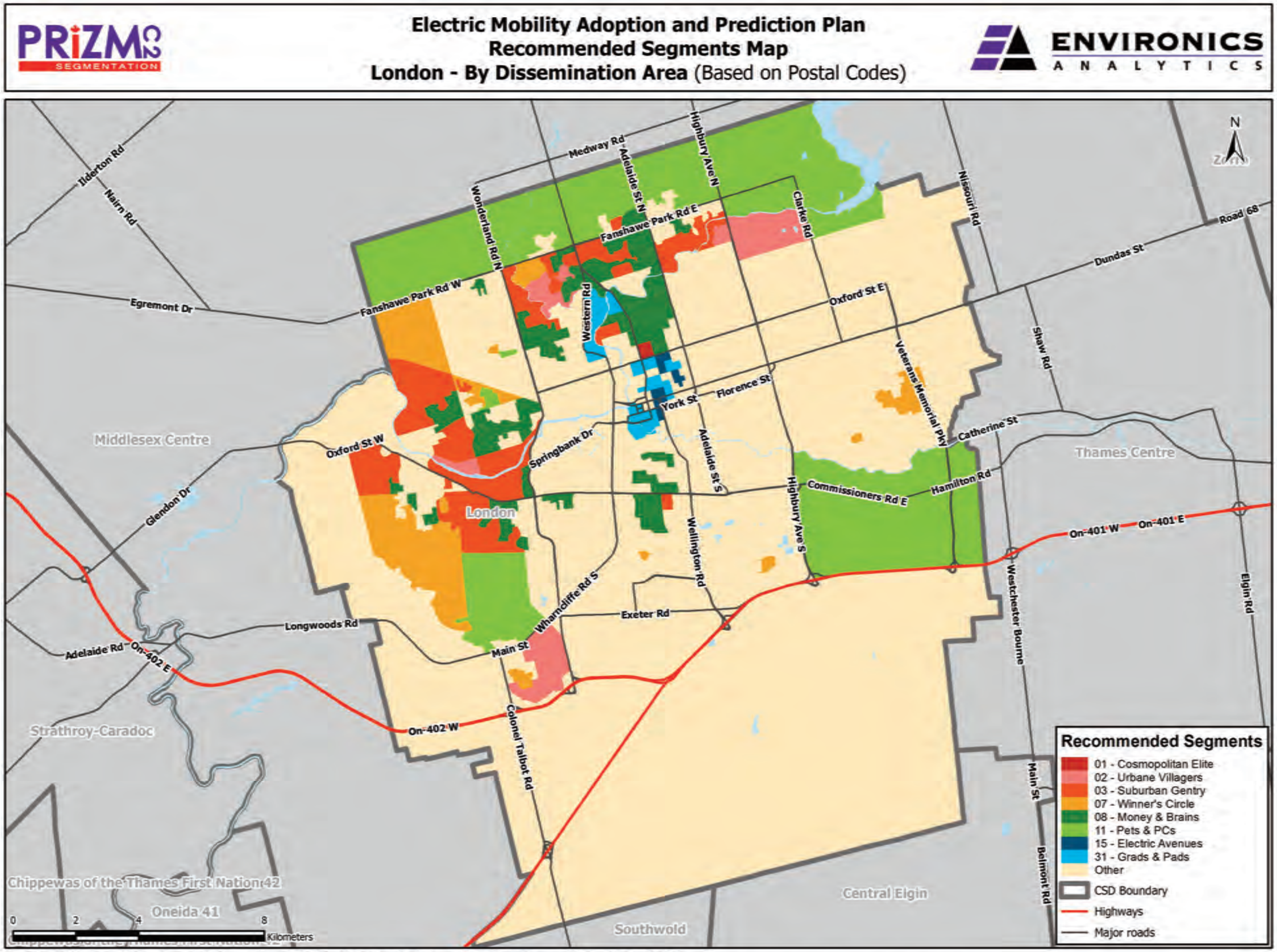
**Electric Avenues:** This group represents young singles and couples pursuing lively urban lifestyles. Concentrated in Canada's largest urban centres, these older, crowded neighbourhoods are known as havens for university graduates who rent apartments, have mid-level jobs and enjoy active leisure lives.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

**Grads & Pads:** This segment is made up of young, ethnically diverse city dwellers living near universities. Grads & Pads includes well-educated singles, couples, students, recent graduates, professionals and service workers just entering the workforce. They enjoy keeping active and are also politically active, working for social causes and volunteering for political parties that support their liberal views.

## Geographic Distribution

A map was created, indicating the geographic distribution of each of the eight target segments within the City of London, 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 London**






Note: CSD – Census subdivision.

## Primary Research to Validate and Characterize Early Adopter Neighbourhoods

In addition to estimating the demand for EVs in the London 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 London residents participated in the survey, which took place between January 30, 2014 and February 15, 2014 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 2010 or newer vehicle within the past three years or be intending to buy or lease a late-model vehicle in the following three 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 respondents, 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 London. They are better educated, with six in ten of those surveyed holding a university degree (bachelor or post-graduate), compared to only 25 per cent of the general population. Potential early adopters are also more than twice as likely as the average city resident to have a household income of $150,000 or more, and a strong majority (78 per cent) live in detached single-family homes and have no children currently living with them.

**Figure 3: Age and Household Income**

| Age | Survey sample, % | London population, % |
|---|---|---|
| Under 30 | 3 | 23 |
| 30 - 44 | 19 | 24 |
| 45 - 59 | 34 | 28 |
| 60+ | 45 | 26 |

| Household income | Survey sample, %* | London population, %* |
|---|---|---|
| Under $60K | 20 | 51 |
| $60 to <$100K | 30 | 25 |
| $100 to <$150K | 24 | 15 |
| $150K+ | 26 | 9 |

*Statistics Canada National Household Survey 2011

### *Vehicle Purchasing Preferences*

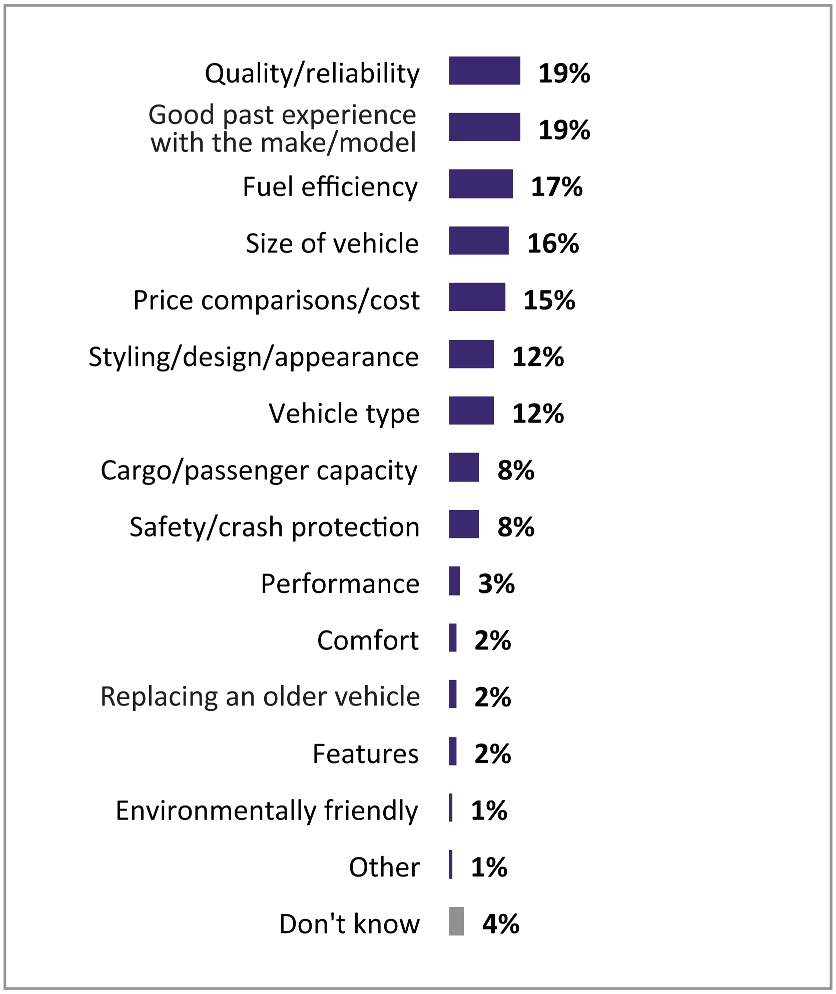
**Personal experience with an EV is linked to greater interest in owning one.**

Of the 750 participants in the household telephone survey, 7 per cent indicated that they currently own a hybrid vehicle (not a plug-in), and one person reported owning a plug-in hybrid vehicle. Among potential early adopters who do not currently own an EV, personal experience with EVs is limited. Only 4 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. One in four of those who later indicated that they would either definitely or likely consider the purchase of an EV in the near future have some previous personal experience with one. 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.

**Reliability and a positive past experience are the main considerations for potential early adopters when they are purchasing a vehicle.**

Reliability and a positive past experience were the top responses from recent buyers when they were asked why they chose their current vehicle. Fuel efficiency, the size of the vehicle and purchase price were also important considerations.

**Figure 4: Top Reasons for Vehicle Choice**

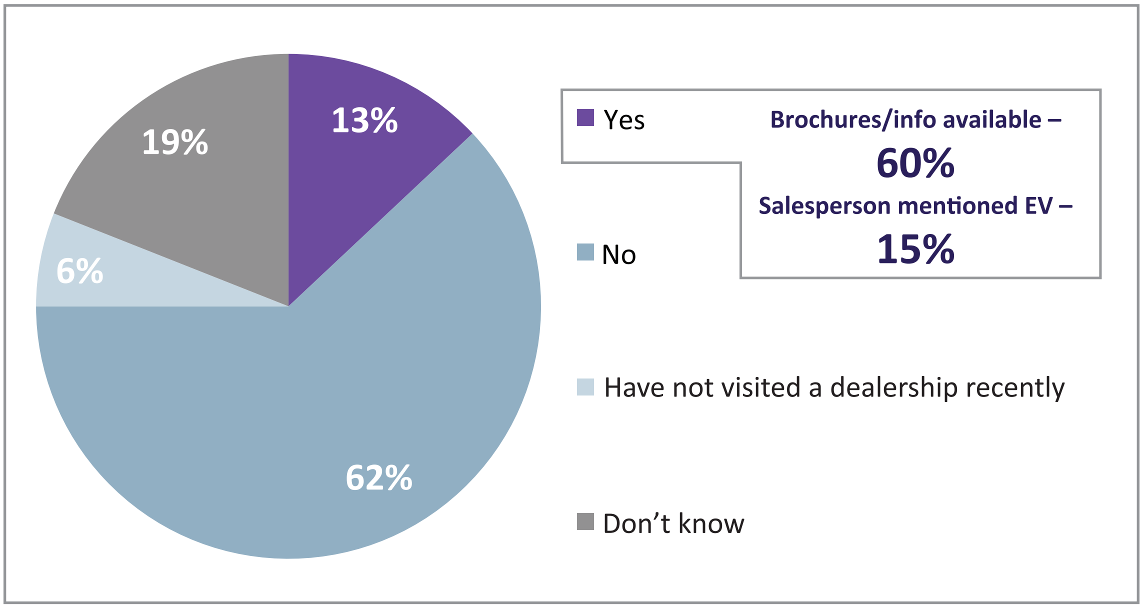



Subsample: Recent purchasers (N=577)

**Few potential early adopters reported an EV being suggested as a purchase option during their most recent visit to a dealership.**

Potential early adopters were asked if, on their most recent visit to a dealership, there were any EVs available for purchase or lease. About one in ten (13 per cent) indicated that there was an EV available while six in ten said that there were none. Only 15 per cent of those who had recently visited a dealership indicated that the salesperson had suggested an EV as a potential purchase or lease option. Sixty per cent of those who responded that there was an EV available for purchase or lease indicated that brochures or other information were available at the dealership.

**Figure 5: Electric Vehicle Availability During Most Recent Visit to a Dealership**

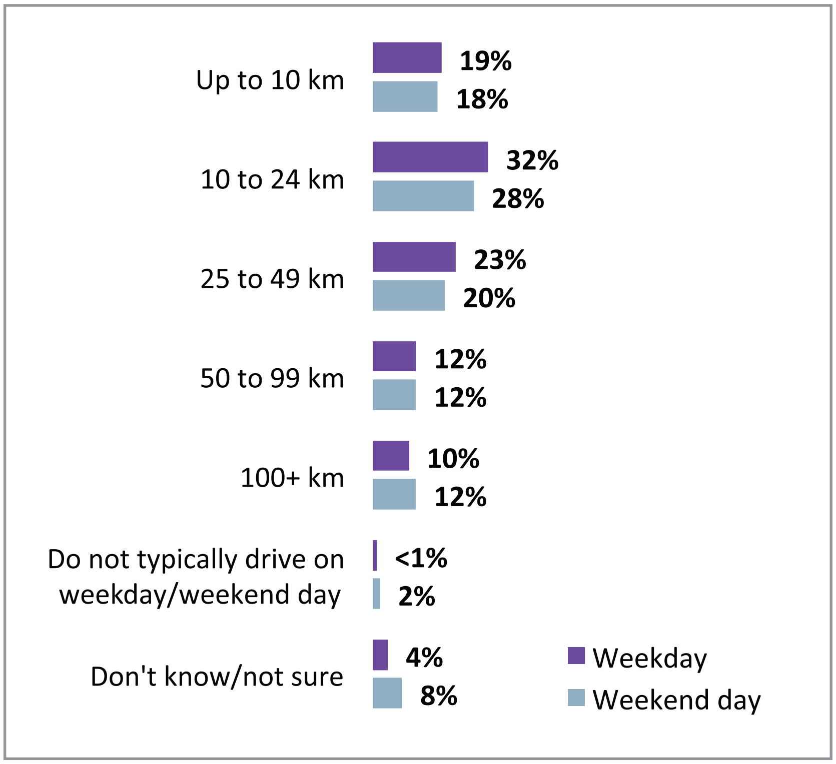



### *Personal Mobility Patterns*

**About half of all potential early adopters use their vehicles every day.**

Just over half of potential early adopters (53 per cent) indicated that they use their vehicles seven days a week. Close to half (45 per cent) of potential early adopters travel more than 25 kilometres on a typical weekday, while 46 per cent drive the same distance on a typical weekend day. Driving every day increases proportionally with the number of vehicles in the household and is highest among those who drive 50 kilometres or more on a typical weekday. It is also higher among those with a child in the home (62 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.

**Figure 6: Kilometres/Day Typically Driven**




**Half of potential early adopters are considered vehicle commuters.**

Around half of potential early adopters (49 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.

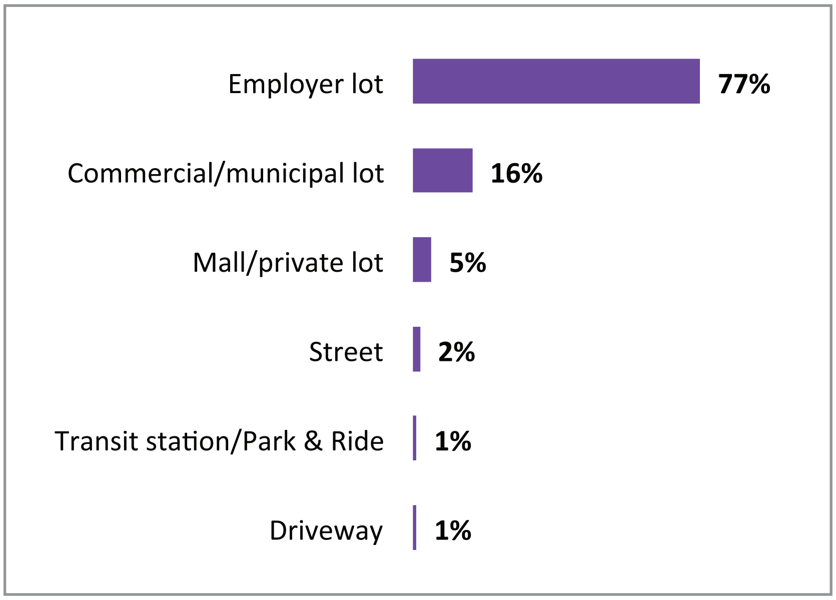
**The majority of vehicle commuters leave home between 7 a.m. and 9 a.m. and return home between 2 p.m. and 7 p.m.**

Most vehicle commuters described a typical workday as one on which they leave home between 7 a.m. and 9 a.m. (58 per cent) and return home between 2 p.m. and 5 p.m. (38 per cent) or between 5 p.m. and 7 p.m. (36 per cent). Vehicle commuters who indicated that they typically drive less than 25 kilometres on a weekday were more likely to say that they return home between 2 p.m. and 5 p.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 four in ten spend seven hours or less parked at this location, while two in ten spend nine hours or more.

**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 (77 per cent) of vehicle commuters indicated that they park in an employer-provided lot.

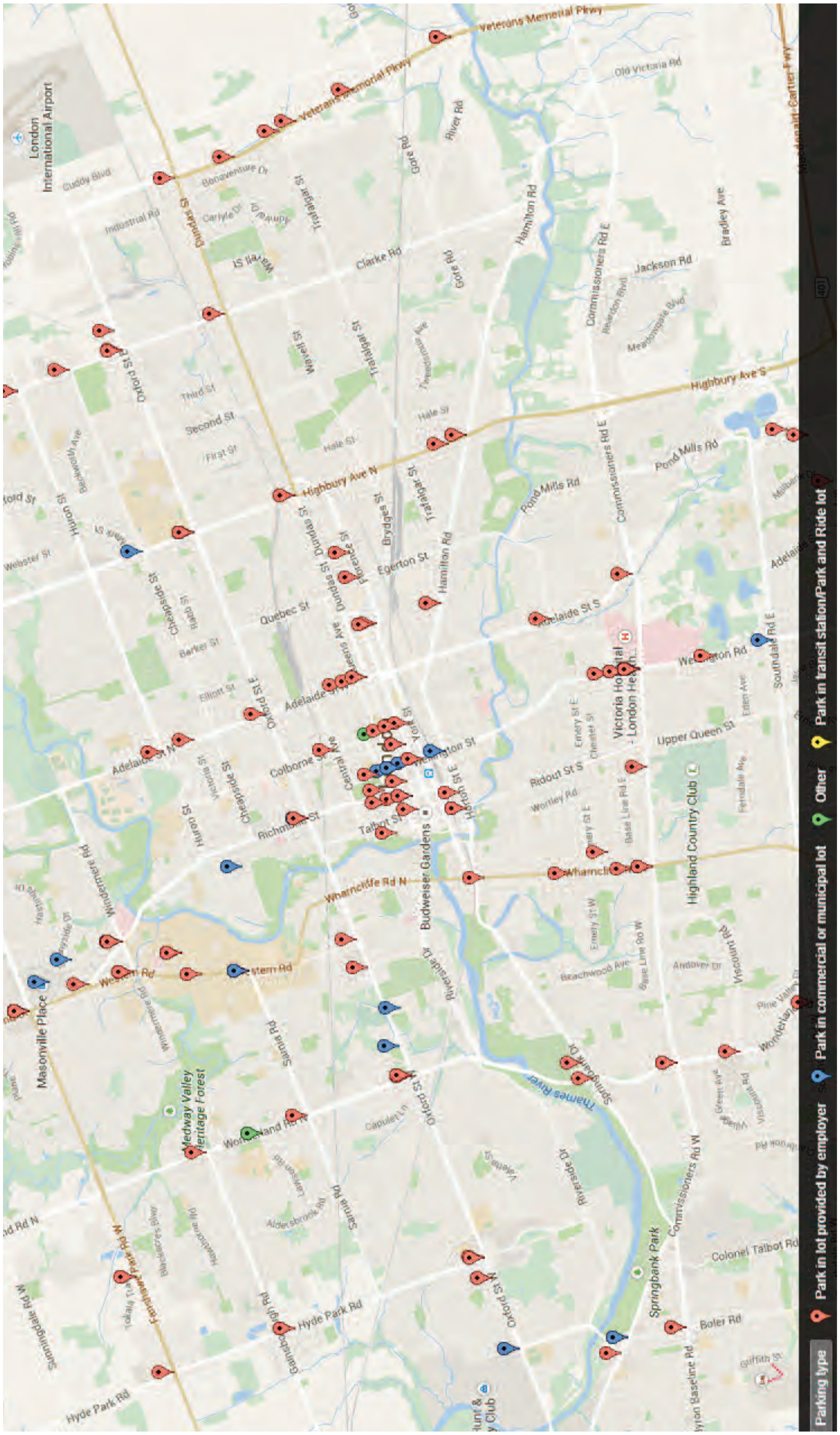
**Figure 7: Type of Parking at Specific Location**




Subsample: Those who leave their vehicle at a specific location at least 3 days per week for at least 3 hours (N=369)

When asked to name the major intersection nearest the location where they typically leave their vehicle, the majority of vehicle commuters reported that they remain in or around London (see Figure 8).

**Figure 8: Vehicle Commuter Parking Locations in London by Lot Type**



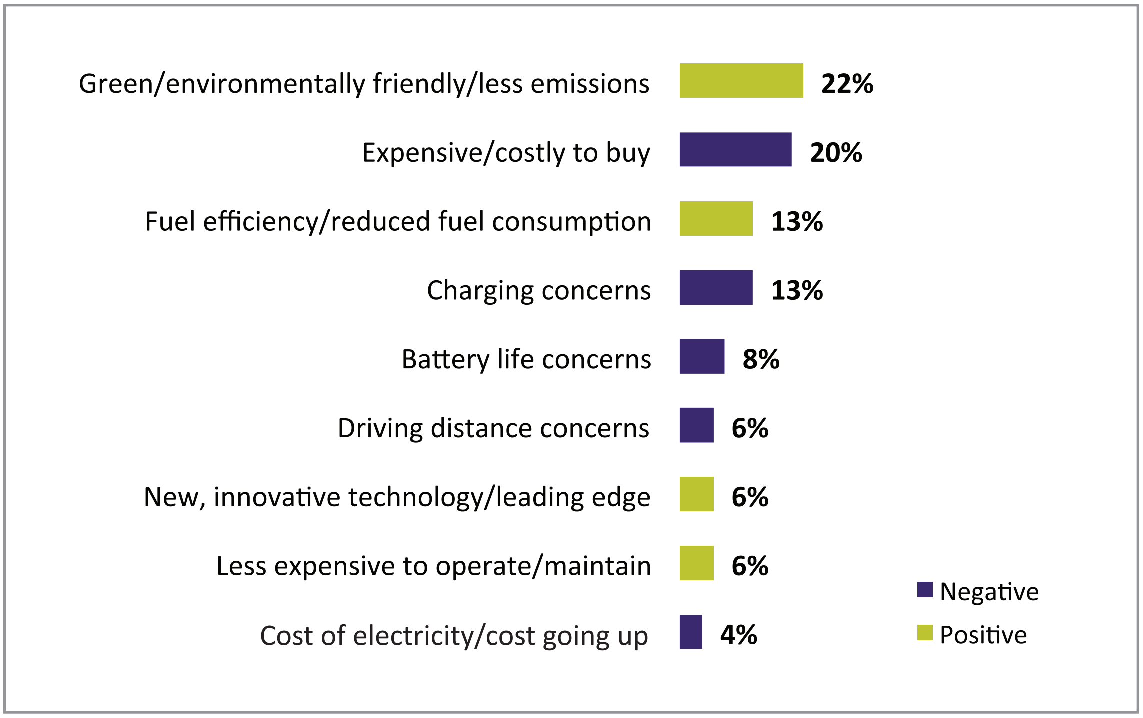
## Awareness and Perceptions of Electric Vehicles

### *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 a positive one – the green or environmentally friendly potential of the vehicle – but about half made some negative mention. The most common negative responses were related to purchase price or range anxiety (battery life, charging concerns or the potentially limiting range of the vehicle). There were more negative mentions from potential early adopters who would likely or definitely not consider an EV than from those who would likely or definitely consider one.

**Figure 9: Most Mentioned Top-of-Mind Impressions of Electric Vehicles**




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

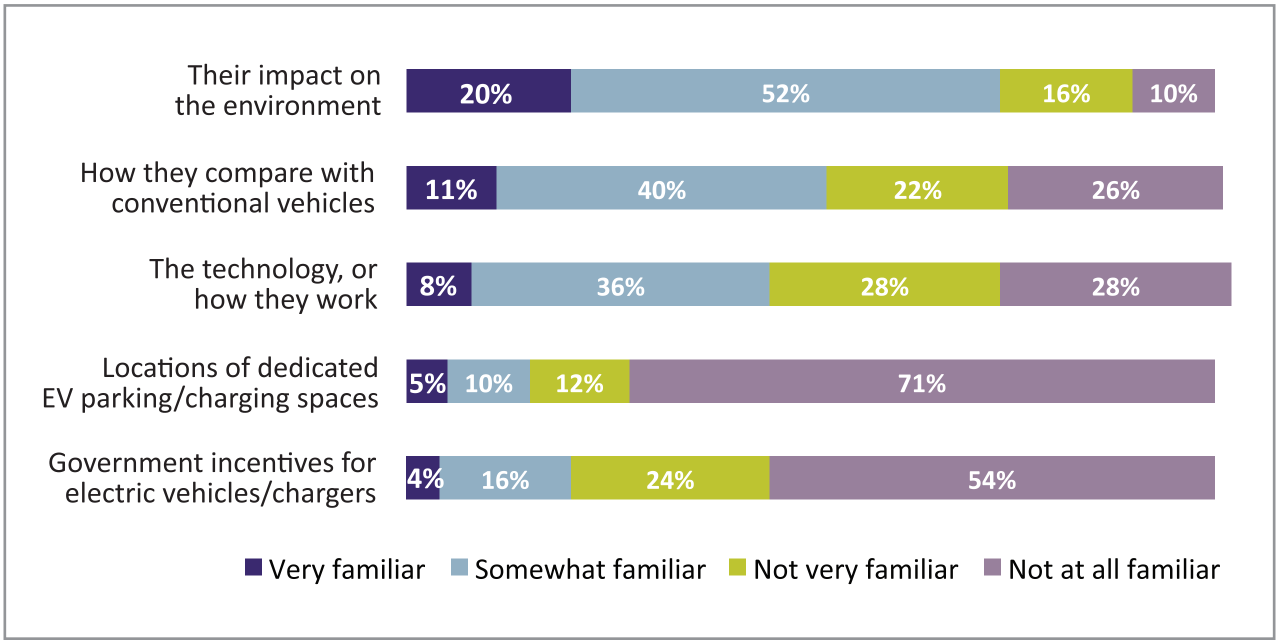
**The majority of potential early adopters are most familiar with the environmental impact of EVs.**

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 location of dedicated EV parking/charging spaces in London

While few respondents claimed to be very familiar with any aspect of EVs, seven in ten said that they were at least somewhat familiar with their environmental impact. Half expressed the same level of familiarity with how EVs compare with conventional vehicles, and four in ten indicated some familiarity with the technology, or how EVs work. Awareness of current government incentives was low, with 71 per cent of respondents indicating that they were not at all familiar with incentives for purchasing an EV or installing a home charging station. A strong majority of potential early adopters indicated that they were not at all familiar with the location of dedicated EV parking/charging spaces in London. Strong familiarity with any of the five aspects of EVs was linked to a definite willingness to consider buying an EV.

**Figure 10: Familiarity with Specific Aspects of Electric Vehicles**



### *Likelihood of Considering an Electric Vehicle*

**One-third of potential early adopters would consider purchasing an EV in the next couple of years.**

Only 30 per cent of potential early adopters said that they would likely (25 per cent) or definitely (5 per cent) consider an EV if they were purchasing or leasing a vehicle in the next couple of years. A majority of 67 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 (21 per cent versus 39 per cent of younger drivers). As previously noted, some experience with an EV is slightly higher among those who would likely or definitely consider purchasing one in the next couple of years.

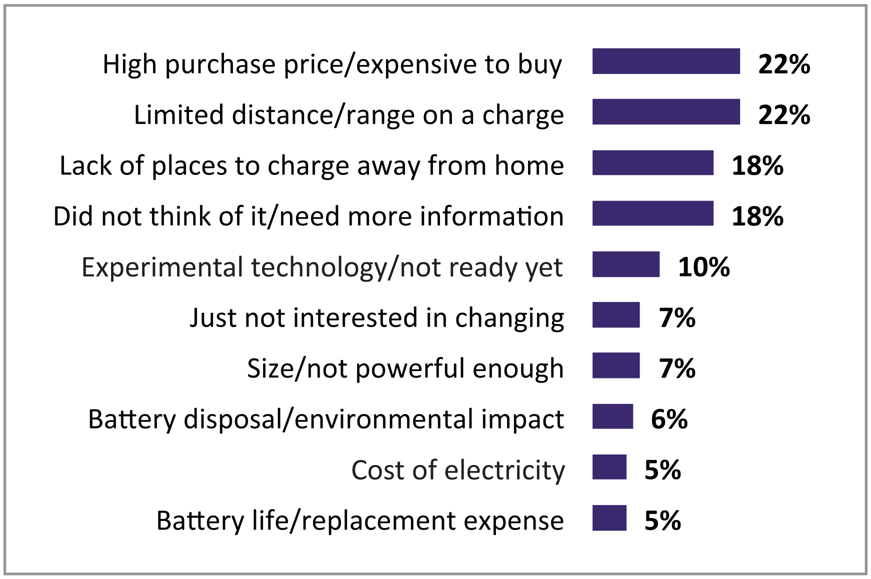
### *Perceived Barriers and Opportunities*

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

Around two-thirds (62 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. Thirty-four 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, the suitability of the vehicle for city driving or the quiet ride.

Two 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 high purchase price of the vehicle. A further 22 per cent mentioned the potentially limiting range of the vehicle, and equal numbers (18 per cent) noted the lack of charging locations away from home and the need for more information on which to base a purchasing decision.

**Figure 11: Top Reasons for Not Considering an Electric Vehicle**



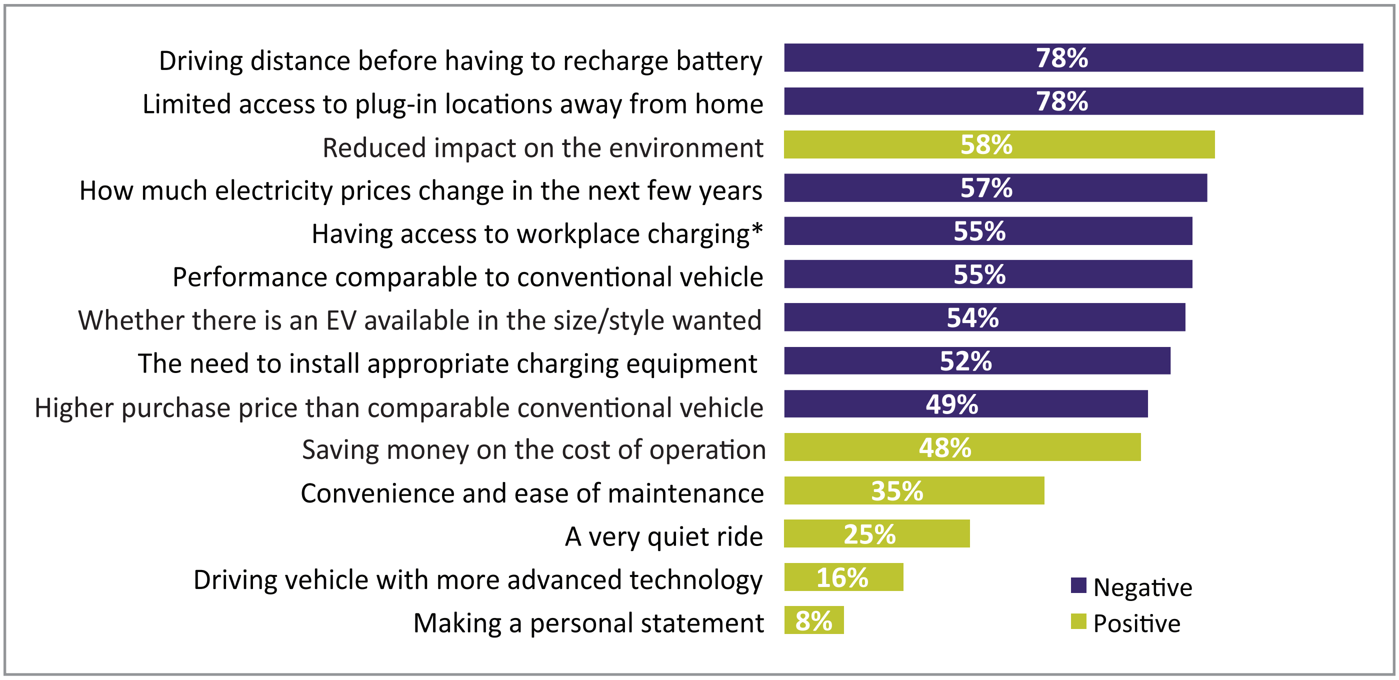

Subsample: Would definitely/likely consider an EV (N=500)

**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, future electricity costs, having access to workplace charging, overall performance compared to gasoline-powered vehicles, and available sizes or styles 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 or likely consider an EV were more likely than others to mention that the positive aspects would be important. However, those who would likely consider an EV were also just as likely as those who would likely not consider one to say that barriers related to range anxiety would be very important.

**Figure 12: Electric Vehicle Aspects Considered *Very Important* in Purchase Decision**




Subsample: Would definitely/likely/likely not consider an EV and do not own an EV (N=522)

*Asked of respondents who are commuters and who use employer-provided parking (N=224)

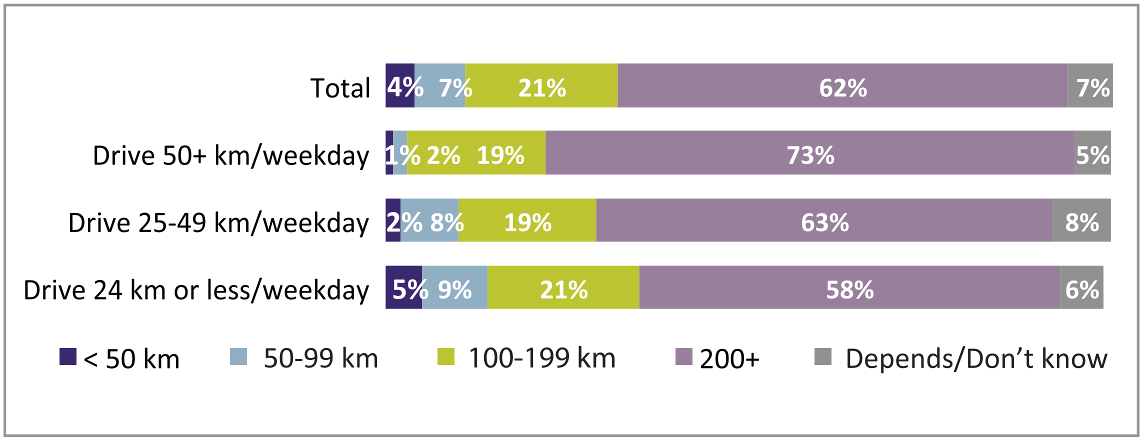
## Charging Expectations

**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 (62 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 almost 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 13: Acceptable Distance for Travel on a Single Charge**

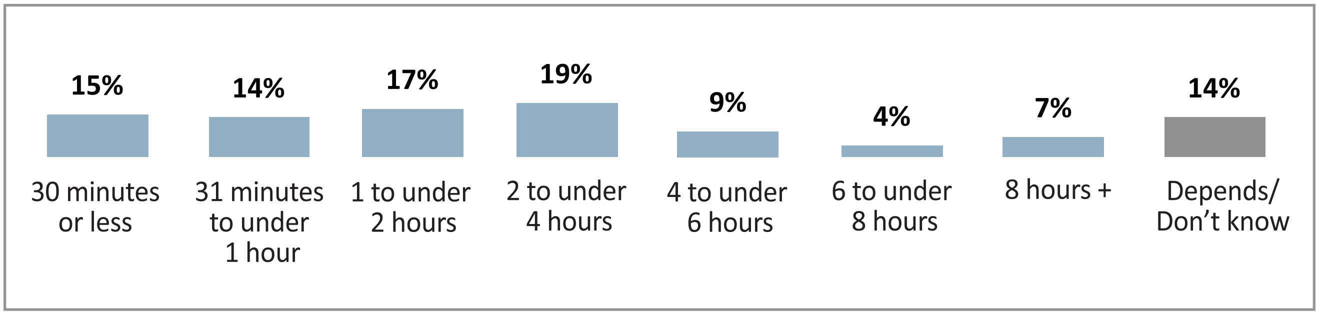



Subsample: Would definitely/likely/likely not consider an EV and do not own an EV (N=522)

**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. Two-thirds of potential early adopters 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. About one-third of those who would consider purchasing an EV felt that it should take less than one hour for a full charge.

**Figure 14: 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=522)

**Access to faster home charging is considered very important.**

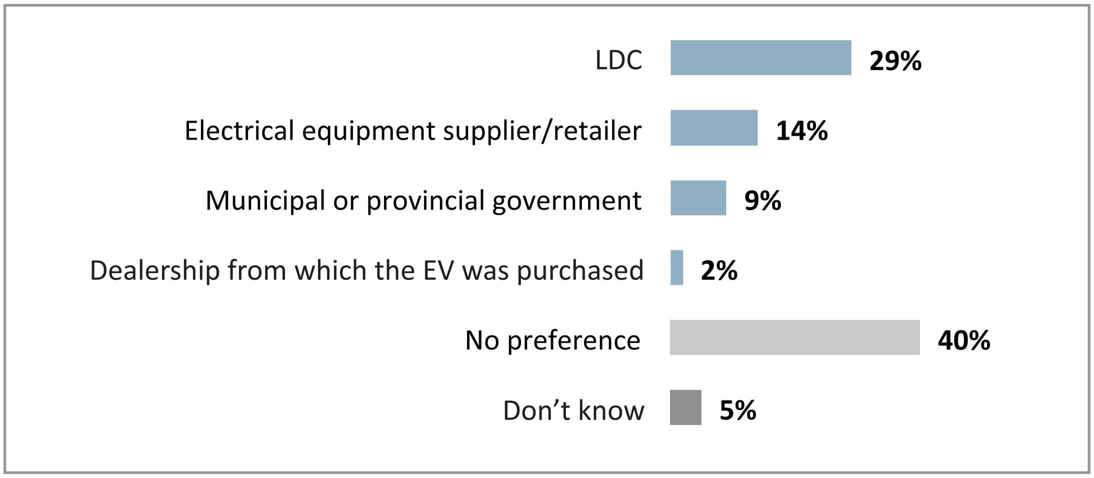
Potential early adopters understand that EVs need time to charge, unlike a gasoline-powered vehicle with a gas tank that can be filled quickly. However, more than half think that it should take less than four hours (similar to the length of time it takes to charge an iPod) to fully charge the vehicle. 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 (73 per cent) or somewhat (21 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 two-thirds 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.

**Three in ten 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 four potential service providers they would prefer to have install and maintain a Level 2 charging station at their home. A majority of four in ten said that they have no particular preference, while 29 per cent would prefer this to be done by the LDC. An electrical equipment supplier/retailer was mentioned by 14 per cent, and 9 per cent would prefer the government to act as the primary service provider. Only 2 per cent indicated a preference for the dealership from which they purchased their EV.

**Figure 15: Preferred Service Provider for Installing and Maintaining an At-Home Charging Station**

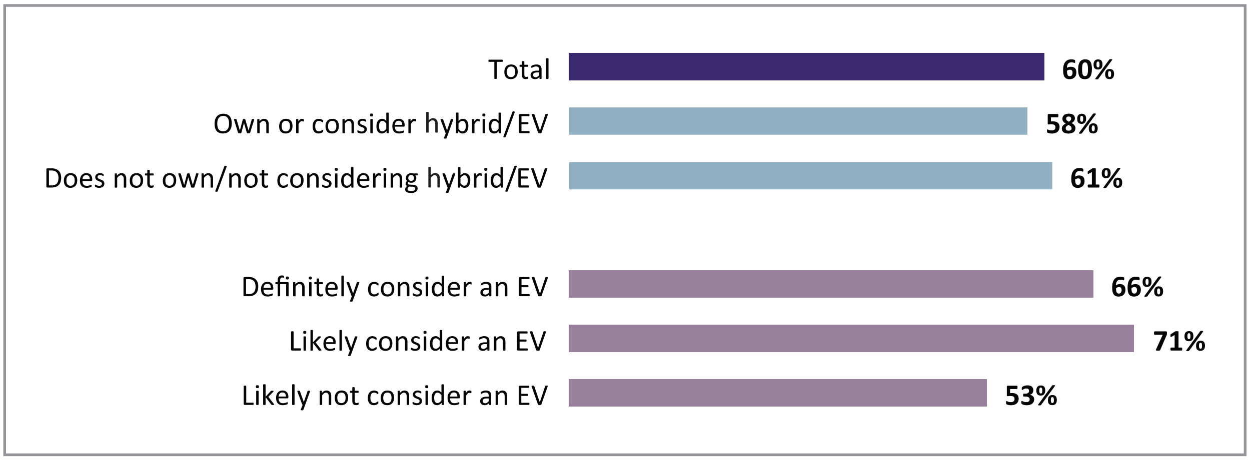



Subsample: Important to charge EV faster (N=496)

**More than half of potential early adopters would be willing to pay two dollars more per hour to charge an EV at a public parking space.**

When those who own an EV or would at least marginally consider one were asked if they would be willing to pay two dollars per hour more than the standard parking rate to be able to charge their vehicle while parking, six in ten said that they would be willing to do so. Just over one quarter of potential early adopters said that they would not pay extra, while one in ten said that it would depend, for example, on how much charge was needed or if other parking spots were available. It should be noted that, in practice, EV owners familiar enough with their vehicle's range might not be willing to pay an extra fee because they would feel confident that they could wait to return home to charge their EV.

**Figure 16: Willingness to Pay an Additional Two Dollars per Hour to Charge at a Public Parking Space**

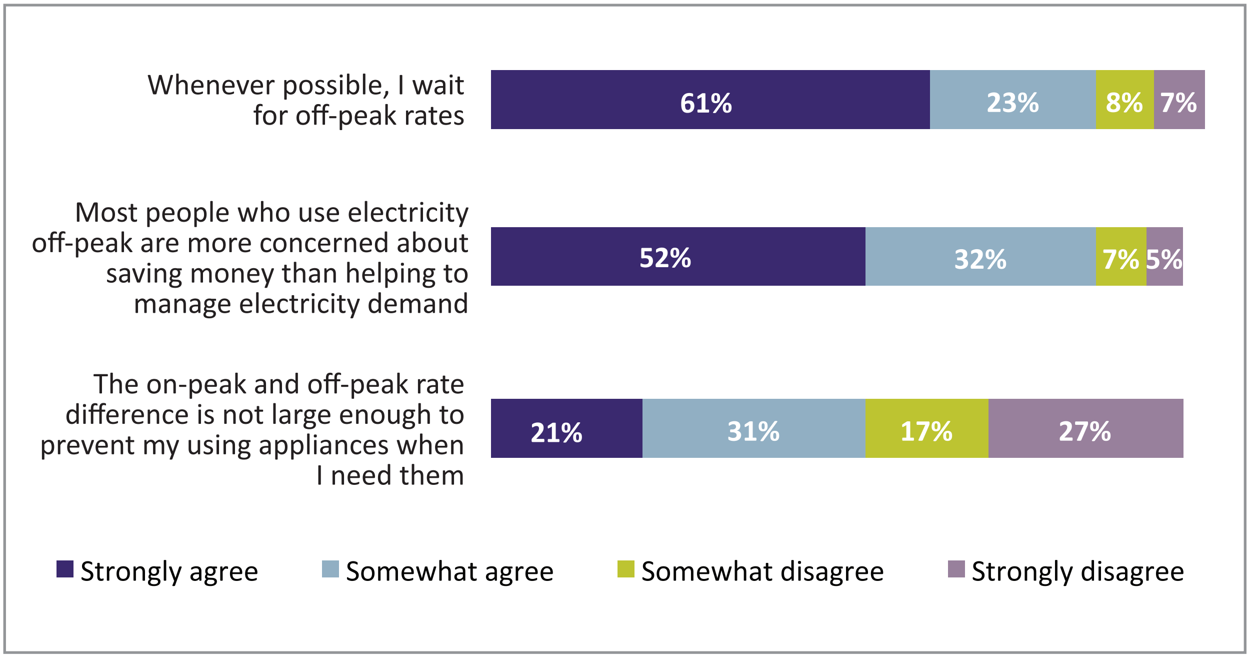



Subsample: Would definitely/likely/likely not consider an EV (N=523)

**The majority of potential early adopters wait to use high electricity consumption devices during off-peak hours.**

Potential early adopters were asked to indicate their level of agreement with three statements about time-of-use rates. The majority strongly agreed that "Whenever possible, I wait for off-peak rates before using high electricity consumption devices, such as clothes dryers or dishwashers." About half also agreed with the following statement: "Most people who use electricity off-peak are more concerned about saving money than about helping to manage electricity use across the grid." However, agreement was divided about the statement "The difference between on- and off-peak rates is not large enough to prevent me from using a high electricity consumption appliance whenever I need it." This suggests that EV charging behaviours would likely be similar, with most potential early adopters opting to charge off-peak to save money if possible but not regarding time-of-use rates as sufficiently compelling to prevent them from charging on-peak if need be.

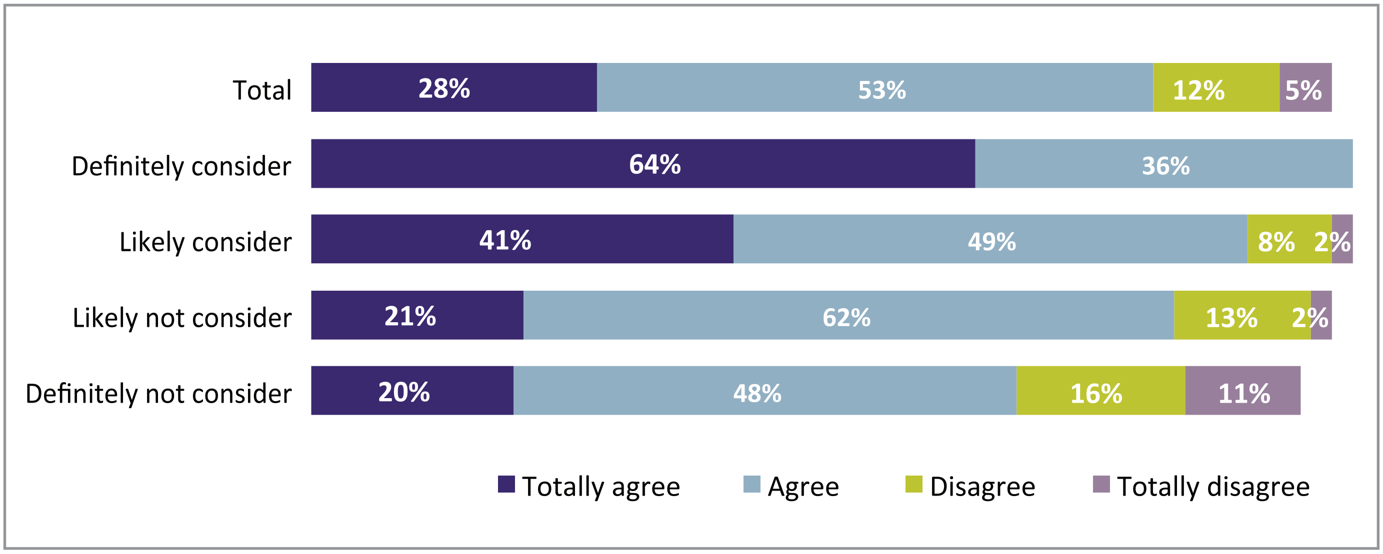
**Figure 17: Statements for Encouraging Off-Peak Charging**




## 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.

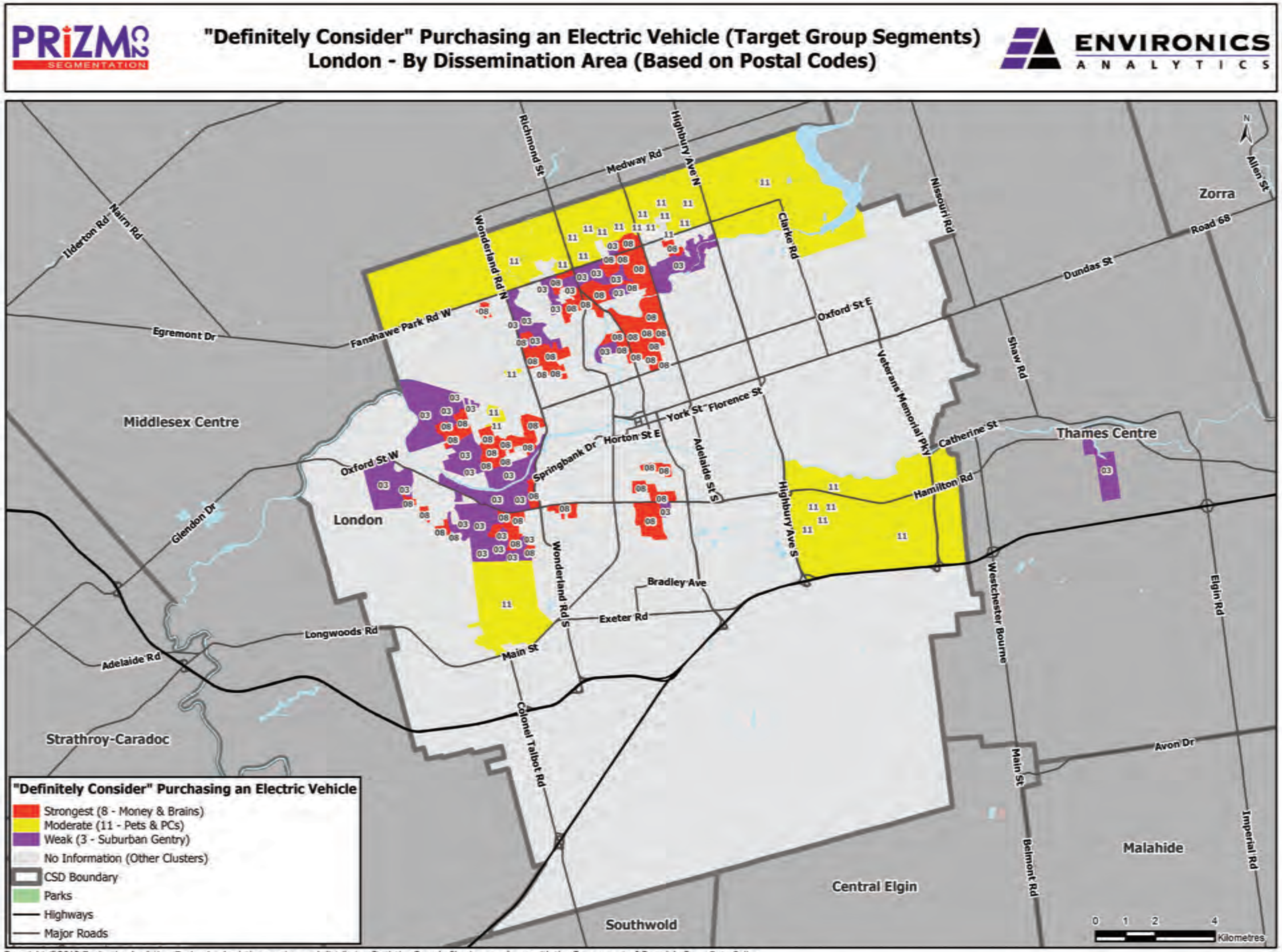
**Figure 18: Responses to the Statement "I am excited about the possibilities presented by new technologies" by Likelihood of Considering an Electric Vehicle in the Next Two Years**




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

Each of the eight 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 19) details the areas in the City of London where the adoption of EVs will likely take place.

**Figure 19: Strength of Interest in Purchasing an Electric Vehicle by Dissemination Area in the City of London**






Note: CSD – Census subdivision.

# 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. The findings from the household telephone survey provide a robust foundation for determining strategies to facilitate the successful uptake and integration of the technology in the City of London.

Potential early adopters in the City of London 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. These findings suggest that a lack of awareness of 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.***

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 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 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 London. 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 London.

***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.***

Section Two of the EMAP report has described the methodology and results of two 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 London 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 could become 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 London. 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 London Hydro service area.

*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.*

# 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 London and the London Hydro 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. Electrons are induced to move by electromagnetic forces, described as voltage.

**Voltage (V)** is a measure of electrical energy, or the *work* that an electromagnetic field can impart to a charged particle. Measured in volts (V), it is the energy that induces electrons to move in a conductor. Volts are also used to express the voltage applied to a circuit by an energy source, such as a battery or an electrical generator; in this context, voltage can also be referred to as **electromotive force**.

**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 and the more the voltage (i.e., the electrical energy) applied to the conductor is 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 to 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**.

**Power** is the time rate at which energy (e.g., the energy of electrons carrying charge to a battery through a conducting wire) 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 1000 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). All load profiles are expressed in kW because, at the customer level, reactive power is very small compared with active power.

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.

### 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.

## 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.

## 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 London is Hydro One Networks, Inc. The transmission lines servicing the city operate at voltages of 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?

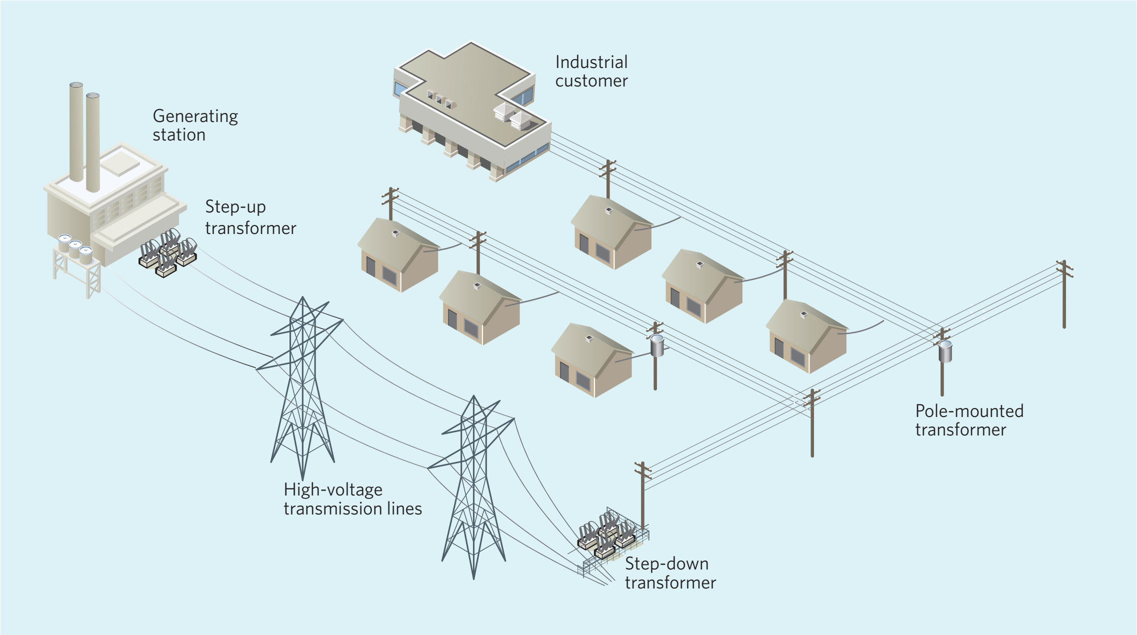
Transformers neither produce nor consume power or energy. But, by regulating power to the right levels, they make it possible for devices of all types and purposes to operate on just a few levels of power supply.

Transformers at their most essential level 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.

## 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, London Hydro is the LDC for the City of London.

**Figure 20: Electricity Generation, Transmission and Distribution System**




The **transformer station** is where the transition from transmission to distribution occurs. These transformers step down the voltage from transmission levels (230 kV and 115 kV) to distribution levels. There are six transformer stations in the London Hydro service area, all owned by Hydro One Networks, Inc. Five of these transformer stations step down voltage to 27.6 kV and one station to 13.8 kV. **Distribution feeders** (electrical cables or conductors) running from transformer stations distribute electrical power to transformers located overhead or underground or to smaller **municipal substations**. In the London Hydro system, the 27.6 kV feeders supply power to such substations, where voltage is then converted to 4.16 kV and, at one substation, to 8.32 kV. It should be noted that both the 4.16 kV and 13.8 kV systems are gradually being decommissioned in an effort to adopt a system-wide supply standard of 27.6 kV.

London Hydro's residential service area is supplied by two different distribution system configurations: the overhead distribution system and the underground distribution system. The overhead distribution system primarily supplies power to the central and older parts of the city, while the underground distribution system primarily provides power to those neighbourhoods located outside the centre of the city. Figures 21 and 22 illustrate the distribution transformers by system voltage for the overhead distribution system and the underground distribution system, respectively.

**Figure 21: London Hydro Overhead Distribution Transformers by System Voltage**

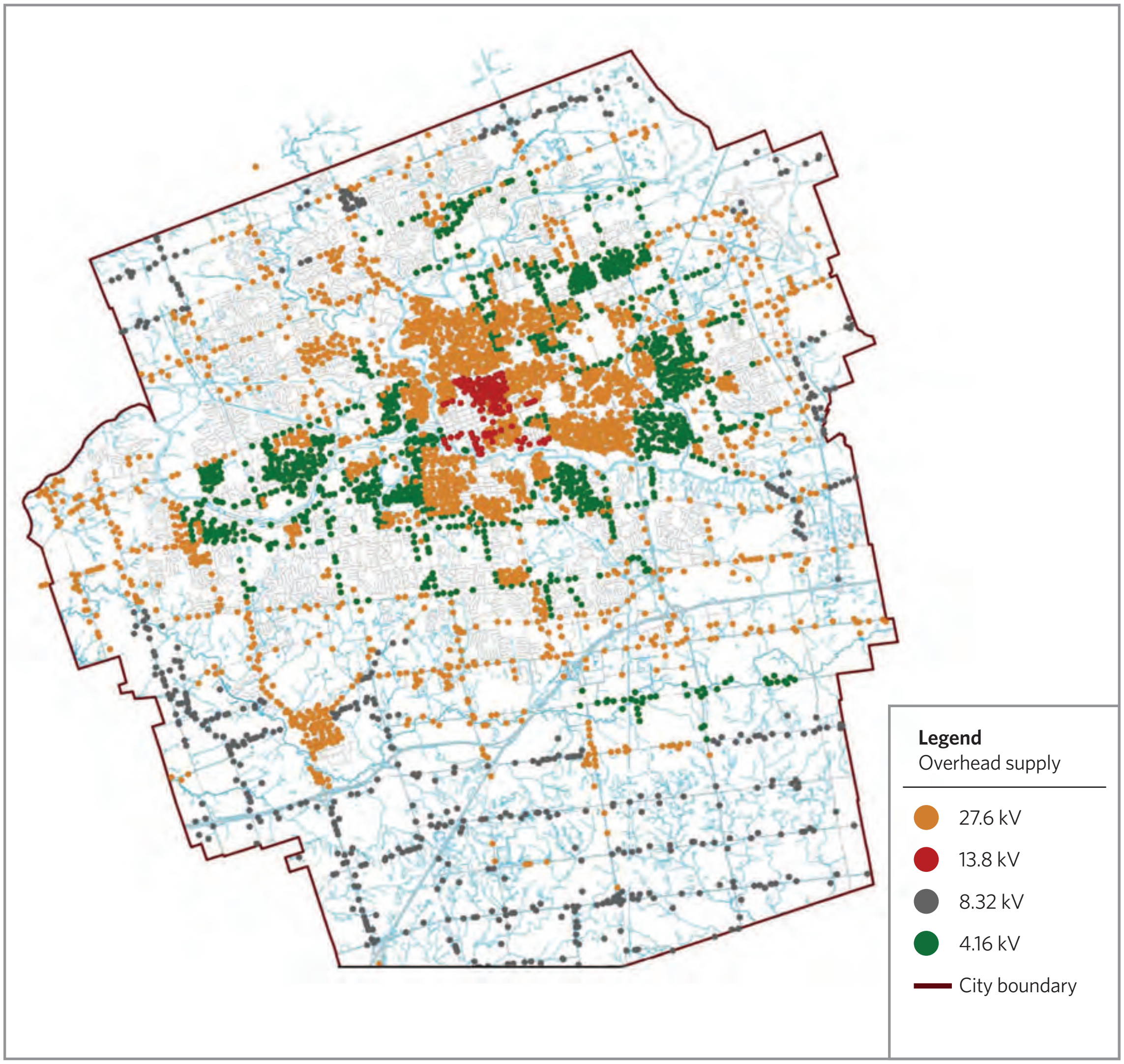
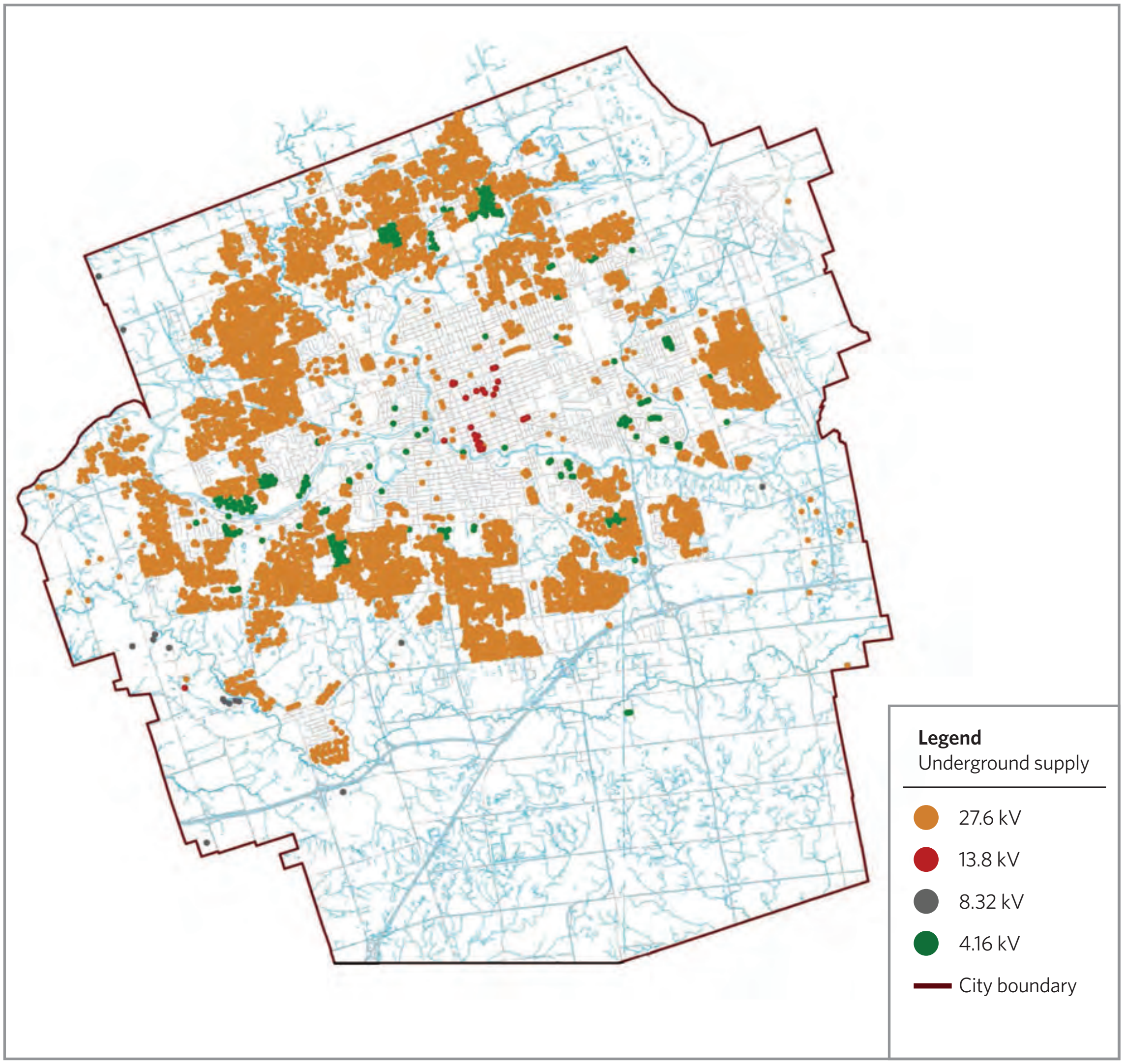


**Figure 22: London Hydro Underground Distribution Transformers by System Voltage**



## LOCAL TRANSFORMERS

Pole- or pad-mounted transformers provide the final voltage transformation in the London Hydro electrical power system.  These transformers step down the voltage from distribution levels to the level appropriate for use by individual households (typically 120 V and 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 slab (pad-mounted).

## SECONDARY CONNECTION SYSTEM

The secondary connection system supplies power from the pole- or pad-mounted transformer to the end-user.  In the overhead system, the secondary connection system for a pole-mounted transformer consists of the following:

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

Pad-mounted transformers typically supply power to end-users through buried service cables that run from the transformer to the individual customer. 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 London, 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 an assessment of the distribution system at the neighbourhood level, including pole- and pad-mounted transformers and the secondary cables responsible for running electrical power to individual households in the overhead distribution system. The impacts of EV charging on the distribution system were simulated by London Hydro, using actual residential transformer loads.

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

### 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. The scenario development consisted of investigating key variables and establishing the effects of EV charging on transformer aging. Some scenarios focused on individual transformers, while others examined the effects of EV charging on pole- and pad-mounted transformers across the entire London Hydro service area.

It is important to note that because the distribution system is made up of a range of transformers, the effects of EV charging will affect each transformer differently, based on its rated capacity, typical load profile, number of households served and the capacity of the vehicle's on-board charger.

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 the 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, three 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 as it currently exists. 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 investigated were

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

The key variables investigated are described in greater detail below.

### *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 it is charging at 240 V (Level 2 charging). For example, the 2014 Nissan LEAF can charge at 6.6 kW at 240 V, but power flows at 1.2 kW when the vehicle is charging at 120 V.

A number of EVs on the market have an on-board charger rated at 3.3 kW (e.g., the 2014 Chevrolet Volt plug-in hybrid electric) or 6.6 kW (e.g., the 2014 Nissan LEAF) 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 three popular EV models used as examples of the charger capacities investigated in this section of this report. Looking at a range of charger capacities allows for more in-depth analysis of the extent to which conditions such as ambient temperature or time of charge can affect the capacity of the electricity distribution system to meet the additional demand for power for EV charging. Level 1 charging is not investigated in this report because the load associated with charging an EV at Level 1 would have relatively little effect on the electricity distribution system and, moreover, the EMAP market research indicates that charging at Level 1 would take longer than the typical early adopter would likely be willing to wait.

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

| EV model | Charging level, V | On-board charger capacity, kW | Battery size, kWh |
|---|---|---|---|
| 2014 Chevy Volt | 240 | 3.3 | 16 |
| 2014 Nissan LEAF | 240 | 6.6 | 24 |
| 2014 Tesla Model S | 240 | 20 | 85 |

Note: The Tesla website references both 20 kW and 22 kW as the on-board charger capacity for the Tesla Model S. For the purposes of this report, only 20 kW will be investigated.

### *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 investigating ambient temperature used transformer load data from the week of the previous summer when demand for power was greatest (July 14 to 20, 2013) to represent the worst-case for summer (i.e., summer peak). Data from the week of the previous winter when demand for power was greatest (January 5 to 11, 2014) were used to represent the worst-case for winter (i.e., winter peak). To determine the percentage load for each individual transformer, its overall load for the summer or the winter peak was divided by its rated capacity. For example, a transformer rated at 50 kVA with a load of 25 kVA during the summer peak would be considered to be loaded at 50 per cent of its rated capacity.

Based on its loading percentage, each transformer was assigned to one of the following three categories:

- **lightly loaded**: less than 50 per cent loaded (transformer loading less than 0.5)
- **moderately loaded**: between 50 and 100 per cent loaded (transformer loading between 0.5 and 1.0)
- **overloaded**: anything above 100 per cent loaded (transformer loading greater than 1.0)

Figures 23 and 24 show the distribution of transformers within the London Hydro service area based on these three categories for the day with the greatest demand for power in the summer (July 18, 2013) and winter (January 7, 2014), respectively. Each coloured area represents either a transformer or a group of transformers from the same category (e.g., blue areas represent a grouping of lightly loaded transformers) within the service area. These figures indicate that for the time periods investigated, a greater number of transformers in the London Hydro service area were considered overloaded during the summer peak than during the winter peak.

**Figure 23: Transformer Loading on the Day with the Greatest Demand for Power in Summer (July 18, 2013)**

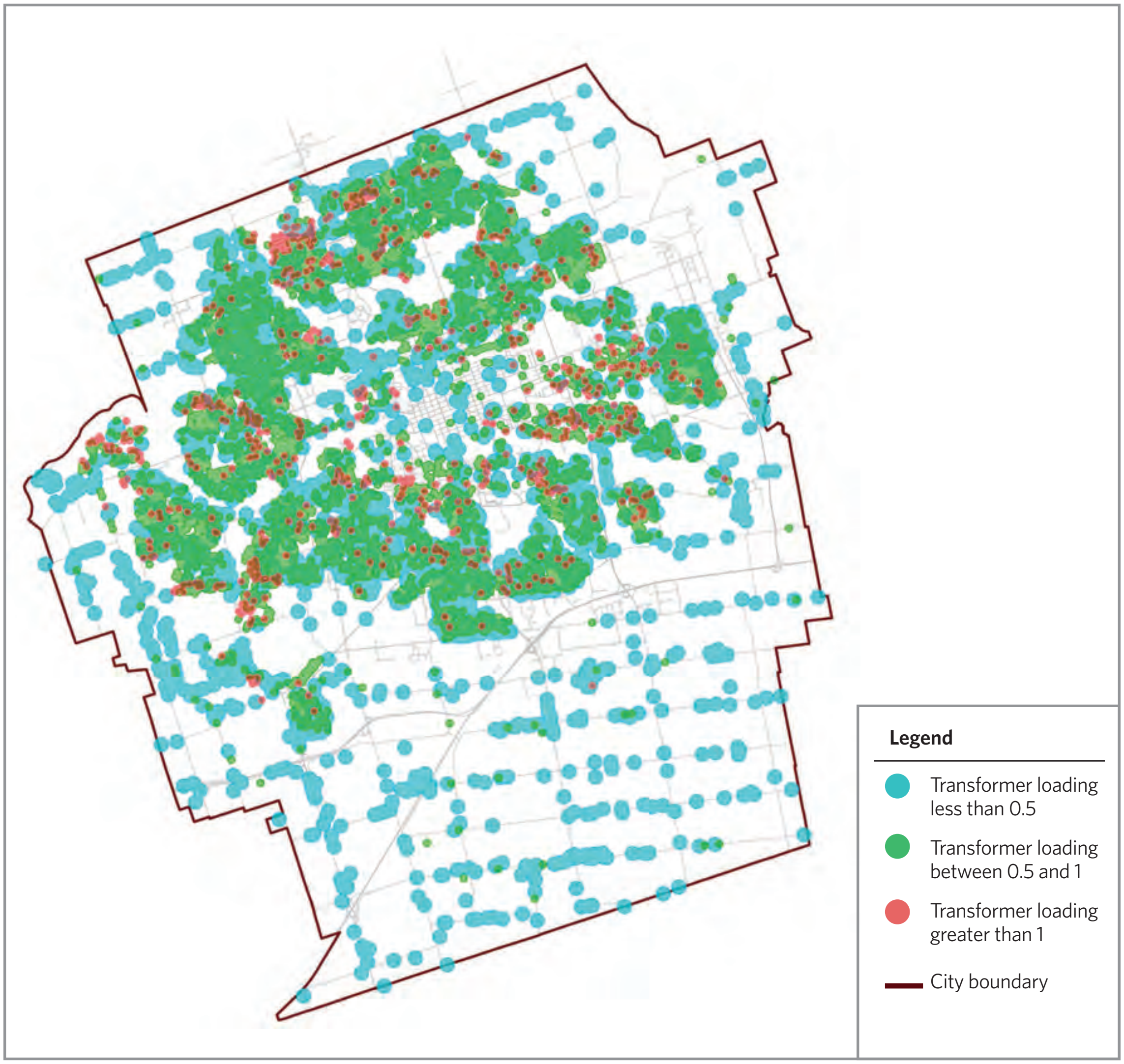
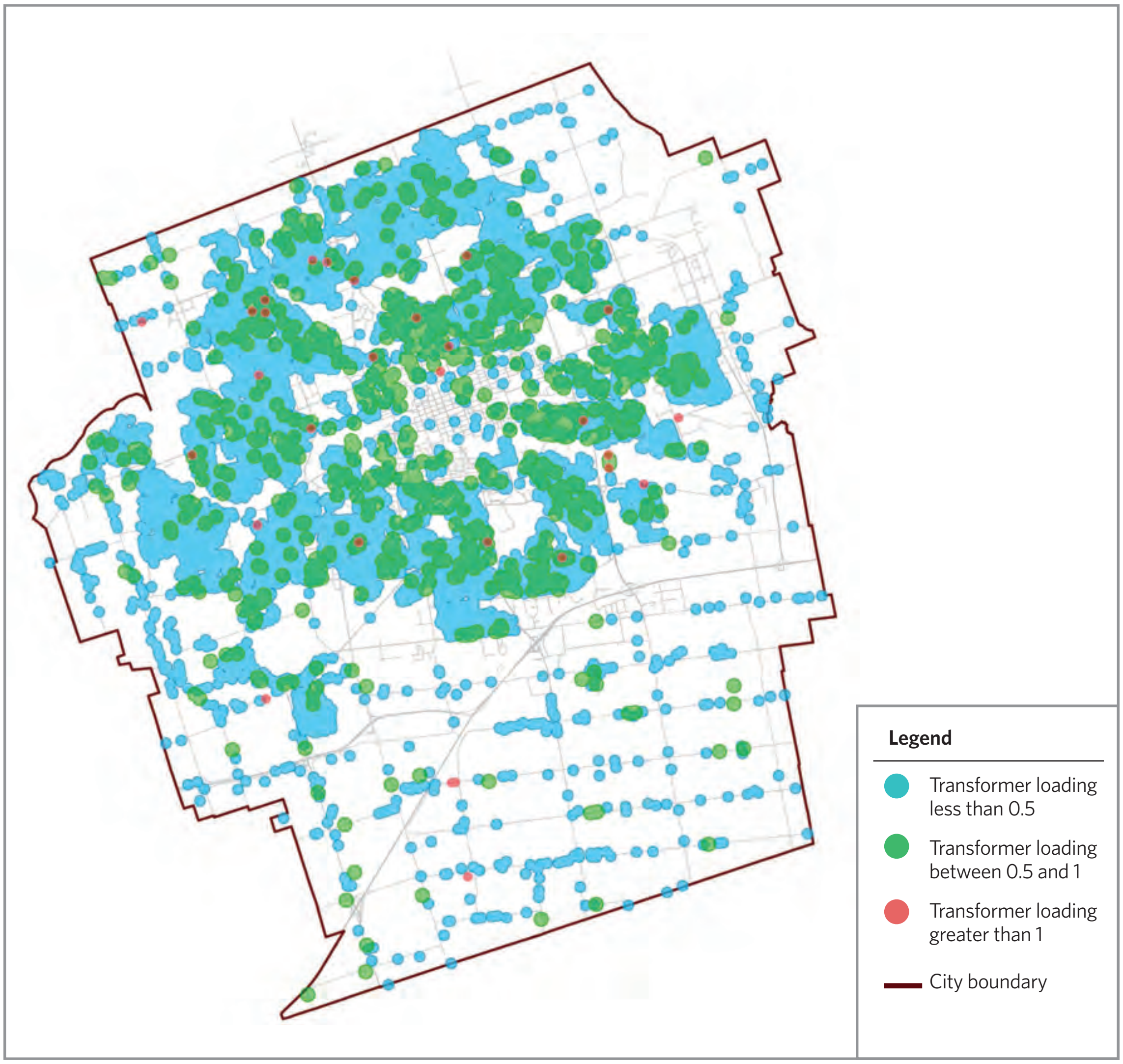


**Figure 24: Transformer Loading on the Day with the Greatest Demand for Power in Winter (January 7, 2014)**




## *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. To better understand how time of charge affects EV charging, two pad-mounted transformers were selected to illustrate the effects of EV charging during on- and off-peak hours. The transformers selected both have a capacity of 50 kVA, a fairly common transformer size for the London Hydro service area.

Further details specific to each of the transformers used as examples are described below.

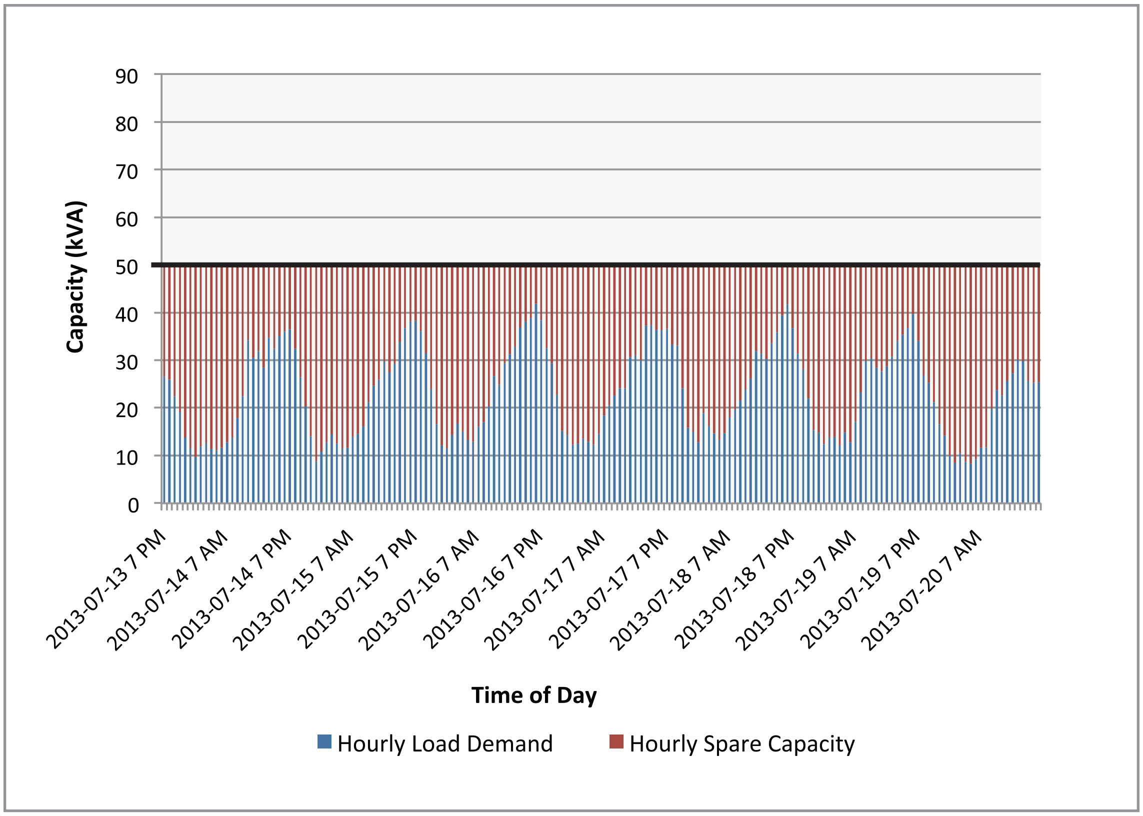
**Transformer 1:** This transformer provides power to seventeen condominium units. It is pad-mounted and, for the purposes of this assessment, considered to be lightly loaded. Condominiums and other multi-residential buildings do not necessarily align with the profile of the EV early adopter and, because of their size, units in such buildings typically demand less power overall than would be required for a typical single-family dwelling. Based on its load profile, this transformer is meant to represent a best-case scenario for EV charging.

**Transformer 2:** This transformer provides power to sixteen single-family dwellings. It is pad-mounted and, for the purposes of this study, considered to be overloaded. The EMAP market research shows that EV early adopters are more likely to reside in single-family dwellings, consistent with those provided with power by this transformer. Based on its load profile, Transformer 2 represents a worst-case scenario for EV charging.

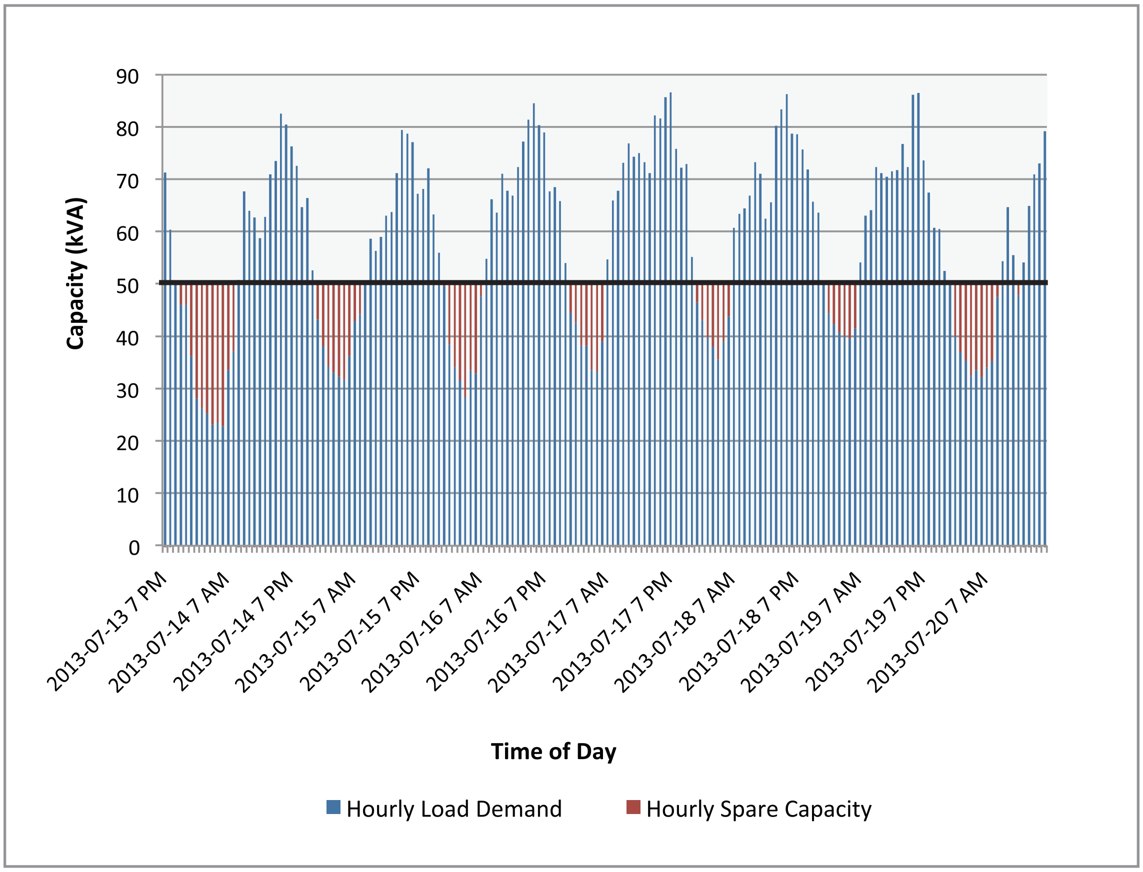
Before any additional loading from EV charging was considered, the 24-hour load profiles for the summer peak were generated for both transformers. Figure 25 shows the load profiles for Transformer 1 and Transformer 2, respectively, and illustrates that the demand for power fluctuates over the course of the day across the week in question. Transformer 1 was operating well below its rated capacity each day, even during times of peak demand. Transformer 2 was operating above rated capacity for the majority of the week, with relatively few intervals with spare capacity.

**Figure 25: Transformers 1 and 2 Load Profiles for Summer Peak**

(a) Transformer 1: supplies 17 condominiums



(b) Transformer 2: supplies 16 single-family dwellings




The hourly load profiles for the days in question were then grouped into the following two categories for further analysis:

- on-peak hours (between 7 a.m. and 7 p.m.)
- off-peak hours (between 7 p.m. and 7 a.m.)

The remainder of the investigation of key variables looks at the effects of different EV on-board charger capacities on the electricity distribution system at on- and off-peak times during the summer peak from the previous year (i.e., July 14 to 20, 2013).

### *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 conductors to meet the demand for power. The following scenarios explore the impact on the transformer resulting from the number of EVs charging.

### EV Penetration for a Single Transformer

The first scenario tested the capacity of a single transformer (Transformer 1) to accommodate vehicles with an on-board charger rated at 3.3 kW. The EV penetration rate was calculated by first determining the spare capacity of the transformer over a 24-hour period (from July 14 at 7 a.m. to July 15 at 6 a.m.). Spare capacity is a measure of the difference between the transformer's rated capacity (i.e., 50 kVA) and its overall load. The transformer's spare capacity was then divided by the rated capacity of the vehicle's on-board charger (i.e., 3.3 kW) to determine the total number of EVs that could be accommodated without exceeding the rated capacity of the transformer.

Figure 26 shows that the number of EVs with a 3.3 kW charger that Transformer 1 can accommodate varies significantly based on the time of charge. Figure 27 shows the average number of EVs that can charge simultaneously during on- and off-peak hours. Given the greater demand for power during on-peak hours, it follows that fewer EVs can charge simultaneously during this period than during off-peak hours without exceeding the rated capacity of the transformer. Despite Transformer 1 representing a best-case scenario, in that the transformer is categorized as lightly loaded, at no point can 100 per cent EV penetration (i.e., assuming one EV per household) with a 3.3 kW charger be accommodated by this transformer on the day in question.

**Figure 26: Number of Electric Vehicles That Could Charge by Hour (3.3 kW On-Board Charger)**

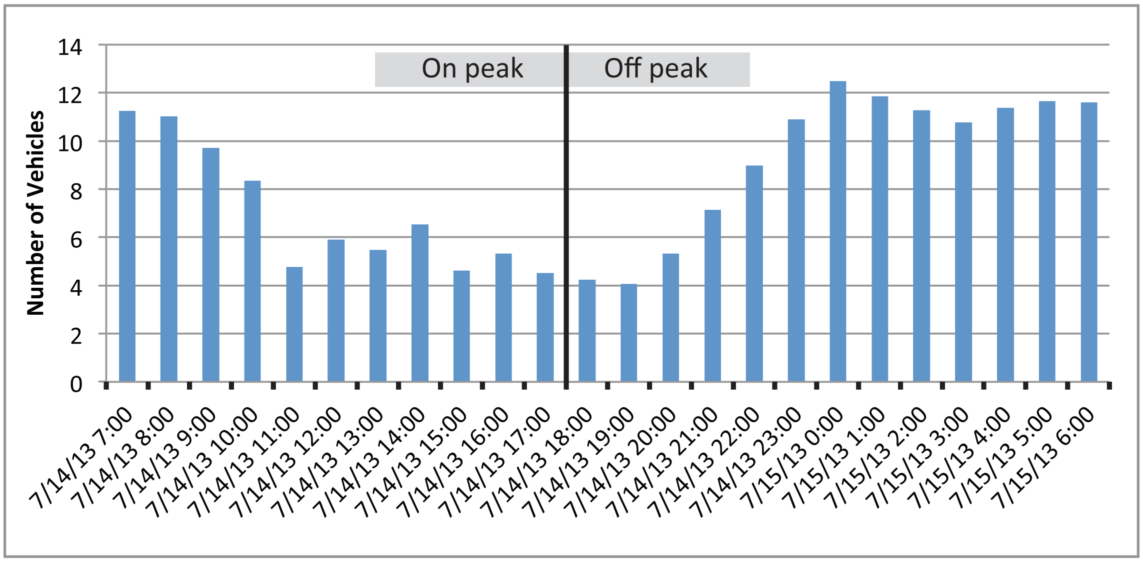
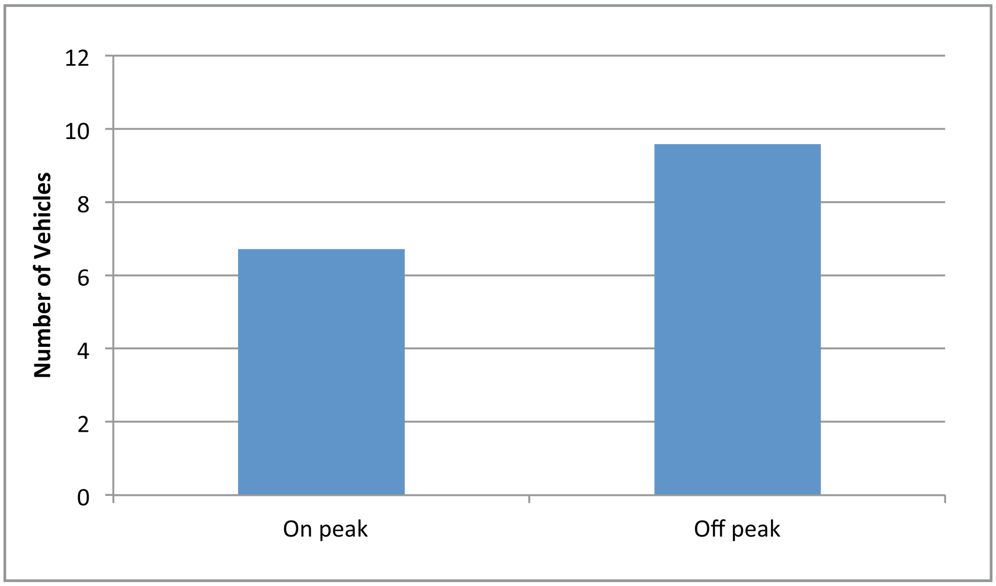


**Figure 27: Average Number of Electric Vehicles That Could Charge On and Off Peak (3.3 kW On-Board Charger)**

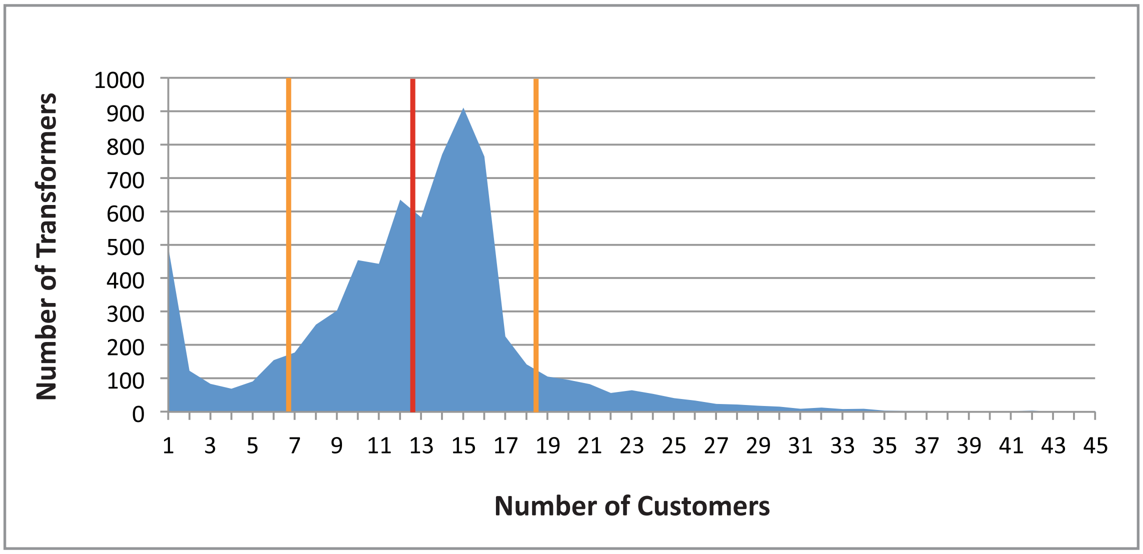



**EV Penetration across the Service Area**

This scenario investigated the average EV penetration rate for pole- and pad-mounted transformers across the London Hydro service area. Before specific scenarios were considered, the number of customers whose power is supplied by each transformer in the service area was determined, based on metering data from London Hydro. Figure 28 shows the distribution of customers served by each neighbourhood-level transformer within the London Hydro service area. An overwhelming majority of transformers provide power to between 6 and 18 customers. The average number of customers on a single transformer is 12 while the most common number is 15.

Around 500 of the total number of transformers investigated within the service area provide power to only one customer. The majority of these customers are either farms located in the rural areas surrounding the city or small commercial services. Because the load profiles for these customers do not align with a typical residential load profile or the early adopter neighbourhoods identified as part of the EMAP study, these transformers were excluded from the assessment, leaving 5,682 transformers (77 per cent of the total) to be assessed.

**Figure 28: Number of Customers per Transformer in the London Hydro Service Area**




Note: The transformers investigated are single-phase units because these are the only type of transformer used to supply power for residential loads in the London Hydro service area.

Three scenarios based on the capacity of the vehicle's on-board charger (3.3 kW, 6.6 kW or 20 kW) were investigated to determine the average number of EVs that could be accommodated by transformers across the electricity distribution system. Each of the 5,682 transformers was assigned to one of the three previously described categories (lightly loaded, moderately loaded or overloaded; see page 47), based on the percentage of its rated capacity at which it was loaded during the summer peak. These scenarios investigated all transformer capacities found within the London Hydro service area (10 kVA, 25 kVA, 37 kVA, 50 kVA, 75 kVA, 100 kVA and 167 kVA).

To evaluate the average number of EVs that could be accommodated by each transformer without exceeding its rated capacity, the average spare capacity for each of the 5,682 transformers was first determined for both on- and off-peak hours. The average spare capacity of each transformer for these time periods was then divided by the capacity of the EV on-board charger (3.3 kW, 6.6 kW or 20kW) to determine the total number of vehicles that could be accommodated on and off peak. These numbers were averaged across each loading category (i.e., less than 0.5, between 0.5 and 1.0, and greater than 1.0) to determine the total number of EVs that could charge on average without exceeding the transformer's rated capacity. The EV penetration rate was then calculated as a percentage by taking the average number of EVs that could charge for each transformer and dividing it by the number of customers provided with power by that transformer. For example, if the transformer could accommodate 5 EVs and provides power to 10 customers, the EV penetration percentage would be 50 per cent, or 1 EV for every 2 households. As a final step, the EV penetration percentage for each of the transformer loading categories was averaged to determine an overall EV penetration rate for each vehicle on-board charger size.

Table 2 shows the degree to which the capacity of the vehicle's on-board charger is a key factor in determining the EV penetration rate. For example, the EV penetration rate for vehicles with an on-board charger rated at 20 kW is much lower than for those rated at 3.3 kW during both on- and off-peak hours. The greater the transformer load before EV charging, the fewer EVs that can be accommodated without exceeding the transformer's rated capacity. In addition, fewer vehicles can be accommodated on peak, when the demand for power is greater, than off peak. It should be noted that the number of vehicles is an average and incorporates all transformer rated capacities across the service area, ranging from 10 kVA to 167 kVA. For example, while 16 EVs with a 3.3 kW charger may easily be accommodated by a transformer rated at 75 kVA or greater, depending on its spare capacity, the same number of vehicles on a 25 kVA transformer would cause overloading. As such, the size and spare capacity of each transformer must both be taken into consideration to determine the effects of EV charging on the electricity distribution system.

**Table 2: EV Penetration across the London Hydro Service Area**

| | Loading factor | Tx count | On-peak penetration rate, % | Off-peak penetration rate, % | Average, % |
|---|---|---|---|---|---|
| **Scenario 1** | Tx < 0.5 | 1660 | 51.6 | 54.0 | |
| **(3.3 kW)** | 0.5 ≤ Tx < 1 | 3575 | 25.5 | 30.2 | **32.4** |
| | Tx ≥ 1 | 447 | 9.0 | 15.2 | |
| **Scenario 2** | Tx < 0.5 | 1660 | 25.8 | 27.0 | |
| **(6.6 kW)** | 0.5 ≤ Tx < 1 | 3575 | 12.8 | 15.1 | **16.2** |
| | Tx ≥ 1 | 447 | 4.5 | 7.6 | |
| **Scenario 3** | Tx < 0.5 | 1660 | 8.5 | 8.9 | |
| **(20 kW)** | 0.5 ≤ Tx < 1 | 3575 | 4.2 | 5.0 | **5.3** |
| | Tx ≥ 1 | 447 | 1.5 | 2.5 | |

Tx = transformer

## Effects of Electric Vehicle Charging on the Secondary Connection System

The capacity of the secondary cables to accommodate EV charging without overloading varies based on the current capacity and characteristics of the conductors. In the London Hydro service area, these factors are primarily a function of when the secondary cables were installed, with a variety of different constructions, sizes and arrangements found throughout the city.

The secondary drop lead, secondary bus and service cable type with the least current capacity in an overhead system within the service area were investigated because they would represent the worst-case scenario in relation to the effects of EV charging on the secondary connection system. See Figure 29 for a representation of a typical overhead secondary connection system.

**Figure 29: Secondary Connection System for a Pole-Mounted Transformer**

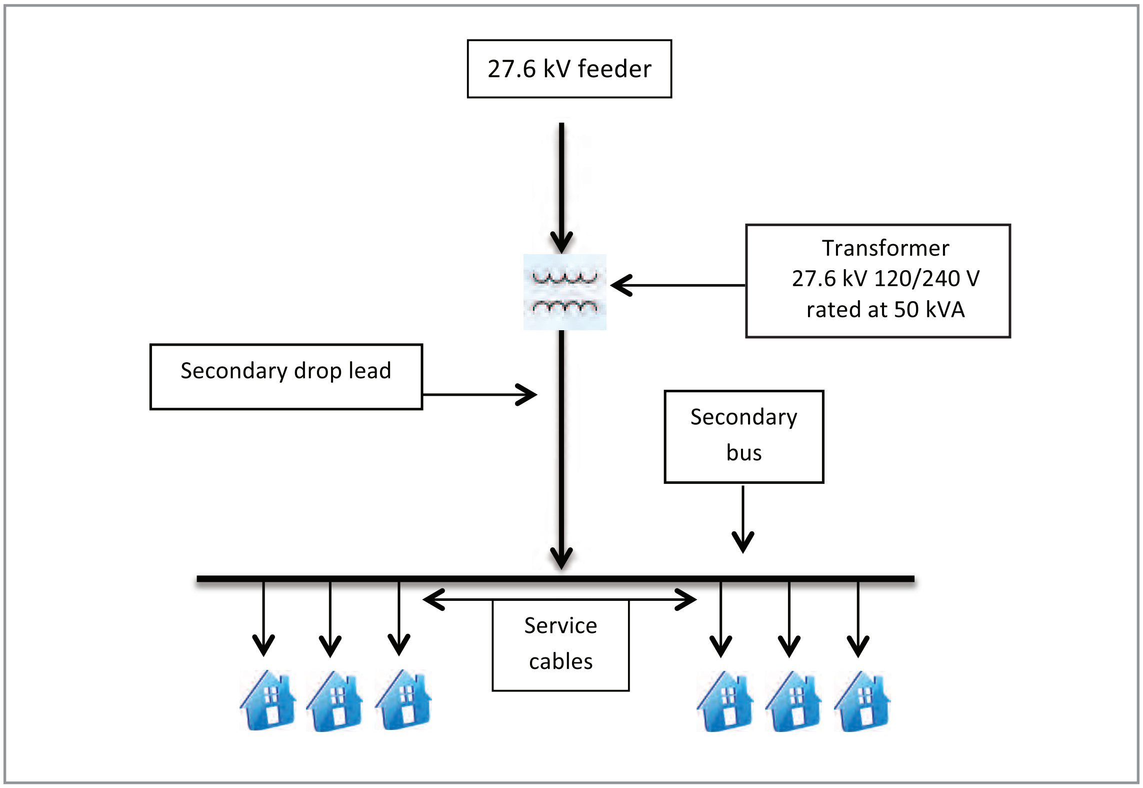



Table 3 shows the results of the assessment of a secondary connection system assumed to be supplying power to a total of 15 customers, with an average household load of 3 kW. The table shows that the secondary drop lead could accommodate 7 EVs with an on-board charger rated at 3.3 kW. However, just two EVs with the same capacity charger could be accommodated without overloading the secondary bus. The individual service cables running from the secondary bus to each household could accommodate only one EV charging with a 3.3 kW charger.

The number of EVs that can charge simultaneously drops dramatically for vehicles with a 20 kW on-board charger, with just two causing overload of the secondary drop lead. The secondary bus and the service cables would be unable to accommodate any EVs with a 20 kW charger without overloading. These findings point to the secondary bus as the limiting factor for each charger size. In other words, for each charger size, of the components of the secondary connection system (secondary drop lead, secondary bus or service cable), it is the secondary bus where overloading would come into play first as a constraint. These results can be used to help to identify potential problems related to the impact of EVs on the secondary connection system.

**Table 3: Capacity of Overhead Secondary Connection System Components to Accommodate Electric Vehicle Charging**

| Secondary connection system component | Conductor size | Rated capacity, A | Number of homes supplied (3 kW average load per household | Number of EVs (Penetration, %) EV charger capacity 3.3 kW | 6.6 kW | 20 kW |
|---|---|---|---|---|---|---|
| Secondary drop lead | No. 1/0 AWG stranded copper | 285 | 15 | 7 (47%) | 3 (20%) | 1 (7%) |
| Secondary bus | No. 2 AWG stranded copper | 215 | 15 | 2 (13%) | 1 (7%) | 0 – |
| Service cables | No. 4 AWG stranded aluminum, triplex | 100 | 1 | 1 (100%) | 1 (100%) | 0 – |

## 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 wear out before other components. The temperature of the transformer insulating materials – more specifically, the hottest location within the transformer components (typically within its windings), known as the internal hot spot – impacts the rate at which the insulation materials deteriorate. The temperature of the hot spot depends on factors such as ambient temperature and the load on the transformer. The transformer's insulation materials deteriorate more rapidly the hotter the internal hot spot 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 greatly affect the lifespan of transformer insulation. Moreover, if EV charging occurs at night, it would cut into the transformer's cooling cycle (reduced loads during off-peak hours and lower ambient temperatures at night typically allow a transformer's insulation temperature to decrease). For these reasons, it is important to better understand the extent to which EV charging could impact the life expectancy of a transformer.

The manufacturer of London Hydro's pad-mounted transformers conducted an assessment of the possible effects of EV charging on transformer aging, using a method outlined in IEEE C57.91-2011, *Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators*. A 120/240 V, single-phase, pad-mounted transformer with a 50 kVA rated capacity, the most frequently used transformer type within the London Hydro service area, was investigated, using design constants established by the manufacturer as inputs to the model.

The following four scenarios were investigated, based on a typical 24-hour transformer load profile:

1. **Transformer operating at rated capacity and ambient temperature of 30 °C.**
2. **Transformer operating at rated capacity and ambient temperatures of 20 °C, 25 °C and 30 °C:** For this scenario, ambient temperatures of 20 °C , 25 °C and 30 °C were assigned, with warmer temperatures assigned to daytime hours and slightly cooler temperatures at night, consistent with typical daytime and nighttime temperature fluctuations during the summer peak. The transformer was assumed to be operating at rated capacity (i.e., 1.0) over the 24-hour period.

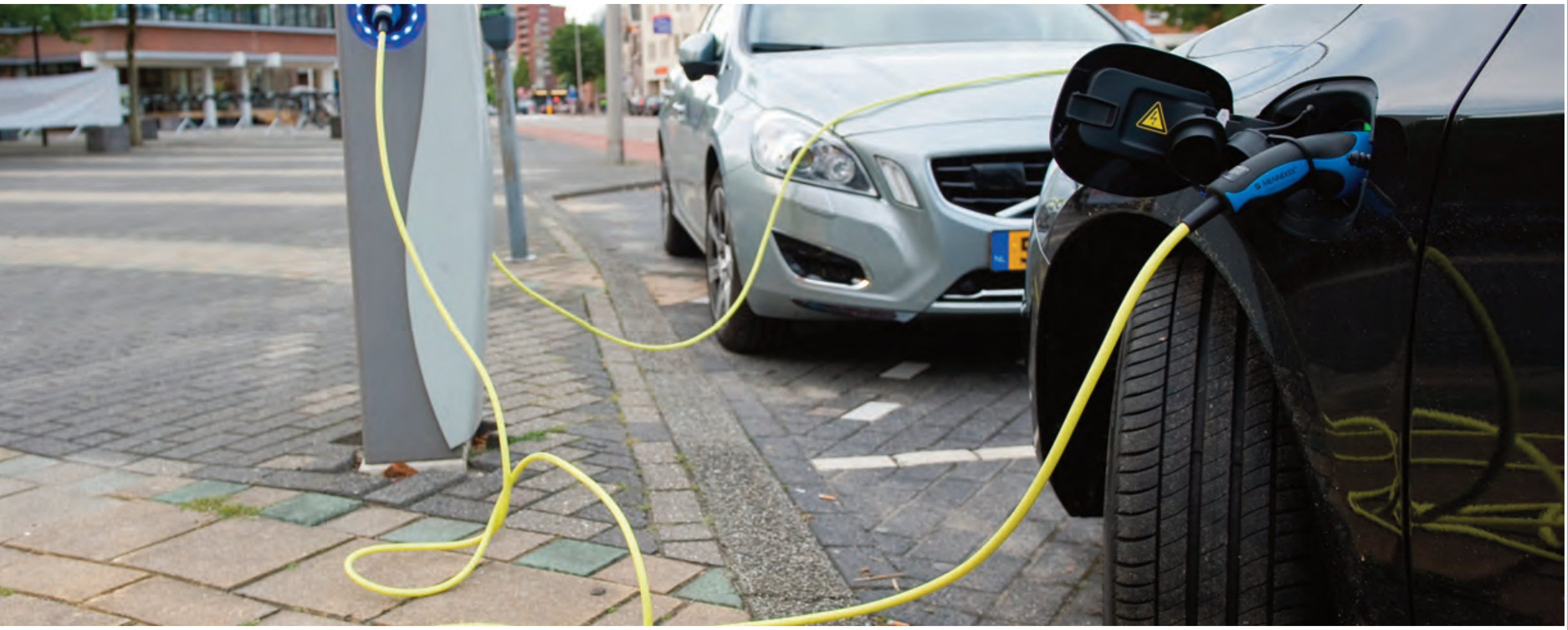
3. **Transformer operating at half or full rated capacity and ambient temperatures of 20 °C, 25 °C and 30 °C:** This scenario investigated the effects of transformer aging with the transformer loaded at half its rated capacity (i.e., 0.5) during off-peak periods (i.e., between 7 p.m. and 7 a.m.) and loaded at rated capacity (i.e., 1.0) during on-peak periods (i.e., between 7 a.m. and 7 p.m.), while ambient temperatures of 20 °C, 25 °C and 30 °C were assigned, consistent with typical temperature patterns (i.e., lower ambient temperatures at night and higher temperatures during the day).

4. **Transformer operating at half rated capacity, at rated capacity or overloaded and ambient temperatures of 20 °C, 25 °C and 30 °C:** The final scenario investigated a combination of loading at half the transformer's rated capacity (i.e., 0.5), at rated capacity (i.e., 1.0) and overloaded (i.e., 1.1 or 1.2). This scenario was designed to represent the best-case scenario for EV charging, i.e., where drivers would plug in their vehicles overnight when the demand for power is typically lowest. It was assumed that this EV load would overload the transformer at night when temperatures are lower (i.e., during the transformer's cooling cycle); the transformer was assumed to be loaded at either half the rated capacity or at rated capacity during the day when temperatures tend to be higher.

For each of the four scenarios, the effect in years on the lifespan of the transformer's insulation of the conditions described was determined. These findings show that ambient temperature and the load the transformer is carrying could greatly affect the life of its insulation material.

**Table 4: Transformer Insulation Life in Years**

| Transformer loading | 1.0 | 1.0 | 0.5 or 1.0 | 0.5, 1.0, 1.1 or 1.2 |
|---|---|---|---|---|
| Ambient temperature over the 24-hour period | 30 °C | 20 °C, 25 °C and 30 °C | 20 °C, 25 °C and 30 °C | 20 °C, 25 °C and 30 °C |
| Calculated insulation life in years | 55.13 | 90.48 | 262.21 | 103.73 |



# Summary

The assessment of the electricity distribution system points to some of the key factors that could affect its capacity to accommodate anticipated EV-related loads at the neighbourhood level. 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 impact the system. As such, it will be important to consider these factors in planning and asset management. Technological advances in EV development, such as more powerful on-board chargers and larger overall battery size, must also be factored into planning.

The results of the electricity distribution system 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 could occur. These risks can be mitigated through continued monitoring, using information systems already in place at London Hydro (e.g., geographic information systems, smart meters) to avoid ineffective investments in new neighbourhood-level infrastructure, including transformers and secondary cables.

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