Oxford County Feasibility Study:

EVSE Data Mapping & Analysis in Support of Oxford County's Electric Vehicle Accessibility Plan (EVAP)

Final Report subject to one revision upon Oxford County request

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Executive Summary

Oxford County aims to achieve ubiquitous accessibility for electric vehicle (EV) charging within all communities via the County's Electric Vehicle Accessibility Plan (EVAP). To achieve this target, the County partnered with CUTRIC to conduct a study to map strategic locations for electric vehicle supply equipment (EVSEs) installation across the region.

First, the report provides a review of criteria that have determined EVSE infrastructure location selections in other jurisdictions. The report reviews the case studies of Tompkins County, San Joaquin Valley, and Uppsala to provide insight into the processes other jurisdictions have undertaken when determining EV charging station placement.

Secondly, the report uses original methodological insights to determine potentially optimal EVSE locations for Oxford County residents, commuters and through-traffic based on descriptive methods using Voronoi polygons, grid partitions, and household activity data, as well as predictive assessments based on a linear model of EV adoption rates assuming 1%, 5%, 10% and 25% adoption of EVs among car owners in and around the Oxford community.

Based on descriptive assessments using GIS-based models, the report concludes that Level 1 and Level 2 chargers should be placed in popular parking locations to serve Oxford residents best, including shopping malls, public parking lots, restaurants, service locations, and hospitals. These locations fill gaps currently demonstrated in the charging network within the Oxford County. The report also concludes Level 2 and Level 3 EV charging stations are best suited to transitory and through-way traffic commuters along highways in and around Oxford, and should be installed near busy highway exits that would be suitable for throughway traffic where demand is demonstrated by existing traffic flows.

Based on predictive assessments using linear models of adoption rates, the report concludes that a total of 163 Level 1, 54 Level 2 and 12 Level 3 chargers will need to be placed in suitable parking locations (i.e., employment workplace parking lots, public parking lots near workplaces, and long-stay public parking spots, such as shopping malls) to serve Oxford residents who adopt EVs in the future and who may or may not have access to home charging units throughout the evening and nighttime for recharging purposes.

In addition, the County intends to continue supporting its tourism industry within rural areas by ensuring adequate EV charging availability for travel to, from, and within the County. This report concludes that charging stations will need to be strategically placed nearby tourism destinations and/or outdoor recreation areas to allow for EV charging while tourists explore the area.

More detailed and granular data analysis on a community-by-community basis could be performed to support Oxford's electrification strategy; however, several data sources cannot be accessed today based on access restrictions imposed by Tesla Motors and the Ontario Ministry of Transportation (MTO) with relation to Tesla-funded and MTO-funded EVSEs and usage profiles in the community. Data utilized in this study have, therefore, been accessed via public sources or provided through the facilitated support of Oxford County directly.

Guiding variables utilized to support the predictive and descriptive assessment portion of this study are heavily based on prominent studies performed in the U.S. Department of Energy's two plug-in electric vehicle infrastructure studies and demonstrations: The EV Project and the ChargePoint America Project. Specifically, descriptive analysis here is influenced by three categories of variables, including optimal location variables, installation costs variables, and EV driver charging patterns needs. Three key variables have also shaped specific siting choices in this report, namely long-term parking opportunities (Level 1 & 2), special applications for Level 2, and highway intersectionality (Level 3).

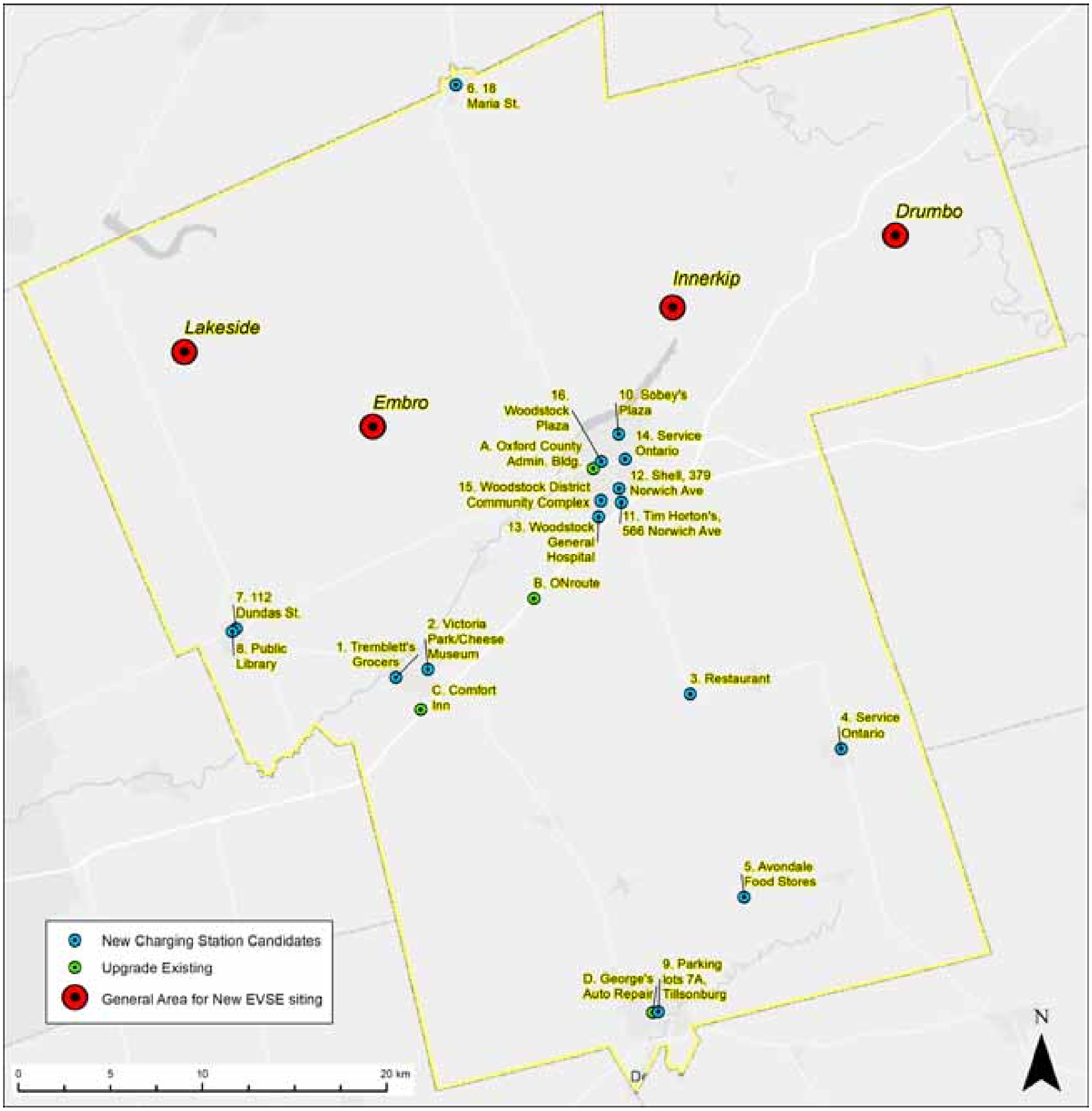
Guiding variables utilized to support the predictive assessment portion of this study include empirical outputs and performance (i.e., range capability) associated with two exemplar vehicle types: (1) Nissan Leaf 2017 and (2) Chevy Bolt 2017. These vehicle models were selected to guide the predictive assessments based on linear adoption rates of EVs in Oxford County due to their “affordability” as vehicles with a starting ticket price in the $30,000-$45,000 CAD, the availability of maximum Ontario government rebates for these model types which reduce their upfront costs to mid-$20,000-mid-$30,000 CAD in Ontario, and their significantly differing driving ranges as a comparative (experimental) variable that generates differing charging system needs within Oxford. In this section of the report, CUTRIC has adopted a “Best Case - Worst Case” scenario assessment, in which the total number of chargers required at a given location or within a given area to **fully satisfy charging needs** is based on the range capabilities of the vehicle, the drive cycle of the EV driver (as a commuter or otherwise), and the minimum required charger to “return to home base” for overnight charging. These assumptions generated a set of predictive “EV owner profiles” or typologies, labelled Types A to Type D, which demonstrate differing charging needs and therefore differing quantities of chargers within Oxford to satisfy all potential EV driver needs in the future.

The results of these predictive analyses demonstrate that Oxford County could address a large portion of commuter EVSE needs through the installation of workplace Level 1 chargers, which also constitutes the cheapest EVSE installation option for private and public sector workplace hosts, along with strategically placed Level 2 chargers in parking lots around the community which serve commuter parking purposes specifically. Meanwhile, out-of-town commuter traffic and tourist traffic will require a combination of Level 2 and Level 3 clusters of chargers.

In a final section of this report, ArcGIS software was used to **map the results from both the predictive and descriptive analyses** to determine optimal EVSE locations in both publicly- and privately-held parking locations. Because of the contrasting geographic controls on location of low-powered (Level 1) and high-powered (Level 2 and Level 3) EVSE, two distinct GIS approaches were adopted. Voronoi polygons were used to optimally locate high-powered EVSEs in relation to distribution of existing EVSEs. Also, a cluster of work places in close proximity with publicly-owned property were used to locate low-powered EVSEs.

Based on these analyses, CUTRIC has prioritized four charging station locations as “in need of upgrading” to address immediate EV charging needs in the community: (1) The Oxford County Administration Building, (2) The ONRoute charger at Ingersoll Travel Plaza, (3) The Ingersoll Comfort Inn, and (4) The charger at George’s Auto Repair at 10 Bridge St., Tillsonburg. However, for the latter location, there is also the alternative option of installing new EVSEs at nearby municipal parking lots 6A and 7A in Tillsonburg.

In addition, CUTRIC has recommended specific and general locations for new EVSE installation locations to accommodate predicted EVSE demand growth based on 1%-25% adoption rate assumptions, as shown in the map below. The report concludes with a descriptive overview of potential EVSE locations as judged using key variables for optimal EVSE locations (derived from literature sources mentioned above).



Reproduction of Figure 4, see Table 9 for site descriptions.

Given that over 90 per cent of EV charging occurs at home for EV owners with home garages (The Economist, 2017), it is sensible to target future low-cost EVSE installations at workplaces so that residents can use workplaces in lieu of home charging if and when no garage option exists (e.g., condominium or apartment dwellers, or home basement renters) or use workplace charging to maximize the daily range of their vehicles when using a shorter-range vehicle (such as a Nissan Leaf 2017) to achieve multiple personal and family-life duties outside of the workplace and after work hours. Meanwhile, it is sensible to target future high-cost EVSE installations (i.e., Level 2 chargers) in densely populated urban areas where EV drivers may access charging systems for periods of 1 to 4 hours typically. Lastly, it is sensible to target high-usage highway intersections with the highest cost EVSE installations (i.e., Level 3 chargers) where drivers expect sub 20-minute stop overs.

Appendix I includes a techno-economic modeling conducted on the transit system in Woodstock, Ontario, with the aim of emphasizing the benefits of clean propulsion systems. Three different buses were used to model an interlined route 3/route 5 – a Nova Bus (76 kWh) and New Flyer Bus (200 kWh) with 450 kW chargers and a typical diesel bus. Light-, medium-, and heavy-duty cycles were simulated to determine edge cases of cost calculations and emissions. Routes were modelled based on topography and length, including exact locations of stops along a bi-directional route.

A typical diesel bus model based on road load calculations was developed to examine the fuel consumption and carbon dioxide emissions of the current diesel fleet using Advanced Vehicle Simulator (ADVISOR) 2002 and MATLAB. The electric buses were also modelled to determine energy consumption and regenerative breaking capacity using MATLAB and Python. Varying grid-to-battery efficiencies, electricity costs, and CO_2eq for electricity generation were then incorporated into the models where appropriate.

The modeling outcomes showed both environmental and economic benefits for electrifying route 3/route 5 within Woodstock's public transit system. The electric buses showed cost savings of between $57,613 to $88,945 and emissions reductions of between 191.12 CO_2eq to 372.28 CO_2eq. It is therefore recommended that Woodstock transit electrify their fleet due to impactful cost savings and environmental benefits.

Appendix II documents a short literature review describing possible variables determining installation of a hydrogen fuelling stations, reviewing the likelihood of H2 fuelling usage within a given community, and defining optimal locational variables to consider in such an installation.

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Introduction

Oxford County aims to become a fully accessible electric vehicle (EV) community equipped with ubiquitous charging opportunities in the near-term future. This objective will be reached through the deployment of the County's Electric Vehicle Accessibility Plan (EVAP).

To successfully achieve the County's EVAP goals, it is necessary to map, analyze and strategically locate electric vehicle supply equipment (EVSEs) going forward. The installation of these systems – if properly done – could encourage the uptake of EVs in and across Oxford County in the future. It could also support new incoming traffic based on the charging needs among long-distance commuters travelling along nearby highway routes.

In general, the EVAP aims to promote the practicality and acceptability of EVs as a mainstream mode of personal transportation to, from, and within Oxford County, which requires an informed and strategic EVSE plan. Oxford County partnered with CUTRIC to assist in this planning process.

Oxford County recognizes the environmental implications of continued fossil fuel use and the growing impacts of climate change. The County is therefore developing a 100 per cent Renewable Energy Action Plan intended to:

(1) Catalyze environmental changes in Oxford;

(2) Create opportunities for renewable energy investment in Oxford; and,

(3) Position Oxford as a renewable energy center of excellence and home for renewable energy education, research and development.

Oxford County has begun to address the challenges of energy sustainability through critical first steps in energy conservation and demand management, as well as demonstrated community leadership in the advancement of renewable energy technologies and their applications. This zero emissions electricity generation and distribution system renders the County an ideal energy/electrical "fuel" landscape for the electrification of transportation (including transit) vehicles, as part of a long-term strategy to reduce transportation-related GHG emissions.

Currently, 48 charging stations including 12 Tesla Superchargers, four Level 3 chargers, 23 Level 2 chargers, four home-share Level 2 chargers, and five Level 1 chargers are located across 22 locations within Oxford County. These charging systems encompass a range of manufacturing makes and models. They have been purchased and installed by a variety of private sector interests (e.g., hotel owners, utility owners, etc.). In some cases, the stations installed have been purchased with support from the Province of Ontario via its Electric Vehicle Charging Ontario (EVCO) 1.0 program, which launched in 2016.

The installation of EVSEs across Oxford has resulted, therefore, in an ad hoc distribution of assets. No significant predictive analysis occurred before the purchase and/or installation of these system to determine the best possible locations for EVSEs based on EV-owner usage requirements. Subsequently, little analysis of actual usage rates has been completed, which would help to inform future policies vis-à-vis the optimal location of chargers in the future across the community.

The current feasibility study aims to address persistent data gaps. In doing so, the second aim of the study is to support the County in its efforts to encourage private sector investment into EVCO 2.0 – a provincial funding program expected to launch in the Fall of 2017/Winter 2018 with deployments likely to occur throughout 2018.

Third, the Study is intended to help increase the overall number of available EVSEs across Oxford County in the near-term and to render Oxford a provincial champion of EVs, by making it a known “charging hub” for local and out-of-County residents and transitory drivers. The current feasibility study will assess current EVSE locations and usage rates, and predictively assess future optimal locations of for EVSEs based on empirically evidenced EVSE usage in the County and in comparative communities.

Fourth, the Study assesses the viability of electric transit options in the community of Woodstock, which is currently among the communities with a traditional transit fleet (Appendix I). The Future Oxford Community Sustainability Plan states that electrification of transit vehicles is considered a part of the County’s long-term strategy to reduce transportation-related greenhouse gas (GHG) emissions.

Finally, the Study also reviews hydrogen fuel cell vehicle pilot projects active in North America. The purpose is (1) to explore the development, launch and commercial outcomes associated with H2 fuel cell pilots; and (2) to assess the likelihood of H2 fuelling usage and optimal locational variables to consider in such an installation (Appendix II).

Definitions

Electric vehicle supply equipment (EVSEs) is an intermediary between a power source and the vehicle’s charging port. Its role is to simply transfer the electric power to the vehicle safely (FleetCarma, 2017).

Level 1 EVSE

Level 1 equipment provides charging through a 120 Volt (V), alternating-current (AC) plug. Level 1 is the slowest form of charging that uses a standard household outlet. Level 1 charging equipment is standard for different vehicle, which is portable and does not require the installation of charging equipment.

Depending on the battery technology used in the vehicle, Level 1 charging equipment generally takes 8 to 12 hours to completely charge a fully depleted battery. The most common place to use a Level 1 EVSE is at the vehicle owner's home, which charging could be conducted overnight (EVTown, 2017).

Level 2 EVSE

Level 2 equipment provides charging through a 240V, AC plug and requires installation of home charging or public charging equipment. Level 2 charging equipment is compatible with all electric vehicles and plug-in electric hybrid vehicles.

Depending on the battery technology used in the vehicle, Level 2 charging equipment generally takes 4 to 6 hours to completely charge a fully depleted battery. Charging time can increase in cold temperatures. Level 2 EVSEs are commonly used in residential settings, public parking areas, places of employment and commercial settings (EVTown, 2017).

Level 3 EVSE

Level 3 equipment is often called *DC Fast Charger* that uses a 480V, direct-current (DC) plug. In this case, the charger is a gas pump-sized machine. Most Level 3 EVSEs provide an 80% charge in 30 to 45 minutes. Cold weather can lengthen the time required to charge (EVTown, 2017).

This type of Level 3 equipment is not compatible with all vehicles; only fully electric cars have access to it. There are three standards for Level 3 EVSEs (Plug ‘N Drive[1], 2017):

- **CHAdeMO** is an Asian standard used by Hyundai, Nissan, Kia and Mitsubishi.

- **SAE Combo** is a European/North American standard used by BMW, Chevrolet, Ford and Volkswagen.
- **Supercharger** is a Tesla-only standard. All Tesla vehicles can be purchased with adapters for the other two.

Section 1:Literature Review

Vehicle owners have historically relied on long ranges due to the high energy density associated with petroleum fuels in gasoline and diesel vehicles. The low-cost of carbon-based fuels (especially in jurisdictions that do not price carbon) combined with more than a century of development and now ubiquitous fueling/gas station networks across the developed world has ensured drivers can travel far distances with relatively little planning required to ensuring fuel availability (Delmas *et al.*, 2016; Langer *et al.*, 2017).

The rise of electric vehicles (EVs) – due to a combination of U.S. Corporate Average Fuel Economy Standards (CAFÉ) and European Fuel Standards over the past 15 years, combined with nascent carbon pricing regimes and gasoline/diesel punitive measures intended to reduce emissions from greenhouse gases (GHGs) in the transportation sectors in North America, Europe and Asia today – has resulted in a budding need for new "fueling", i.e., "charging", infrastructure.

Municipal, regional and federal governments are therefore struggling against the private market pull of ongoing gasoline and diesel car demand (which protects the status quo in petroleum fueling infrastructure) with public pressures to reduce emissions by encouraging fuel switching and EV adoption whereby EVs are charged from renewable power sources (e.g., hydro, wind and solar power, among other renewables) overtime.

This tug-of-war between the status quo and a necessary low-carbon future of transportation has produced demands for electric vehicle supply equipment (EVSE) – or "charging station" – optimization analyses that assess where, when and to what extent governments and private sector entities should be investing in or be forced to invest in charging system infrastructure to enable EV adoption for both light-duty vehicles (e.g., passenger cars and light trucks) and heavy-duty vehicles (e.g., heavy-duty trucks, buses, shuttles, and coaches).

The financial investments associated with these choices are enormous. Thus, a paradigm shift in transportation and mobility thinking towards a low-carbon future requires the most optimal, strategic and efficient investments into EVSEs as possible. This is a complex process given the current lack of general EV adoption today (EVs still represent less than 1% of all new vehicle purchases in North America, including Canada, today), which means there is precious little descriptive and empirical data demonstrating how human drivers behave when the range of vehicles is limited by the lesser energy density associated with relatively expensive battery technologies compared to relatively cheap petroleum fuels in propulsion applications.

Prospective EV adopters will need to perceive EV technologies as suitable to existing or desired lifestyles, while private sector stakeholders will require a reasonable return-on-investment (ROI) for upfront investments into new vehicle fueling technologies as a push out market shift strategy.

To encourage the uptake of EVs and their market economic viability, visibility and access to essential charging infrastructure has been cited as a critical factor to consider from a public policy and private investment perspective (Sierzchula *et al.*, 2014). Yet, many programs – including Ontario's own first round of "Electric Vehicle Charging funding, has proceeded with mostly ad hoc installations of EVSEs leading to the concern that trivial or non-optimal implementations of the technology can hinder EV adoption rather than support it by negatively influencing public perception towards the value of EVSE investments and EVs in general.

Often left unacknowledged or underappreciated in this dialogue (including in Canada today) is the significant difference between EV driver and conventional gasoline or diesel vehicle driver fueling/behavioral patterns. As documented and assumed in this report, a majority of households in Canada with EVs as primary or secondary vehicles will support home-charging at a Level 1 and/or Level 2 capacity (Axsen & Kurani, 2012). With recent legislation passed in British Columbia (2014) and proposed in Ontario (2017) that mandates condominium developers install EVSE capabilities in condo buildings, this likelihood is expanding to include condo dwellers as well as detached or semi-detached home owners (Government of Ontario, 2017; Plug in BC, 2014).

Therefore, the placement of gasoline or diesel fueling stations today does not constitute a primary variable to consider or utilized when determining where EVSEs *ought* to be placed for optimal usage in the future (given that most home owners do not own gasoline or diesel fueling stations at home, and therefore engage in differing fuelling behaviours compared to EV drivers).

In addition, given that the time necessary for an EV to acquire a full battery charge is significantly longer than the time it requires to fuel a petroleum-based conventional car that relies on an internal combustion engine (ICE) (time-to-charge ranging from 20 minutes with a Level 3 charger to more than 48 hours with a Level 1 charger, depending on battery size and onboard charging capabilities (i.e., the vehicle's on-board AC/DC converter), as well as the specifications of the off board circuit delivering power to the charging station, charging station networks will need to be designed in alignment with long-term stop-over strategies for many EV drivers, rather than solely the quick-stop strategy associated with the design of contemporary gasoline and diesel fueling station networks.

These substantial differences in fueling strategies and EV driver behaviors need to be considered in future decision-making (public and private sector) to ensure the effectiveness of location prediction tools to justify the initial costs of infrastructure (including installation).

The placement of a charging station is worth deep strategic consideration. Jurisdictions invested in the uptake of EVs in the market should concern themselves with placement of the stations in locations that will result in the greatest most efficient (i.e., optimal) usage. Other areas of relevant inquiry include determining the number of charging stations that should be present to achieve supplemental social goals (such as accessibility, as opposed to optimization of usage solely), as well as necessary power requirements (minimal or desired) that impact grid-side investments required, and open or closed communications standards that digitally network or isolate charging station visibility, management and accessibility by drivers (Brooker & Qin, 2015).

Charging profiles for visitors to fast food establishments, for example, might merit higher-cost Level 3 EVSE installations, as opposed to the overnight charging profiles describing the patterns of charging behavior for visitors to hotels – the latter of which might merit lower-cost Level 2 or Level 1 installations. Some establishments might also merit two differing charging strategies – hospitals, for example, might be well-suited to explore higher cost Level 2 chargers for visitors, but lower-cost Level 1 installations for employees (such as nurses and doctors) whose "stay" period might range from 8 to 24 hours. In sum, private or public institutions and organizations that are planning to install EVSEs are best guided to consider the visitation profile, and therefore the charging profile, of EV drivers who visit respective establishments to determine the optimal level of charging required and associated costs for installation and maintenance overtime to optimize user experiences and satisfaction.

Variables that optimize EVSE locational choices: A global review of variables identified as critical in the assessment of EVSE siting locations

One indicator to evaluate EVSE placement is “EV adoption behaviour” which refers to the process in which a jurisdiction may target areas with known higher rates of EV uptake to drive the clustering or initial installation choices for EVSEs. This methodology is based on sociodemographic characteristics associated with “early adopter” EV owner profiles. These characteristics have typically demonstrated that EV owners as “early adopters” are predominantly male, highly educated, and high income earners (ethnic or racial information is not typically available). Problematically, therefore, an EVSE deployment strategy that focuses solely or primarily on the areas within which “early adopters” reside or charge their vehicles will tend to favour privileged sectors of the highly educated male population rather than society at large.

In addition, “early adopter” characteristics may not relate in any causal or systematic fashion to the characteristics defining “average adopters” or typical car drivers in the future – i.e., generalized characteristics defining the overall car driving population. In brief, due to the immense knowledge gaps and informational voids that currently hinder EV adoption predictions globally (i.e., knowledge gaps related to which variables drive forward adoption at the greatest rate, such as carbon prices, road pricing, punitive gasoline taxes, or EV incentives, etc.), analysts and public policy makers are hindered in their ability to accurately assess the state of the EVSE market based on early adoption characteristics primarily. The expansion of consideration to include other key variables extracted from public and private data sources related to mobility patterns and mobility needs, in general, may enable more informed evidence-based EVSE siting choices, therefore.

Useful transportation data sets that document mobility patterns can be assessed alongside EV sales data to inform and shape potential EVSE infrastructure placement choices. Such a holistic and comprehensive methodology would integrate considerations of sociodemographic data that predict the likelihood of EV adoption in given communities (given employment and household income) alongside driving and mobility variables for households (such as the number of commuters in a household, and the number of children or family members accessing extra-curricular or personal matters outside of the home). These sociodemographic household details help to clarify the nature of a community’s daily commute patterns, daily driving range requirements, and potential charging access points (e.g., garages at home, at workplaces, or elsewhere). These data may shape the type of electrified vehicle (i.e., hybrid, plug-in hybrid, or fully battery electric) a household is likely to adopt given charging network options locally in the near-term, mid-term and long-term future. Collecting this type of robust socio-demographic data for Oxford County would require a comprehensive household survey of car owners and potential car owners in the community. Without these data sets currently, CUTRIC has adopted a model that utilitizes general typologies of driver and car owner “types” which span the sociodemographic possibilities for daily and ad hoc drivers into and out of Oxford County.

Several of the assumptions made in the predictive model utilized in this report build upon empirical variables identified in the assessment of EV drivers or potential drivers in other communities globally. In this section, we will review a series of those studies to clarify the assumptions embedded in Section Three of this report. A limited number of studies have attempted to evaluate criticial EVSE placement variables in a comprehensive manner to optimize or potentially streamline decision-making processes among public and private sector investors (i.e., governments, property and retail owners, etc.). This sub-section details examples of studies that have attempted to identify optimal locations for EVSE placement in communities across North America, Europe and Asia.

Currently, there are several competing schools of thought as to how to best approach the issue of EVSE infrastructure placement within local communities; there are also competing views as to which key variables are the most important in such considerations, and which variables should receive the greatest weighting in the decision-making process. The unifying theme across this varied body of research is that EVSE placement decision making, which considers variables other than “early adopter” variables defining current EV drivers, produce better localized dialogue and a greater likelihood of scaled-up, mass adoption of EVs which extends beyond the privileged class of current EV owners, in general.

Distance considerations in EVSE placement in local communities: Voronoi diagram methodology and outputs

One of the initial infrastructural location studies produced in the field of EVSE placement research was an analysis of Musashino, Japan (in the Greater Tokyo Metropolitan area) (Koyanagi & Yokoyama, 2010). To identify the optimal places for implementing charging stations, researchers implemented a Voronoi diagram methodology, which is a topological technique that demonstrates the equi-distant layout of equipment after taking into account the following factors (ibid.):

1. The actual ability of an EVSE owner to install equipment in existing facilities (i.e., ownership rights, electrical capacity, etc.).
2. The availability of at least two parking lots as a base minimum for EVSE installation.

The purpose of this methodology is to fill gaps in an EVSE network; this methodology assumes that it is best to place EVSEs at equi-distances from one another to the extent possible to ensure drivers have access to EVSEs throughout a community and never find themselves too far away from an EVSE to make longer range driving infeasible.

For the 33 prospective locations that met the initial two criteria identified above, researchers used a weighting methodology to account for public transportation connections, main road intersections and ramps, multi-entrance availability, and the convenience of the facilities from a user or customer perspective. This method for selecting refined or idealized sites resulted in three priority locations, as identified through Voronoi and perspective demand measurements. The locations included a department store mall and two supermarket areas in Musashino for EVSE installations as priorities.

A follow-on study built up the Voronoi model designed for Musashino by integrating deeper considerations of traffic flow intersection nodes to represent existing road traffic patterns (Feng *et al.*, 2012). The study calculated the users’ minimum loss of time on the way to the charging station as a variable driving the optimal placement of a charging station. Similar to other similar studies, the coverage of each partition and the locations of charging stations were adjusted repeatedly to locate optimal sites based on time parameters. A limited number of more contemporary studies have also implemented or repeated references to the methodology developed here to further develop the field of EVSE siting (Brooker & Qin, 2015; Mehar *et al.*, 2015; Shareef *et al.*, 2016; Sheppard *et al.*, 2016). These studies suggest that Oxford County could locate optimal locations for EVSE placement by identifying “gaps” in the EVSE network that are equi-distance from one another, roughly, and which constitute accessibility points based on time parameters (i.e., a 10-minute walking distance limit from major sites of employment to EVSEs, or a maximum 20 minute driving distance from other chargers, etc.).

In the outputs prepared below, CUTRIC has assumed, for example, a walking parameter limit of 150 meters from the site of EVSEs. By imposing this distance limitation, the Voronoi method produces a series of parking lot sites that would be “optimal” from the perspective of enabling drivers to park and walk with relative ease to nearby locations for extended stop overs (e.g., workplaces).

Grid partition considerations in EVSE placement in local communities

A separate type of study has been proposed as a method for locating and sizing EVSEs based on “grid partition” variables. Instead of focusing on a concentrated area or cluster of EVSEs, researchers used a hypothetical scenario that could be broadly applied to any urban environment in which they proposed a partition method that would minimize users’ loss on route to the charging station, while also integrating considerations of traffic density and the charging station’s capacity constraints (Ge *et al.*, 2011). The coverage of each partition and the sites of the charging stations were repeatedly amended to develop a feasible output of the charging station area (ibid.). Similar to the Voronoi area models above, the grid partition approach is a stochastic methodology, which means it integrates a series of randomly selected variables as defining parameter conditions (e.g., distance to EVSE from starting point, availability of EVSE during certain hours, desirability of EVSE due to other social factors such as amenities nearby). This type of methodology has been used to generate exploratory research in differing EV fleet scenarios (Rahman *et al.*, 2016; Wang *et al.*, 2016; Mohsenzadeh *et al.*, 2017). For example, a facility location model for electric taxi charging stations in Seoul, South Korea considered the placement of EVSEs assuming key variables dividing the jurisdiction ought to include itinerary-interception and queue delay; this approach was adopted as an innovative approach suggesting EVSE locations on the basis that an emerging shared mobility economy will alter charging needs among drivers and users of shared EVs (Jung *et al.*, 2014).

In the outputs prepared below, CUTRIC has adopted a stochastic approach in some respective, integrating the random parameter of a 150 metre walking limit for employees as well as a ranking of “rich” versus “poor” amenities nearby to proposed EVSE locations. These paramters have helped to identify “optimal” charging locations across Oxford based on the needs of drivers rather than the driving ranges of cars, or other technical car-related needs.

Household activity data considerations in EVSE placement in local communities

Household activity data have also been used to determine optimal EVSE site location planning in some jurisdictions. A study in Seattle, Washington followed respondents over two consecutive weekdays in which the respondents had to keep a travel diary. Diary documentation collected thereafter resulted in 3,700 traffic analysis zones generated based on people’s actual travel patterns (Chen *et al.*, 2013) (ibid.). Parking locations (by parcel, then aggregated by traffic analysis zones) and durations of parking periods were determined for all trips away from home and for all stops that were at least 15 minutes in duration (as research assumed a 15-minute stop over period as a base minimum justifying a potential EVSE installation in the future). Parking duration information was used to formulate demands for land-use and parking to frame individual trip characteristics (ibid.).

The outcome of this study resulted in a computer-generated map with areas demonstrating the highest “demand” potential for charging stations for the 80 allocated stations across 900 traffic analysis zones within 10 miles of the city’s downtown core (ibid.).

A similar study could be completed in the Oxford County jurisdictions. It would require a survey-based methodology in which residents are asked to keep travel logs and diaries over an extended period of time to generate evidence of mobility, traffic and transportation patterns. Such a study is outside the scope of the present Report, but it is certainly worth considering as a future empirical exercise in the County if officials require additional evidence to justify publicly-funded EVSE installations in the future.

EVSE usage in small communities: Key outcomes to consider in making EVSE placement choices

Electric vehicle uptake in some urban communities (including Toronto) has grown exponentially over the past 36 months. In addition, new makes and models by various automotive manufacturers are being released on a near quarterly basis as of late-2017, which has resulted in more consumer choice in battery technologies, range performance, and vehicle characteristics overall.

The following sub-section provides a few examples of the EVSE deployment in small communities similar to Oxford County. The purpose of this section is to explore the costs associated with chargers and other installation considerations that drive municipal siting criteria.

Tompkins County: An example of installation cost considerations in EVSE siting choices

Tompkins County is located in the state of New York and has a population of approximately 105,000 residents (United States Census Bureau, 2016). Installation costs for an EVSE at different sites around Tompkins County were found to vary from $2,000 to $12,500 USD depending on site-specific characteristics and installation variables (Energetics, 2017).

Charging stations can either be mounted on a concrete base for a free-standing pedestal unit or mounted onto an existing structure for a wall unit. The material the charging station is installed upon will affect cost (e.g., pavement, concrete sidewalk, dirt) based on the ease for which the EVSE conduit can be built. Increased distances between the charging station location and electric box will increase the costs through additional construction requirements. The state of the electrical service or panel must also be assessed and upgraded to support EVSE's where necessary (ibid.).

Tompkins County also installed preventative measures against accidental vehicular damage when installing EVSEs. Existing structures could be utilized, such as curbs, or charging stations could be mounted at an elevated spot on the wall. In some cases, Tompkins County opted to install either a tire stop (costing approximately $350 USD per space) or bollards ($1,000 USD each) in front of the charging station to protect it (ibid.).

Advertisement and signage to users should also be considered when installing EVSEs. Adequate signage is necessary to regulate how charging stations are used, by clearly marking the spot as an EV-only parking spot, advertising who sponsors the station. Businesses could use this to their advantage to attract EV customers to demonstrate sustainability objectives, and to create awareness for non-EV drivers. Signage of this nature was found to add up to an additional $500 to the total station cost (ibid.).

Most commercial charging station models can be networked, which means the station utilizes cellular communications to report and track real-time data from the charging station. Networked stations cost more to purchase due to additional cellular communication modules which allow for the sending and receiving of information. This feature adds $1,000 USD to the installation cost to verify the site has sufficient cellular signal and the activation and verification of proper communication (ibid.).

Following installation, EVSEs require ongoing expenses, which include network fees, electricity, and maintenance. Networking fees cover the required cellular data plan and services to maintain the networking features, and are approximately $300 USD per charging port per year. Additional transaction fees for billing EV drivers are not included in the $300 USD estimation. Ongoing station maintenance costs are unique to each location and usage patterns, but if properly cared for (e.g., coiling the cord, occasionally wiping it clean, and clearing and snow or debris accumulated around the base) only minor repairs should be required costing less than $1,000 USD over the 10-year lifespan of the station (ibid.).

Preliminary monitoring data from installed EVSEs in Tompkins County showed that on average, one charge event dispended about $1.00 USD of electricity to an EV, which equals to approximately 7.7 kWh at an electricity rate of $0.13 USD per kWh. In the state of New York, 700 charging ports are monitored by the New York State Energy Research and Development Authority, and findings conclude there is an average of 2.5 charging events per week per port. This frequency translates into approximately 150 charging events per year, costing each site $150 USD in electricity (ibid.).

The Tompkins County study estimates total costs for the installation of Level 2 charging stations for the first year at different sites with varying characteristics and found costs ranging between $11,250 and $23,400 USD (ibid.). Given the variance in the costs, it becomes evident that optimal EVSE installation is not only dependent upon broader criteria, but is also very dependent upon placement at a given location based on existing infrastructures.

San Joaquin Valley: An example of ad hoc EV driver needs in EVSE siting criteria and considerations

The San Joaquin Valley Air Pollution Control District and the San Joaquin Valley Plug-in Electric Vehicle Coordinating Council (PEVCC) have identified optimal locations for public EVSEs in ten Valley cities based on three different siting categories: fast charging infrastructure, public access charging, and workplace charging (San Joaquin Valley Air Pollution Control District, 2014).

To determine optimal locations for fast charging, sites had to be located within a half-mile of a highway exit, easily accessible, well-lit, offering facilities and shelters for drivers while charging along with a “destination” point. The types of destinations chosen based on those criteria were supermarkets, department stores, shopping malls, restaurants and short-term parking spots at airports. The locations should also be equipped with transformers with a capacity to support fast chargers alongside existing parking availability (ibid.).

Public access charging sites were chosen in urban areas and destinations where drivers could park their vehicle for more than one hour. This assessment included locations that attract out-of-town visitors (e.g., art galleries, zoos, museums and amusement parks) and places where community members often visit (e.g., libraries, universities and parks). After assessing travel survey data, the following places were determined to attract drivers to travel “medium-to-long” distances from their home, and remain parked for at least one hour, which was deemed to be generally sufficient time to charge an EV using a Level 2 charger to complete a return trip home (ibid.). Examples of locations that involve a service or entertainment worthy of an extended (i.e., one hour or more) wait time may include:

- Airport
- Amusement park
- Aquarium
- Art gallery
- Campground
- Hospital
- Library
- Local government office
- Lodging
- Movie theater
- Casino
- Dentist’s office
- Department or big-box store
- Doctor’s office
- Grocery store or supermarket
- Restaurant
- Shopping mall
- Stadium
- Train station
- University

- Museum
- Park
- Zoo

Workplace charging stations were sited by assessing the number of employees within travel analysis zones, where zones with more employees were assumed to contain higher numbers of current or future EV drivers at the workplace (ibid.).

Uppsala: An application of GIS modelling in predicting optimal EVSE siting locations

A thesis study conducted in the City of Uppsala, Sweden, used GIS mapping to determine optimal EVSE locations for three cases: slow charging stations, fast charging stations and charging alongside roads. Slow charging stations were assumed to provide public charging within city regions while cars were parked for elongated periods. Demand for this type of charging would be in pre-existing parking lots close to where residents live or work. Input data to ArcGIS include road grids, parking areas, and residential statistics (Lindblad, 2012).

Fast charging stations are assumed to have the highest suitability when located close to heavily trafficked roads. The input data for this case included road grids, electric grids (to assess capacities to support fast charging), suitable stops, and traffic density. Medium to fast charging systems were sited based on their ability extend EV range alongside roads and key highway routes and roads. The input data for this case included road grids, electric grids, suitable stops, and popular EV model ranges (ibid.).

Another example of GIS site suitability analysis emanates from the Los Angeles County GIS analysis. The study identified the most efficient placement of Level 3 stations included government offices, public libraries, and public parks within a half-mile radius of a highway. This siting criterion enabled easy travel from one end of the county to the other and an ability to ease range anxiety for interregional and intraregional commutes (Shengji Jin, 2016).

Optimal locations for Level 2 chargers at public libraries and parks have been derived from demographics related to EV owners indicating a majority of EV owners are middle-aged, possess a bachelor's degree or higher, and have a relatively high household income. Therefore, public libraries and parks within neighborhoods of residents fitting this demographic profile were chosen as ideal for Level 2 charger installation (ibid.).

Lastly, Level 2 chargers have been recommended for installation at Los Angeles County government offices since workplaces are the second more frequently utilized charging location (after home charging). The study recommended the Los Angeles County government could purchase and install chargers at all government offices as an exemplary workplace initiative (ibid.).

Other U.S. examples of optimal EVSE location selection criteria

Prominent studies emanating from the U.S. Department of Energy, as well as plug-in electric vehicle (PEV) infrastructure studies and demonstrations, include "The EV Project" and the "ChargePoint America Project" which, combined, form the largest PEV infrastructure demonstration in the world. The two projects installed 17,000 EVSEs between 2011-2013, in 22 regions across the U.S., comprised of both Level 2 and Level 3 EVSEs. The projects were not only created to install EVSEs, but to also monitor their usage patterns and develop lessons learned that could be applied to future deployment of PEVs and charging infrastructure (Francfor *et al*., 2015). The following is a summary of main findings, which inspired CUTRIC's descriptive analysis.

Optimal location considerations

The study concluded that an overwhelming majority of charging was done at home and work, with about half of the project participants exclusively charging their EVs at home. Even though the vast majority of charging occurs at residential or workplace EVSEs, it does not mean that public charging stations are not necessary or desirable. Some fast charging stations experienced heavy use and allowed for intra and inter-city driving. Although these stations did not experience frequent usage, the charging provided to the driver was very important to that driver's commute (Francfor *et al*., 2015).

A small number of Level 2 chargers drew consistently high usages and were located in areas where cars were parked for a while, including shopping malls, airports, commuter lots, and downtown parking lots of garages with easy access to a variety of venues. Conversely, some Level 2 EVSEs installed in locations perceived as optimal had surprisingly low usage. It was therefore very difficult to pinpoint exact criteria for optimal placement of EVSEs across regions and seemed to be more dependent upon community-specific factors (ibid.)

The stated results indicate that a ubiquitous charging network (similar to ubiquitous gasoline and diesel fueling stations) are not required in the future to support wide-spread EV adoption and/or optimized long-range driving.

The studies demonstrated charging episodes and infrastructure will be clustered at homes, workplaces, and in public "hot spots". Installation of public charging stations were found to be more expensive than residential or workplace units with large installation cost variance in different regions and venues. The report authors conclude the cost and usage patterns associated with publicly available EVSEs underscore the fact the bulk of chargers should be installed at homes and workplaces with additional public chargers installed *only* at strategic points in the transportation network (ibid.).

Installation costs assessment

The installation costs for a public Level 2 charger ranged from $600 to $12,660 USD, with an average cost of $3,108 USD. The costs were primarily dependent on the distance between the facility's electric panel and the charging station, and these costs varied regionally due to labour rates. Workplace charger installations averaged $2,223 USD per unit, which is 28 per cent less than the average public Level 2 charger cost. This difference in cost was attributed to increased flexibility at workplaces to choose optimal locations for the charging station and the type of equipment needed. However, employers found that once all of the optimal charging station installation sites were taken, prices increased quite a bit for less ideal spots (Francfor *et al*., 2015).

Installation costs for Level 3 chargers were between $8,500 to over $50,000 USD, with an average cost of $22,626 USD. Many of the DCFC installations required additional electrical services to support the 60-kW power rating and requirement for 480-volt outputs, creating significant increases to the installation costs (ibid.).

Charging patterns assessments

The study also monitored whether EV owners typically used Level 2 or Level 3 chargers when charging away from their home, and it was found that drivers of the Chevy Volt used Level 2 chargers half the time and Level 1 charging the other half of the time (either from a dedicated charging station or a standard 120-volt outlet). For Nissan Leaf owners, only eight per cent of charging events away from home were done using Level 3 chargers, and the rest were done with Level 1 or 2 chargers (Francfor *et al*., 2015).

Workplace charging behaviors were also examined and charging habits were seen to vary based on conditions such as fees and rules for use. Drivers were less likely to plug-in at work if they were required to pay for charging or if they had to move their vehicle after charging was complete. However, EV drivers did show a willingness to use communication tools (e.g., an online message board) to coordinate the use of charging stations with other employees. There was also an observed common courtesy and willingness from employees to follow practices such as plugging in a neighboring EV for charging after unplugging their own fully charged EV. These behaviors led to high charging station usage in certain workplaces and allowed for a large number of employees to regularly charge their vehicles (ibid.).

Summary

The studies documented above have helped CUTRIC identify several location siting variables to invoke when assessing optimal EVSE placement in Oxford County based on driving behavioural patterns (expected), EV make and model needs for charging support, and charging location appropriateness based on equi-distance or "gap" filling in an EVSE matrix locally and based on ad hoc parameters such a walking and driving distance and/or amenities nearby.

The placement of electric vehicle supply equipment (EVSE) across the Level 1 to Level 3 system spectrum requires a comprehensive consideration of all of these variables – to the extent possible, with the data sources currently available – in Oxford County. As more data become available over time, this analysis can be reiterated to refine the locational optimization of EVSEs not yet installed in the community.

In the next sections of this Report, we document the predictive and descriptive outcomes associated with mapping EVSE siting locations based on the following factors:

1. Predicted increases in EV uptake by commuters (varied types) and tourists
2. Current EVSE usage and clustering
3. Gaps in the EVSE network in Oxford County based on distance considerations
4. Gaps in the EVSE network based on locations serving amenities and/or workplaces

Section 2: Assessment of EVSE Usage and EVSE Network Gaps in Oxford County

In reviewing the literature sources identified earlier to assess EVSE siting experiences globally, and in assessing the outcomes of the Voronoi method for mapping clusters of pre-existing and potential extended sites of EVSE installations, it is evident that an analysis of existing EVSEs in Oxford County would be – on its own – insufficient for predicting how many EVSEs need to be integrated into the community in the future, or where they ought to be optimally located given future EV adoption rates and driver usage and charging patterns.

Therefore, CUTRIC has developed here a series of predictive and descriptive outcomes that help to map gaps in the EVSE network in Oxford County and identify mechanisms going forward to fill those gaps or ensure efficient clustering of EVSEs in high-use or likely high-use areas based on varied types of commuter (employee) and/or tourist traffic.

The assessment of how many chargers may be needed in the community is followed by an assessment of where those charges may be located optimally in the future.

Data collection opportunities and challenges

Table 1 summarizes the required data to optimally locate new charging stations in Oxford County, as well as barriers CUTRIC faced in acquiring those data sets. The following targeted communities of potential EVSE users have been identified to guide the data collection process:

- Oxford residents
- Transitory and through-way traffic
- Tourists

Despite the fact Oxford County's Manager of Strategic Initiatives is a champion in this project and has supported iterative rounds of data collection activities, CUTRIC has faced several challenges acquiring appropriate empirical data sets related to localized EV adoption and EVSE usage. Developing a robust localized predictive model would be enabled, for example, by having real-time access to EVCO and Tesla charging system databases from Oxford's installed charging systems. Data analysis for Oxford County in this regard requires access to these data sets. Therefore, CUTRIC has identified the benefits to both the MTO (for future EVCO planning) and Tesla (for charging system optimization analysis) that would arise from allowing undisclosed access and analysis of the datasets for the purposes of this study.

Accessing these datasets proved to be challenging under current government and commercial restrictions. To clarify, (1) the Government of Ontario's Ministry of Transportation refused to relinquish access rights to MTO EV charging data sets from chargers co-funded through the province's EVCO 1.0 program (launched in 2016); (2) Tesla similarly refused to allow access to charging system data from Tesla chargers in the community.

Although CUTRIC intends to inform and shape public policy in an evidence-driven fashion, the lack of access to empirical evidence demonstrating real-time charging patterns in the community means the methodology adopted here is largely predictive in nature, and based on reasonable but static assumptions regarding potential EV adoption rates in the community.

TABLE 1: DATA COLLECTION OUTLINE

Required Data	Source(s)	Data Availability
Information about existing charging stations (i.e., location, make, model, quantity)	Inquiry from Oxford County	Received.
	EVCO Map	Publicly available.
	PlugShare Map	Publicly available.
	AddEnergie Flo Map	Publicly available.
Usage patterns of existing charging stations (i.e., number and length of daily EV charging episodes; power level and electricity demand)	Tesla charging system databases (for chargers located at the Quality Inn Hotel parking area)	1. Hotel management does not collect EV charging data despite owning chargers on site. 2. Tesla stated it is "unable to release any charging data for the purposes you have requested. Tesla operates under a very strict privacy policy with respect our proprietary data, which is commercially sensitive in nature."
	AddEnergie Flo Database	Access provided by AddEnergie [facilitated by Oxford County].
	Inquiry from MTO/MyEV (for EVCO funded chargers)	MTO stated: 1. "We will not be able to provide access to their database due to the highly sensitive nature of data and personal information of Ontarians. 2. Moreover, Electric Vehicle Chargers installation was supposedly to complete in March 2017, and first usage data report is due October 31st, thus presently we do not have any information about usage patterns of electric vehicle chargers.

Required Data	Source(s)	Data Availability
		3. We are in the process of modifying our database to cater varying information needs, and may probably be able to provide limited access in future but cannot promise anything right now.”
Information about existing EVs in the County	Green License Plate Data (MTO)	Received.
Location of main parking areas for short-terms stays (1hr-3hrs) [Shopping malls, cinemas, hospitals, etc.]	Oxford County & Municipalities Land Use Maps	Not available publicly. Oxford County’s Manager of Strategic Initiatives requested each municipality provide an appropriate list. Google satellite imagery data used as a complementary source.
	Oxford County Business Directory	Information retrieved from business directory and mapped manually. Google satellite imagery data used as a complementary source..
Location of employer-owned parking areas for long-term stays (8hrs +) [Hospitals for employees, workplaces, etc.]	Oxford County & Municipalities Land Use Maps	Not available. Oxford County’s Manager of Strategic Initiatives requested each municipality provide an appropriate list. Google satellite imagery data used as a complementary source.
	Oxford County Business Directory	Information retrieved from the business directory and mapped manually. Google satellite imagery data used as a complementary source.

Required Data	Source(s)	Data Availability
Oxford County population and urban density	2016 Census	Publicly available.
Events and attractions attracting outside traffic to Oxford County	Oxford County & municipal tourist catalogues and events guides (inquiry from Tourism Oxford)	Received.
Highway map and traffic flow (annual average daily traffic)	MTO Website	Publicly available.

Descriptive analysis considerations based on literature

Three key variables guided Oxford County's EVSE siting efforts. They include:

1. **Long-term parking opportunities** (Level 1 or Level 2 Systems)
    a. Level 1 characteristics: locations typically involving 8-24 hour stop-overs or overnight stays, such as hospitals, employment sites for employees, train stations (for commuters who park and ride), bus stations (for commuters who park and ride), hotels.
    b. Level 2 characteristic: locations typically involving 1-3 hour stop-overs, such as cinemas, shopping malls, hospitals (visitors), airports, farmers markets, etc.
2. **Special applications for Level 2**, including summer farmers' markets, festival locations, and other tourist attraction locations that experience high-volume at non-uniform periods within the annual year cycle.
3. **Highway intersectionality (Level 3)**, including nearby highway off ramps, and "On Routes" or other similar nearby off-highway stopping points that allow for 10-30 minute stop overs for travellers and highway commuters (ideally), or incoming resident traffic.

Both cost and usage of charging stations (based on local community needs) should be considered in the decision-making process of siting new EVSEs to ensure the effectiveness in location prediction as well as choosing the right type to justify the initial costs of infrastructure depending on the locale. In the Canadian context, the cost of charging stations are as follows:

Level 1 EVSE Costs: The price of Level 1 chargers range from $800 to $1,200 CAD to purchase. The installation costs are [on average] between $800 and $1,000 CAD (both parts and labour), however, the installation cost varies from case to case depending on permits, garage modifications, and additional features (HomeAdvisor, 2017; Plug 'N Drive[2], 2017).

Level 2 EVSE Costs: Established EVSE networks in Canada appear to be: Sun Country Highway, ChargePoint, and FLO.

- Sun Country Highway provides prices for Level 2 chargers ranging from $829 to $2,799 CAD depending upon the durability of the station, including warranties, weather resistance, etc (Sun Country, 2017).
- Level 2 chargers can be categorized according to whether they are "networked" or "non-networked", i.e., smart enabled systems. Networked stations have internet connections and allow the owner to control access to the station, charge a fee for service and print usage/maintenance reports among other features. They range from $8,000 to $10,000 CAD to purchase. Non-Networked units do not have internet connections and cannot be controlled, which range from $2,000 to $4,000 CAD to purchase (Plug 'N Drive[2], 2017).
- Distance to the breaker box is usually the most important factor in determining installation cost, typically ranging from 15 to 30 meters. Runs longer than 45 meters are usually too expensive to justify station installation. Parking garage installations are the easiest and most economical public charging stations. Conduit and wiring can be wall mounted. Curbside and surface lot stations tend to be much more expensive than parking garage installations because they frequently require costly trenching or directional boring to run conduit and wire to the station (CleanTechnica, 2014).
- Installing a multi-port station, or multiple stations at once, reduces the cost per charger, but demand must exist to justify the extra capacity. Cost is reduced mainly because a single trench/bore, conduit, and wire can be used to service the adjacent stations.

Multiple stations are more likely to require a breaker box upgrade, and the feeder wire that is run from the box to the stations will be slightly more expensive, but the added cost can be divided across the extra stations. There are other efficiencies in mobilization, repetition, permitting, etc (ibid).

Level 3 EVSE Costs: The current cost of Level 3 charger is an order of magnitude higher than a Level 2 charger, ranging from $40,000 to $100,000 CAD per station. Installation and civil works ranges from $15,000 to $60,000 CAD depending upon site complexity. There are two main contributors to their high cost: 1) expensive equipment and 2) frequently the need to install a 480V transformer (EVSE, 2017).

Predictive analysis: Assessing future EV adoption impacts on EVSE needs in Oxford County

Predictive analysis offered here adopts a linear model based on current and predicted future EV adoption rates, along with an integrated traffic flow analysis. Additionally, the model assumes two types of electric vehicles as "baseline" vehicle systems – namely, the Nissan Leaf 2017 and the Chevy Bolt 2017 – to determine range performance on a daily and annual basis as applied to a variety of potential in-town and out-of-town commuters and drivers.

These vehicles were selected based on the following variables:

- Price range ($37,000 – $45,000 CAD), which suggests a more affordable vehicle compared to luxury makes of fully electric vehicles (for example BMW and Tesla models);
- Government of Ontario's rebate of $14,000 CAD for both vehicles, which reduce pricing further to a value comparable with a new hybrid vehicle, such as a Prius V, for Canadian households;
- Varying driving range capacity with the Leaf demonstrating approximately 175 km in range and the Bolt demonstrating approximately 383 km (as reported by manufacturers, and depending on ambient conditions and drive cycles).

The selection of these vehicles allows for a comparative assessment between two similarly priced vehicles that demonstrate varying driving ranges. When applied in the context of Oxford County and assumed as a proportion of all cars in the community, these vehicles create differing charging system requirements outside of homes, at workplaces, at common places of extended parking (e.g., shopping malls), and on highways and other road intersections in the community.

The following section outlines the typologies CUTRIC has created to capture potential driver "types". These types of drivers constitute idealizations meant to capture potential categories of driver types and drive cycle requirements (i.e., range requirements among EV drivers in Oxford) that would shape EVSE needs and requirements in the community in the future. The table below outlines assumptions embedded into the definition of these driver idealizations. An optimal source of data that could be generated to justify or characterize data required to conduct the analysis and the assumptions made to assist formulating the final results are described.

Driver typologies: Type A – Type D EV Owners and Drivers

CUTRIC has adopted a "Best Case - Worst Case" predictive model to estimate the number of chargers that a regional location would need to host to *fully satisfy* charging needs based on assumptions regarding battery range, home charging, and travel patterns.

In this model, the Best Case Scenario (as judged from the perspective of an EVSE owner/host) requires the minimum number of EVSEs to be installed to serve a local community or a stakeholder sector (i.e., employee).

- **The Best Case Scenario is the least expensive scenario, as judged from the perspective of the EVSE owner, as it requires the fewest number of EVSE units and the least amount of EVSE installation and/or electricity provision.**

No assumptions have been made in this model regarding priced versus un-priced (or "free") electricity.

The Worst Case Scenario (as judged from the perspective of an EVSE owner/host) requires the maximum number of EVSEs to be installed to serve a local community or a stakeholder sector (i.e., employee).

- **The Worst Case Scenario constitutes the most expensive scenario, as judged from the perspective of the EVSE owner, as it requires the most number of EVSE units and the most amount of EVSE installation and/or electricity provision.**

No assumptions have been made in this model regarding priced versus un-priced (or "free") electricity.

To inform this model, CUTRIC has created a set of EV owner typologies, whose profiles can be characterized as follows:

1. **Type A:** Work Commuter (Principal Car)
    a. **Type A1:** In town commute
    b. **Type A2:** Out of town commute
    c. **Type A3:** Out of town commuting into town
2. **Type B:** Family Commuter (Secondary Car)
3. **Type C:** Tourist Commuter
4. **Type D:** Inter-city Commuter transiting through Oxford County between city locations (for work or leisure)

Vehicle make and model technical specifications and assumptions

Table 2 lists the technical and battery pack information for the Nissan Leaf and Chevy Bolt, which are used in this analysis. Working hours are assumed 7am - 7pm (12 hours). This section provides a short description of the other assumptions made to develop the predictive modeling.

TABLE 2: TECHNICAL AND BATTERY PACK INFO

	Nissan Leaf 2017	Chevrolet Bolt 2017	Source
Battery Pack (kWh)	30	60	Plug 'N Drive
Time to charge for L1 Chargers (Hours)	≈ 20 (1.5 kWh of charging per hour) - 30 (1kWh of charging per hour)	≈ 40-60	Meo Electric & ChargeHub
Time to charge for L2 Chargers (Hours)	4.5	9.5	Plug 'N Drive
Time to charge for L3 Chargers (Hours)	< 30 min for 80% charge	< 2 hours	Meo Electric
Estimated Range (km)	172	383	Plug 'N Drive

Current and future EV ownership for Type A1

Data received from MTO indicates that the total number of existing EVs in the County is 163 (as of 2017 figures). Based on the *EV Sales Report in Canada* (3rd quarter 2017), the current adoption rate of EVs across Ontario is 0.8 per cent (FleetCarma, 2017).

To generate a predictive model for this feasibility study, CUTRIC assumed an incremental linear increase in EV volumes (one per cent, five per cent, 10 per cent, and 25 per cent) to predict the number of future EVs in Oxford County, assuming 163 EVs (as of 2017) constitutes 0.8 per cent of total vehicles owned in Oxford County currently (Table 3).

TABLE 3: NUMBER OF TYPE A1 EVS

Adoption Rate	Number of EVs
0.8%	163
1%	204
5%	1019
10%	2038
25%	5094

Current and future EV ownership for Type C

To create a predictive tool to assess incoming EV traffic into the Oxford County community, CUTRIC explored tourist events that would attract predictable estimations of incoming traffic flow based on annual occurrences.

Tourism Oxford advises there are **two** rural and **four** urban "high attendance" venues in the County with rural events attracting approximately 4,000 people and urban events attracting 10,000 people per instance. However, there are no data identifying how many event goers constitute out-of-town travelers versus in-town visitors. Therefore, CUTRIC has utilized the general approximation provided by Tourism Oxford that 48,000 tourists visit Oxford County annually.

To generate a predictive model for incoming tourists, CUTRIC has assumed four visitors travel in each incoming vehicle (i.e., a standard family unit). This generates a value of approximately 12,000 cars traveling into the County annually, which CUTRIC has utilized as the base value to assess EVSE needs for Type C EV owners.

Considering the incremental adoption rates noted above, Table 4 demonstrates the number of Type C EVs estimated as entering Oxford annually for events and festivals.

TABLE 4: NUMBER OF TYPE C EVS

Adoption Rate	Number of EVs
0.8%	96
1%	120
5%	600
10%	1200
25%	3000

Current and future EV ownership for Type A3 & D

To assess EVSE requirements among commuters (both in town and out of town daily commuters), CUTRIC has leveraged Annual Average Daily Traffic (AADT) data associated with the busiest highway routes surrounding of Oxford County. The AADT for Oxford County (2017) ranges between 67,151 and 74,200 vehicles with a median value of 70,675 vehicles commuting through or into Oxford on a daily basis, as based on surrounding highway traffic flow.

Using the linear adoption rates identified above, and assuming one per cent of the AADT constitutes vehicles that actually stop in Oxford County for work/daily commuting purposes, this model estimates the number of cars entering the County as commuter vehicles is approximately 707 per day. Considering the incremental adoption rates notes above, Table 5 demonstrates the number of Type A3 EVs that **may stop in Oxford** County and require charging infrastructure.

TABLE 5: NUMBER OF TYPE A3 EVS

Adoption Rate	Number of EVs
0.8%	6
1%	7
5%	35
10%	71
25%	177

In addition, assuming 99 per cent of the AADT constitute inter-city commuters who transit through or across Oxford County en route to a work location outside of or adjacent to Oxford County another estimated 69,968 vehicles may require a stop over in Oxford County along highway route intersections.

Considering incremental EV adoption rates identified above, Table 6 demonstrates the number of Type D EVs (inter-city commuters) who may require a stopover for brief "fuelling" or "charging" in Oxford County, as assumed in this model.

TABLE 6: NUMBER OF TYPE D EVS

Adoption Rate	Number of EVs
0.8%	560
1%	700
5%	3,496
10%	6,997
25%	17,492

Usable battery range assumptions

The predictive model presented below utilizes two electric vehicles (Nissan Leaf, 2017 and Chevy Bolt, 2017) to demonstrate possible charging requirements for Type A-D EV owners/drivers *in and around* the Oxford County.

Make-Model (1): Nissan Leaf 2017

Usable battery (estimated) range is calculated as follows:

- Nissan Leaf 2017 average range is approximately 172 km (in normal ambient conditions).
- Buffer/battery SOC loss assumptions:

- Over the life of the car, approximately 25% degradation (43 km loss) in a worse
- case scenario over a 10-year lifecycle.
- Cold or extreme hot weather conditions, 30% temporary loss in range (51 km loss) in a worse case scenario.

- Total usable battery estimated range under all conditions (i.e., 10 year lifecycles, and extreme weather conditions): 78 km

Make-Model (2): Chevrolet BOLT 2017

Usable battery (estimated) range is calculated as follows:

- Chevy Bolt 2017 average range is approximately 383 km (in normal ambient conditions).
- Buffer/battery SOC loss assumptions:
  - Over the life of the car, approximately 25% degradation (96 km loss) in a worse case scenario over a 10-year lifecycle.
  - Cold or extreme hot weather conditions, 30% temporary loss in range (114 km loss) in a worse case scenario.
- Total usable battery estimated range under all conditions (i.e.,10-year lifecycles, and extreme weather conditions): 173 km

CUTRIC has developed a map of current usage to predict future usage in the community based on current EV sales, as well as future EV sales growth; in addition, CUTRIC has mapped current and future EV charging behavioural patterns in and around the community.

The results of these analyses are presented in Table 7 for both the Nissan Leaf estimation model, and Table 8 for the Chevy Bolt estimation model.

TABLE 7: PREDICTIVE ANALYSIS FOR NISSAN LEAF 2017 APPLICABILITY: LEVEL 1, 2, & 3 CHARGER REQUIREMENTS

EV Owners Charging Profile (Nissan Leaf)		**Base Minimum Number of Level 1 Required Chargers**				
Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	**Best Case Scenario**: Assume Type A1 commuter travels less than 78 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.).	In this case, there is no need for L1 chargers in the County because there is enough charge to complete travel based on home charging.				
	Worst-Case Scenario: Assume Type A1 commuter travels more than 78 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.). Requires top up at work of minimum 8 hours. Assume one, 8-hour charging block over a 12-hour work day period, equates to one charging episode.	163	204	1,019	2,038	5,094
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but it is outside of Oxford County.	In this case, there is no need for L1 chargers in the County because commuters travel outside of the County.				
Type A3: Out of town commuting into town	Charging at home, leaving with 100% SOC, requires a full or significant charge at work.	In this case, there is no need for L1 chargers in the County because significant or full charge for Leaf takes 20-30 hours which exceeds a 12-hour working episode/period.				
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC, requiring a potential 30-45 minute top up charge.	In this case, there is no need for L1 chargers in the County because a 30-minute charging period with an L1 charger does not provide enough charge to justify EVSE installation.				
Type C: Tourist Commuter	Leaving home with 100% SOC, requiring a full charging period upon entry to Oxford.	In this case, there is no need for L1 chargers in the County because a full charging episode for the Leaf takes 20-30 hours, which is not practical for a tourist who may stay less than a 24-hour period.				
Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required).	In this case, there is no need for L1 chargers in the County because a full charging episode for the Leaf takes 20-30 hours which is not applicable to a commuter who may spend a maximum of 30-45 minutes at a transit point on route.				

EV Owners Charging Profile (Nissan Leaf)	**Base Minimum Number of Level 2 Required Chargers**

Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	**Best Case Scenario**: Assume Type A1 commuter travels less than 78 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.).	In this case, there is no need for L2 chargers in the County because there is enough charge to complete travel based on home charging.				
	Mid-Case Scenario: Assume Type A1 commuter travels more than 78 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.). Requires top up at work of minimum one hour. No access to L1 Chargers. Chargers are smart-enabled and give warning to the drivers to move the vehicle at end-of-charge period (or face a penalty).. Assume 2-hour charging blocks over a 12-hour workday period, equating to 6 charging episodes.	27	34	170	340	849
	Worst Case Scenario: Assume Type A1 commuter travels more than 78 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.). Requires top up at work of minimum one hour. No access to L1 Chargers. Chargers are smart-enabled and give warning to the drivers to move the vehicle at end-of-charge period (or face a penalty). Assume 4-hour charging blocks over a 12-hour work day period, equating to 3 charging episodes.	54	68	340	679	1,698
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but it is outside of Oxford County.	In this case, there is no need for L2 chargers in the County because commuters travel outside of the County.				
Type A3: Out of town commuting into town	**Best Case Scenario**: Charging at home, leaving with 100% SOC, requires a full or significant charge at work. Assume 2- hour charging blocks over a 12-hour workday period, equating to 6 charging episodes.	1	1	6	12	30
	Worst Case Scenario: Charging at home, leaving with 100% SOC, requires a full or significant charge at work. Assume 4-hour charging blocks over a 12-hour workday period, equating to 3 charging episodes.	2	2	12	24	59
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC, requiring a potential 30-minute top-up charge within the County; assume 1% of Drivers are EV owners with after-work activity requirements.	The longest route across and around Oxford County roads is 52 kilometres in length; thus, there is no need for L2 chargers within the County because				

		there is enough charge to complete travel based on home charging.				
Type C: Tourist Commuter	**Best Case Scenario**: Leaving home with 100% SOC, requiring a top up charge upon entry to Oxford. Assume 2-hour charging blocks over 16 hours, equating to 8 charging episodes.	12	15	75	150	375
	Worst Case Scenario: Leaving home with 100% SOC, requiring a full charging period upon entry to Oxford. Assume 4-hour charging blocks over 16 hours, equating to 4 charging episodes	24	30	150	300	750
Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required),	In this case, there is no need for L2 chargers in the County because a full charging episode of the Leaf takes 4.5 hours, which is not applicable to a commuter who spends a maximum 30-45 minutes at a transit point on route.				

EV Owners Charging Profile (Nissan Leaf)		**Base Minimum Number of Level 3 Required Chargers**				
Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	All Scenarios	Not required due to the high price and available time at work for Work Commuter to use L2 chargers.				
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but is outside of Oxford County.	In this case, there is no need for L3 chargers in the County because people travel outside of the County.				
Type A3: Out of town commuting into town	Charging at home, leaving with 100% SOC, requires a full or significant charge at work. 24 charging episodes within 12 hours (working hours).	0	0	1	3	7
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC, requiring a potential 30-minute top-up charge.	In this case, there is no need for L3 chargers in the County because L2 chargers would fulfill the local needs.				
Type C: Tourist Commuter	Leaving home with 100% SOC, requiring a full charging period upon entry to Oxford.	In this case, there is no need for L3 chargers in the County because L2 chargers would fulfill local needs.				

Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required). 48 charging episodes within 24 hours	12	15	73	146	364

TABLE 8: PREDICTIVE ANALYSIS FOR CHEVY BOLT 2017 APPLICABILITY: LEVEL 1, 2, & 3 CHARGER REQUIREMENTS

EV Owners Charging Profile (Chevy Bolt)		Base Minimum Number of Level 1 Required Chargers				
Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	**Best Case Scenario**: Assume Type A1 commuter travels less than 173 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.).	In this case, there is no need for L1 chargers in the County because there is enough charge to complete travel based on home charging.				
	Worst Case Scenario: Assume Type A1 commuter travels more than 173 kilometers per day to and from work and in-between stops, e.g., shopping, pick ups, etc. Assumes no Level 2 charger at home. The Bolt requires approx. 40-60 hours to charge via AC Level 1, depending upon voltage and amperage, meaning a Bolt owner cannot fully charge up over a 24-hour period at home. This may require top-up charging at the workplace, leading the Bolt owner to use or demand workplace charging to accommodate battery capacity needs. In this scenario, workplace charging allows a Bolt owner to use the workplace as a complement to home charging at AC Level 1.	163	204	1,019	2,038	5,094
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but is outside of Oxford County.	In this case, there is no need for L1 chargers in the County because the commuter travels outside of the County.				
Type A3: Out of town commuting into town	Charging at home, leaving with 100% SOC, requires a full or significant charge at work.	In this case, there is no need for L1 chargers in the County because the Bolt requires approx. 40-60 hours to charge via AC Level 1, depending on voltage and amperage which far exceeds an assumed a 12-hour working episode/period.				
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC, requiring a potential 30-minute top-up charge at AC Level 2.	In this case, there is no need for L1 chargers in the County because 30 minutes with a L1 charger does not				

		provide enough charge to justify EVSE installation.
Type C: Tourist Commuter	Leaving home with 100% SOC, requiring a full charging period upon entry to Oxford.	Only applicable if overnight opportunity available (i.e., at least a 24-hour period)
Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required).	In this case, there is no need for L1 chargers in the County because the Bolt requires approx. 40-60 hours to charge via AC Level 1, depending upon voltage and amperage which is not applicable to a commuter who might spend a maximum of 30-45 minutes at a transit point on route.

EV Owners Charging Profile (Chevy Bolt)		**Base Minimum Number of Level 2 Required Chargers**				
Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	**Best Case Scenario**: Assume Type A1 commuter travels less than 173 kilometers per day (to and from work and in-between stops, e.g., shopping, pick ups, etc.).	In this case, there is no need for L2 chargers in the County because there is enough charge to complete travel based on home charging.				
	Mid-Case Scenario: Assume Type A1 commuter travels more than 173 kilometers per day [which is unlikely] (to and from work and in-between stops, e.g., shopping, pick ups, etc.). Assumes no Level 2 charger at home. Bolt requires approx. 9.5 hours to charge fully via AC Level 2, depending on voltage and amperage, meaning a Bolt owner cannot fully charge up over an 8-hour work period, but could over a 12-hour work period. In this scenario, workplace charging allows a Bolt owner to use the workplace as a complement to home charging at AC Level 1, assuming 2-hour charging blocks with smart enabled chargers that penalize owners for overstaying their charge period, resulting in 6 charging episode periods in 12 hours. This assumes access to a charger for 2 hours, every second workday.	14	17	85	170	425

	Worst Case Scenario: Assume Type A1 commuter travels more than 173 kilometers per day [which is unlikely] (to and from work and in-between stops, e.g., shopping, pick ups, etc.). Assumes no Level 2 charger at home. Bolt requires approx. 9.5 hours to charge fully via AC Level 2, depending on voltage and amperage, meaning a Bolt owner cannot fully charge up over an 8-hour work period, but could over a 12-hour work period. In this scenario, workplace charging allows a Bolt owner to use the workplace as a replacement to home charging at AC Level 1 and/or AC Level 2. Assuming 9-hour charging blocks (does not require smart enabled charger), resulting in one charging episode in 12 hours. Assumes a full daily charging period (i.e. work period).	163	204	1,019	2,038	5,094
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but it is outside of Oxford County.	In this case, there is no need for L2 chargers in the County because the commuter travels outside of the County.				
Type A3: Out of town commuting into town	Charging at home, leaving with 100% SOC, requires substantial charge at work, and is located inside of Oxford County.	Assuming incoming commuter expends approx. 25% SOC upon arriving due to highway travel of up to 100 kilometers inbound, outbound and return to home, which exists within the Bolt range with no workplace top up charging required.				
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC.	In this case, there is no need for L2 chargers in the County because the high battery capacity and resulting range.				
Type C: Tourist Commuter	**Best Case Scenario**: Leaving home with 100% SOC, requiring a top up charge upon entry to Oxford. Assume 4- hour charging blocks over 16 hours, equating to 4 charging episodes.	24	30	150	300	750
	Worst Case Scenario: Leaving home with 100% SOC, requiring a significant or full charging period upon entry to Oxford. Assume 8-hour charging blocks over 16 hours, equating to 2 charging episodes.	48	60	300	600	1,500
Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required).	In this case, there is no need for L2 chargers in the County because the Bolt requires 9.5 hours to charge via AC Level 2, which is not applicable to a commuter who might spend a maximum of 30-45 minutes at a transit point on route.				

EV Owners Charging Profile (Chevy Bolt)		Base Minimum Number of Level 3 Required Chargers				
Type A: Work Commuter (Principal Car)	Description	**0.8%**	**1%**	**5%**	**10%**	**25%**
Type A1: In town commute	All Scenarios	Not required due to the high price of EVSE installation, and available time at work for Work Commuter to use L2 chargers.				
Type A2: Out of town commute	Charging at home, leaving with 100% SOC, requires a full or significant charge at work, but is outside of Oxford County.	In this case, there is no need for L3 chargers in the County because the commuter travels outside of the County.				
Type A3: Out of town commuting into town	Charging at home, leaving with 100% SOC, requires a full or significant charge at work. 6 charging episodes within 12 hours (i.e. working hours).	1	1	6	12	30
Type B: Family Commuter (Secondary Car)	Leaving home with 100% SOC.	In this case, there is no need for L3 chargers in the County because of the high battery capacity and resulting range.				
Type C: Tourist Commuter	Leaving home with 100% SOC, requiring a full charging period upon entry to Oxford.	In this case, there is no need for L3 chargers in the County because L2 chargers would fulfill local needs.				
Type D: Inter-city commuter transiting through Oxford County between city locations (for work or leisure)	Leaving home with 100% SOC, requiring a full charge period upon entry to highway location (DCFC required). 12 charging episodes within 24 hours.	47	58	292	583	1,458

Summary

The results of CUTRIC's predictive analysis indicates the number of required EVSEs are as follows (based on the current adoption rate, 0.8%):

- Level 1: 163
- Level 2: Min: 54 – Max: 163
- Level 3: Min: 12 – Max: 47

This aggregated estimation summarizes the results of Table 7 and Table 8 considering worst Case Scenario for all types of drivers.

Assuming an average price of $1000 CAD for Level 1, $2,500 CAD for Level 2, and $60,000 CAD for Level 3 chargers, Oxford County should invest minimum $ 1,018,000 CAD - excluding installation costs which depends on the selected location – to meet the needs of different types of EV drivers including work commuters (Type A), family commuters (Type B), tourist commuter (Type C), and inter-city commuters (Type D).

Section 3: GIS Mapping Methodology – Geographical Distribution Drivers for EVSE Upgrades and Extended Installations

The EVSE station location methodology is separated into two processes reflecting the contrasting geographic factors that influence location of high-power (Level 1 and Level 2) and low power (Level 1) EVSE. Firstly, to ensure appropriate high-power charging accessibility across Oxford County, Voronoi polygons are used to visualise the quality of the existing high-power EVSE network in order to identify either **existing** EVSE upgrade candidate sites or **new** EVSE stations. New EVSE stations should be located to optimally densify the existing network in respect of access to amenities as well as major highways while equalising distance between adjacent chargers. This process is ideal for locating Level 2 and Level 3 chargers for Type B-D users. Locating Level 1 chargers for Type A users depends less on amenity access and more on proximity to place of work and this controls the second GIS process where clusters of places of work are identified throughout Oxford County and these clusters are used to locate those long residence time chargers.

Figure 1 demonstrates the current distribution of EVSEs in Oxford County. This EVSE distribution pattern is dominated by two clusters of EVSEs – the first in Woodstock with 6 stations and the second in Ingersoll with 8 stations, including one shared/home charger. A third loose clustering of stations exists in Tillsonburg with four stations, which includes one shared home charger made available by a private home owner for EV drivers.

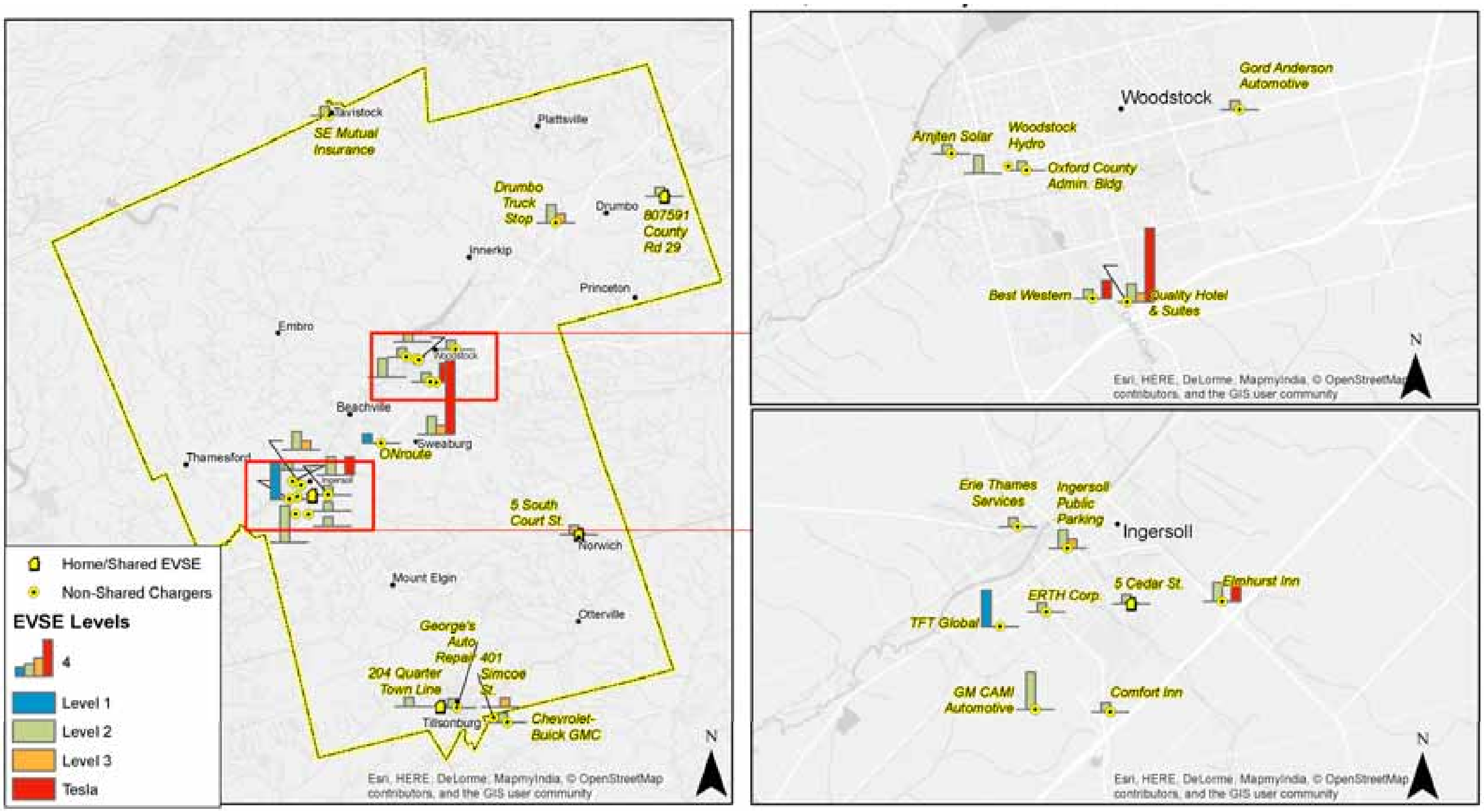

FIGURE 1: LOCATION OF EXISTING EVSES WITH CHARGING LEVEL

Voronoi polygons (Appendix III) were used to define the catchment of particular stations. An EVSE 'catchment' is a polygon that includes all locations that are closest to that particular station. The Voronoi polygon is a standard geographic technique to optimally allocate resources and municipal assets **with respect to proximity to the end-user** which has been used successfully with other EVSE station siting studies (Song *et al.*, 2015; Tang *et al.,* 2013).

A useful corollary of Voronoi polygons is that any point on a line separating two polygons associated with two EVSEs is **equidistant from the two EVSEs** (Figure 2). Such locations are useful **densifying a charging station network.** New installations designed in this way will ensure that the high-powered EVSE network is adequately dispersed within populated areas and close to amenities. Clustering of high-power EVSE installations should be avoided because of anticipated extra traffic congestion but also negative effects of highly localised charging on the electric grid (Schmidt, 2017).

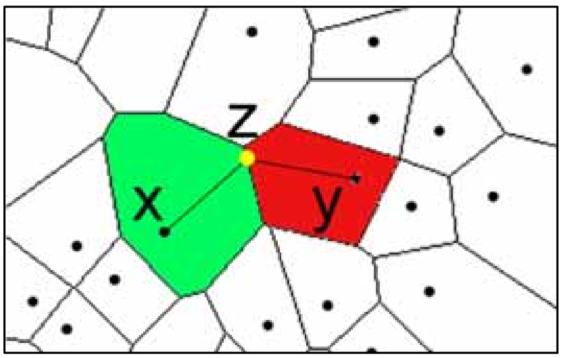

FIGURE 2: EXPLANATORY FIGURE OF VORONOI POLYGONS. ALL POINTS IN THE GREEN POLYGON ARE CLOSEST TO EVSE CHARGER "X"; ALL POINTS IN THE RED POLYGON ARE CLOSEST TO EVSE CHARGER "Y". CANDIDATE LOCATION "Z" IS ALONG A LINE SEPARATING THE RED AND GREEN POLYGONS AND IS THEREFORE EQUALLY DISTANT BETWEEN EVSE "X" AND "Y".

To quantify the charging capabilities associated with a particular station, CUTRIC formulated a "Charging Index" (CI), which is the sum of the number of chargers at a particular station weighted by the charging level. To calculate the CI, the charger weight is proportional to the charging voltage normalised by that of an L1 charger. Therefore, the Charging Index is 2*#L2+4*(#L3+#Tesla), where "#L2" means number of L2 chargers at that charging station. Note that the number of L1 chargers is not used because the Charging Index only quantifies high-powered charging.

A colour temperature scale symbolises CIs in Figure 3 with cool colours representing low values of CI scaling up to red representing high CI values. Uncoloured and dark blue polygons in Figure 3 therefore indicate gaps in EVSE coverage. In this report, CUTRIC has proposed addressing particular gaps in EVSE coverage along the 401 artery by upgrading the existing EVSE centred in those particular polygons.

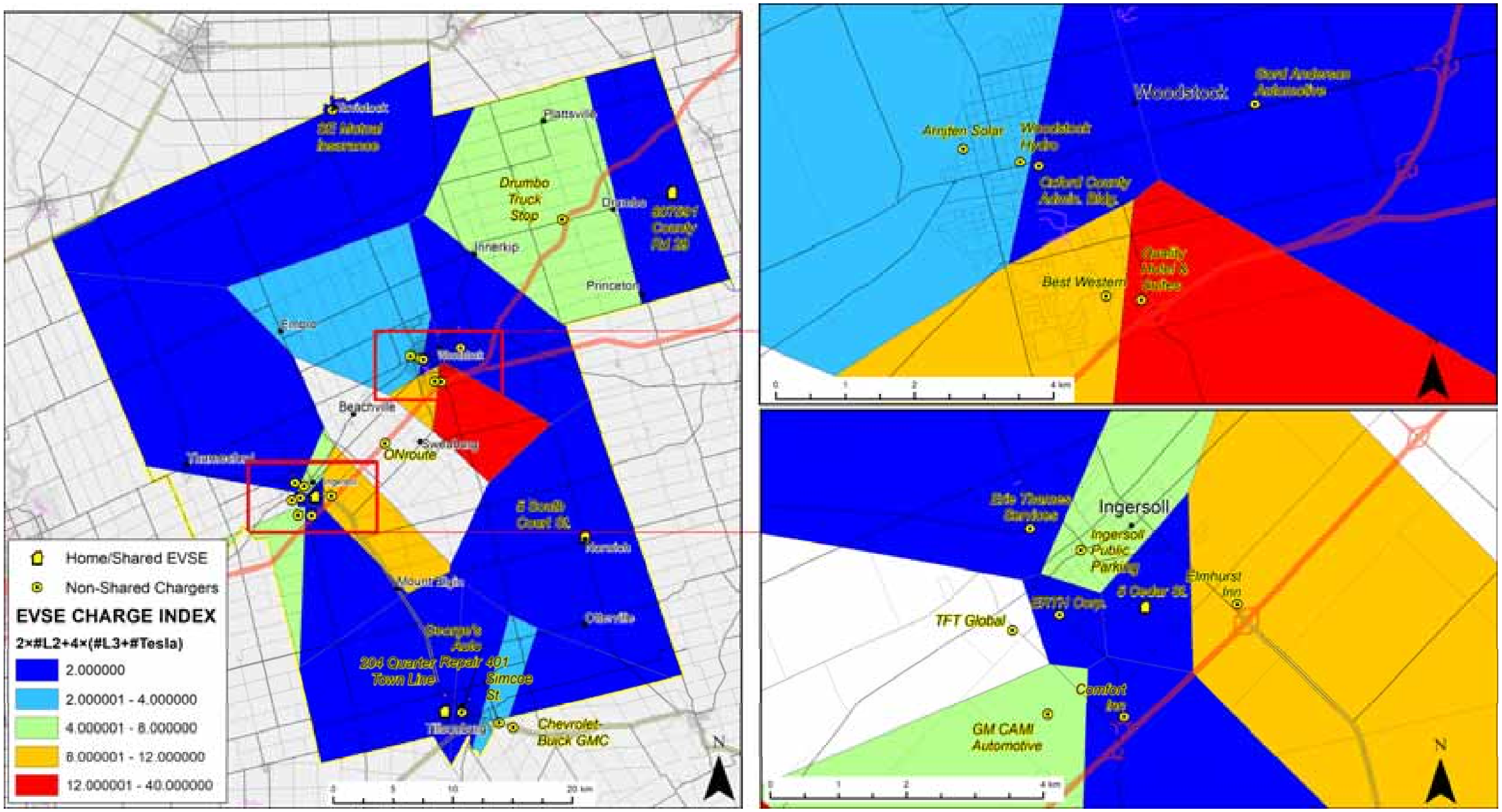

FIGURE 3: REPRESENTATION OF EXISTING EVSE SPATIAL COVERAGE. LOCATIONS FALLING INSIDE DARK BLUE POLYGONS INDICATE THAT THEIR NEAREST EVSE HAS CURRENTLY VERY LOW QUANTITIES OF HIGH-POWER CHARGING CAPABILITY (ONE L2 CHARGER). UNCOLOURED POLYGONS INDICATED NO HIGH-POWERED CHARGING FACILITIES ARE PRESENT. RED AREA INDICATES THAT THE NEAREST EVSE HAS VERY HIGH CHARGING ABILITY (CI=40, INDICATING EIGHT TESLA CHARGERS, ONE L3 AND TWO L2 CHARGERS).

Along major transport arteries, including, Highway 401, and minor transport arteries, including Highway 19 between Ingersoll and Tillsonburg, there are seven low-CI (dark blue) and one uncoloured polygon associated with eight charging stations:

1. 807591 County Road 29 (Home/Shared Station) (One Level 2 charger);
2. Gord Anderson Automotive (One Level 2 charger);
3. Oxford County Admin Building (One Level 2 charger) (A);
4. ONRoute charger at Ingersoll Travel Plaza (Zero high-powered charging, One Level 1 charger) (B);
5. Comfort Inn at Ingersoll (One Level 2 charger) (C);
6. 5 Cedar St. (Home/Shared Station) (One Level 2 charger);
7. 204 Quarter Town Line, Tillsonburg (Home/Shared Station) (One Level 2 charger);
8. Georges Auto Repair, 10 Bridge St., Tillsonburg (One Level 2 charger) (D).

To provide adequate coverage for users of these transport arteries, all of these locations could be upgraded with installation of 54 Level 2 chargers. However, only locations 3, 4, 5, and 8 possess adequate amenities nearby; the remaining EVSEs will probably not benefit from upgrading since there are either inadequate amenities or they are within private dwellings. The four recommended upgrade sites, henceforth denoted by A, B, C, and D, are mapped in Figure 4.

Recommendations for new EVSE locations

Type B, C, and D EV Users

In addition to the latter recommendations for upgrading existing charging sites, CUTRIC recommends new locations for sites to host EVSEs to accommodate a potential increase in EV demand identified in an earlier section of the report.

These locations should be situated optimally with respect to existing charging sites in populated areas that lie along the Voronoi polygon boundaries, i.e., equidistant from the nearest two existing EVSEs, and also should be close to amenities. These locations are denoted by blue dots in Figure 4.

Locations 6, 7, and 9 in Figure 4 are municipal parking lots that have been proposed by municipal workers in their municipalities (Tavistock, Thamesford, and Tillsonburg) as being suitable for EVSE installation. Note that the latter location (Location 9) is located very close to the existing EVSE at George's Auto Repair (Location D). In this case, either upgrading the existing EVSE or installing new EVSE will affect the same end-users. Similarly, Location 6 in Tavistock is already close to the existing EVSE at SE Mutual Insurance. Upgrading or new installation is also an option in Tavistock.

Four general areas have been proposed for new high-powered EVSE installation. Of these general areas, Drumbo is the highest priority since there is very low EV chargeability in this region through which Highway 401 passes. One option would be to upgrade the already very good EV charging service at Drumbo Truck stop where there are already two L2 and one L3 EVSEs.

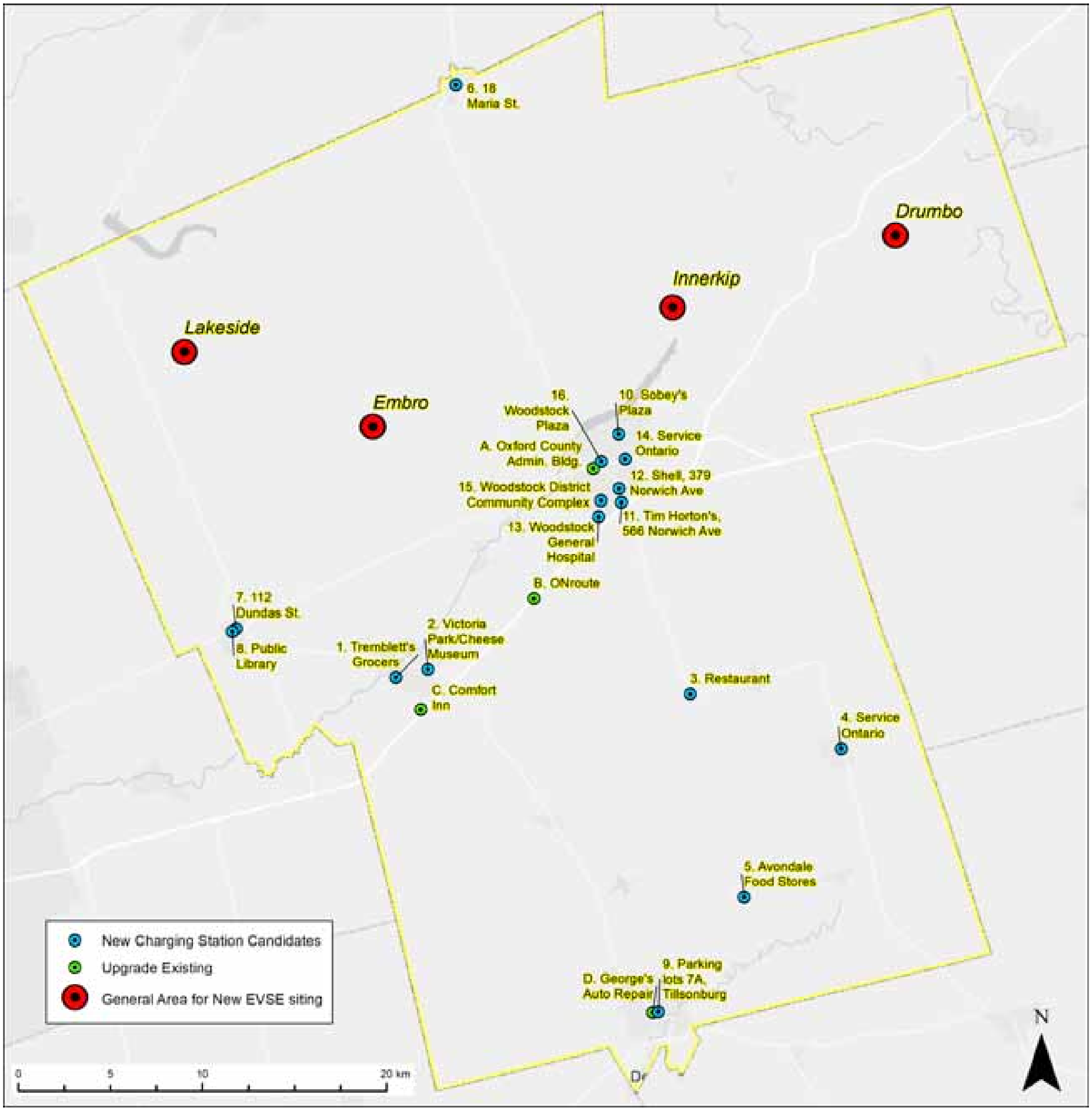

FIGURE 4: CANDIDATE LOCATION MAP FOR NEW AND UPGRADED EVSES. LOCATION 15 IS IDENTIFIED AS SUITABLE FOR LEVEL 1 EVSE ONLY WHILE LOCATION C IS SUITABLE FOR LEVEL 1 AND HIGH-POWERED CHARGING; THESE LOCATIONS ARE DISCUSSED IN THE FOLLOWING SECTION CONCERNING TYPE A USERS. ALSO SHOWN ARE GENERALLY IDENTIFIED AREAS FOR NEW EVSE INSTALLATION.

Type A EV Users

Type A users have much longer residence times at the charging station because they may charge their vehicle while at work. Level 1 EVSE charging is sufficient for this type of EVSE installation and proximity to amenities is not a consideration for siting the charging installation. However, in terms of geography it is beneficial if the EVSE(s) are located within easy walking distance of more than one employer. CUTRIC's review of studies to date demonstrates that easy proximity to place of work is a critical parameter in determining whether an EVSE will have impact. In this report, CUTRIC has chosen 150 metres as a reasonable estimate of whether an EVSE is considered proximal or not. Furthermore, it is assumed that publicly-, or municipally-, owned sites are preferred to sites that are privately owned in terms of ease of EVSE installation.

Figure 5 maps major private and government places of work in Oxford County that have very few, if any, amenities close-by and which are therefore not suited for Level 2 EVSE installation. Coloured circles denote clustering of places of work within a 150-metre radius. From this analysis, only one municipally owned location, Woodstock District Community Complex, serves more then two places of work and therefore seems suitable for installation of L1 chargers.

In addition to its own employees, L1 EVSE situated at Woodstock District Community Complex would also serve employees at nearby Fanshawe College and St. Mary's Catholic School. St. Patrick's Catholic Elementary School is also a ten-minute walk away.

Elsewhere in Woodstock, the region surrounding Woodstock Fire Station #1 is suitable for location L1 EVSE since there are many places of work clustered. However, there is probably insufficient parking at the fire station itself and safety would have to be considered with regard to ease of ingress and egress of emergency vehicles. Therefore, in this region installation of L1 EVSE would have to happen on private land.

Tillsonburg also exhibits good clustering of places of work illustrated by the yellow and red circles and hence potential for high impact of centralised L1 EVSE charging stations but there is apparently no municipally owned land on which to install L1 EVSE. New installation of L1 EVSE would have to be carried out in Tillsonburg on private lands. CUTRIC recommends concentrating in the yellow and red circles to ensure EVSE facilities are used.

Ingersoll has also good clustering of places of work and high impact potential of L1 EVSE installation but there is also no municipally owned land in this industrial area. However, station C, Ingersoll Comfort Inn, previously recommended for upgrading of its L2 capability is situated in close vicinity to places of work such as Glassford Chrysler, FreshAuto, Pow Engineering, J-Tech Design, Ingersoll Home Hardward, Hydra Dyne Tech, and Hammond Air Conditioning. CUTRIC therefore recommends L1 charging capability to be upgraded or installed at this vicinity to cater for local employees, and overnight Comfort Inn guests, in addition to upgrading L2 charging capability to cater for Type B, C, and D users of the nearby 401.

In summary, CUTRIC has identified that Level1 charging capability would have substantial impact on Woodstock District Community Complex and Ingersoll Comfort Inn. Issues concerning land ownership preclude EVSE installation at places of work in Tillsonburg, however, the maps could be used as a guide as where to install Level 1 chargers for maximum impact.

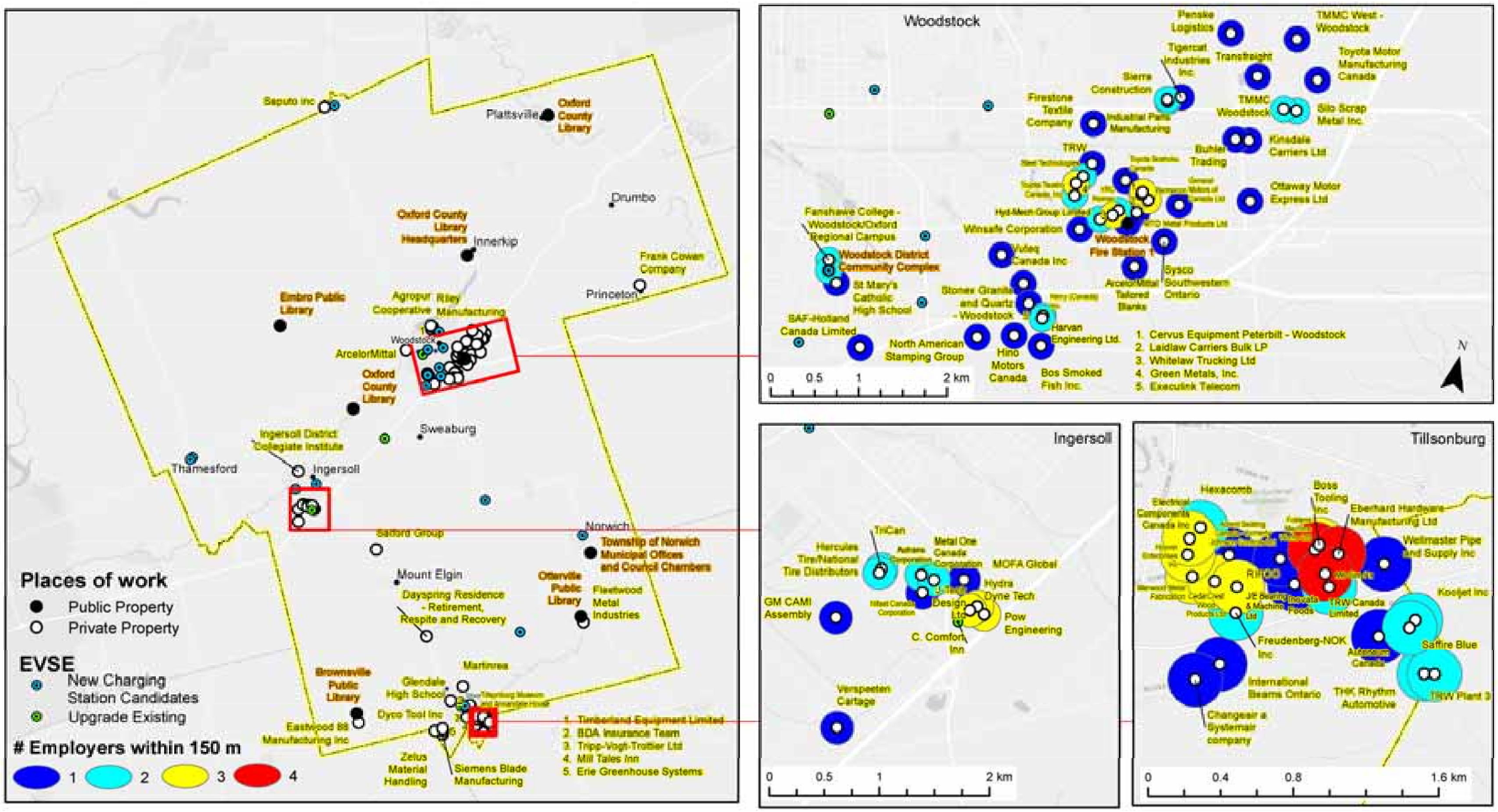

FIGURE 5: OXFORD COUNTY EMPLOYERS. COLOURED CIRCLES DENOTE HOW MANY EMPLOYERS WITHIN AN EASILY-WALKABLE 150 M RADIUS. SITING AN EV CHARGER WITHIN AREAS THAT SERVE MORE THAN ONE EMPLOYER IS PREFERRED. FOR REFERENCE, THE EVSES FOR TYPE B-D USERS FROM FIGURE 4 HAVE BEEN REPRODUCED HERE.

Summary: Recommended Locations and Quantity of EVSEs

Based on the descriptive mappings provided above, along with the typologies provided in Section 2 of this Report, Table 9 below provides a list of recommended locations for EVSEs in which candidate locations to install new EVSEs are numbered, suggested locations to upgrade existing EVSEs are lettered, and suitable locations in general to densify the Oxford County EVSE network are labeled “G”.

The suggested number of required EVSEs identified in this table is based on the results of the predictive analysis considering only the current adoption rate of 0.8%. In other words, the number of Level 1 – Level 3 chargers required at each of these sites is based on an assessment of how many chargers are required to fully serve EV driver needs in and around Oxford today at current EV adoption rates. It is important to note that the existing number of chargers is deducted from the minimum number of required EVSEs to reach the final recommendation.

TABLE 9: CANDIDATE (NUMBERED), UPGRADE (LETTERED), AND GENERAL ("G") LOCATIONS MAPPED IN FIGURE 4

#	Locality	Property Description	Ownership	Name	Parking spaces	Amenities	L1	L2	L3
1	Ingersoll	Free-standing supermarket	Private	Tremblett's Grocers, 306 King St. W. Ingersoll	>20	Large grocery store	-	2	-
2	Ingersoll	Non-commercial sports complex	Private	Victoria Park/Cheese Museum, 290 Harris St, Ingersoll	<20	Petrocanada gas station	-	1	-
3	Norwich	Automotive fuel station with or without service facilities	Private	Restaurant, 593737 CR-59, Burgessville	<20	One restaurant only	-	1	-
4	Norwich	Service Ontario	Public	Service Ontario, 34B Main St W, Norwich	>20	Many	-	2-10	-
5	Springford	Free-standing supermarket	Private	Avondale Food Stores, 3 West Street N, Springford	<20	Convenience Store only	-	1	-
6	Tavistock	Municipal Parking	Public	18 Maria St, Tavistock	<20	Canada Post, Pharmacy, Scotiabank	-	1	1

#	Locality	Property Description	Ownership	Name	Parking spaces	Amenities	L1	L2	L3
7	Thamesford	Municipal Parking	Public	112 Dundas St., Thamesford	24	RBC Royal Bank, Tim Horton's, R&J Family Restaurant Bar & Grill	-	1	-
8	Thamesford	Public Library	Public	Thamesford Public Library	>20	Many	-	2	-
9	Tillsonburg	Municipal Parking 6A and 7A	Public	Intersection of Bridge St. and Lisgar St.	287 (6A) 243 (7A)	Shoppers Drugmart, Walmart	-	2	2
10	Woodstock	Neighbourhood Shopping Centre	Private	Sobey’s Plaza, 984 Devonshire Ave, Woodstock	>20	Sobey's, Scotiabank, restaurants	-	2-10	-
11	Woodstock	Restaurant - Fast-food, National chain	Private	Tim Horton's, 566 Norwich Ave, Woodstock	>20	Many Restaurants, Holiday Inn Express, Days Inn, Quality Hotel and Suites	≈40	2	-
12	Woodstock	Automotive fuel station with or without service facilities	Private	Shell, 379 Norwich Ave, Woodstock	>20	Cafe, many restaurants	-	2	-
13	Woodstock	Hospital	Private	Woodstock General Hospital, 310 Juliana Dr, Woodstock	>20	Hospital, Country Pride Truck Stop	-	2-10	2
14	Woodstock	Service Ontario	Public	Service Ontario, 925 Dundas St. Unit 5A, Woodstock	>20	Many	-	2-10	-
15	Woodstock	Woodstock District Community Complex	Public	Woodstock District Community Complex, 381 Finkle St., Woodstock	>20	Few, only suitable for L1 at this site	≈40	-	-

#	Locality	Property Description	Ownership	Name	Parking spaces	Amenities	L1	L2	L3
16	Woodstock	Neighbourhood Shopping Centre	Private	Woodstock Plaza, 645 Dundas St.	>20	Goodlife Fitness, Foodland, many others	-	2	-
A	Woodstock	Municipal Building	Public	Oxford County Admin. Bldg., 21 Reeve St., Woodstock	>20	Banks, Restaurants, Woodstock Museum	≈40	2	-
B	Foldens	Travel Plaza	Private	Woodstock Travel Plaza, 401223 Hwy 401 West, Ingersoll	>20	Purpose-built travel plaza with Tim Hortons, Starbucks, restaurants, etc.	-	2	2
C	Ingersoll	Hotel	Private	Ingersoll Comfort Inn, 20 Samnah Crescent, Ingersoll	>20	Hotel, Restaurants, CIBC, Tim Hortons	≈40	2	1
D	Tillsonburg	Auto Repair	Private	George's Auto Repair, 10 Bridge St.	<20	Supermarket, Restaurants, Banks, Service Ontario	Either 9 or D. 9 is a better location.		
G	Lakeside	N/A	N/A	N/A	N/A	N/A			
G	Embro	N/A	N/A	N/A	N/A	N/A			
G	Innerkip	N/A	N/A	N/A	N/A	N/A			
G	Drumbo	N/A	N/A	N/A	N/A	N/A			

Concluding Remarks

The electric car market has been growing exponentially in the past few years. But it is still a small percentage of the new car market in most places, typically representing less than 1% of new car sales. Currently, in Ontario the EV market share is 0.8 per cent (Canadian EV Sales, 2017).

The results of a series of EV surveys (which conducted with over 2,000 participants from the U.S., Canada, the U.K., and Australia) shows that one of the key benefits cited by EV owners was the convenience of home charging for their vehicle, and the avoidance of going to a gas station and having to refill their tank at those locations. However, EV drivers also indicated that having more abundant EV charging would be the number one way to promote EV adoption. Non-EV owners cited more abundant charging infrastructure as the second-best solution to increase EV adoption, behind better financial incentives (Shahan, 2015).

When potential EV owners were asked about factors that would increase their likelihood of purchasing an EV, 65 per cent stated that they would be significantly more attracted to a fully electric model if they had access to a fast-charging network of Level 3 charging stations (ibid.). However, it is important to note that the costs of Level 3 systems installations is around $50,000 USD, but with the inclusion of costs for project development, design, permitting, and electric system upgrades, the total costs for deployment could reach up to $300,000 USD each. The high costs limit the business argument for Level 3 or DCFC chargers, with the ability to afford such a charger being dependent upon rate design, ownership, and utilization rates. It may therefore be more beneficial for a jurisdiction to offer rebates on the installation of home or workplace Level 2 charging stations to best serve the charging patterns of EV owners (Fitzgerald & Nelder, 2017).

In addition, 26 per cent of EV owners frequently find that current charging infrastructure presents a limitation on where they may want to go with their EV, while another 29 per cent state that it is sometimes a limitation. A total of 36 per cent of EV owners indicate that charging infrastructure only becomes an issue on long trips, while only 9 per cent of EV owners indicate that EV charging infrastructure availability is never a problem or limitation on travel. It is important to note that of all respondents, approximately 30 per cent owned a Plug-In Hybrid Electric Vehicle (PHEV) or Extended Range Electric Vehicle (EREV) and 28 per cent owned a Tesla; therefore, even owners of high-capacity long-range electric vehicle models experience some limitations in available charging infrastructure (Shahan, 2015). The availability of EVSEs and improvements to current charging infrastructure constitute an important solution in addressing consumer limitations regarding EV adoption and in supporting demand growth within the EV market.

The final section of this report provides several normative recommendations that may help the County optimally locate and deploy EVSEs based on the guiding principle that increasing EV ownership and best supporting current EV owners in the community today will help to achieve Oxford's long-term sustainability plans.

General recommendations

Charging Systems dedicated to condominium and high-rise buildings

Over 90 per cent of EV charging occurs at home for EV owners with home garages. For owners living in dwellings with parking garages or on-street parking, where the installation of a charging station is out of their control, EV adoption may be less likely without an expanded public charging network. The good news for these individuals is that the EV charging station market is growing exponentially, with carmakers, governments and commercial charging firms all investing in the installation of new EVSEs. Tesla is planning to expand its global network of 145 kW "supercharger" stations to 10,000. Nissan now has a global network of 4,000 fast chargers. In 2016, Daimler, BMW, Volkswagen and Ford also stated their intention of collectively installing 400 public charging-point in Europe delivering 350 kW (The Economist, 2017).

Therefore, for further EVSE expansion, it might be better to focus any data collection, targeted at accommodating personal vehicle use for Oxford County residents, on densely populated urban areas with condominiums and apartments. Residents within these buildings looking to purchase a personal EV are often dependent on the landlord to install EV chargers in the underground parking lot. If insufficient condominium or apartment building charging is available, then providing charging stations at workplaces could help building residents receive adequate access to charging infrastructures. The data collection may include gathering information about the location of high-rise condominiums, and whether there are any EV owners living in those buildings.

Workplace charging systems

Another opportunity to encourage EV adoption is the workplace charging stations. The U.S. Department of Energy PEV studies found that around 30 per cent of drivers almost exclusively charged up at work, showing that workplace charging availability could make EVs viable for people without access to home charging stations (Francfor *et al.*, 2015). Chargepoint - a California-based company that runs many charging stations worldwide - encourages businesses to offer employees free [or discount rate] charging in the office car lot (ibid.).

Innovative solutions

Innovative business models and technology should also increase the availability of charging options for EV owners. For example, an app called Chargie (similar to PlugShare in Canada and U.S.) was recently launched in Britain that allows owners of home chargers to rent them to the public, similar to an Airbnb rental. Technological innovations such as wireless inductive charging from road to car is already a technically feasible, albeit expensive, but boasts strong merit for vehicles that sit idle such as taxis (ibid.).

Ownership models

There is no set EVSE ownership or billing structure as of yet, and EV owners have complained about crossing over from one network to another and needing to carry a variety of cards or accounts to charge their vehicles in different jurisdictions. When determining EVSE ownership roles, it is beneficial to assess EVSE ownerships in nearby areas or along highway routes to determine what would be most convenient for EV owners and encourage the highest usage (Fitzgerald & Nelder, 2017).

According to a report published by the Rocky Mountain Institute (RMI), there is no ideal ownership model for EVSE and jurisdictions should test various models through pilot projects to determine what works best in a given region (ibid.). Examples of different ownership models include ownership by the state authority as a form of public utility, municipalities, charging network operators and businesses.

Most legislative and regulatory bodies are in agreement that utilities should be permitted to build and own make-ready locations (i.e., power supplied to the point where a charging station might be installed), and to recover the investments through the rate base as a general social good. Allowing utilities to create make-ready locations would align with the long-established principle of line extension, where all customers pay for extending the distribution grid, including new service for rural customers where the cost of providing that service is far greater than that for customers living in densely populated urban environments (ibid.).

Following this reasoning, the extension of the grid to support EVSEs is not justified through a cost-benefit analysis when burdened only by a specific group of customers. The value of the entire network is considered to be shared by all customers and the environmental benefits of EV will reach all customers. This reasoning allowed telephone companies to build out the pay phone network; each new phone wasn't necessarily expected to make a profit, but installation was considered necessary to create a functional and accessible network (ibid.).

Utilities owning and installing charging stations could be the fastest way to deploy EVSEs since utilities have access to large amounts of low-cost capital and an ability to recover investments over decades. Utility ownership may also serve to regulate electricity markets and avoid overpricing by private sector companies (ibid.).

However, regulators should also be cautioned against creating a situation where a utility could leverage its low internal cost of power generation and delivery to undercut private sector competitors on retail charging prices. Full utility ownership could prevent a competitive private sector market in charging stations, and utilities may not be as innovative in terms of technology or business model design as the private sector would likely be. If regulators choose utility ownership as the primary model, they should ascertain some opportunity for private sector companies or ensure that once the EVSE market matures in an area, it is possible for private companies to re-enter the market (ibid.).

EVSEs ownership models exclusively for private sector companies would likely yield the installation of chargers since private businesses are less likely to have large amounts of patient capital and may wait for guaranteed demand of charging station and market maturation prior to installation. The California Public Utilities Commission (CPUC) exemplified this pattern. The CPUC initially thought that competitive benefits from a private market would outweigh the benefits of utility ownership and therefore deployed an exclusive private market model. However, the rate of EVSE installation was found to be too slow to meet the state's objectives, and an alternative model with mixed utility ownership is now being tried (ibid.).

Tariff models

It is important for utilities to offer appropriate tariffs for EV charging early on before EV penetration is large. Once EV drivers acquire their charging habits it can be hard to break them. It is important that the tariffs are developed appropriately to guide charging towards the valley of system load profiles and away from the peaks. Field experiences studied indicate that optimal tariffs for EV charging use a time-of-use (TOU) design. Tariffs should also be lower for Level 1 and Level 2 charging than for Level 3 systems, because the cost of providing service to Level 1 and 2 chargers is lower and they are easier to manage and deliver grid services (Fitzgerald & Nelder, 2017).

To encourage off-peak charging, a business may find that a commercial tariff with a flat rate for electricity is best for its general, nondiscretionary loads, but that Level 2 charging stations installed for customers and employees should have a TOU tariff that features a large differential between on- and off-peak rates. For this occur, many utilities require that a charging station be connected through a dedicated meter, separated from other loads at the site, although this does incur an additional cost to the business (ibid.).

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Appendix I: A Literature Review of Factors Determining Siting of Hydrogen Fueling Stations

The absence of Hydrogen infrastructure in terms of Hydrogen storage, distribution and refueling capacities had been a significant barrier to the large-scale entry of hydrogen fuel cell vehicles (HFCVs) in the market and their on-road deployment. Some countries, including the U.S., U.K., Germany, Norway and Canada, have launched initiatives to develop hydrogen refueling facilities on expressways (He *et al.*, 2017). The demonstration projects were unable to increase the rate of hydrogen vehicle adoption because the high rates of hydrogen production and resultant high cost of HFCVs remained economically unfeasible for most parties. Site selection and design of hydrogen refueling plants could reduce hydrogen delivery costs per HFCV, therefore being an important criterion for selection. Future initiatives need to focus attention on deriving maximum value from investments made to meet the capital and operation costs for refueling stations (He *et al.*, 2017).

The California Hydrogen Highway Project was a government-sponsored project dedicated to the development of Hydrogen infrastructure to support the on-road deployment of HFCVs (California Energy Commission, 2010). Locations for refueling stations was an important component of the project to ensure that HFCV deployment could occur over an extended range. The refueling stations were initially clustered around the deployment zone (California Air Resources Board, 2008).

The station capacity, which was governed by daily fuel dispensation rate (kg/day), remains a critical characterization parameter for refueling stations. In order to account for the heightened traffic during daylight hours, which lead to underutilization and longer wait times, SAE came up with a modified dispensation rate in terms of peak kg/hour to characterize the refueling stations (Society of Automotive Engineers, 2009).

Brown *et al*. (2012) analyzed the operational parameters of a hydrogen refueling station, established as part of the California Hydrogen Initiative. This station had dual dispensing pressures (35 and 70 MPa) and an extended storage capacity. Due to an increased demand for refueling, this station had operated significantly above its design capacity with a long wait time. Despite the station remaining open for 24 hours, the refueling was concentrated during waking hours. The hydrogen, delivered in a liquid state, was stored in three storage tubes capable of storing a total of 52 kg hydrogen at 54 MPa by means of a compressor. For refueling 35 MPa vehicles, hydrogen was first dispensed from the lowest pressure storage tubes while the higher-pressure tubes came into operation once the pressure in the vehicle tank equalizes the pressure in the low-pressure storage tube. The refuelling of higher capacity vehicles having 70 MPa capacity required the existing low-pressure storage tube at 54 MPa to be further pressurized to 80 MPa by means of a reciprocating pump (Brown *et al*., 2012). The high-pressure compression requires that additional heat dissipation equipment be encompassed in the infrastructural needs.

Enhanced operation of the hydrogen refueling station during certain hours of the 24-hour operation causes the consumption rate to be higher than the average (2 kg/hr), resulting in a shortage of hydrogen. The main constraints to increasing the hydrogen dispensation included the type, rate and scheduling of filling events. Long waiting times and inadequate filling due to low pressure were key issues faced by both the 35 MPa and 70 MPa capacity vehicles. There was an additional requirement of pre-cooling for the 70 MPa capacity vehicle. Higher temperatures from the combination of ambient and high-pressure dispensing resulted in an automatic cut-off of dispensing until the temperature cooled down (Brown *et al.*, 2012).

A behavioural trend was observed, whereby 70 MPa capacity vehicle owners opted for lower range 35 MPa to avoid longer waiting times. From 2007-2011, there was an increase in the total hydrogen dispersed per year, average hydrogen dispersed per day, average hydrogen per fill and maximum hydrogen dispensed in one day. It was also observed that the nominal design dispensing capacity of 25 kg/day (based on compressor capacity of 2 kg/hour with 50% duty cycle) was exceeded for 40% of the working days in 2011. Various physical processes, such as compression, refrigeration, dispensing, control systems and lighting, utilized electric energy at an almost linear rate of 5.18 kWh per kg of hydrogen dispensed. In terms of the power requirements, 35 MPa and 70 MPa refilling leads to a peak load of 12 kW and 30-35 kW, respectively (Brown *et al.*, 2012).

Melaina (2003) highlighted the key underlying factors which have remained instrumental in determining the location of refueling stations: 1) proximity to regions with high traffic volume; 2) ease of accessibility to potential first HFCV buyers; 3) ability to fuel vehicles for long distance trips; and 4) proximity to high profile areas to increase public awareness. This work demarcated the hydrogen fuel refueling stations into metropolitan oriented or interstate oriented with the realization that the metropolitan oriented stations would be the “prime” stations while the interstate oriented stations would be “placeholder” stations, ensuring hydrogen availability for rare events or long-distance trips (Melaina, 2003).

This work chronologically divided the hydrogen vehicle adoption process into two stages - the first involved the installation of enough refueling stations to support environmentally sensitive individuals adopting HFCV, and the later stage involved the installation of a larger number of refuelling stations to cater to the general public. A phased increase in the production volumes of HFCV is expected, to match the predicted high sales when Phase 2 arrives (Melaina, 2003).

Ni *et al.* (2005) utilized population density, car ownership, market penetration rate, and fuel use from GIS maps to estimate hydrogen demand. A clusterization approach is utilized to demarcate areas with demand density greater than a given threshold, to represent regions of high hydrogen demand (Ni *et al.*, 2005). Melendez & Milibrandt (2005) also planned a network of hydrogen refueling stations on highways to enable interstate travel based on HFCVs. This was achieved by estimating the HFCV demand and the corresponding hydrogen refueling station requirement through literature review and through interviews with experts. Various parameters were evaluated to gauge consumer’s potential interest in buying a HFCV and were assigned weights to account for consumer’s preferences. The sum total of all weights is considered a measure of consumer’s potential interest (Melendez & Milibrandt, 2005). This technique, involving the division of geographical area into distinct entities while ensuring equal distribution of households followed by quantifying relevant numerical or behavioral parameters for assessment, has been utilized in further studies (Greene *et al*., 2008; Kuby *et al*., 2009).

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Appendix II: Individual Voronoi maps for Existing Level 1, Level 2, Level 3, and Tesla chargers in Oxford County

The Charging Index, formulated to quantify the charging ability of a particular EVSE location,

As previously mentioned.

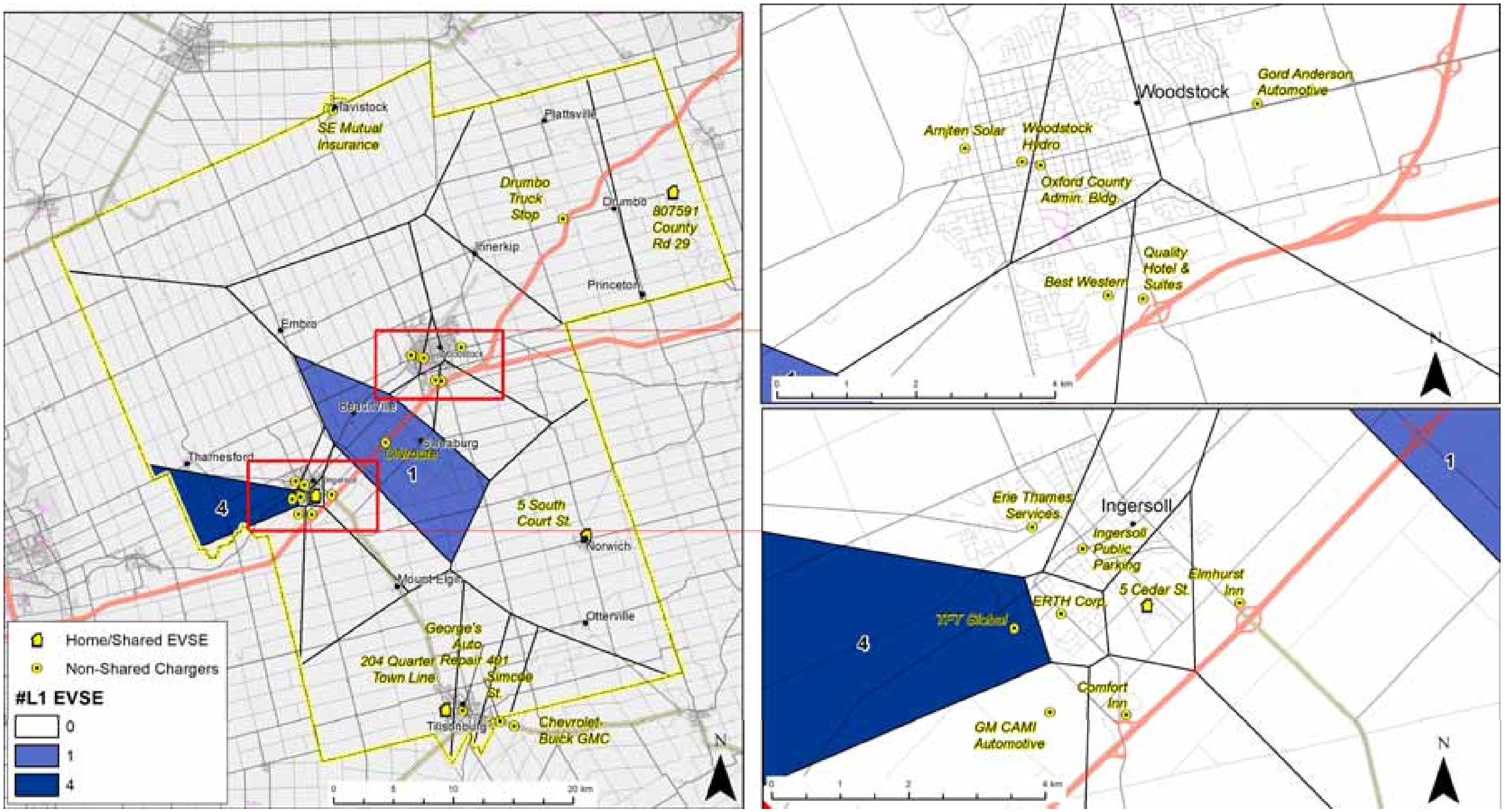

Figure VII: Voronoi polygon representation of L1 EVSE catchments. Polygon numbers and colours correspond to the number of L1 chargers at the nearest EVSE installation.

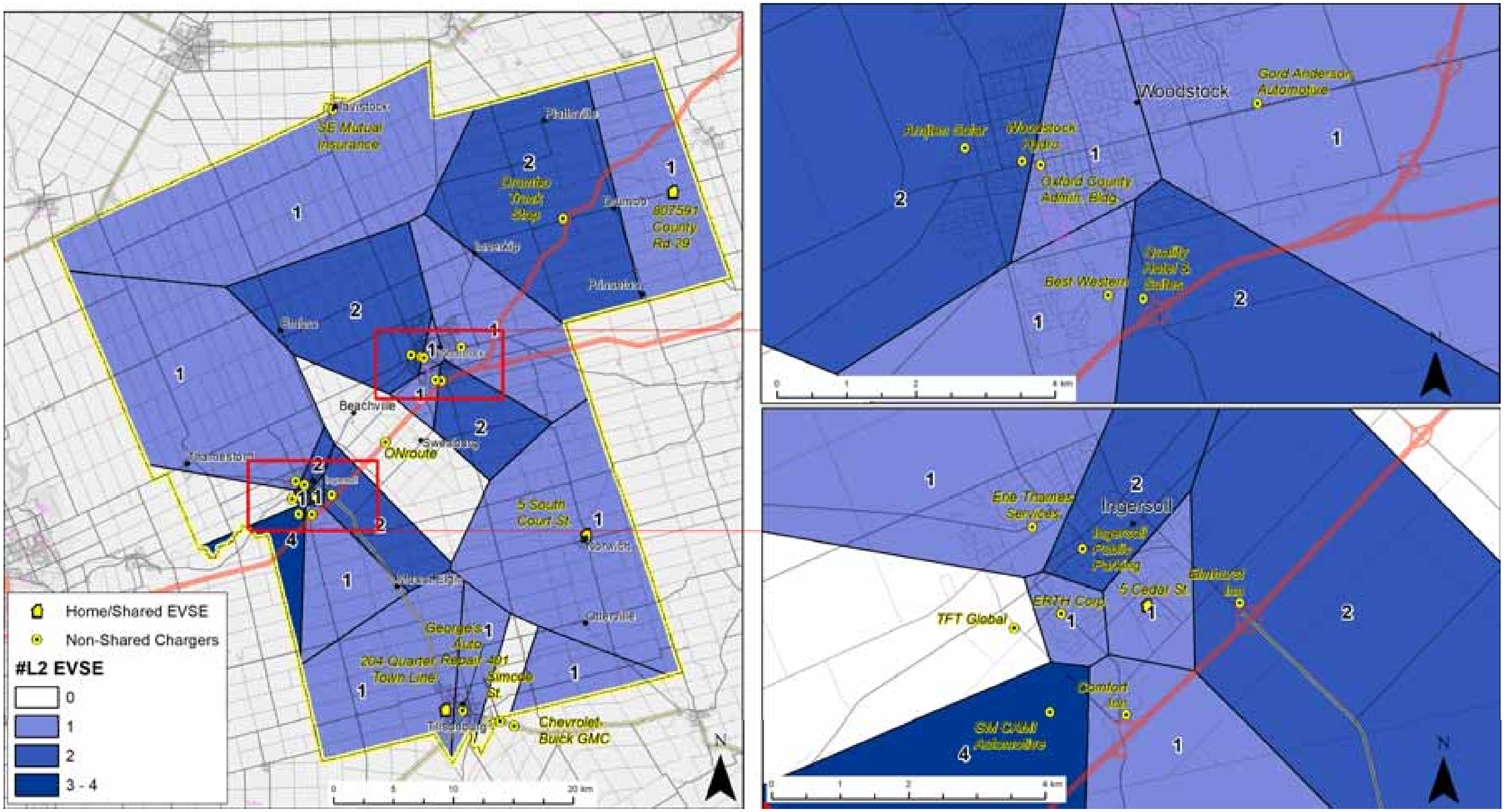

Figure VIII: Voronoi polygon representation of L2 EVSE catchments. Polygon numbers and colours correspond to the number of L2 chargers at the nearest EVSE installation.

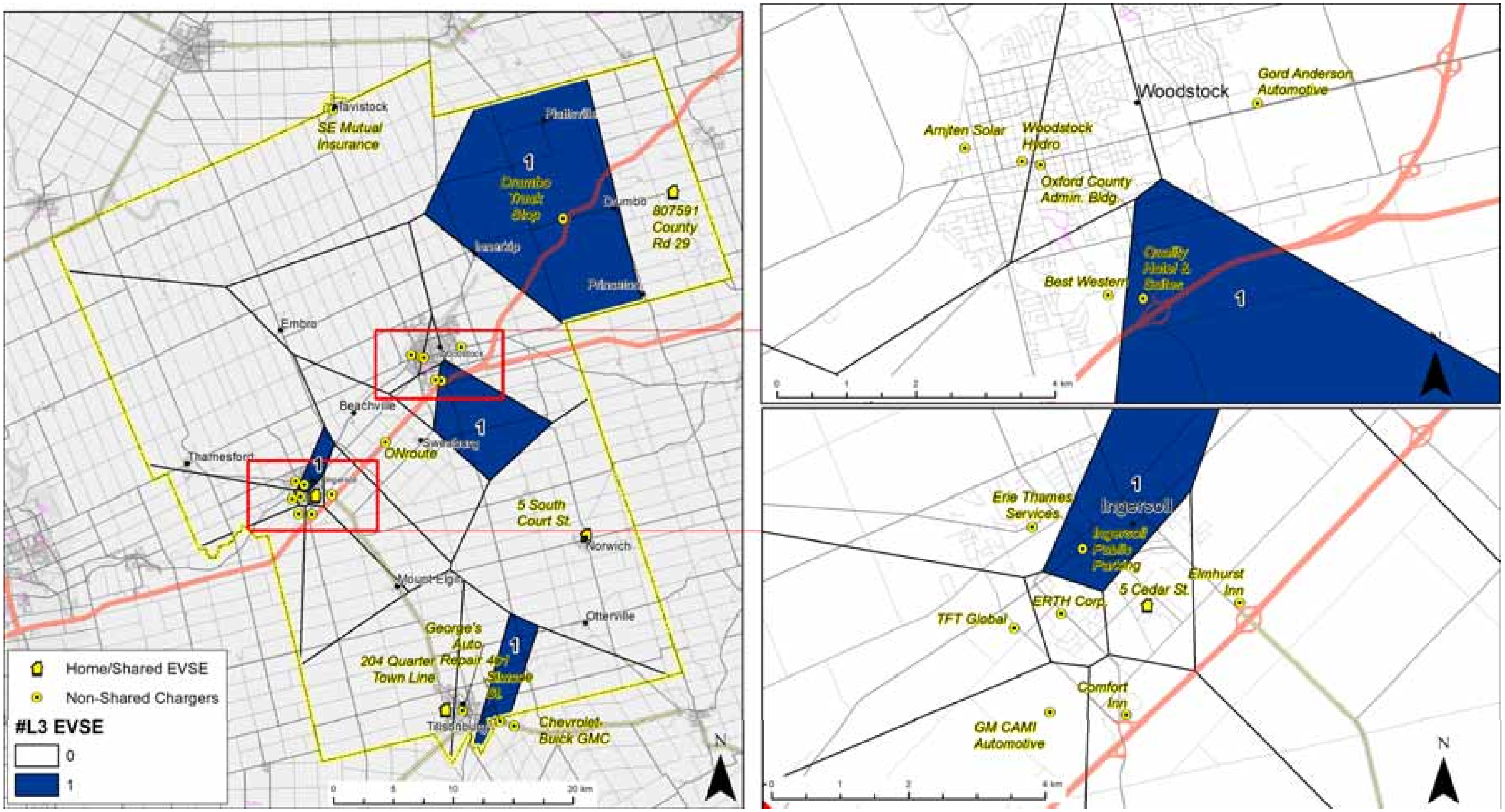

Figure IX: Voronoi polygon representation of L3 EVSE catchments. Polygon numbers and colours correspond to the number of L3 chargers at the nearest EVSE installation.

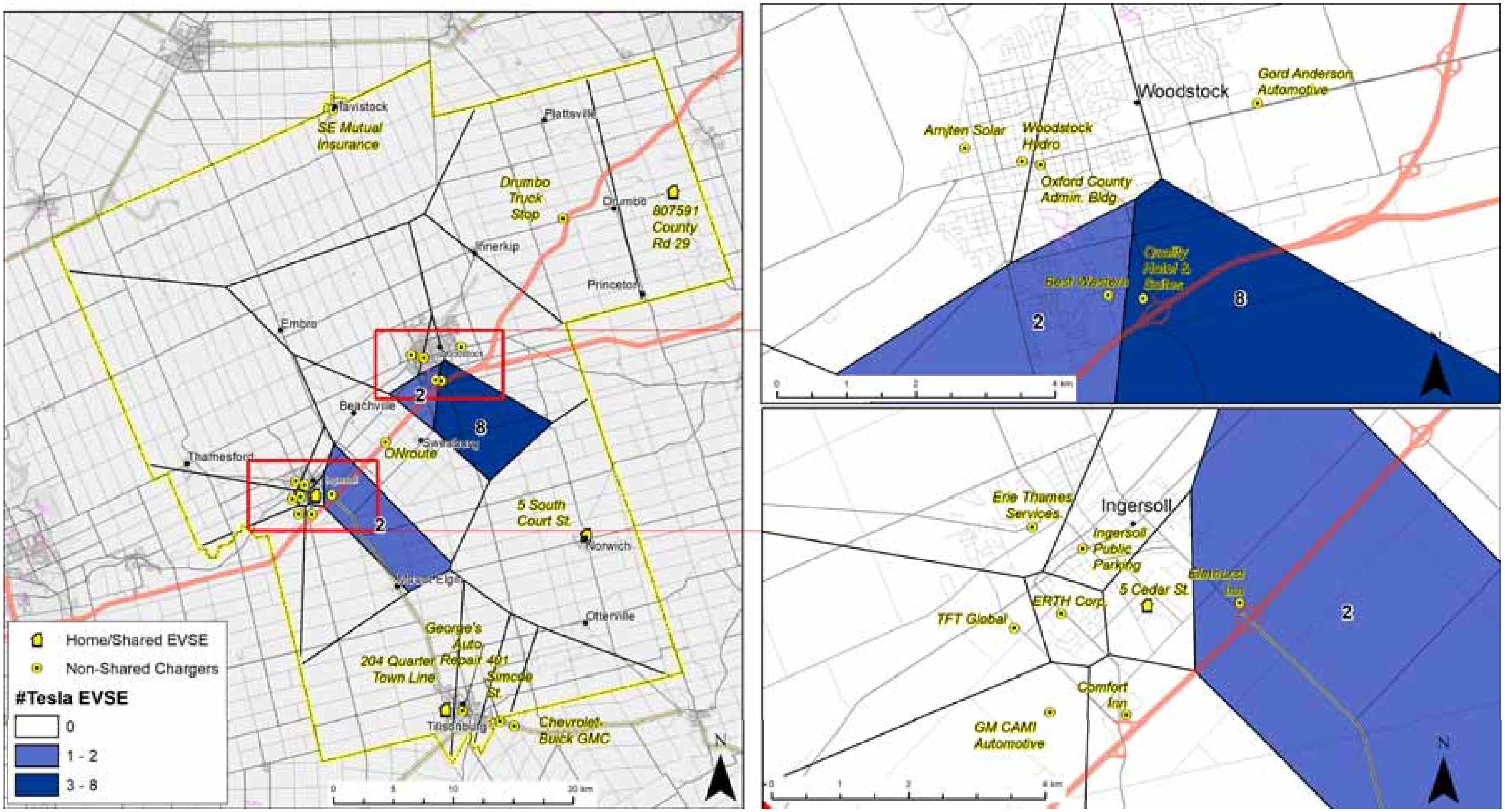

Figure X: Voronoi polygon representation of Tesla EVSE catchments. Polygon numbers and colours correspond to the number of Tesla chargers at the nearest EVSE installation.