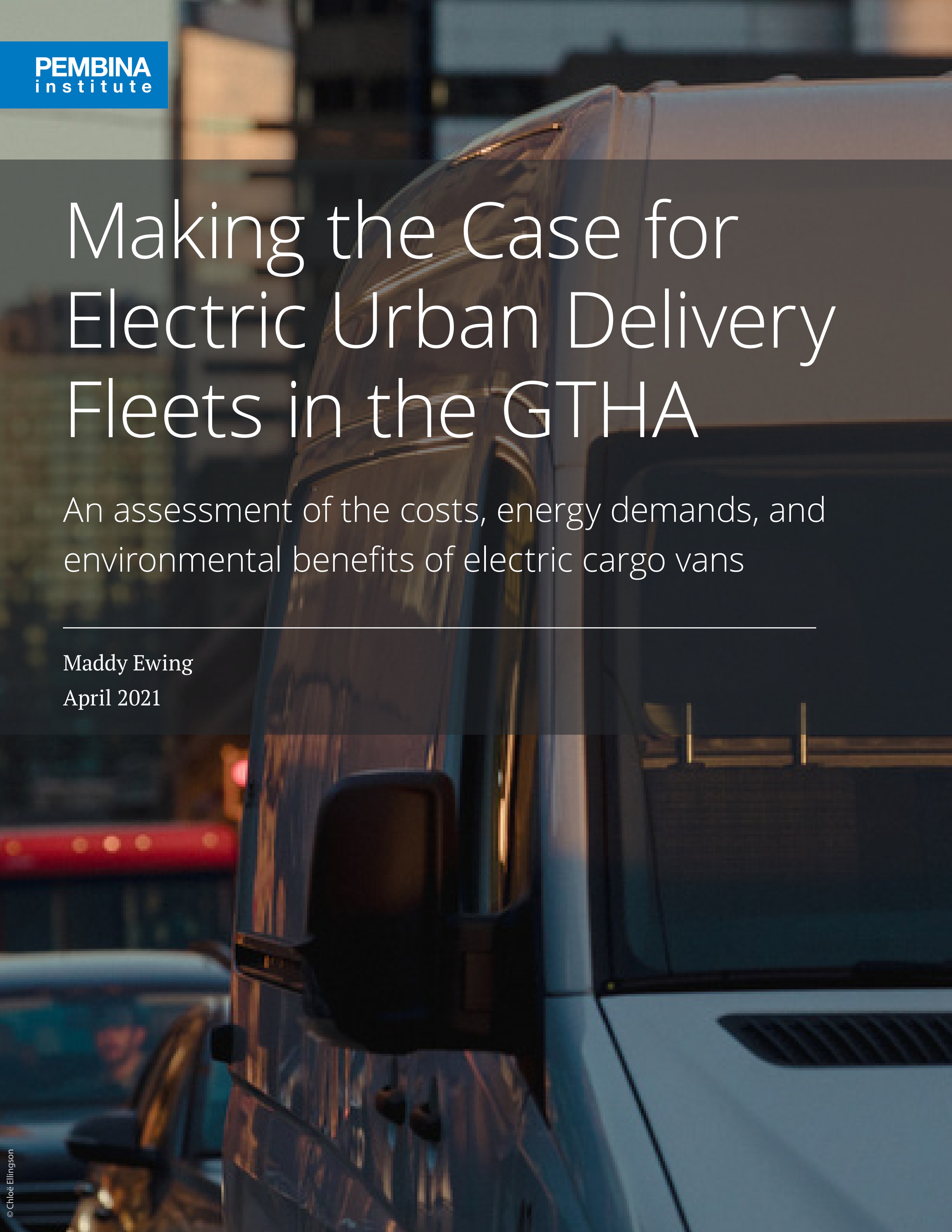

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Making the Case for Electric Urban Delivery Fleets in the GTHA

An assessment of the costs, energy demands, and environmental benefits of electric cargo vans

Maddy Ewing

April 2021

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Contributors: Carolyn Kim
Design/Layout: Roberta Franchuk

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The Pembina Institute
219 19 Street NW
Calgary, AB
Canada T2N 2H9
Phone: 403-269-3344

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Executive summary

As door-to-door deliveries increase year-to-year in Canadian cities, a switch to electric cargo vans — one of the most common vehicle types used for urban deliveries — is one way for businesses and fleet operators to mitigate their impact on climate change and air quality. In the Greater Toronto and Hamilton Area (GTHA), where the greenhouse gas (GHG) intensity of grid electricity is particularly low, battery-electric vehicles (EVs) are expected to offer significant GHG emission reductions in comparison to internal combustion engine vehicles (ICEVs). Moreover, EVs do not produce tailpipe emissions and thus do not contribute significantly to the degradation of local air quality. But the reality is that although this zero-emission technology exists today and there are examples of electric delivery vans operating in other global and Canadian cities, the deployment of fully electric delivery vans in the GTHA is still in its infancy.

Switching to fully electric vehicles is complex and requires businesses and fleets to have a comprehensive understanding of existing and future operational needs, infrastructure, and energy demands, along with the costs associated with transitioning to a new transportation and energy system. To help businesses understand the costs and benefits of operating battery-powered electric urban delivery vehicles in the GTHA, this analysis sets out to uncover the expected costs, energy demands and GHG emission savings associated with a switch to electric cargo vans. A set of 13 drive cycles were created to understand the average energy demands of electric cargo vans travelling in the GTHA under various conditions. These cycles were informed by on-the-ground experience and operations of several major urban delivery businesses, as well as real-time operating data. Considerations were given to external temperature, number of delivery stops, congestion levels, cargo load, and the slope of the terrain. Fuel cost estimates have been calculated and combined with total cost of ownership data provided by clean transportation non-profit organization CALSTART on the upfront vehicle, maintenance and charger costs associated with an electric urban delivery vehicle to identify the average payback period of electric cargo delivery vans operating in the GTHA. The charging infrastructure that is required to support typical return-to-base delivery operations is also identified, as well as potential GHG emission reductions in comparison to an equivalent ICEV.

This modelling exercise demonstrates that fleet operators delivering parcels and packages in the GTHA can realize notable economic and environmental benefits as a result of switching to an EV. Based on the modelling analysis, the key findings are as follows:

- **Daily energy demands:** Return-to-base urban delivery EVs have low daily energy demands. All electric cargo van models currently available on the market today, as well as new models under production, are expected to satisfy the daily energy demands of urban delivery companies in the GTHA — even under the most energy-demanding scenario that was explored.
- **Charging requirements:** As a result of relatively low daily energy demands, EVs can charge overnight using Level 1 or Level 2 charging across all of the scenarios that were explored — even those that explored the impact of "stressful" conditions such as extreme cold temperatures. This means that businesses in the GTHA may not be required to invest in direct current fast charging (DCFC) infrastructure, which can significantly increase their capital costs.
- **Fuel cost savings:** EVs are expected to result in considerable fuel cost savings in comparison to ICEVs. Over the course of a year, businesses can expect to save an average of $3,800 to $4,400 per vehicle for Level 1 and Level 2 charging, respectively. (These cost savings do not reflect the impact of carbon pricing, which provides further incentive to switch to EVs.)
- **Payback period:** The higher upfront capital costs of an EV compared to an ICEV are expected to be recovered by annual cost savings in approximately seven to eight years. This payback period is reasonable as it falls within the typical vehicle ownership cycle of the businesses that participated in this study.
- **GHG emission savings:** EVs offer substantial GHG emission savings in comparison to ICEVs. On average, an annual reduction of 12 tonnes CO_2e per vehicle is expected. This is equivalent to taking 2.6 passenger cars off the road for one year.

Table 1 highlights the key performance metrics associated with the operation of an electric cargo van under the baseline scenario. This scenario reflects the average operations of door-to-door urban delivery vehicles in the GTHA.

Table 1. Key results associated with EV operation under baseline scenario

Performance Metric	Value (per vehicle)
Daily energy demand	10.3 kWh
Rate of battery consumption	0.18 kWh/km
Level 1 charging time	7.3 hrs
Level 2 charging time	1.6 hrs
Rate of fuel cost savings – Level 1 charging	$0.21/km
Rate of fuel cost savings – Level 2 charging	$0.18/km
Payback period – Level 1 charging	6.8 years
Payback period – Level 2 charging	7.8 years
Rate of GHG emission savings	0.56 kg CO_2e/km
Annual GHG emission savings	12 tonnes CO_2e

Overall, even under scenarios where the most stressful conditions were modelled — vehicles operating in cold temperatures, with heavy payloads, and many stops — fully electric cargo vans are expected to be relatively easy to charge and cost-effective, and to significantly reduce emissions in comparison to ICEVs.

While our analysis demonstrates the economic and environmental benefits for urban delivery electrification based on some costs and average conditions, the extent or the magnitude of cost savings and GHG emissions abated will vary significantly from one business to another and will be contingent on other site-specific factors and considerations; for example, the cost of infrastructure and grid upgrades to accommodate existing and future energy demands, costs associated with software and network contracts, and electricity costs. Therefore, the results in this report are intended to be a starting point for businesses as they undergo their own assessment and planning efforts to switch to EVs.

1. Introduction

The Greater Toronto and Hamilton Area (GTHA) is home to one of the fastest growing metropolitan regions in Canada and the United States.[1] Greenhouse gas (GHG) emissions from transportation represent one-third of the region's total emissions, and emissions from this sector continue to grow despite improvements in vehicle efficiency and the use of cleaner fuels.[2] As municipal governments in the region develop their plans and strategies to tackle emissions from transportation, it is critical that they do not overlook the freight and goods movement sector. Though commercial vehicles only represent approximately one-fifth of the region's transportation-related GHG emissions,[3] activity from the sector is growing.

In particular, there has been a significant rise in the number of parcel deliveries since the onset of the COVID-19 pandemic, which has accelerated the shift towards e-commerce as more Canadians choose to shop online. It's estimated that Canadian retail e-commerce sales grew by 54% in 2020 alone and will grow another 27% by 2023.[4] The rise in demand for home delivery, however, can lead to an increase in the number of delivery trucks and vans on city streets, which can contribute to a rise in greenhouse gas (GHG) emissions and the potential degradation of local air quality. Prior to the onset of the COVID-19 pandemic, freight-related GHG emissions were already on the rise in Canada and were projected to surpass those of passenger vehicles by 2030.[5] The increasing popularity of e-commerce and the proliferation of delivery trucks on city streets will only exacerbate this trend.

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[1] City of Toronto, "City of Toronto Takes Top Spot as Fastest Growing City in Canada and U.S.," June 12, 2020. https://www.toronto.ca/news/city-of-toronto-takes-top-spot-as-fastest-growing-city-in-canada-and-u-s/

[2] Maryam Shekarrizafard and Juan Sotes, *Reality Check: Carbon Emissions Inventory for the Greater Toronto and Hamilton Area 2018* (The Atmospheric Fund, 2021), 11. https://taf.ca/wp-content/uploads/2021/02/TAF_RealityCheck-Emissions-Inventory-2018.pdf

[3] *Reality Check.*

[4] Canada Post, "A Record-Setting End to an Unprecedented Year Provides Canada Post with Key Learnings for 2021 and Beyond," *Cision*, January 18, 2021. https://www.newswire.ca/news-releases/a-record-setting-end-to-an-unprecedented-year-provides-canada-post-with-key-learnings-for-2021-and-beyond-891786722.html

[5] Government of Canada, *Canada's Fourth Biennial Report on Climate Change* (2019), 122. https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/1687459_Canada-BR4-1-Canada%E2%80%99s%20Fourth%20Biennial%20Report%20on%20Climate%20Change%202019.pdf

A switch to electric delivery vans and trucks can help mitigate some of the potentially negative impacts of urban delivery in the GTHA and other Canadian cities and regions. Electric vehicles (EVs) draw their power from the electricity grid, and thus can have significant climate benefits in areas where the GHG intensity of grid electricity is low. The electricity grid in Ontario has a relatively low average GHG intensity (40 g CO_2e/kWh),[6] and as such, EVs adopted in the GTHA are expected to generate little GHG emissions and offer significant benefits over their fossil-fuelled counterparts. Moreover, EVs produce no tailpipe emissions, and therefore can reduce negative impacts on air quality in local communities.

Urban delivery vehicles are well-suited for electrification. They tend to travel relatively short distances and so are unlikely to provoke "range anxiety." Urban delivery vehicles also typically return to a central depot at the end of each shift and so can easily take advantage of overnight charging when electricity rates are lowest. In fact, CALSTART's beachhead strategy for zero-emission commercial medium- and heavy-duty vehicles, which identifies the stages of market transformation by vehicle segment, has identified delivery as the second "wave" of electrification, after transit.[7] It's expected that lessons learned from early electric transit bus deployment can help advance electrification of the urban delivery vehicle market.

Several major North American companies have announced their commitment to urban delivery electrification. For instance, Amazon has announced that it is purchasing 100,000 custom-made electric cargo vans from Rivian.[8] UPS, meanwhile, has purchased 10,000 electric vans from Arrival,[9] and FedEx has acquired 1,000 from Chanje.[10] Purolator has been testing low-speed electric vehicles on delivery routes in Toronto and Montreal, and in March 2021 announced the deployment of full-speed electric delivery

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[6] Canada Energy Regulator, "Canada's Renewable Power Landscape 2017 – Energy Market Analysis." https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/electricity/report/2017-canadian-renewable-power/canadas-renewable-power-landscape-2017-energy-market-analysis-ghg-emission.html

[7] Dan Welch, Cristiano Facanha, Rob Kroon, David Bruil, Floris Jousma and Harm Weken, *Moving Zero-Emission Freight Toward Commercialization* (CALSTART, 2020), 24. https://globaldrivetozero.org/site/wp-content/uploads/2020/12/Moving-Zero-Emission-Freight-Toward-Commercialization.pdf

[8] Amazon, "Amazon's Custom Electric Delivery Vehicles Are Starting to Hit the Road," February 3, 2021. https://www.aboutamazon.com/news/transportation/amazons-custom-electric-delivery-vehicles-are-starting-to-hit-the-road

[9] Victoria Tomlinson, "UPS Invests in Arrival and Orders 10,000 Generation 2 Electric Vehicles," *Arrival*, April 24, 2020. https://arrival.com/news/ups-invests-in-arrival-and-orders-10000-generation-2-electric-vehicles

[10] FedEx, "FedEx Acquires 1,000 Chanje Electric Vehicles," November 20, 2018. https://newsroom.fedex.com/newsroom/fedex-acquires-1000-chanje-electric-vehicles/

vehicles in Vancouver — the first to be deployed by a Canadian courier company.[11,12] To the author's knowledge, no full-speed electric urban delivery vehicles have been deployed in the GTHA to date.

Several vehicle manufacturers are producing new vehicle models that could be utilized for urban deliveries. For example, Ford announced the production of an all-electric version of their Transit van,[13] the Mercedes eSprinter has already been released in Europe,[14] and GM has announced plans for its EV600 electric cargo van.[15] Other manufacturers, such as Lightning, SEA Electric, Adomani, Motiv and Workhorse, are also offering electric cargo vans and step vans suitable for urban deliveries.

To better understand the impact of EV adoption on businesses with urban delivery operations in the GTHA, this project sets out to uncover the costs, energy demands and GHG emission savings associated with the use of EVs in the last mile of urban goods distribution.

[11] Purolator Inc., "Purolator Launches Innovative Delivery Vehicles in Toronto and Montreal to Improve Urban Centre Logistics and Expand Zero-Emission Fleet," October 19, 2020. https://www.newswire.ca/news-releases/purolator-launches-innovative-delivery-vehicles-in-toronto-and-montreal-to-improve-urban-centre-logistics-and-expand-zero-emission-fleet-880887168.html

[12] Purolator, "Purolator hits the road as first national courier to deploy fully electric delivery vans," March 29, 2021. https://www.purolator.com/en/articles/purolator-hits-road-first-national-courier-deploy-fully-electric-delivery-vehicles

[13] Ford, "2022 E-Transit." https://www.ford.ca/commercial-trucks/e-transit/2022/

[14] Mercedes-Benz, "The Successful Van Now in an Emission-Free Variant: the eSprinter!" https://www.vans.mercedes-benz.com/vans/en/mercedes-benz-vans/insights/stories/mercedes-benz-esprinter-emission-free

[15] GM, "GM Launches BrightDrop, a New Business That Will Electrify and Improve the Delivery of Goods and services," January 1, 2021. https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2021/jan/ces/0112-brightdrop.html

2. Understanding urban delivery operations in the GTHA

This analysis examines some of the costs and benefits for urban freight electrification by estimating the energy requirements, GHG emission savings and costs associated with a switch to EVs in the GTHA (Figure 1). The study focuses on the "last mile" of urban goods movement, where goods are transported from a consolidation centre to their final destination. It specifically focuses on door-to-door deliveries within the business-to-consumer segment. The study relied on a survey of prominent urban delivery businesses in the GTHA and real-time operating data from Geotab to model the operations of one of the most common vehicle types used for urban deliveries: a cargo van.

Figure 1. GTHA boundaries

The National Research Council (NRC) was commissioned to develop a model that would compare the energy demands of an electric versus a conventional gas-powered cargo van. This involved the creation of both a vehicle model and representative drive cycles.

The specific parameters for the vehicle model were developed using information consolidated from a variety of sources, including publicly available information on currently available or forthcoming electric cargo van models, as well as an existing Nissan Leaf vehicle model. A full list of the vehicle model inputs can be found in Appendix A. The resulting vehicle model is manufacturer-agnostic but is meant to represent something similar to what could be procured in Canada: a 2-axle cargo van with an approximate mass of 3,000 kg that is equipped with a lithium-ion battery pack with a capacity of roughly 87 kWh (Figure 2).

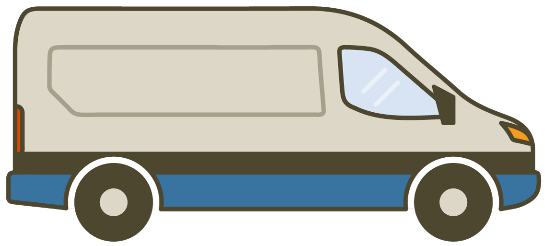

Figure 2. Cargo van model

Deliveries across the GTHA are done in a range of temperatures, for clients that require few or many stops, with various cargos of various weights, and more. It was important to capture the range of driving conditions to understand the range of outcomes when switching to EVs. To inform the development of the drive cycles, a total of 13 scenarios were defined to determine the relative impact of external factors on the energy consumption of an electric cargo van. This included a baseline scenario that is representative of average door-to-door delivery operations in the GTHA and 12 additional scenarios that explored the impact of:

- High/low external temperature
- High/low number of stops
- Max/min congestion
- High/low cargo load
- Uphill/downhill slope of the terrain
- Max/min energy demands

With the scenarios defined, a series of drive cycles were created to understand the energy demands of electric cargo vans travelling in the GTHA under various conditions. Key parameters associated with each of the drive cycles created for the 13 scenarios are provided in Table 2. The total time, driving time, distance, average speed and ignition off count all reflect statistics from a dataset obtained through Geotab, which reflects the actual operation of urban deliveries in the GTHA collected through the company's telematics systems. Values for temperature, cargo load and slope were selected based on the researchers' own assumptions and informed by feedback from businesses. More details on how the drive cycles were generated can be found in Appendix A.

Table 2. Drive cycle statistics for each of the 13 scenarios

Scenario	Total Time (h)	Driving time (h)	Distance (km)	Avg Speed (km/h)	Ignition Off Count	External Temp (°C)	Initial Slope (°)	Initial Cargo Load (kg)
1 - Baseline	8.48	2.19	59.4	27.2	31	10	0	910
2 - Extreme Cold	8.48	2.19	59.4	27.2	31	-25	0	910
3 - Extreme Heat	8.48	2.19	59.4	27.2	31	35	0	910
4 - High Ignition Off	11.67	2.41	56.2	23.4	82	10	0	910
5 - Low Ignition Off	4.92	1.68	61.6	36.6	7	10	0	910
6 - High Congestion	9.28	2.51	60.0	23.5	31	10	0	910
7 - Low Congestion	7.58	1.68	59.4	35.3	31	10	0	910
8 - Heavy Cargo Load	8.48	2.19	59.4	27.2	31	10	0	2000
9 - Light Cargo Load	8.48	2.19	59.4	27.2	31	10	0	100
10 - Uphill Slope	8.48	2.19	59.4	27.2	31	10	0.48	910
11 - Downhill Slope	8.48	2.19	59.4	27.2	31	10	-0.48	910
12 - Maximum Demand	12.26	2.42	93.4	38.6	82	-25	0.48	2000
13 - Minimum Demand	4.27	1.37	36.0	26.3	7	20	-0.48	100

The operation of the EV was simulated across the 13 defined drive cycles. For each scenario, the energy consumption was identified. By determining the energy needs of cargo delivery vans, GHG emission reductions and fuel cost savings in comparison to an equivalent internal combustion engine vehicle (ICEV) could be calculated, as well as the expected charging requirements. Fuel cost estimates for the EV were combined with data provided by CALSTART on upfront vehicle, chargers and maintenance costs in order to identify the average payback period of EVs in comparison to an ICEV.

This analysis does not capture the wide variation in electricity and infrastructure costs expected for businesses across the GTHA, and instead simply reflects baseline conditions. It is expected that electricity costs will vary significantly depending on fleet size, existing electricity demand and charging times, among other factors. Infrastructure costs associated with construction, as well as electricity transmission or grid upgrades have been excluded, since these costs will vary significantly from one business to the next.[16] This analysis has also excluded any costs associated with software and other network access contracts that may be required to manage "smart" or connected technology, or with training personnel.

[16] Chris Nedler and Emily Rogers, *Reducing EV Charging Infrastructure Costs* (Rocky Mountain Institute, 2019), 22. https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf

3. Results

3.1 Energy consumption

A thorough understanding of an EV's expected energy consumption is critical. It can help fleet managers determine the battery capacity required on any EVs procured and inform the development of fuel cost estimates. For each of the 13 defined scenarios, the total energy consumption of an electric cargo van was identified, as well as the rate of battery consumption (see Table 3). An EV operating under the baseline scenario assumptions, which represents average operations of urban delivery vehicles in the GTHA, is expected to have energy demands of approximately 10.3 kWh. These energy requirements are notably low considering the fact that currently available/announced electric cargo van models have battery capacities as high as 105 kWh.[17,18] In theory, an EV operating under baseline scenario assumptions could go several days without charging. Meanwhile, the maximum demand scenario leads to a demand of approximately 43 kWh.[19,20]

A detailed breakdown of battery consumption, including the portion of energy consumed by the motor, HVAC system and any auxiliary components (e.g. lights, sound system, horn, etc.), as well as the amount of energy supplied by regenerative braking can be found in Appendix A.

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[17] Adomani, "High Top Logistics Cargo Van." https://adomanielectric.com/high-top-logistics-cargo-van/

[18] Lightning eMotors, "Transit Cargo Van." https://lightningemotors.com/lightningelectric-ford-transit-cargo/

[19] Including Adomani's All Electric High-Top Cargo Van, SEA Electric's Ford Transit Cargo Van and Lighting's Ford Transit LEV60/120

[20] Ford, "Leading the Charge: All-Electric Ford E-Transit Powers the Future of Business with Next-Level Software, Services and Capability," *Ford Media Centre*, November 12, 2020. https://media.ford.com/content/fordmedia/fna/us/en/news/2020/11/12/all-electric-ford-e-transit.html

Table 3. Total battery consumption and battery consumption rate under each scenario

Scenario	Distance Travelled (km)[21]	Battery Consumption (kWh)	Battery Consumption Rate (kWh/km)
1 - Baseline	57.4	10.3	0.18
2 - Extreme Cold	57.1	15.0	0.26
3 - Extreme Heat	58.8	11.7	0.20
4 - High Ignition Off	54.5	10.8	0.20
5 - Low Ignition Off	61.5	12.7	0.21
6 - High Congestion	58.6	13.9	0.24
7 - Low Congestion	51.1	8.5	0.17
8 - Heavy Cargo Load	58.0	11.1	0.19
9 - Light Cargo Load	55.9	9.6	0.17
10 - Uphill Slope	56.5	11.4	0.20
11 - Downhill Slope	57.7	11.2	0.19
12 - Maximum Demand	87.9	43.2	0.49
13 - Minimum Demand	32.2	3.0	0.09

The battery consumption rate is expected to range from 0.09 kWh/km under the minimum demand scenario assumptions, to 0.18 kWh/km for the baseline, and up to 0.49 kWh/km under maximum demand conditions. A few key parameters have a notable impact on the rate of battery consumption. For one, higher cabin heating requirements resulting from extreme cold temperatures (-25°C) are expected to lead to a rise in energy consumption of over 40% in comparison to the baseline. Second, high levels of congestion, which lead to more time spent idling and travelling at low speeds, are expected to result in an increase in energy consumption of approximately one-third. Neither cabin A/C requirements resulting from extreme heat nor low levels of congestion have as notable an impact of the rate of energy consumption.

[21] Battery consumption rates were calculated using the simulated distance travelled, rather than the distance defined in the drive cycles in Table 2. The tool used to generate the drive cycles creates artefacts in the drive cycle with quick accelerations and decelerations. The vehicle model is unable to reach these accelerations because of limits on the driver control system, and as such, simulated distance varied somewhat from the defined distance. A direct comparison of the simulated and defined distance can be found in Appendix A.

For EVs, the rate of energy consumption does not increase linearly with speed. Instead, they are most efficient when travelling at approximately 25 to 30 km/h.[22] EVs travelling at speeds above or below this threshold will have a higher rate of energy consumption. This impact of lower and higher speeds on energy consumption is exemplified by the higher rate of energy consumption seen in both the high and low ignition off scenarios. While increasing the number of ignition off instances leads to a greater percentage of time spent travelling below this threshold, decreasing the number of ignition off instances results in an increase in the amount of time spent travelling above this threshold. In both scenarios, the rate of energy consumption is higher than the baseline.

The size of the cargo load that was selected does not appear to have a substantial impact on the rate of energy consumption. Increasing the cargo load to 2,000 kg or decreasing it to 100 kg only results in a 5% change in energy consumption in either direction relative to the baseline scenario in which cargo load is 910 kg.

As expected, the uphill slope scenario has a slightly higher rate of energy consumption than the downhill slope scenario. Both scenarios, however, result in a slightly higher rate of energy consumption than the baseline scenario. This is because the model reflects return-to-base operations, and so even in the downhill scenario where the vehicle travels downhill for the first half of the route, the vehicle must travel uphill during the second half in order to return to its home base. The energy consumption for the downhill scenario is slightly lower due to the fact that it has a lighter load when travelling uphill during the second half of the route. Moreover, a greater amount of energy is generated through regenerative braking since the vehicle is carrying a heavier mass when travelling downhill at the beginning of the route.

Based on feedback that was received in the business survey, some businesses with delivery operations in the GTHA have predictable routes, while others do not. For companies whose routes vary from day-to-day, range anxiety may be more prominent. Table 4 outlines the predicted vehicle range for battery packs ranging in size from 25 to 75 kWh using the battery consumption rate for each scenario.

[22] Shubham Agrawal, Hong Zheng, Srinivas Peeta and Amit Kumar, *Routing Aspects of Electric Vehicle Drivers and Their Effects on Network Performance*, Transportation Research Part D: Transport and Environment 46 (2016), 246-266. DOI: 10.1016/j.trd.2016.04.002 https://www.researchgate.net/publication/299603220_Routing_Aspects_of_Electric_Vehicle_Drivers_and_Their_Effects_on_Network_Performance

Table 4. Predicted driving range under each scenario with different battery packs

Scenario	Driving Range (km)		
	25 kWh pack	50 kWh pack	75 kWh pack
1 - Baseline	139	279	418
2 - Extreme Cold	95	190	285
3 - Extreme Heat	125	250	375
4 - High Ignition Off	126	252	378
5 - Low Ignition Off	121	243	364
6 - High Congestion	106	211	317
7 - Low Congestion	150	300	450
8 - Heavy Cargo Load	131	262	393
9 - Light Cargo Load	146	292	439
10 - Uphill Slope	124	248	372
11 - Downhill Slope	128	257	385
12 - Maximum Demand	51	102	153
13 - Minimum Demand	272	545	817

3.2 Charging demands

EVs are able to charge overnight across all of the scenarios explored using either Level 1 or Level 2 charging. Based on feedback that was received through the business survey, it's expected that EVs adopted by businesses conducting urban deliveries in the GTHA will be charged indoors overnight and will have at least eight hours to achieve a full charge.[23] Across a number of the scenarios, Level 1 charging — which is the slowest charging speed and equivalent to plugging the vehicle into a standard wall outlet — is expected to be sufficient (Table 5). Using Level 2 charging, which charges vehicles at a faster speed, however, ensures that vehicles will be able to reach a full charge overnight across all scenarios. In fact, most vehicles are able to recharge in under 2.5 hours using Level 2 charging, with the only exception being the maximum energy demand scenario which requires 6.7 hours. These findings demonstrate that EVs used for urban deliveries in the GTHA are expected to be able to fully charge overnight using either Level 1 or Level 2 charging and that direct current fast chargers (DCFC) are likely not required.

[23] A maximum state of charge of 90% was assumed.

As a result of the fairly low energy demands of urban delivery vehicles and ample time to charge, this analysis explored the possibility of using Level 1 and Level 2 charging to satisfy the charging requirements under each scenario. It was assumed that Level 1 charging provides approximately 1.68 kW of power, whereas Level 2 charging provides approximately 7.2 kW of power[24,25] and has a somewhat higher efficiency (89.4%) than Level 1 charging (83.8%).

Table 5. Level 1 and Level 2 charging duration for each scenario

Scenario	Distance Travelled (km)	Charging Demands (kWh)	Charging Duration (h)	
			Level 1	Level 2
1 - Baseline	57.4	10.3	7.3	1.6
2 - Extreme Cold	57.1	15.0	10.7	2.3
3 - Extreme Heat	58.8	11.7	8.3	1.8
4 - High Ignition Off	54.5	10.8	7.7	1.7
5 - Low Ignition Off	61.5	12.7	9.0	2.0
6 - High Congestion	58.6	13.9	9.9	2.2
7 - Low Congestion	51.1	8.5	6.0	1.3
8 - Heavy Cargo Load	58.0	11.1	7.9	1.7
9 - Light Cargo Load	55.9	9.6	6.8	1.5
10 - Uphill Slope	56.5	11.4	8.1	1.8
11 - Downhill Slope	57.7	11.2	8.0	1.7
12 - Maximum Demand	87.9	43.2	30.7	6.7
13 - Minimum Demand	32.2	3.0	2.1	0.5

[24] Justine Sears, David Roberts and Karen Glitman, *A Comparison of Electric Vehicle Level 1 and Level 2 Charging Efficiency*, 2014 IEEE Conference on Technologies for Sustainability (2015). DOI: 10.1109/SusTech.2014.7046253

[25] *A Comparison of Electric Vehicle Level 1 and Level 2 Charging Efficiency.*

3.3 Cost comparison

3.3.1 Fuel cost savings

Fuel cost savings relative to a gasoline baseline are expected across all scenarios. For the baseline scenario, fuel costs are expected to be approximately $0.04 and $0.07 per km, which translates to cost savings of $0.21 and $0.18 per km for Level 1 and Level 2 charging, respectively. Assuming that a vehicle is in operation 365 days of the year, EVs operating under the baseline scenario assumptions are expected to produce fuel cost savings of $3,800 to $4,400 per year. Our analysis does not incorporate the impact of carbon pricing. As the price of carbon increases in the coming years, the fuel cost savings of EVs will only be greater.

The estimated cost to charge a cargo van using Level 1 or Level 2 charging is presented in Table 6 alongside the estimated cost savings relative to what it would cost to fuel an equivalent gasoline-powered ICEV. Note that for Level 2 charging, the higher power of each charging instance increases the cost of power relative to Level 1 charging; however, the efficiency of Level 2 charging is higher than that of Level 1, thus reducing the energy cost.

Table 6. Level 1 and Level 2 charging costs and cost savings relative to an equivalent gasoline-powered vehicle

Scenario	Charging Costs ($/km)		Cost Savings ($/km)	
	Level 1	Level 2	Level 1	Level 2
1 - Baseline	0.04	0.07	0.21	0.18
2 - Extreme Cold	0.05	0.08	0.20	0.17
3 - Extreme Heat	0.04	0.07	0.21	0.18
4 - High Ignition Off	0.04	0.07	0.21	0.18
5 - Low Ignition Off	0.04	0.07	0.21	0.18
6 - High Congestion	0.05	0.08	0.20	0.17
7 - Low Congestion	0.04	0.07	0.21	0.18
8 - Heavy Cargo Load	0.04	0.07	0.21	0.18
9 - Light Cargo Load	0.04	0.07	0.21	0.18
10 - Uphill Slope	0.04	0.07	0.21	0.18
11 - Downhill Slope	0.04	0.07	0.21	0.18
12 - Maximum Demand	0.08	0.10	0.17	0.15
13 - Minimum Demand	0.03	0.09	0.22	0.16

To calculate these cost savings, the average electricity rate charged by local distribution companies (LDCs) in the GTHA was calculated for general service customers ranging in size from 50 to 5000 kW.[26] There are three major components that make up electricity charges in Ontario: the electricity commodity charge, the delivery charge and the regulatory charge. See Appendix C for more details on how fuel costs were calculated.

While average electricity charges have been used, it is important to note that some of these charges will vary significantly from one business to the next. For instance, global adjustment (GA) charges are scaled according to the total amount of energy used each month (MW) and can make up a significant portion of a businesses' electricity charges. If a large fleet of EVs is charged simultaneously, this could significantly increase the total power used each month, resulting in a large increase in the GA charge. Since this charge will vary considerably from one business to another, this analysis incorporates the average GA charge.

To calculate gasoline prices, Canada Energy Regulator's 2020 estimate for Ontario of $1.03 per litre ($30.54/GJ) was used.[27] An average fuel consumption of 24 L per 100 km was assumed, as per feedback received in the business survey. This translates to an average cost of $0.25 per km across each of the scenarios.

3.3.2 Average payback period of EVs

Though EVs are expected to offer fuel and maintenance cost savings over their ICEV counterparts, the capital cost of EVs is still significantly higher than ICEVs. To see how these two technologies compare over the course of their lifetime, a total cost of ownership analysis was conducted. By comparing annual and upfront costs, it was found that the payback period of an EV (i.e. when the difference in capital costs between an EV and ICEV is recovered by annual cost savings of an EV) is about 6.8 years when factoring in Level 1 charging costs, and about 7.8 years when factoring in Level 2 charging costs (see Figure 3). Businesses that were engaged over the course of this analysis reported vehicle ownership periods that range from as little as five to seven years, up to as long as 20 years. It's expected that businesses will experience cost savings as a result of switching to EVs within typical vehicle ownership cycles.

[26] LDCs included Alectra Utilities, Burlington Hydro Inc., Oakville Hydro Electricity Distribution Inc., Milton Hydro Inc., Halton Hills Hydro Inc., Newmarket-Tay Power Distribution Ltd., Elexicon Energy Inc., Oshawa Power and Utilities Corporation, Hydro One and Toronto Hydro.

[27] Canada Energy Regulator, "Canada's Energy Future Data Appendices." https://doi.org/10.35002/zjr8-8x75

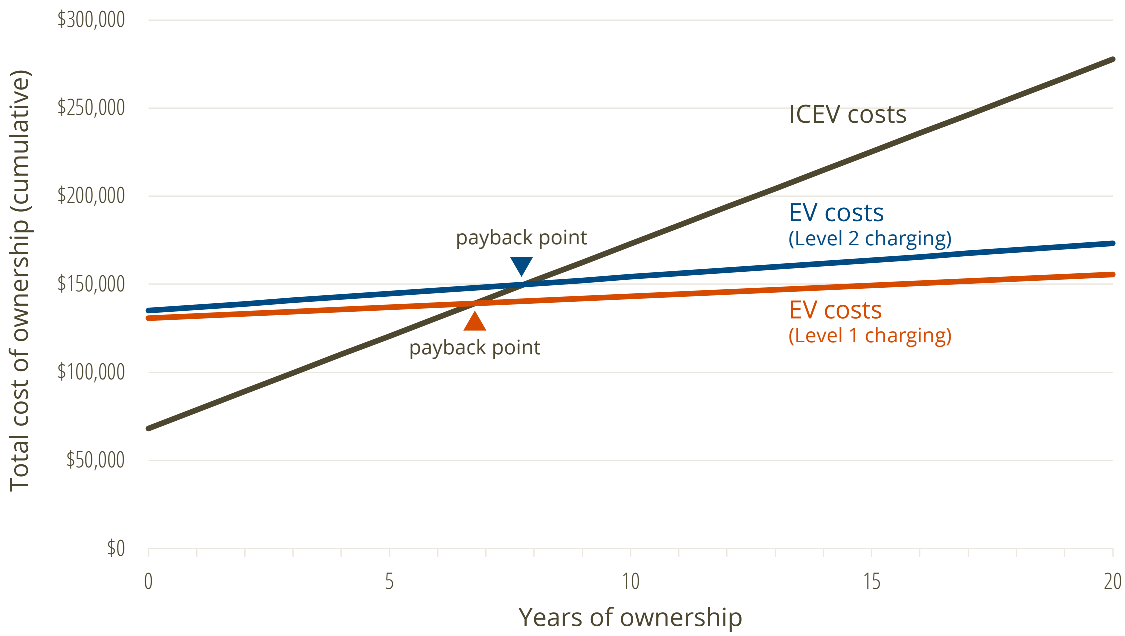

Figure 3. Comparison of the total cost of ownership of EVs and ICEVs

The total cost of ownership analysis that was conducted incorporates costs pertaining to the purchase of a vehicle, fuel, maintenance, and charging infrastructure. Data was obtained from CALSTART on average upfront vehicle costs, charger hardware and installation costs and annual maintenance costs for a class 3 urban delivery vehicle, and this was combined with this study's fuel cost estimates for the baseline scenario. A summary of the costs included in the analysis can be found in Table 7.

EVs currently have an upfront vehicle cost nearly twice that of an ICEV. This difference may be prohibitively high for some businesses. Federal financial incentives could play a role in bringing these higher upfront vehicle costs down, and also reduce the overall payback period of EVs.

Table 7. Cost comparison of an ICEV and EV cargo delivery van in the GTHA

Cost	ICEV	EV (Level 1 charging)	EV (Level 2 charging)
Upfront vehicle cost	$68,290	$130,660	$130,660
Charger cost	-	-	$4,500
Annual fuel cost	$5,370	$820	$1,480
Annual maintenance cost	$5,090	$420	$420

Electricity and infrastructure costs associated with EVs are highly variable. This analysis is only representative of average conditions. Electricity costs will vary considerably from one business to another as a result of differences in EV charging schedules, fleet size, total electricity demand and electricity rate class, among other factors. Charging infrastructure costs are also highly variable. If a business decides to install DCFC infrastructure, costs can increase to as much as $100,000 per charger.[28] Moreover, some businesses may be required to undergo infrastructure upgrades if the power reaching their site is insufficient to support chargers. The U.S.-based Rocky Mountain Institute estimates that the cost to upgrade a transformer can range from US$35,000 to US$173,000.[29] While it is difficult to estimate the average cost of infrastructure for businesses with urban delivery operations in the GTHA due to differences in fleet sizes and power requirements, these costs will have a notable impact on the payback period of EVs. Ultimately, while this analysis demonstrates that EVs may be financially viable for urban delivery businesses operating in the GTHA, it will be important for businesses to conduct their own assessment factoring in site-specific conditions.

3.4 GHG emission savings

As expected, EVs used for urban deliveries in the GTHA offer notable GHG emission savings in comparison to their gas-powered counterparts (see Table 8). For the baseline scenario, one EV is expected to lead to GHG emission savings of 32.4 kg CO_2 per day. Over the course of a year (assuming the vehicle is in operation 365 days per year), this translates to an annual reduction of nearly 12 tonnes of CO_2e per vehicle, equivalent to taking 2.6 passenger vehicles off the road for one year.[30] Under the maximum demand scenario, this climbs up to an annual reduction of nearly 18 tonnes CO_2e, or the equivalent of taking up to four passenger vehicles off the road. There is little difference between the rate of GHG emission savings between Level 1 and Level 2 charging as the only difference between these two scenarios is a slightly higher assumed charging efficiency associated with Level 2 charging (89%) in comparison to Level 1 charging (84%). On average, the rate of GHG emission savings is 0.56 kg CO_2e per km.

To calculate GHG emissions associated with the use of electric cargo vans for urban deliveries in the GTHA, the total energy consumption associated with each scenario was combined with Canada Energy Regulator's average GHG intensity of electricity

[28] Data provided by CALSTART

[29] Chris Nedler and Emily Rogers, *Reducing EV Charging Infrastructure Costs* (Rocky Mountain Institute, 2019), 22. https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf

[30] United States Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

generation for Ontario (40 g CO_2e/kWh).[31] To estimate GHG emissions stemming from the operation of gasoline-powered cargo vans in the GTHA, an average fuel consumption of 24 L/100km was assumed, based on feedback received in the business survey. To determine the associated GHG emissions, GHGenius, a life cycle assessment tool, was used to generate a rate of emissions for the operation of class 3 vehicles with a fuel consumption of 24 L/100 km in 2020.[32] The rate of GHG emissions was identified as 0.57 kg CO_2e/km.

Table 8. Total GHG emissions and GHG emissions saved

Scenario	Emissions (kg CO_2e)				
	ICEV	Level 1 EV		Level 2 EV	
		Charging	Emissions Saved	Charging	Emissions Saved
1 - Baseline	32.9	0.492	32.4	0.461	32.4
2 - Extreme Cold	32.7	0.716	32.0	0.671	32.0
3 - Extreme Heat	33.6	0.558	33.0	0.523	33.1
4 - High Ignition Off	31.2	0.516	30.7	0.483	30.7
5 - Low Ignition Off	35.2	0.606	34.6	0.568	34.6
6 - High Congestion	33.6	0.663	32.9	0.622	33.0
7 - Low Congestion	29.2	0.406	28.8	0.380	28.8
8 - Heavy Cargo Load	33.2	0.530	32.7	0.497	32.7
9 - Light Cargo Load	32.0	0.458	31.5	0.430	31.6
10 - Uphill Slope	32.4	0.544	31.9	0.510	31.9
11 - Downhill Slope	33.1	0.535	32.6	0.501	32.6
12 - Maximum Demand	50.3	2.062	48.2	1.933	48.4
13 - Minimum Demand	18.4	0.143	18.3	0.134	18.3

[31] Canada Energy Regulator, "Canada's Renewable Power Landscape 2017 – Energy Market Analysis." https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/electricity/report/2017-canadian-renewable-power/canadas-renewable-power-landscape-2017-energy-market-analysis-ghg-emission.html

[32] (S&T) Squared Consultants Inc., "GHGenius 5.0f." https://www.ghgenius.ca/index.php/downloads

4. Conclusion

Based on real-time data from urban delivery vehicles and operations information from prominent businesses with return-to-base urban delivery operations in the GTHA, this analysis has determined that switching from ICEVs to EVs can result in notable fuel cost savings and a reduction in annual GHG emissions.

This study demonstrates that the expected energy requirements of an electric cargo van performing urban deliveries in the GTHA is 10.3 kWh (under a baseline scenario) and may reach up to 43 kWh (under a maximum demand scenario). The three electric cargo van models available on the market today in Canada,[33] as well as Ford's forthcoming Transit EV, all offer sufficient battery capacity to meet the energy needs of urban delivery cargo vans operating in the GTHA.

For businesses with return-to-base operations and at least seven hours of downtime between shifts, Level 2 charging is expected to supply sufficient power to charge EVs overnight even under the most energy demanding scenario assessed in this study. Under the baseline scenario, EVs are expected to charge in as little as 1.6 hours using Level 2 charging or 7.3 hours using Level 1 charging.

As expected, the cost to recharge a cargo delivery van is considerably lower than the cost to refuel with gasoline. Under all scenarios examined, EVs are expected to lead to fuel cost savings in comparison to ICEVs. For the baseline scenario, it was found that EVs lead to fuel costs savings of $0.18 per km using Level 2 charging, which translates to annual savings of $3,800 per vehicle in comparison to an equivalent ICEV. EVs, however, have considerably more expensive upfront capital costs than equivalent ICEVs. A comparison of their total cost of ownership over time demonstrates that the payback period of EVs operating under baseline conditions is expected to be 7.8 years when using Level 2 charging. In other words, the additional upfront cost of an EV is recovered through fuel cost savings in roughly eight years. When Level 1 charging is employed, this goes down to 6.8 years.

When it comes to the environmental benefits, the annual GHG emission savings achieved by switching from a gasoline-powered cargo van to an electric cargo van in the GTHA are nearly 12 tonnes per vehicle under the baseline scenario. This is equivalent to

[33] Including Adomani's All Electric High-Top Cargo Van, SEA Electric's Ford Transit Cargo Van and Lighting's Ford Transit LEV60/120.

taking 2.6 passenger vehicles off the road for one year.[34] Under the most energy demanding scenario, GHG emission savings climb up to 18 tonnes per year, or the equivalent of 4 passenger vehicles taken off the road.

While the results of this analysis make a strong case for urban delivery electrification, these estimates are intended to be a starting point for businesses operating urban delivery fleets in the GTHA to consider the switch to EVs. Transportation electrification is a complex process and it's critical that businesses conduct their own assessment that takes into account site-specific considerations. Costs associated with a transition to EVs are expected to differ significantly from one business to another, and this analysis only captures average conditions. Electricity costs will vary significantly as a result of differences in total electricity demand and EV charging schedules, among other factors. Furthermore, there is much more to electrification than just the charger and the vehicle. Costly infrastructure upgrades, such as grid or transformer upgrades, may be part of the transition to EVs for certain businesses and can vary significantly. Businesses will also be required to train personnel and invest in software and other network access contracts to manage any "smart" or connected technology.

Businesses may still face major barriers to scaling up EVs in their fleets. For instance, while the incremental cost of an electric cargo van is expected to be recovered in about eight years, the capital required to cover the upfront cost of an EV may prohibit some businesses from making the switch. Moreover, electricity charges such as the global adjustment charge and delivery charges are scaled according to peak demand and could increase significantly if a large fleet of EVs charges in parallel. Electricity rate structures in the GTHA should be assessed to ensure that EV charging does not result in a spike in costs that act as a disincentive to transportation electrification. Policy, regulations and incentives are needed to ensure that businesses in Canada have access to a wide range of vehicle models to suit their needs, electricity rates are attractive to incent wide-spread adoption, and the high upfront capital and operational costs can be more manageable.

[34] United States Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator." https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Appendix A. Modelling methods

Modelling methods are presented in detail in the report *Urban Freight Electrification in the GTHA: Simulation and Feasibility Analysis* prepared by David Holt of the National Research Council (NRC).

A.1 Urban delivery operations in the GTHA

To accurately identify the costs and benefits of electric urban delivery vehicles, the first step is to better understand the operations of urban delivery companies in the GTHA. A survey was distributed to several companies with prominent delivery operations in the GTHA regarding their vehicle models and routing.

Vehicles

- Three most common vehicle models used in urban delivery fleets
- Average fuel consumption of each vehicle model
- Auxiliary power needs (e.g. climate control systems, power lifts, etc.) of the vehicles
- Specific electric vehicle models currently available on the market that the company is interested in procuring in the near-term

Routing

- Fixed or varied routes from day-to-day
- Average distance travelled in a single shift
- Whether vehicles returned to a central depot, and if so:
  - How often they returned (e.g. at the end of each shift)
  - Whether all vehicles arrived at the same time or staggered
  - How long they stayed in the depot
  - Whether they were parked inside or outside

Responses were received from four notable delivery companies operating in the GTHA. Three of the four companies are major parcel delivery companies in the GTHA, while the fourth is a local grocer.

Results of the business survey allowed the analysis to be narrowed down to a specific vehicle model and type of operations. Three of the four companies listed various cargo van models as their most common vehicle models, and all of the companies indicated that vehicles returned to a central depot daily at the end of each shift. Thus, this analysis focuses on return-to-base urban deliveries performed using a cargo van.

A.1.1.1 Vehicle model development

To create the vehicle model, researchers at the National Research Council (NRC) used MapleSim, a multi-domain modeling tool. The model was adapted from the Fleet Forward product, which was developed in collaboration between the NRC and MapleSim for the purposes of studying the range of electric transit buses. The model is made up of several subsystems, including driver controller, motor, vehicle dynamics, regenerative braking, HVAC, electrical and battery subsystems.

The specific parameters for the vehicle model were developed using information consolidated from a variety of sources, including publicly available information on currently available or forthcoming electric cargo van models and an existing Nissan Leaf vehicle model which had been developed for a past project. A full list of the vehicle model inputs can be found in Appendix A.

The resulting vehicle model is manufacturer-agnostic and is meant to represent something similar to what could be expected on the market. It is a 2-axle cargo van with an approximate mass of 3,000 kg that is equipped with a lithium-ion battery pack with a capacity of roughly 87 kWh.

A.1.2 Route model development

In addition to the vehicle model, the NRC generated GTHA-specific routes to represent the operation of a cargo van. These routes were created using data provided by Geotab, which represented the real time operation of urban delivery vehicles in the GTHA. This dataset is described in detail in the following section. The NRC created 13 different routes which represent multiple use cases in order to determine the relative impact of external factors on energy consumption.

Geotab dataset

To complement the data that was obtained through the business survey, Geotab was also engaged to develop a customize a dataset that documented the route characteristics of cargo delivery vans operating in the GTHA. Geotab sells telematics solutions, which transmit a vehicle’s data to a computer, in order to help companies better manage their fleets. Through the GPS tracking devices installed on their customer's vehicles, Geotab was able to aggregate a significant amount of data pertaining to the operational characteristics of the vehicles equipped with their devices.

Geotab provided an aggregated and anonymized dataset, which was filtered according to the following parameters:

- One-year timespan between October 1, 2019 through September 30, 2020
- Class 3 vehicles (i.e. those weighing between 4,535 to 6,350 kg)[35]
- Door-to-door vocation
- Average distance between 25 to 100 km per day[36]
- Trips within the GTHA

Data was aggregated for each day of the week within each month (e.g. for all Mondays in April or all Fridays in October). Table 9 provides an overview of the metrics that were provided.

Table 9. Geotab dataset metrics

Metric	Description
Total number of idle instances between X to Y seconds	Total number of GPS points that had an idle period between X to Y seconds per day. Idle is defined as having zero speed with the ignition on within the trip. Only includes idling instances less than or equal to 200 seconds. Those greater than 200 seconds are considered ignition off instances.
Sum of idle time (seconds)	Total idling duration in seconds per day. Only includes idling instances less than or equal to 200 seconds.
Total idle instances	The number of times the vehicle transitions from moving (>0 km/h) to stop (0 km/h) during all trips of the day.
Duration of speed between X to Y km/h (seconds)	Seconds spent traveling within a certain range in speed (e.g. 0 to 20 km/h) per day. Ranges were separated into 20 km/h buckets.
Driving duration (minutes)	Total travel time per day.
Average speed (km/h)	Weighted average of each trip's average speed over all trips within a given day. This is calculated by excluding zero speed values.
Driving distance (km)	Total distance travelled per day.
Daily ignition off count	Number of ignition off instances per day for each vehicle.

[35] Cargo vans typically fall between the 2b/3 weight classes. Unfortunately, there was insufficient coverage to include class 2 data.

[36] This was the average range in activity reported by the companies who participated in the business survey. 85% of trips within Geotab's dataset of class 3 vehicles performing door-to-door deliveries fell within the bounds of 25 to 100 km.

Sum ignition off time (minutes)	Sum of all the ignition off times per day per vehicle excluding instances greater than 8 hours. Ignition Off time is defined as the time between two consecutive trips which can be a pick-up, delivery or rest time with the ignition off or an idling instance with the ignition on that has been long enough to cause a trip breakdown.

For each metric, the following statistics were provided for each day of the week and each month:

- count
- mean
- standard deviation
- 5th, 25th, 50th, 75th and 95th percentile

Scenario development

A series of scenarios were defined to determine the relative impact of external factors on the energy consumption of an electric cargo van. In partnership with the NRC, 13 scenarios were defined, which represent the range of operating conditions expected to apply to urban delivery vehicles in the GTHA. These scenarios were developed to test the limits of electric vehicle performance and ensure that the technology could meet the needs of urban delivery companies in the GTHA.

An overview of the 13 scenarios is provided in Table 10. Apart from the baseline and max/min energy demand scenarios, each of the scenarios aims to explore the impact of a single factor (e.g. temperature, number of stops, etc.). In some cases, multiple parameters needed to be modified due to the interconnected nature of some of the parameters, such as idling and driving duration, or idling and average speed.

Table 10. Overview of the 13 scenarios

No.	Name	Description	Parameterization
1	Baseline	Average door-to-door delivery route in the GTHA	All mean values from the Geotab dataset
2	Extreme Cold	Route performed during peak winter	-25°C constant external temperature
3	Extreme Heat	Route performed during peak summer	35°C constant external temperature
4	High Ignition Off	Route with a high number of stops	Above average number of ignition off instances and total time spent with ignition off

			Above average time spent driving at slower speeds (0-40 km/h) Below average time spent driving at faster speeds (40+ km/h) Below average overall speed
5	Low Ignition Off	Route with a low number of stops	Below average number of ignition off instances and total time spent with ignition off Below average time spent driving at slower speeds (0-40 km/h) Above average time spent driving at faster speeds (40+ km/h) Above average overall speed
6	High Congestion	Route with significant congestion	Above average number of idle instances and total time spent idling Above average time spent driving at slower speeds (0-40 km/h) Below average time spent driving at faster speeds (40+ km/h) Below average overall speed
7	Low Congestion	Route with little congestion	Below average number of idling instances and total time spent idling Below average time spent driving at slower speeds (0-40 km/h) Above average time spent driving at faster speeds (40+ km/h) Above average overall speed Below average driving duration
8	Heavy Cargo Load	Route with a heavy payload	Heavier than average initial cargo load
9	Light Cargo Load	Route with a light payload	Lighter than average initial cargo load
10	Uphill Slope	Route that requires uphill travel during first half of trip	Travelling uphill for first half of route when cargo load is heaviest, and travelling downhill for the second half as the vehicle returns to its home base
11	Downhill Slope	Route that requires downhill travel during first half of trip	Travelling downhill for first half of route when cargo load is heaviest, and travelling uphill for the second half as the vehicle returns to its home base
12	Maximum Demand	Route with peak energy demands	Above average number of idling instances and time spent idling, ignition off instances and time spent with the ignition off, total driving distance and time spent driving at very high speeds (60+ km/h)

			Above average overall speed and time spent travelling at high speeds (20-60 km/h) Below average time spent driving at slow speeds (0-20 km/h) -25°C constant external temperature Very heavy initial cargo load Uphill travel during first half of route when cargo load is heaviest
13	Minimum Demand	Route with a driver in energy conservation mode	Below average number of idling instances and time spent idling, ignition off instances and time spent with the ignition off, total driving distance and time spent driving at very high speeds (60+ km/h) Below average overall speed and time spent travelling at high speeds (20-60 km/h) 20°C constant external temperature Very light initial cargo load Downhill travel during first half of route when cargo load is heaviest

With the scenarios defined, drive cycles were generated. Key parameters associated with each of the drive cycles created for the 13 scenarios are provided in Table 2. The total time, driving time, distance, average speed and ignition off count all reflect statistics from the Geotab dataset, which represents real-time operation of urban deliveries in the GTHA. Values for temperature, cargo load and slope were selected based on the researchers' own assumptions.

The baseline scenario covers a distance of nearly 60 km. While the total time for this scenario is approximately 8.5 hours, only about a quarter of that time is actually spent driving; otherwise, the vehicle is idling or has the ignition off. Under the baseline scenario, there are 31 ignition off instances. The vehicle travels at an average speed of 27 km/h.

A constant external temperature of 10°C was selected for the baseline as it represents the approximate annual average temperature in the GTHA.[37] External temperature climbs up to 20°C in the minimum energy demand scenario and down to -25°C in the maximum energy demand scenario to explore the impact of moderate and extreme weather on HVAC demands.

[37] Climate-Data.org, "Toronto Climate." https://en.climate-data.org/north-america/canada/ontario/toronto-53/

Since the GTHA is not particularly hilly, a 0° slope of the terrain was assumed for the baseline scenario. For the uphill slope scenario, the elevation change in Hamilton was used, which is larger than that of Toronto and is approximately 249 m. For a route length of 60 km (i.e. the baseline assumption), this equates to a slope of approximately 0.48°. To represent the worst-case scenario for slope (i.e. the uphill slope scenario), the vehicle first ascends when its cargo load is heaviest, before descending to return back to base when the cargo load is lightest.

For cargo load, an initial load of 910 kg was selected, and it was assumed that the load linearly decreased to 0 kg through the duration of the route. This initial cargo load was calculated by taking the midpoint of package weights listed on Shopify's website (5 lbs),[38] and assuming an average density of 200 parcels per 4 m^3 and a cargo van volume of 8 m^3.[39,40] The minimum and maximum cargo loads were set as 100 and 2000 kg, respectively, using the same methodology, but instead assuming average parcel weights of 0.5 lbs and 30 lbs.

Accounting for idling and ignition off instances

From the Geotab dataset, data was available on the number of idle instances, total amount of time spent idling, the number of ignition off (i.e. delivery) instances, and the duration of ignition off time. There was not, however, data on the total time spent idling or with the ignition off during each instance, or the relative timing of each idling and ignition off occurrence.

Histograms were generated which allowed for the random generation of idle instance times within groupings of 0 to 30 seconds and 30 to 2000 seconds, which added up to the total idling time expected for each drive cycle. Meanwhile, the total duration of ignition off time was divided by the number of ignition off instances, which generated uniform ignition off instance times. As ignition off time only impacts HVAC demands, cumulative time was deemed more important than individual instance time. Idle and ignition off instances were randomly ordered.

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[38] Shopify, "Packages and Shipment Weights." https://help.shopify.com/en/manual/shipping/understanding-shipping/packaging-and-weights

[39] Sam Clarke and Jacques Leonardi, *Parcel deliveries with electric vehicles in Central London* (Greater London Authority, 2017), 12. https://westminsterresearch.westminster.ac.uk/download/c85e71d2c0a2f04f6de57ee874b6f72adeccabce82d20e6d2bf5bf9ef82d1645/4896435/GLA-Agile3-DataReport-4May2017.pdf

[40] Ford, "Cargo Van." https://www.ford.ca/trucks/transit-passenger-van-wagon/models/transit-cargo-van/

To generate speed-time curves, a tool that was previously developed for the generation of transit bus drive cycles from stop location, stop duration, leg distances, leg speeds and cargo load was adapted for these research purposes. Idling and ignition off instances were considered the stop locations and their times the stop durations. The limitations of the tool are that it uses a static acceleration and deceleration curve. For each leg of each route (i.e. the time between two idling or ignition off instances), the vehicle accelerates to the given speed, and decelerates from it after the provided distance has been travelled.

In real life, instead of a static acceleration, it is expected that the vehicle speed will have many micro accelerations and decelerations. As a result, appropriate acceleration and deceleration curves from studies of vehicles at four-way stops were sourced. A quadratic curve was fit to the data, which accurately models high end acceleration, but overestimates low-end acceleration. The deceleration was selected to be a static -2 m/s^2.

To determine the length of the legs (i.e. the distance between each idle or ignition off instance), the total route distance was divided by the number of idle and ignition off instances to get the average leg length. A random normal distribution of individual leg lengths was created and applied to the route with the mean leg value as the mean, a normalized standard deviation of one, and a minimum distance of five metres.

The speed limit for each leg was determined by a histogram randomly selecting speeds between set limits based on the leg length. These histograms were adjusted for each route model, as required.

Drive cycle calibration

The development of drive cycles using statistics from the Geotab data required a certain degree of calibration. To create the defined drive cycles, the raw data needed to be manipulated somewhat to reflect scenarios that could be achieved in the real world. Several parameters within the drive cycles are dependent on one another. For example, average speed is dependent on the total idling time — if there is an increase in the time spent idling at 0 km/h, this will result in a decrease in the average speed. The drive cycle definitions targeted specific statistics (e.g. mean or 95th percentile) for each parameter that were derived from the Geotab dataset. The target values for each parameter, however, didn't always seamlessly combine to reflect a drive cycle that made sense. For instance, the combination of values selected for driving duration (min) and driving distance (km) could result in a value for average speed that differs somewhat from the target value (e.g. the mean value of 30.3 km/h was targeted, however, needed to be 28.0 km/h to make sense in combination with the other parameters).

The values that have ultimately been incorporated into the defined drive cycles used throughout this analysis are within +10% to -10% of the values targeted in the Geotab dataset. For instance, the baseline drive cycle deviates 0.2% in distance travelled, 10.2% in average speed, 7.2% in driving duration, and 6.1% in idling time from its target values. These values correspond to variance of 0.1 km, 3.1 km/h, 9.8 min, and 111 sec, respectively. For the baseline case, where the target was the mean of the Geotab data, all the values fall well within the standard deviation. This is the case for several of the other drive cycles whose descriptions vary only in parameters not related to the route construction itself (e.g. slope, cargo load, temperature).

Simulated versus defined distances

The simulated distance varied slightly from the values that were defined in the drive cycles, because the tool used to generate the drive cycles creates artefacts in the drive cycle with quick accelerations and decelerations, and as a result of limitations of the driver control system, the vehicle model is unable to reach these accelerations. A comparison of the simulated and defined drive cycle distances is provided in Table 11. The simulated distance has been used to calculate the outputs of this analysis, namely charging demands, charging costs and GHG emissions.

Table 11. Comparison of simulated and defined drive cycle distances

Scenario	Defined Distance (km)*	Simulated Distance (km)**	Distance Coverage (%)
1 - Baseline	59.4	57.4	97%
2 - Extreme Cold	59.4	57.1	96%
3 - Extreme Heat	59.4	58.8	99%
4 - High Ignition Off	56.2	54.5	97%
5 - Low Ignition Off	61.6	61.5	100%
6 - High Congestion	60.0	58.6	98%
7 - Low Congestion	59.4	51.1	86%
8 - Heavy Cargo Load	59.4	58.0	98%
9 - Light Cargo Load	59.4	55.9	94%
10 - Uphill Slope	59.4	56.5	95%
11 - Downhill Slope	59.4	57.7	97%
12 - Maximum Demand	93.4	87.9	94%
13 - Minimum Demand	36.0	32.2	89%

*Values included in the drive cycle definitions created for this analysis

**Actual distance achieved in the model simulations

Appendix B. Vehicle model parameters

This appendix details the parameters of the vehicle model developed for this analysis, a manufacturer agnostic electric cargo van. The vehicle model was developed by researchers at the National Research Council (NRC), and the information included in Table 12 draws from the report they developed for the Pembina Institute for the purposes of this project.[41]

Table 12. Vehicle model inputs

Parameter	Assumed Value	Source
Motor		
Efficiency Map	Available upon request	Nissan Leaf & other heavy-duty motors
Torque-Speed Curve	Available upon request	Adapted Nissan Leaf torque-speed curve
Power Limit	140 kW	Approximate average of electric cargo van models currently available in Canada
Moment of Inertia	0.05	Doubled value of Nissan Leaf motor
Drivetrain		
Differential Ratio	12	NRC assumed value
Transmission Ratio	1	Direct Drive, no transmission
Drivetrain Efficiency	0.9	X-Engineer.org[42]
Power Distribution	AWD	NRC assumed value
Axles & Wheels & Brakes		
# Axles	2	NRC assumed value; consistent with existing cargo van models
# Wheels/Axle	2	NRC assumed value; consistent with existing cargo van models

[41] David Holt, *Urban Freight Electrification in the GTHA: Simulation and Feasibility Analysis*, prepared for the Pembina Institute (2021).

[42] X-Engineer.org, "Drivetrain Losses (Efficiency)." https://x-engineer.org/automotive-engineering/drivetrain/transmissions/drivetrain-losses-efficiency/

Tire Radius	0.35	TireSize.com[43]
Slip Ratio	0.1	NRC assumed value; static for most situations
Axle Inertia	2	NRC assumed value
Tire Coefficient of Friction	1	Bosch Automotive Handbook 10th edition[44]
Rolling Resistance Coeff	0.008	Bosch Automotive Handbook 10th edition; tires on asphalt[45]
Brake Distribution	0.75 front	NRC assumed value; presumption of weight over front axle, brakes generally defer to front for safety purposes
Braking Torque Max	10000 Nm	NRC assumed value; enough that either set of brakes could stop vehicle
Vehicle Structure		
Mass	3000 kg	NRC assumed vale; approximation of collected electric cargo van values
Wheelbase	3.75 m	Ford Transit van
X Com Vehicle	1.25m	NRC assumed value; 1/3 of way through wheelbase; unknown because of placement of batteries
Z Com Vehicle	0.5 m	NRC assumed value
Max Load	2000 kg	NRC assumed value; calculations detailed in Appendix A of the report
X Com Load	3.00m	NRC assumed value; cargo mass located well toward back of vehicle
Z Com Load	1.25 m	NRC assumed value
Aerodynamics		
Air Pressure	1.2 kg/m3	NRC assumed value
Frontal Area	3.5	NRC assumed value
Drag Coeff	0.35	Bosch Automotive Handbook 10th edition; high end value for vans[46]
Battery & Inverter		
Cell Chemistry	LMO	Nissan Leaf pack assembly
Ncells S Per Module	96	Nissan Leaf pack assembly
Module Ah	32.67	Nissan Leaf pack assembly

[43] TireSize.com, "Tires by Vehicle." https://tiresize.com/tiresizes/235-65R16.htm

[44] Bosch, *Automotive Handbook: 10th Edition* (2018).

[45] *Automotive Handbook: 10th Edition*

[46] *Automotive Handbook: 10th Edition*

SOCmin, SOCmax	10/90	NRC assumed value
Total Pack (V)	~380	Nissan Leaf pack assembly
Total Pack (kWh)	~87 kWh	Approximate value from cell VoC & Ah & Assembly
Battery Cell Resistance	Dynamic	NRC assumption based on Nissan Leaf tests
Inverter Efficiency	0.99	NRC assumed value
Regenerative Efficiency	0.375 * Motor efficiency	NRC assumed value
Auxiliary Systems		
HVAC Power	6 kW	NRC assumed value; based on Bosch Automotive Handbook 10th edition[47] and currently available electric cargo van specifications
Heat Pump Efficiency (kW Heat/Electricity)	2.2 at 0°C 3.3 at 10°C	NRC assumed values; based on source at NRCan
HVAC Set Temp	20	NRC assumed value
Heat/Cool Set Temperatures	18/22°C	NRC assumed values
Thermal Conductivity	830 kJ/K	NRC assumed value; upscaled from Nissan Leaf
Vehicle Heat Capacity	200 W/K	NRC assumed value; upscaled from Nissan Leaf
Other Aux Demands	1kW	NRC assumed value

[47] *Automotive Handbook: 10th Edition*

Appendix C. Fuel cost calculations

To calculate fuel cost savings, the average electricity rate charged by local distribution companies (LDCs) in the GTHA was calculated for general service customers ranging in size from 50 to 5000 kW.[48] There are three major components that make up electricity charges in Ontario: the electricity commodity charge, the delivery charge and the regulatory charge.

To calculate the electricity commodity charge, the average Hourly Ontario Energy Price and Global Adjustment (GA) charges from 2019 were used, which amounts to approximately $0.13 per kWh.[49]

The regulatory charge, which includes the wholesale market service rate charge and, in some cases, the rural rate protection charge, is relatively uniform across all LDCs in the GTHA. This charge also includes the regulatory service supply charge of $0.25 per month; however, this has been excluded as it will be charged independently of EV adoption.

The delivery charge, meanwhile, differs somewhat from one LDC to another, and also across different customer classes. This charge is primarily made up of the distribution volume charge, transmission connection charge and transmission network charge. In some cases, a line loss factor is applied to account for electricity losses along the transmission line. It was found that the price of power ranged from $0.26 to $0.51/kW across LDCs in the GTHA with an average price of $0.33/kW.

Each bill also includes a monthly service charge ranging from $51.65 to $3,688.21 per site, however, this charge has not been captured in the calculations due to the fact it will be charged regardless of EV adoption.

To calculate the daily electricity costs, the following formula was used:[50]

$$Cost = (Charge_{Delivery} * Power_{Peak}) + ((Charge_{Electricity} + Charge_{Regulatory}) * Energy_{consumed-daily} / Eff_{Level\ 1\ or\ Level\ 2})$$

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[48] LDCs included Alectra Utilities, Burlington Hydro Inc., Oakville Hydro Electricity Distribution Inc., Milton Hydro Inc., Halton Hills Hydro Inc., Newmarket-Tay Power Distribution Ltd., Elexicon Energy Inc., Oshawa Power and Utilities Corporation, Hydro One and Toronto Hydro.

[49] IESO, “Price Overview.” https://www.ieso.ca/en/Power-Data/Price-Overview/Hourly-Ontario-Energy-Price

[50] *Urban Freight Electrification in the GTHA: Simulation and Feasibility Analysis*

Appendix D. Breakdown of energy consumption

Multiple components within EVs draw power from the battery: the motor, the HVAC system, as well as any other auxiliary components, such as a powered-lift or radio. The battery on-board an EV is also supplied with energy captured through regenerative braking, a process that recovers kinetic energy during deceleration. For each of the scenarios explored in this analysis, a breakdown of the EV's energy consumption can be found in Table 13. Results reflect those that have been presented in the NRC's report developed for the Pembina Institute for the purposes of this project.[51]

Table 13. Breakdown of energy consumption across each drive cycle

Scenario	Distance (km)	Consumption (kWh)				Regen Supply (kWh)
		Battery	Motor	HVAC	Auxiliary	
1 - Baseline	57.4	10.3	7.1	2.4	2.7	2.0
2 - Extreme Cold	57.1	15.0	7.1	7.1	2.7	2.0
3 - Extreme Heat	58.8	11.7	7.4	3.6	2.7	2.1
4 - High Ignition Off	54.5	10.8	6.5	3.2	2.8	1.9
5 - Low Ignition Off	61.5	12.7	11.8	1.4	2.2	2.8
6 - High Congestion	58.6	13.9	10.0	2.9	3.6	2.6
7 - Low Congestion	51.1	8.5	6.8	1.7	1.7	1.7
8 - Heavy Cargo Load	58.0	11.1	8.3	2.4	2.7	2.5
9 - Light Cargo Load	55.9	9.6	6.2	2.3	2.7	1.7
10 - Uphill Slope	56.5	11.4	8.5	2.3	2.7	2.2
11 - Downhill Slope	57.7	11.2	8.3	2.4	2.7	2.3
12 - Maximum Demand	87.9	43.2	40.0	8.7	3.3	9.2
13 - Minimum Demand	32.2	3.0	2.3	0	1.4	0.8

[51] *Urban Freight Electrification in the GTHA: Simulation and Feasibility Analysis*