EV300 Final Report

Prepared for:

Toronto Atmospheric Fund

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Report submitted:

Friday, November 29th, 2013

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1.0 Introduction

1.1 FleetCarma

FleetCarma is a division of CrossChasm Technologies. Founded in 2007, CrossChasm provides engineering support to for major OEM vehicle design process and control system integration. FleetCarma leveraged this expertise to create a service for fleets based on real-world data logging, prediction, and results.

FleetCarma currently focuses on two core service offerings. The first employs data loggers within a fleet to accurately measure real-world fuel consumption, and characteristics of a vehicle's duty cycle. FleetCarma's predictive modeling and simulation accurately assess the performance of electric vehicles within the logged duty cycle. The second core service FleetCarma provides is in-service performance monitoring. FleetCarma data loggers access hard-to-get data on electric vehicles, such as battery state-of-charge and electricity consumption, and provide insights with that data to key stakeholders, customers, and partners.

1.2 Electric Vehicle Modeling and Simulation

Through expertise in powertrain design, FleetCarma developed a service in which vehicle models could simulate the performance of electric vehicles in the real world. This analysis not only predicts the fuel and power consumption of electric vehicles but predicts the range and charge capabilities of the simulated vehicles. This analysis involves running the real-world drive cycle through a vehicle model which can then predict whether or not, under the same real-world conditions as the baseline vehicle, the electric vehicle would have enough range to complete the duty cycle. The charging capability of the vehicle is assessed in a similar way. In order to determine if the vehicle has enough time at night to charge, the simulated vehicle is run through the duty cycle for each day. Analysis determines if there is sufficient time between the last trip of the day, and the first trip of the following day for a vehicle to charge. Based on the analysis of range capability, charge capability, fueling considerations and other operational costs, a score is assigned to each simulated vehicle. The highest scoring vehicle is chosen as the 'best fit vehicle'.

1.3 In-Service Performance Monitoring

FleetCarma's C5 data logger was designed to log signals from electric vehicles. Other loggers on the market, while able to provide information on vehicle position and speed could not access signals relating to the electric vehicle powertrain, such as battery state-of-charge, or power used while driving and charging. FleetCarma's C5 data logger records these signals to an online web portal which provides key metrics for fleet managers, researchers, utilities and other organizations collecting real-world data on electric vehicles.

The in-service performance monitoring provides several insights for fleet managers. Accessible through a web portal, data can be accessed showing the vehicle's utilization and distance travelled, driver behaviour metrics, and charging information.

On each day the vehicle is used by the fleet, the system estimates the available range for the vehicle based on charging done at night (bulk charging) or in between trips throughout the day (opportunity charging). Daily range estimates are dynamically changing, however, based on several factors including the average daily temperature, auxiliary loads for each trip, and driver behaviour including acceleration and braking behaviours.

Included in the web portal is a fleet-wide report to allow fleet managers to aggregate all their EV utilization metrics and benchmark their fleet’s performance against other fleets managing electric vehicles within the EV300 program and beyond.

2.0 Methodology

2.1 Electric Vehicle Modeling and Simulation Process

Electric vehicle modeling and simulation was conducted by installing a small data logger into fleet vehicles. These vehicles were driven for a period of approximately 3 weeks to collect a sufficient amount of data on their duty cycle including any routine variation in the requirements of the fleet application. This information was used to create a baseline vehicle to benchmark against the comparable electric vehicles as substitutes.

The predictive performance of five electric vehicle models was obtained by using the data gathered from the baseline (existing) vehicle to drive the computer models of EVs in the same duty cycle. This analysis not only predicts the fuel and electricity consumption of plug-in vehicles but predicts the range and charge capability of electric vehicles completing those duty cycles. As part of this process, the total cost of ownership for the baseline vehicles were compared to the duty-cycle-specific costs of owning and operating compare EVs doing the same jobs.

2.2 In-Service Performance Monitoring Process

In-service performance monitoring was accomplished with a FleetCarma C5 data logger. The data logger collected information on the vehicle's mileage and utilization, fuel and power consumption, charging information, and driver behavior. This data was uploaded by fleet managers into an online web portal periodically over approximately one year.

Data from the logger were processed by FleetCarma's back-end system and key performance metrics were provided in the web portal and used to generate a report for each vehicle.

2.3 Analysis

Analysis done for this report to evaluate the real-world performance of electric vehicles began with an assessment of trip by trip data logs and their associated key performance metrics. Data analysis for this report excluded trips less than 2 km from aggregate reports as their performance metrics are often skewed by the short distance travelled and did not reflect the same results as longer trips, particularly relating to electric range estimations.

When considering the potential savings, or making direct comparisons in duty cycles between electric vehicles and baseline vehicles in the EV300 program the Best Fit vehicle is used. Based on the analysis of range capability, charge capability, fueling considerations and other operational costs, a score is assigned to each simulated vehicle. The highest scoring vehicle is chosen as the Best Fit electric vehicle.

3.0 The Choice to Work with Fleets

Fleets are a natural choice for the early adoption of electric vehicles for several key reasons. Fleets have often been the leaders of new technologies, demonstration vehicles and pilot programs. A fleet's structure allows for greater implementation of a new technology as a large number of vehicles can be purchased and used.

Fleets contain many different vehicles used for a variety of applications. This suits the integration of electric vehicles into fleets as electric vehicles can first be implemented in duty cycles which are ideal for a plug-in vehicle. This targeted early implementation allows for greater initial success while fleet operators, drivers, and the organization adapt to the new technology.

Fleets are an ideal testing ground due to their control over driving patterns and operation. Fleets often keep track of driving cycles and have up-to-date information on when, how, and specifically how much each vehicle is used.

Fleets also have some control over the implementation of the infrastructure beneficial to electric vehicle adoption. Fleets can ensure that drive cycles have charging points at various locations the vehicle may be travelling to, and can also ensure regular hours for the vehicle to charge.

Fleets have a business interest in integrating alternative technologies, and specifically electric vehicles into their fleet due to the increasing cost of gasoline. Fueling a vehicle takes up a considerable portion of the fleets budget, and while incremental decreases in fuel consumption are helpful, replacing vehicles with electric vehicles has a much more significant decrease in operational costs.

Maintenance costs are also an important consideration for fleet operators. Electric vehicles require less maintenance than the internal combustion engine vehicles which, combined with fuel savings, help to reduce payback periods on the premium paid for plug-in vehicle technology.

Fleet operators also act as leaders in vehicle implementation and leaders in developing a sustainable transportation framework. The efficiency of vehicles within a fleet and the consequential reductions in greenhouse gas emissions is an environmental benefit that an organization can rely on to support their sustainability programs. That benefit can be used to achieve internal targets for emissions reductions or used as a highlight the work is doing in this regard to external stakeholders, citizens, and customers.

4.0 Electric Vehicles and Fleet Considerations

4.1 Plug in Hybrid Electric Vehicles Included

4.1.1 Chevrolet Volt

The Chevrolet Volt is a 4-passenger plug-in hybrid electric vehicle that contains a 16 kWh battery with 10.4 kWh of usable capacity. Chevrolet advertises a battery only range between 40-80 kilometers, depending on driving conditions. Based on the size of the battery pack, the Volt qualified for an $8,231 tax credit from the Ministry of Transportation in the province of Ontario.

4.1.2 Toyota Prius Plug-in

The Prius Plug-in is a 5-seater hatchback that has a 4.4kWh lithium ion battery, giving the Prius Plug-in a rated electric range of approximately 18km. The Prius Plug-in has an advertised fuel consumption of 2.5 L/100km$_{eq.}$ Based on the size of the battery pack, the Prius-Plug-in qualified for a $5,000 tax incentive in the province of Ontario during the time of this report.

4.2 Plug in Hybrid Electric Vehicle Considerations for Fleets

The core objective for fleet managers that are integrating plug-in hybrids into their fleet portfolio is often to reduce their environmental impacts through improved vehicle efficiencies. To achieve this it is important for the fleet managers to ensure that the amount of electric driving as a proportion of total vehicle utilization is as high as possible. Some strategies to achieve this will be discussed throughout this report.

4.3 Battery Electric Vehicles Included

4.3.1 Nissan Leaf

The Nissan Leaf is a 5-passenger, 100% electric vehicle, that contains a 24 kWh battery pack. Nissan Canada advertises a range of 160 km however this range will vary with different temperatures and driving conditions, as is the case with other electric vehicles. The amount of time for a full recharge varies depending on the level of charger used, but could range from 8 hours to 20 hours. Based on the size of battery pack the Nissan Leaf qualified for an $8500 Ontario Electric Vehicle purchase price incentive at the time of this report.

4.3.2 Ford Transit Connect Electric

The Ford Transit Connect Electric is an all-electric van produced through a collaboration of Azure Dynamics and Ford Motor Company. The manufacturer advertised range is 130 km, EPA tested range is 90km of all electric range with a rated fuel consumption of 3.8 L/100 km$_{eq}$. With a 28 kWh lithium ion battery, the Transit Connect Electric vehicle is often used as a delivery van for documents, parcels, and other goods within a fleet operation.

4.3.3 Mitsubishi i-MiEV

The Mitsubishi i-MiEV is a 4-passenger vehicle an all-electric vehicle, first released in 2009, with a rated range of 100km. Powered by a 16 kWh lithium ion battery pack, the i-MiEV's advertised fuel economy is 2.1 L/100km$_{eq.}$ Based on the size of the battery pack, the i-MiEV qualified for an $8,231 tax credit in Ontario at the time of this report.

4.4 Battery Electric Vehicle Considerations for Fleets

4.4.1 Range Anxiety

Range anxiety is a significant concern for new electric vehicle owners or drivers that are unfamiliar with the vehicle's technology. Range anxiety is the feeling experienced by the driver of a battery electric vehicle, such as the Nissan Leaf, when they are unsure about the range the vehicle has available to complete their planned trips. Range anxiety results in negative feelings towards electric vehicles and viewing electric vehicles are undependable.

Range anxiety can be effectively addressed with adequate driver training and education on the best practices of driving an electric vehicle. With adequate training and experience, drivers can feel confident when operating the vehicles and develop strategies to reduce potential daily range issues.

4.4.2 Managing Payback Periods

One of the unique challenges for fleet operators integrating battery electric vehicles into the fleet portfolio is to find an application where the vehicle will have enough daily driving to take advantage of low operating costs and reduce payback periods, without running the risk of having the vehicles stranded on the side of the road. Ensuring that they deploy the all-electric vehicles to achieve this sweet-spot of utilization that minimizes payback periods given the range limitations is the key success factor to integrating all electric options into the fleet program.

5.0 Current Fleet Results

Data used to simulate electric vehicles were recorded from a set of baseline fleet vehicles. These vehicles operated in a variety of duty cycles and were used in fleets for municipalities, airports, transportation agencies, car-sharing companies and other organizations. A summary of baseline vehicle metrics collected is provided in Table 1.

Table 1: Metrics on utilization of conventional vehicles within the EV300 program

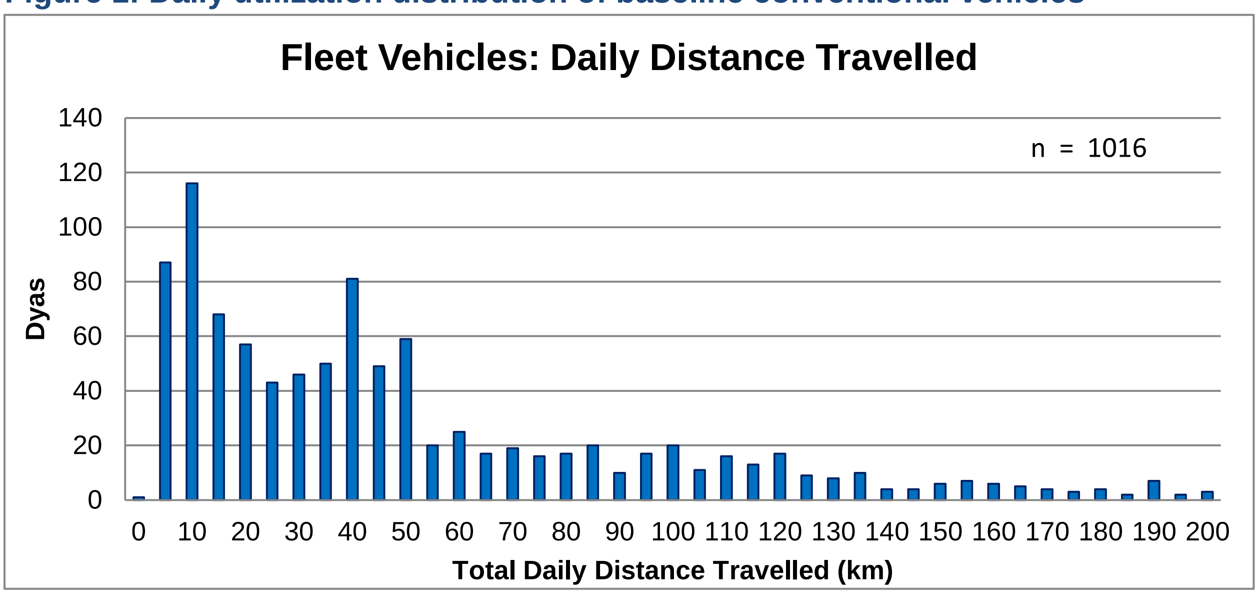
Utilization Metric	Average Result
Average Daily Distance	54.4 km
Average Real-World Fuel Consumption	12.8 L/100km
Average Idle Time (%)	19.5%
Average Carbon Emissions Intensity	30.5 kg/100km
Average Fuel Spend per 100 km	$16.67/100km

With nearly a fifth of all operational time spent idling, the baseline fleet vehicles saw tremendous opportunities for fuel savings with powertrain electrification.

5.1 Daily Distance

Daily distance travelled is an important indicator of a vehicle's utilization and duty cycle needs. At a glance, the vehicle's daily distance travelled may give early indications of suitable replacement vehicles. The average daily distance travelled by baseline internal combustion engine vehicles was 54.4 km. This average distance is within the advertised ranges of the all-electric vehicles as well as the all-electric range of the Chevrolet Volt.

Figure 1: Daily utilization distribution of baseline conventional vehicles



The distribution of the daily distance travelled by baseline vehicles is shown in Figure 1. From the distribution we can see that most often vehicles are utilized up to 50 km each day. The usage of the baseline vehicles indicates that many of the simulated electric vehicles will have adequate range capability to perform the same duty cycle. For the vehicles that recorded days with a greater distance travelled than the simulated range of the vehicle, a plug-in hybrid electric vehicle would be more appropriate.

5.2 Range and Charge Capabilities

Vehicles' range and charge capabilities were assessed by determining the number of times a vehicle failed to be range capable, or charge capable for each the duty cycle examined. This would help determine which model of electric vehicle was suitable to replicate the performance of the baseline vehicle without any modifications to the baseline vehicle's duty cycle.

Range and charge capabilities are primarily a concern for battery-electric vehicles. When a plug-in hybrid electric vehicle, such as the Chevrolet Volt, runs out electric range, the back-up range extender uses gasoline and the vehicle can still complete the duty cycle required.

Table 2: Perfect range capability for battery electric vehicles in baseline fleet duty cycles:

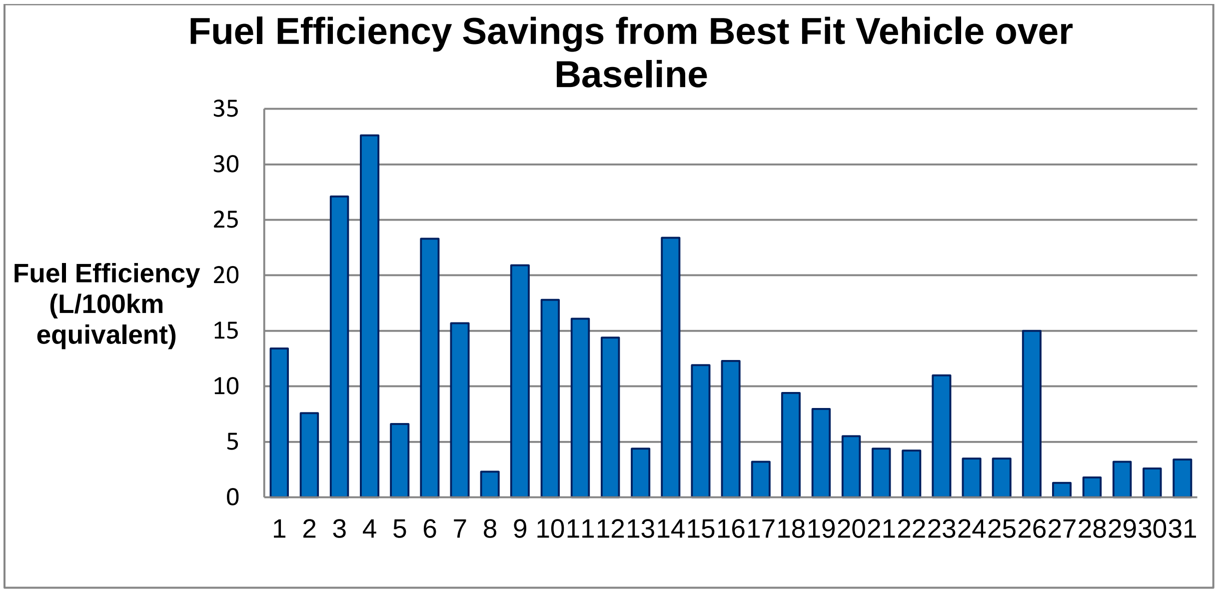
Battery Electric Vehicle Model	No Range Concerns on baseline duty cycle
Ford Transit Connect Electric	61% of days studied
Mitsubishi i-MiEV	61% of days studied
Nissan Leaf	67% of days studied

5.3 Fuel Efficiency Savings

Fuel efficiency is a concern for fleets as fuel constitutes a large portion of the operational budget. The integration of electric vehicles into fleets inevitably results in reduced fuel consumption.

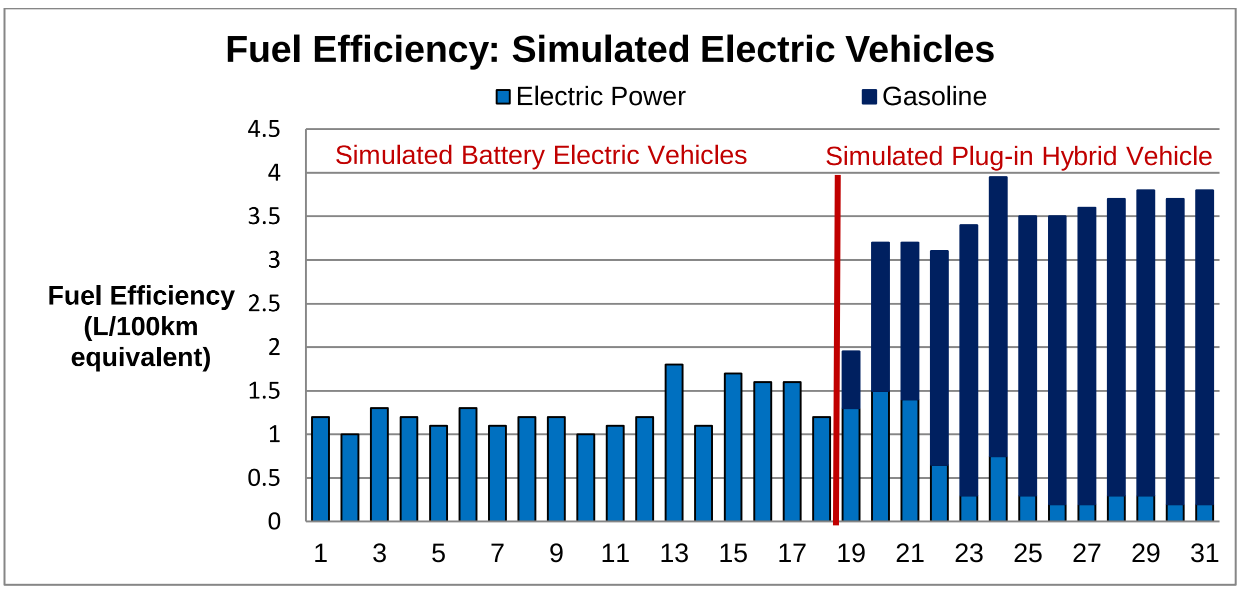
Figure 2 shows the variation in fuel saved from logged baseline vehicles and simulated electric vehicles. The electric vehicle chosen for comparison is the 'best fit' electric vehicle, based on the total cost of ownership and range and charge capabilities.

Figure 2: Fuel Efficiency Savings gained by replacing baseline fleet vehicles with Best Fit simulated electric vehicle.



Further inspection of the fuel used by the Best Fit electric vehicles shows the difference in fuel usage between the battery electric vehicles and plug in hybrid vehicles recommended.

Figure 3: Fuel Efficiency of Simulated Electric Vehicle. Combined L/100km equivalents of electric power and gasoline to create a total fuel savings amount



While using plug-in hybrid vehicles increases fuel consumption relative to all-electric vehicles, plug-in hybrids still achieved 57% improvement on average over baseline vehicles. The battery electric vehicles improved fuel consumption by 88%, on average.

6.0 Real-World Electric Vehicle Performance

There were four models of electric vehicle monitored and included in this analysis. Table 3 shows how many of each vehicle model that is included in this analysis.

Table 3: Vehicle Models used in analysis

Vehicle make and model	Vehicles included in analysis
Nissan Leaf	20
Mitsubishi i-MiEV	1
Ford Transit Connect Electric	10
Chevrolet Volt	15
Plug-in-Prius	6

Electric vehicles within a fleet can be evaluated by several key metrics surrounding their utilization and performance. Daily distance travelled is an indicator of overall performance. Oftentimes, trip distances for fleet vehicles are much shorter than the overall daily distance, suggesting that fleet vehicles take many short trips throughout the day.

This discrepancy can be shown in Table 4. From the table, we can see that with the Mitsubishi i-MiEV as an exception, the average daily distance travelled exceeds the average trip distance. This indicates that on average, fleet vehicles monitored by the EV300 program take more than one trip each day.

Table 4: Average Trip and total daily distances electric vehicles within the EV300 program travel

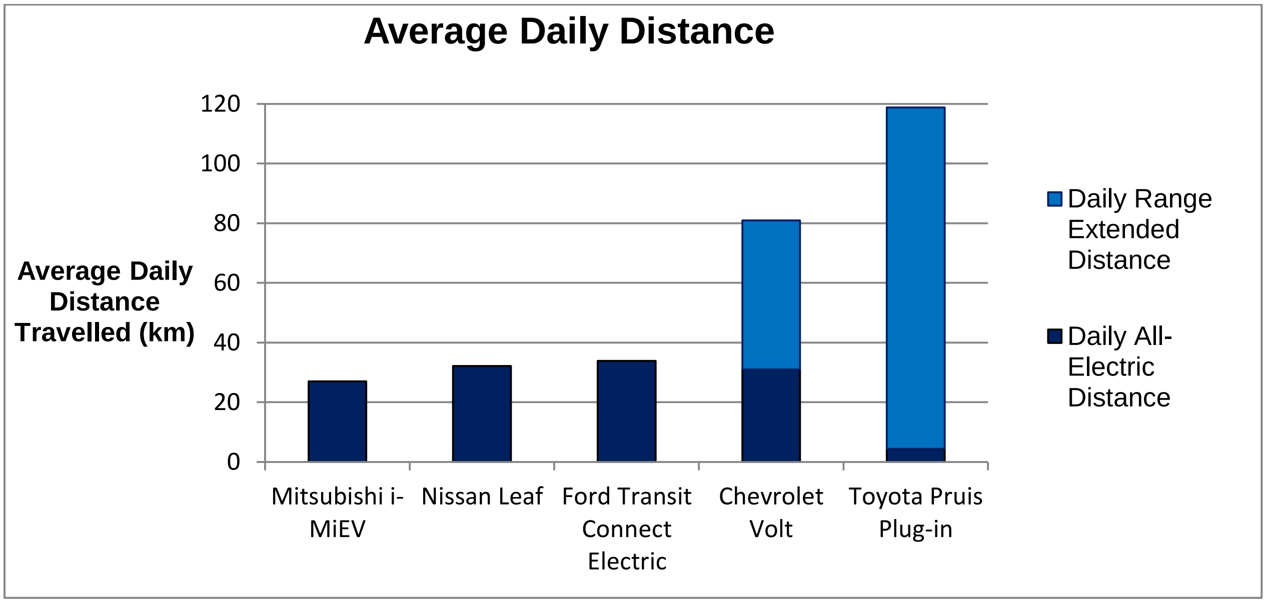
Vehicle make and model	Average Trip Distance (km)	Average Daily Distance (km)
Nissan Leaf	21	32.1
Mitsubishi i-MiEV	32	27
Ford Transit Connect Electric	9.8	33.8
Chevrolet Volt	31.5	80.8
Plug-in-Prius	47.4	188.8

Fleet managers can take the time between trips to charge the vehicles, but it may rely on multiple charging sites throughout the daily duty cycle or publicly available infrastructure to do so. This opportunity charging can help to increase the electric distance vehicles travel in later trips.

6.1 Vehicle Utilization

Vehicle utilization is analyzed by investigating the overall distance travelled each day. This provides insight into the overall mileage a vehicle may achieve, and has the benefit of looking at the total distance travelled throughout many trips.

Figure 4: Average daily distance travelled by electric vehicles within the EV300 program



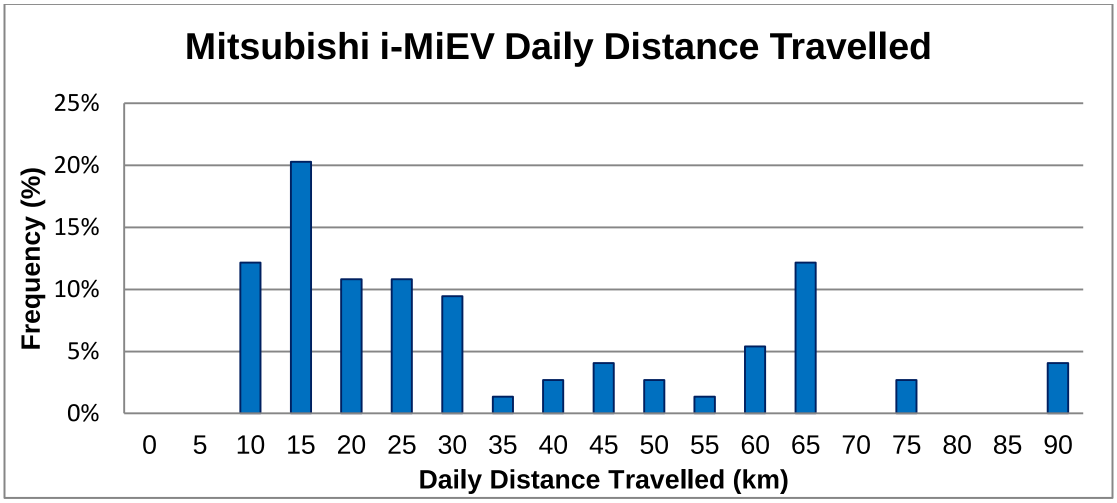
The daily utilization plot shown in Figure 4 demonstrates the ***average*** real-world utilization of electric vehicles within the EV300 program, note that the distribution of daily utilization values varies considerably and are presented in the follow section. The vehicle model with the highest average utilization is the Toyota Prius Plug-in. However the Toyota Prius Plug-ins within the EV300 fleet ended up having minimal usage of the vehicles all-electric range. The Chevrolet Volts within the EV300 program also employ the on-board range extender, but for a much smaller portion of operation. Additionally Chevrolet Volts within studied here achieved as much daily electric utilization as the battery electric vehicles within the fleet, despite having a smaller advertised range.

6.1.1 All Electric Utilization by Vehicle Model

To further investigate the differences between vehicle models with regards to their daily utilization, we will look at the distribution of distances that these vehicles travel in a day. This can highlight some vehicle specific characteristics.

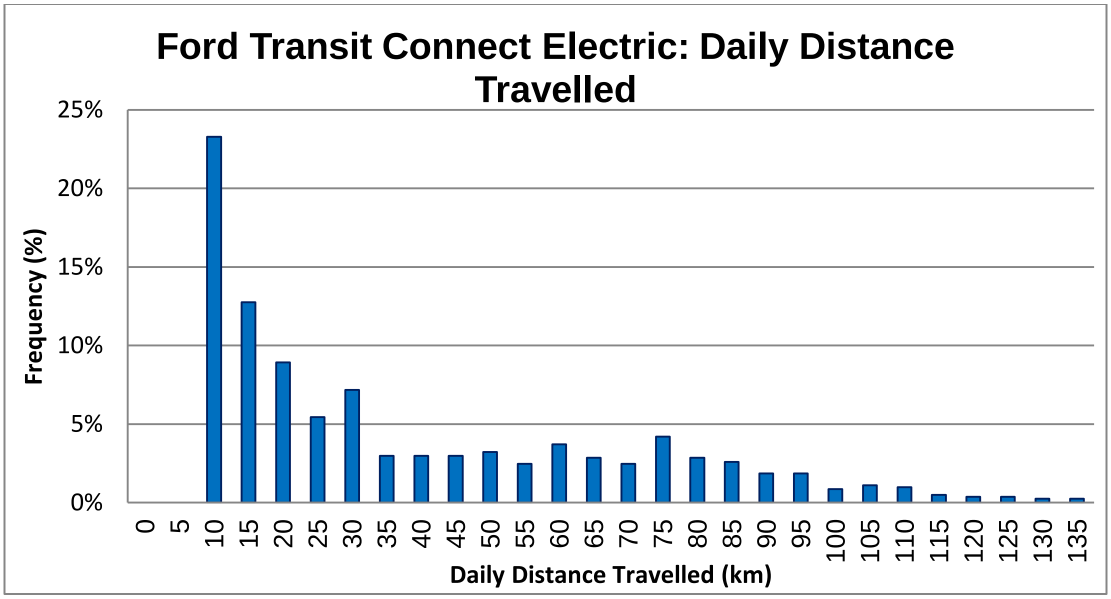
It is important to note that these distances represent the total distance the vehicle has travelled throughout the day. This may include several trips and can include opportunity charging done in between trips, extending the distance the vehicle travels in a day beyond the advertised range. These distribution plots also do not indicate the daily distance that would be possible for each of the vehicles to travel but rather the distance that they were used.

Figure 5: Mitsubishi i-MiEV Daily Utilization Distribution



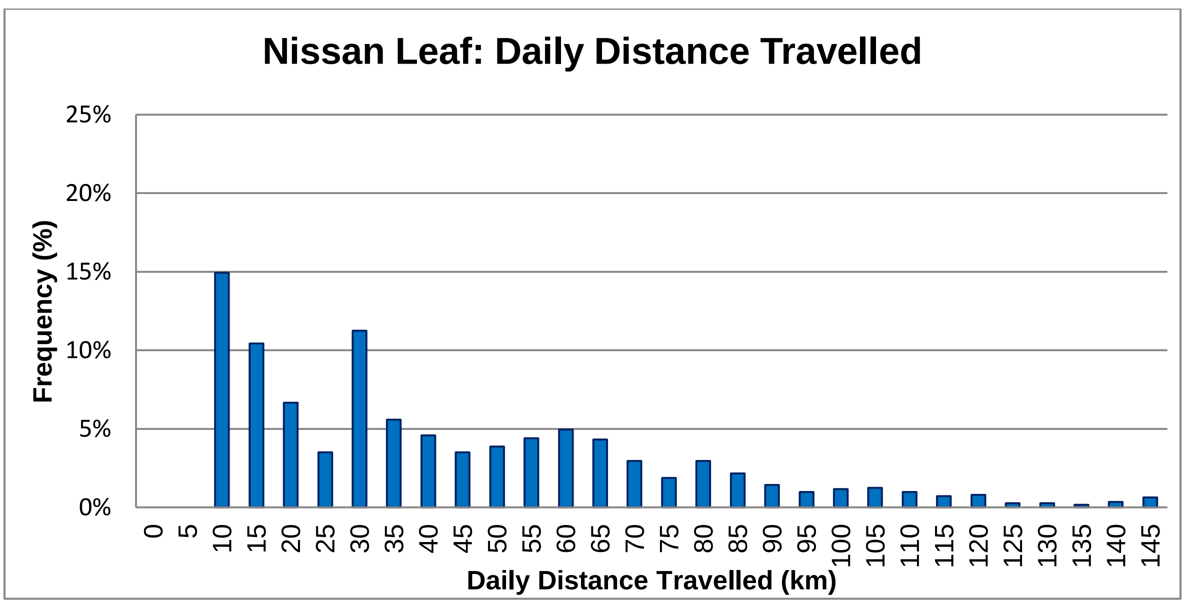
The Mitsubishi i-MiEV most often travels approximately 15 km a day. However the vehicle has days in which greater utilization was achieved, even up to 90 km a day. All of this utilization is within the advertised range of the vehicle. The Mitsubishi i-MiEVs most frequently travelled a combined 15 km each day.

Figure 6: Ford Transit Connect Electric daily utilization distribution



Ford Transit Connect Electric Vehicles within the EV300 program were most often used to drive 10 km each day. The data from these vehicles also showed daily utilization taper off significantly, suggesting that they could be utilized much more each day.

Figure 7: Nissan Leaf daily utilization distribution

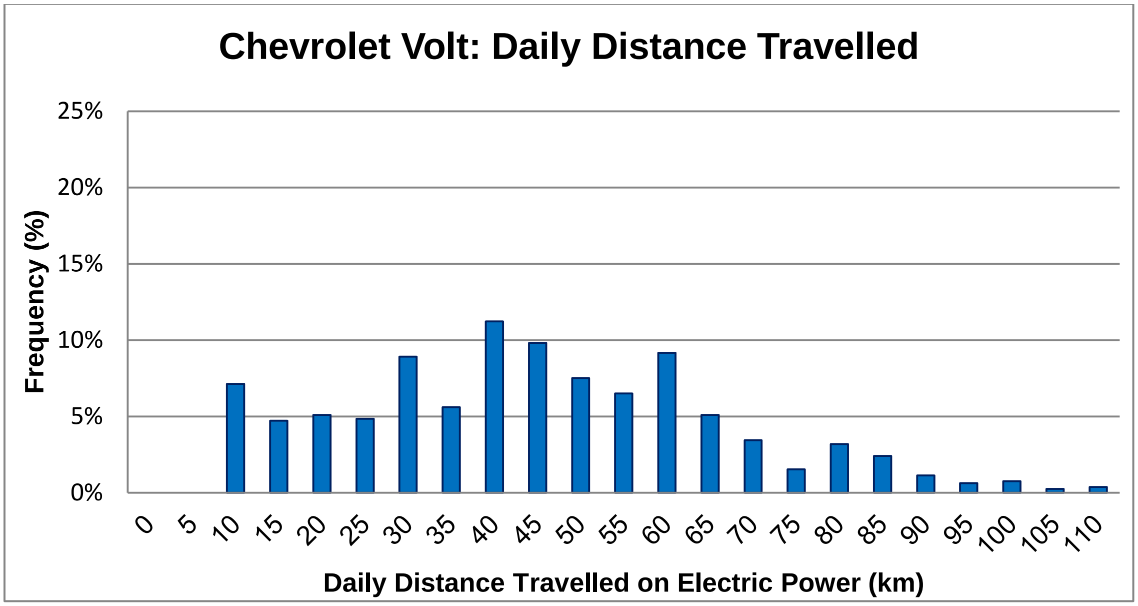


The Nissan Leaf vehicles within EV300 follow other battery electric vehicles within fleets. The average daily distance most often seen was 10km/day; however, the average daily distance travelled across all days for the LEAFs was 32 km.

6.1.2 Plug-in Hybrid Vehicle Electric Utilization

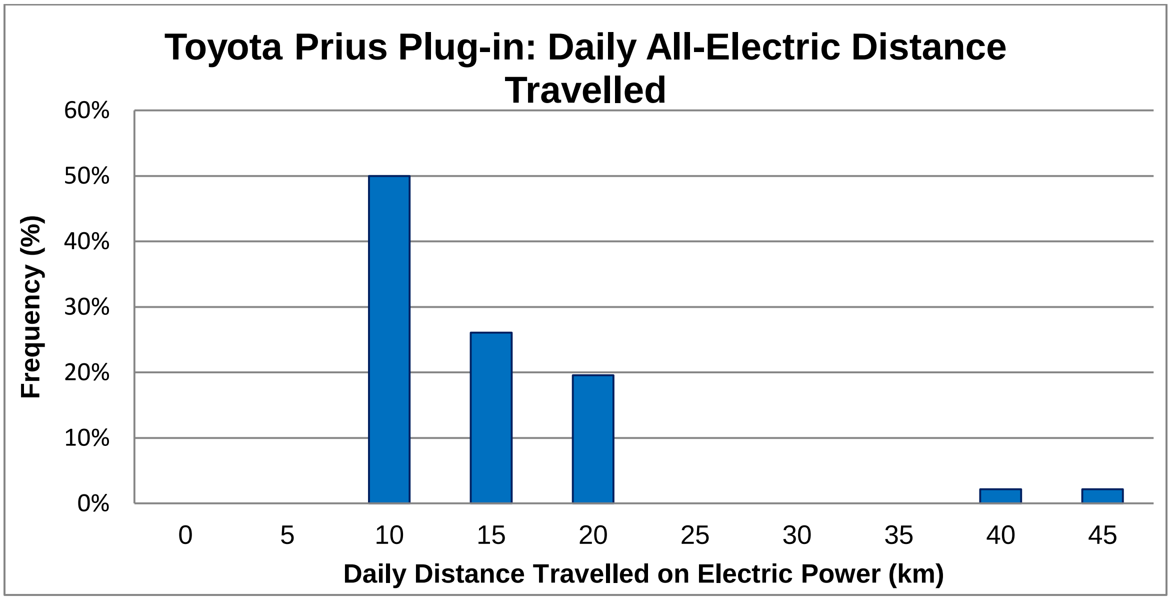
The following figures take into account only the utilization that occurred while powered by the battery. This investigation is helpful because increasing this utilization is what provides the greatest environmental benefits and operational savings for fleets.

Figure 8: Chevrolet Volt daily all-electric utilization distribution



For the Chevrolet Volt, overall utilization was fairly high, and often exceeded the electric-only range of the vehicle. This suggests that on several days these vehicles were able to benefit from opportunity charging throughout the day to achieve a greater electric range.

Figure 9: Toyota Prius Plug-in daily all-electric utilization distribution



For Toyota Prius Plug-In vehicles included in this study, the percentage of distance travelled on electric power each day was only 3%. These vehicles present a significant opportunity for fuel savings within the EV300 program compared to ICE vehicles, but seems like more opportunities exist to increase the amount of electric driving as a proportion of total utilization.

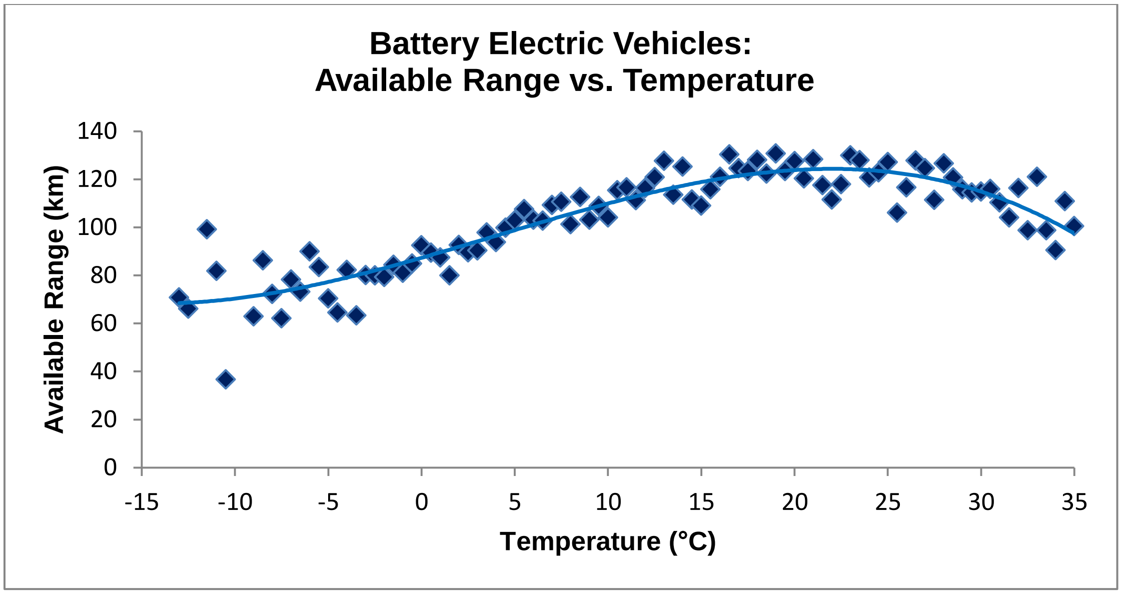
6.2 Factors Affecting Electric Utilization

6.2.1 Temperature Effects on Battery Electric Vehicles

Temperature can affect a battery electric vehicle in a variety of ways. Cold temperatures can affect the efficiency of the battery, and auxiliary loads used to heat or cool the cabin are consuming energy from the vehicle's battery pack that could reduce its electric driving range.

A step in maximizing the daily electric utilization of a vehicle is to ensure that the vehicle has adequate range to do the duties required, or take on additional duties. Operators must be comfortable with the amount of range a vehicle has available, and may be hesitant when the available range decreases more quickly than expected.

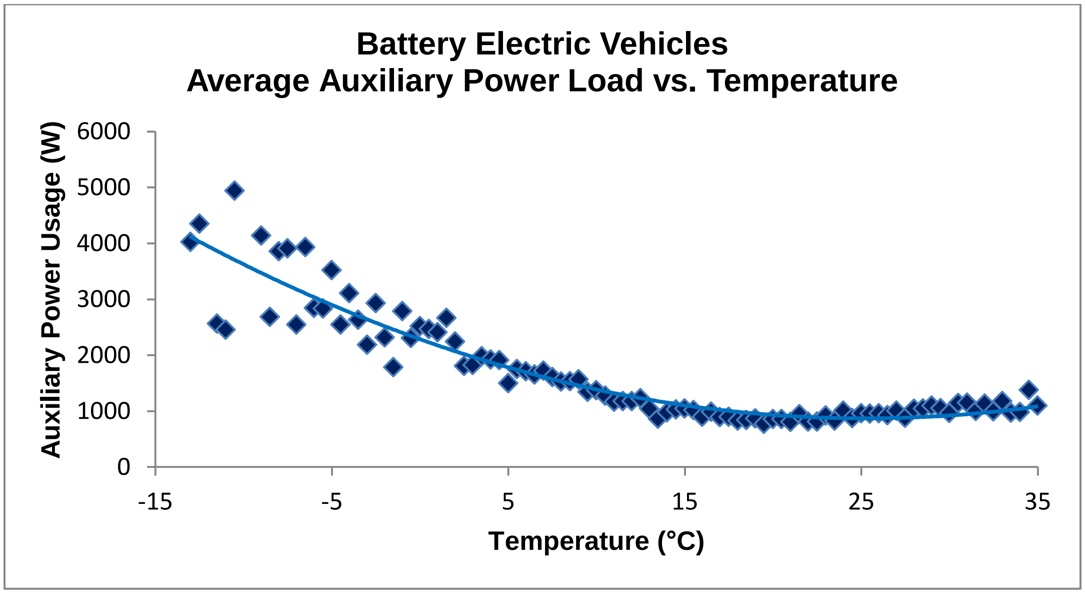
Figure 10: The average available range across battery electric vehicle trips taken at particular temperatures



From Figure 10 we can see that the average range a battery electric vehicle has available varies according to the ambient temperature outside. Colder temperatures (those below 15 ºC) have a greater impact on range than warmer temperatures (those above 25 ºC).

The optimal temperatures for maximizing electric vehicle range appeared to be between 15-25 ºC. Variability in range for electric vehicles is often due to heating and air conditioning to keep the cabin at a comfortable temperature. The effect of heating and air conditioning on range can be investigated by plotting the auxiliary load usage with temperature. Most vehicle models record the ambient temperature during a trip. This information is passed on to the FleetCarma EV data logger. In Figure 11 the average ambient temperature throughout the trip is plotted against the average auxiliary load throughout the trip.

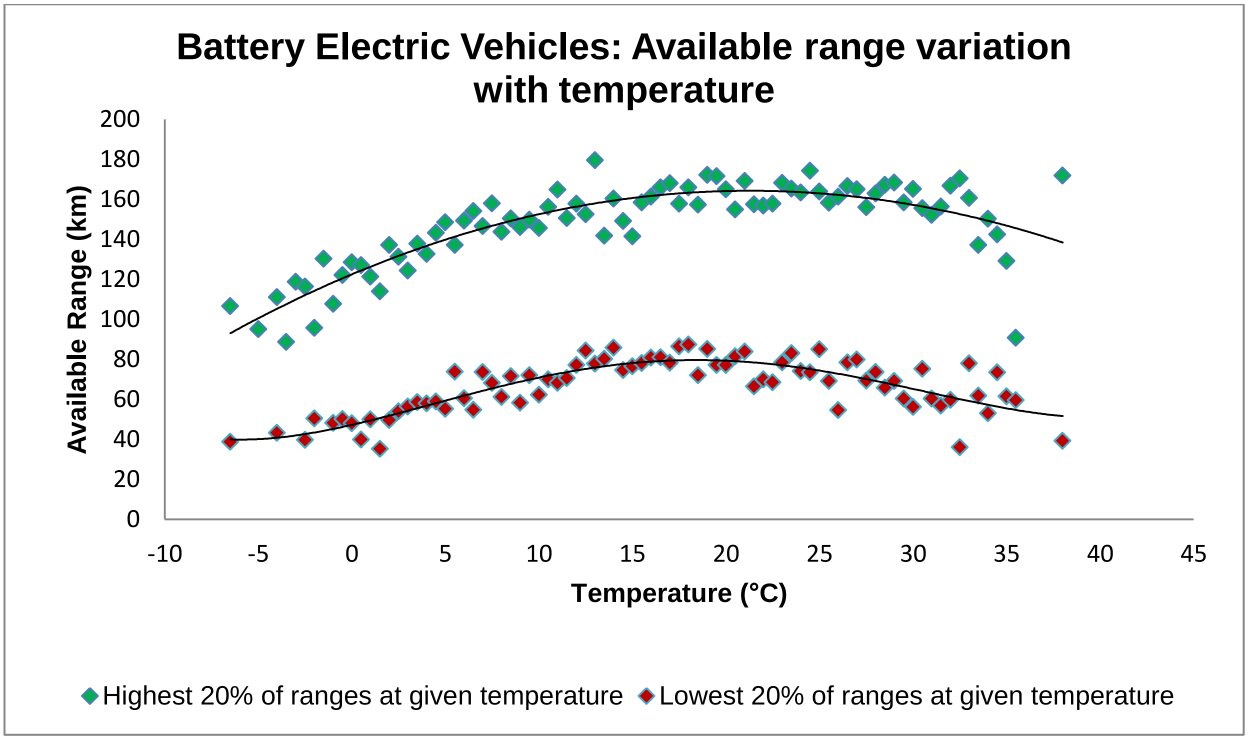
Figure 11: The average auxiliary load range across battery electric vehicle trips taken at particular temperatures.



The relationship between auxiliary power usage and temperature indicates that auxiliary power usage is a significant component in the loss of available range at high or low temperatures. As with the temperature and range plot, the effect of auxiliary power usage is much more pronounced at colder temperatures than warmer temperatures.

Figures 10 and 11 above provide a clear sense that temperature changes impact the driver's available electric range, however, a closer examination of the data also revealed that there was a large amount of variation in the estimated driving range at any given temperature point in the graph. To demonstrate this variation further, each trip analyzed was divided into categories of range performance at any given temperature. The top 20% of available range per trip and bottom 20% of available range per trip was plotted by temperature. Examining the available ranges across the spread of temperature readings showed a substantial gap between the top 20% and the bottom 20% groups. The results are shown in Figure 12 below.

Figure 12: Estimated driving range differences between top and bottom performing drivers of battery electric vehicles, plotted by temperature

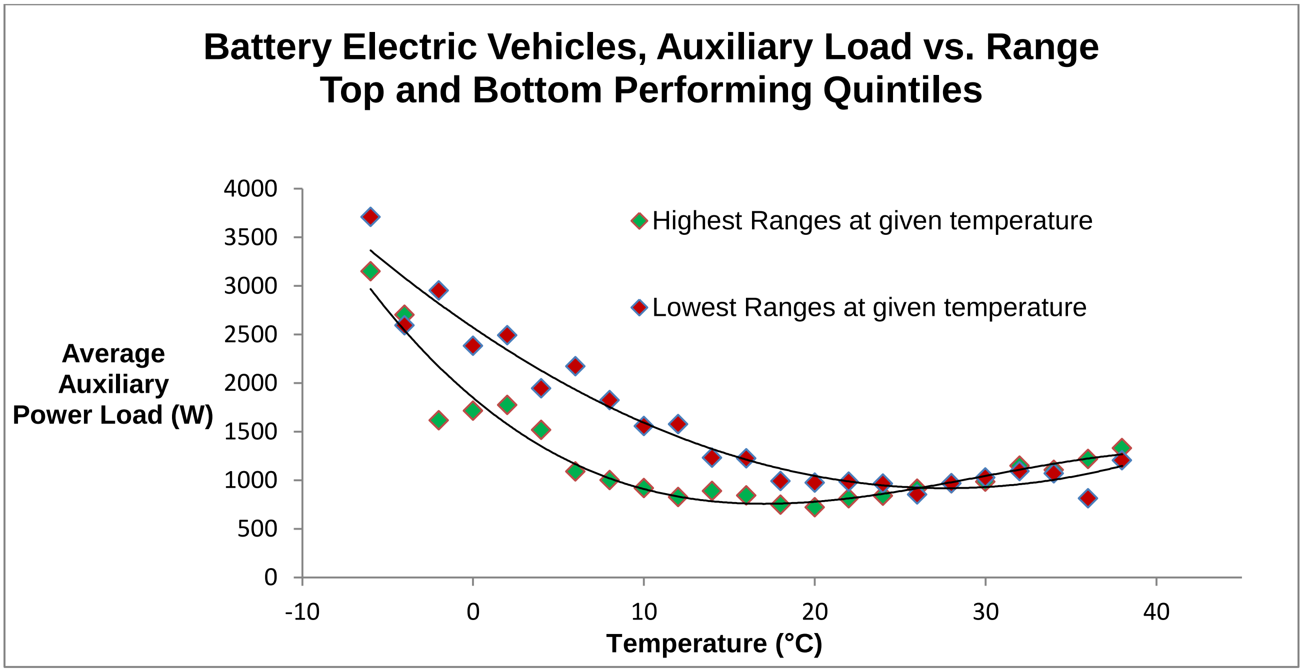


When the average available range for each of the two groups are plotted at a given temperature a large variation is shown. While both groups display a similar trend to the average available range temperature plot (Figure 10), there is a separation of 50-80 km between the two groups.

This shows that although there is a trend between available range and the ambient temperature during the trip, there are a variety of other factors that impact range, including use of HVAC systems, driver behaviours, driving conditions, etc. So, it is important to not simply state that range decreases when it gets colder, but to demonstrate that the amount of impact on driving range can be mitigated.

For example, a portion of the performance gap can be accounted for in the difference between auxiliary (HVAC) loads for each of the group. The top performing group used an auxiliary load approximately 18.5% lower than the bottom performers. However this factor diminishes with increasing temperature, as shown in Figure 13.

Figure 13: The average auxiliary load between the top and bottom performers of battery electric vehicles



When examining the difference between the top and bottom performing groups, we examined the auxiliary load levels employed during each trip. In Figure 13 we can see that the auxiliary load of the group achieving the highest ranges is generally lower than the auxiliary load of the group achieving the lowest ranges. This difference in operation exists primarily at colder temperatures.

These plots suggest that auxiliary load is a major factor differentiating a vehicle's sensitivity to temperature. However auxiliary load is not the only factor, only a significant and easily isolated factor. Other factors, such as changes in altitude, poor weather or driving conditions, passengers or weight load combine to account for the wide variation in the ranges achievable by this vehicle.

Fleet managers can aim to reduce the need for additional auxiliary loads through several strategies. Storing the vehicle in a garage, or pre-conditioning the vehicle while still charging are effective ways for the cabin to start at a comfortable. During operation, drivers can employ seat and steering wheel warmers in addition to using some of the heating system for a more comfortable driving experience.

The electric vehicle industry as a whole can look at alternative ways to heat and cool electric vehicles to reduce the impact of auxiliary load on range, these alternatives may include additional seat warmers, or heat pumps as seen in the 2013 Nissan Leaf.

6.2.2 Plug-in Hybrid Electric Vehicles Temperature Considerations

Plug in hybrid vehicles also see a variation of their electric range as temperature changes.

As with battery electric vehicles, the all-electric range of plug-in hybrid vehicles has similar sensitivity to temperature. Similar to battery electric vehicles, the range of plug-in hybrids is most affected by colder temperatures (less than 15 ºC) than warmer temperatures.

Figure 14: The variation in average available range for plug-in hybrid vehicles at different temperatures

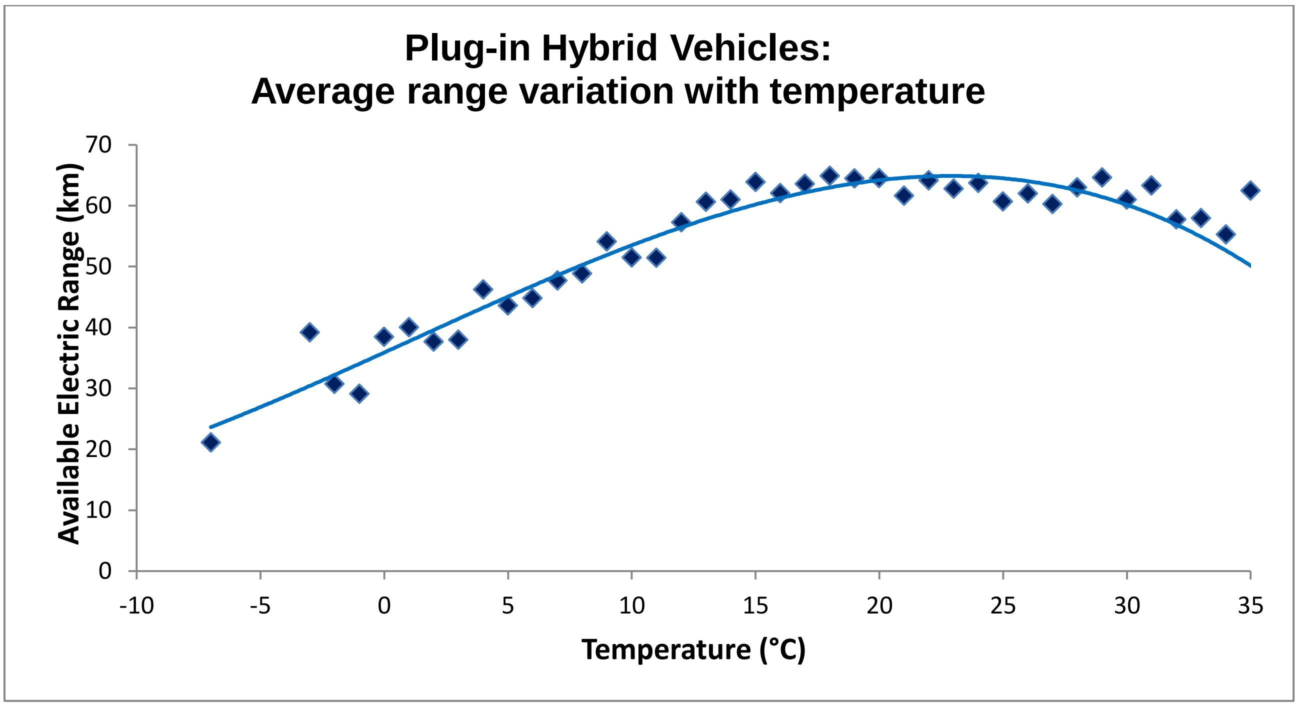
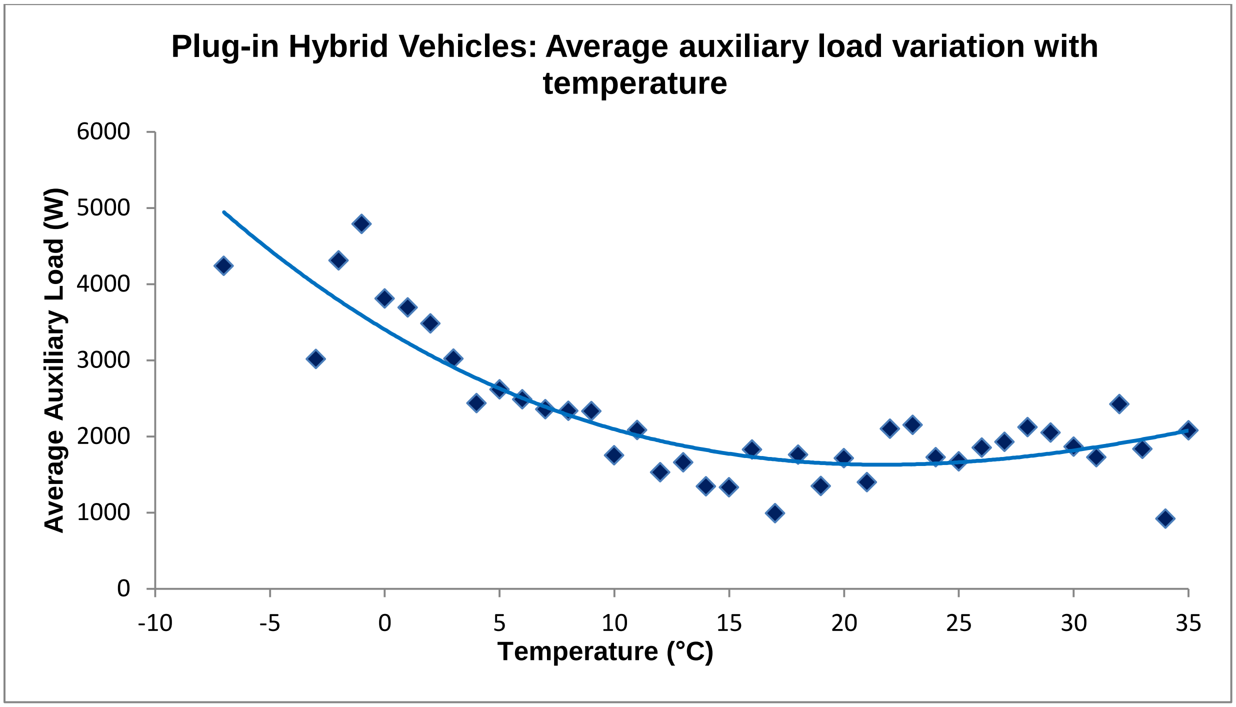


Figure 15: The average auxiliary power used over all-electric trips of plug-in hybrid electric vehicles in EV300 program



Plug-in hybrid range reductions correspond with an increased auxiliary load as temperatures decrease. As with the battery electric vehicles, plug-in hybrid electric vehicles see greater auxiliary loads and subsequent reduction in range with colder temperatures when the cabin requires heating. This is not as great of a concern for plug-in hybrid vehicle drivers as they have the on-board range extender to eliminate any range anxiety or concerns.

6.2.3 Driver Behaviour

6.2.3.1 Driver Behaviour and Fuel Economy

To measure the impact of acceleration and braking on the energy consumption of the vehicle's drive cycle, acceleration and braking events were processed by FleetCarma's back-end system and categorized as 'hard acceleration' and 'hard braking' or normal acceleration or normal braking. These hard acceleration and hard braking events were counted each trip and expressed as a percentage of total events in order to compare driver behaviour between different trips.

In Figures 16 and 17, data from plug-in hybrid electric vehicles is used to evaluate the impact that hard acceleration and hard braking have on the vehicles fuel economy.

Figure 16: Effect of hard acceleration on fuel consumption of plug-in hybrids

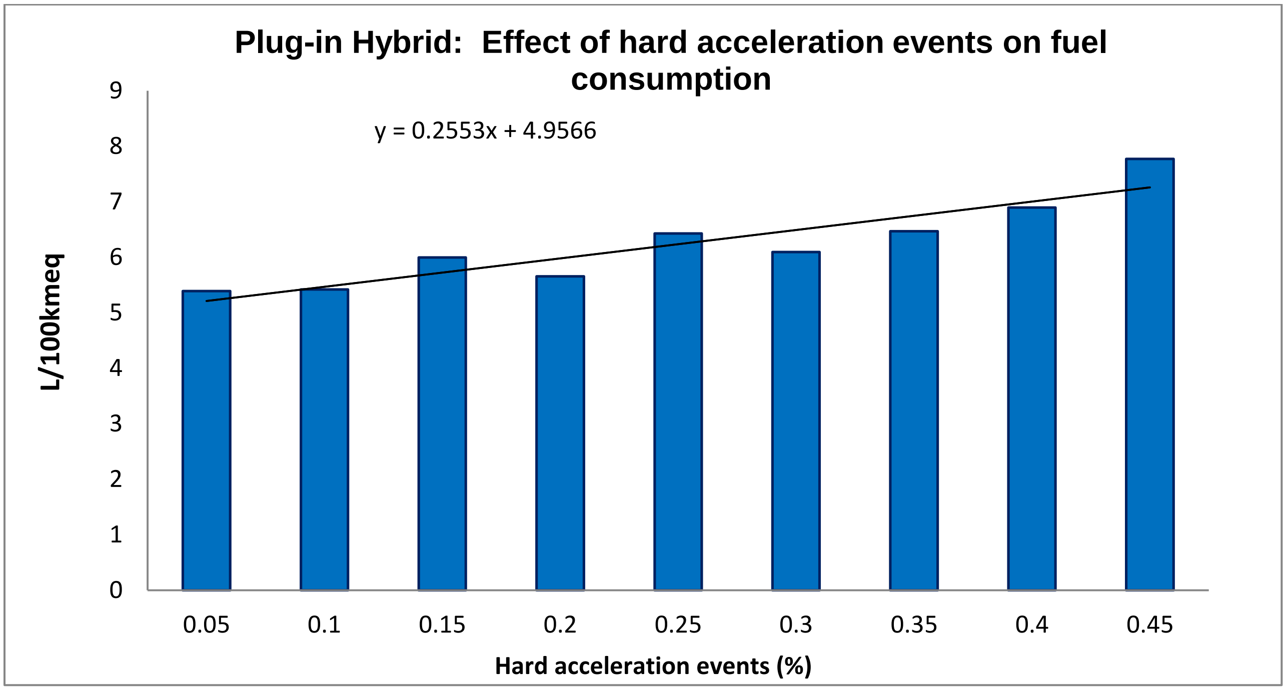
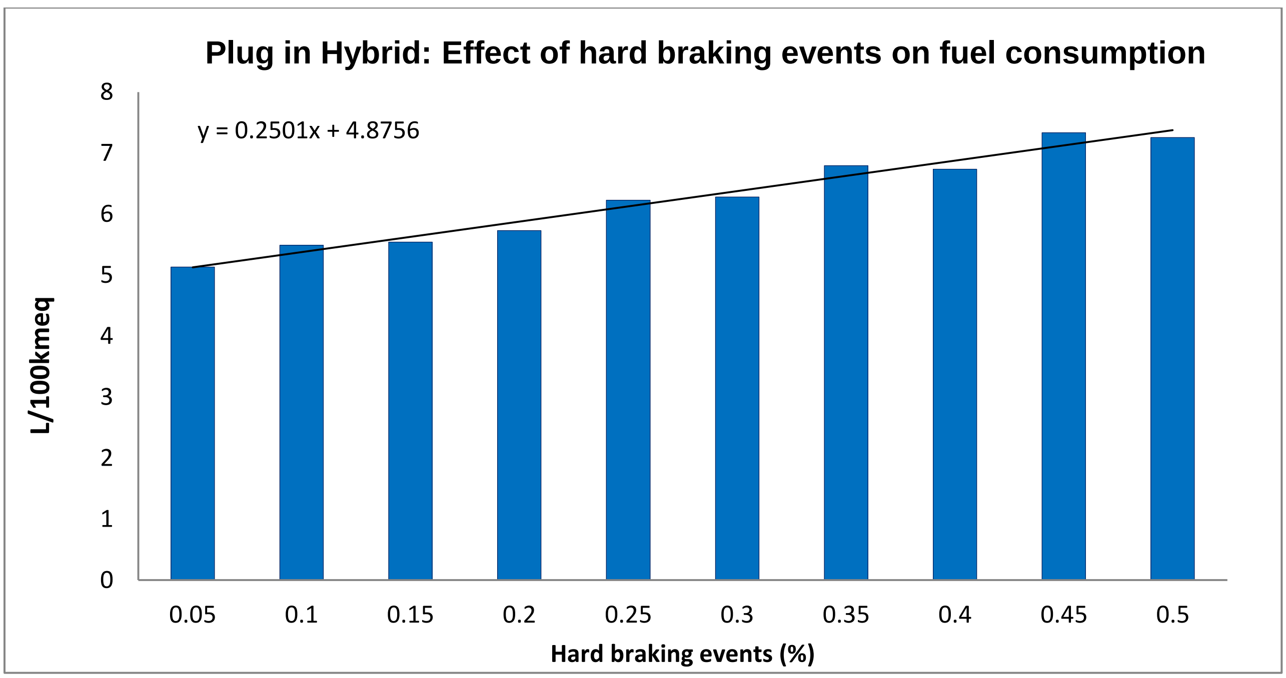


Figure 17: Effect of hard braking on fuel economy of plug-in hybrids



The slopes of the lines in Figures 16 and 17 indicate that fuel consumption per kilometre increases as the percentage of hard acceleration and hard braking increases. Also, these results suggest that hard acceleration had a slightly greater impact at increasing fuel consumption per kilometre than hard braking for plug-in hybrids.

6.2.3.2 Driver Behaviour and Range

In the case of battery electric vehicles, data were examined to determine the extent to which driver behaviour was impact all-electric driving range. The results are shown in Figures 18 and 19 and indicated that more aggressive acceleration and braking did reduce driving range by as much as 14 to 23 kilometres, respectively.

Figure 18: The available range of battery electric vehicles relative to hard acceleration

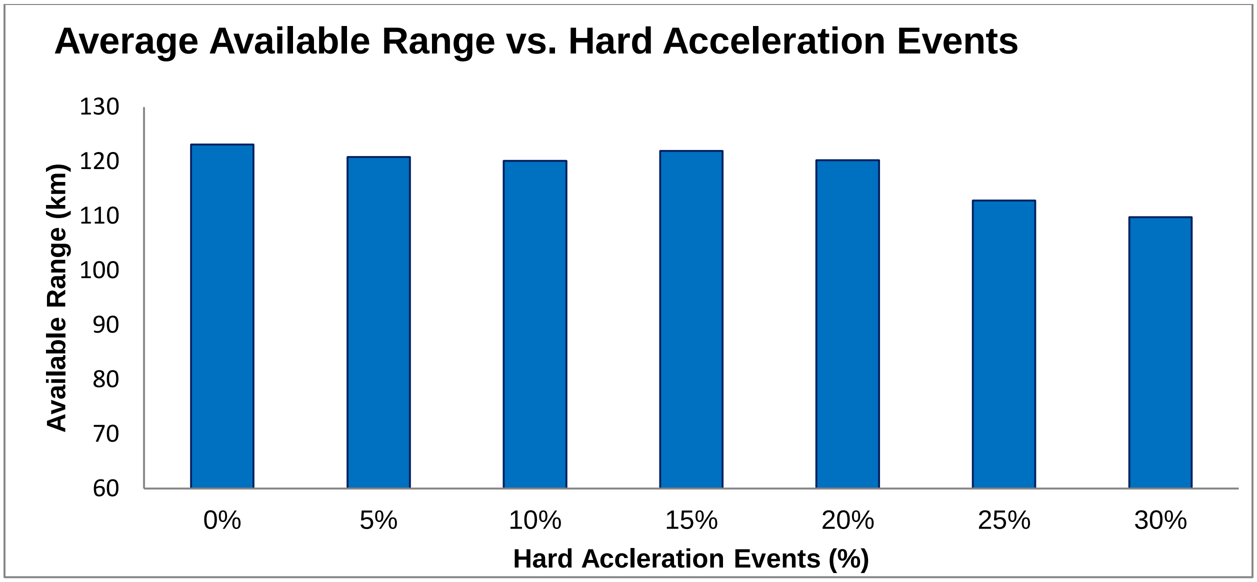
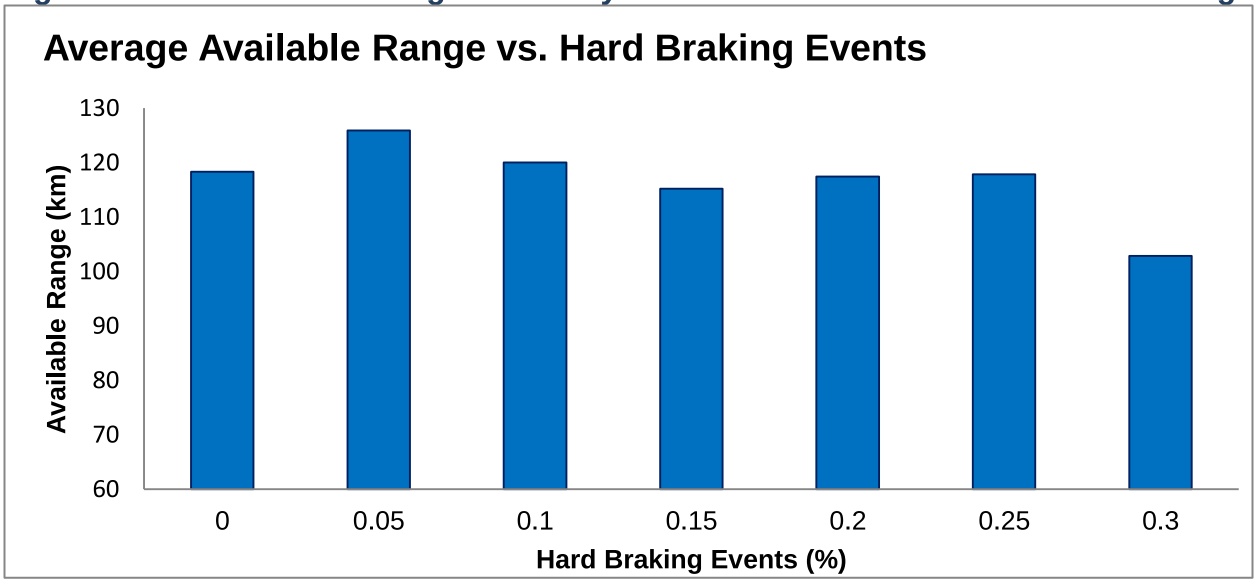


Figure 19: The available range of battery electric vehicles relative to hard braking

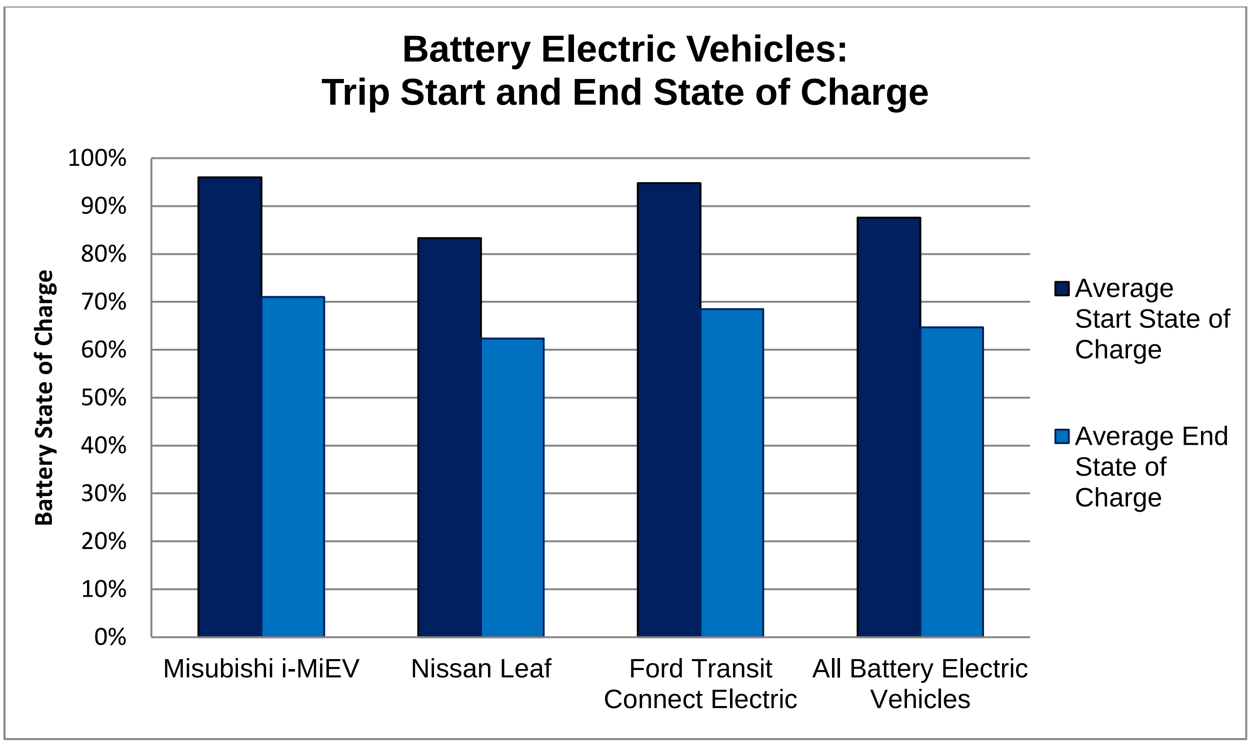


6.3 Charging Behaviour

Figure 20 displays the starting and ending state of charge (SOC) of the battery electric vehicles, by make and model in the EV300 program.

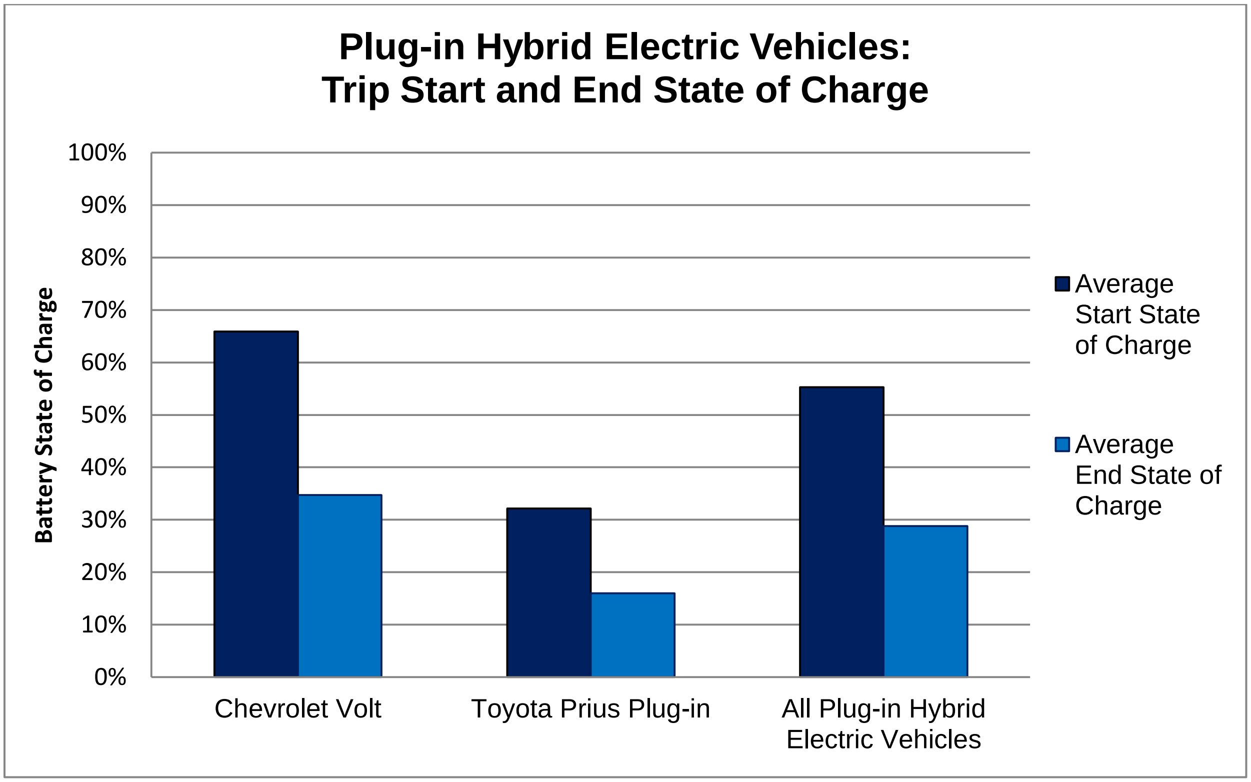
Across all vehicle models, the starting SOC is on average 88% of the battery's available capacity. The average ending state of charge for these vehicles is 64%. This shows that the vehicles are only utilized to a small extent of their potential. Greater utilization can be attained by charging the battery more both at night as well as between trips throughout the day, as well as taking longer trips that would deplete the battery and displace more usage, presumably, of gasoline-powered vehicles.

Figure 20: The average starting and ending state of charge for each trip for battery electric vehicles



The state of charge values displayed here are the percentage of the usable battery capacity that is available.

Figure 21: The average starting and ending state of charge for each trip for plug-in hybrid electric vehicles



This graph displays the battery's starting and ending state of charge for plug-in hybrid vehicles, which had, on average, a larger use of their battery's overall available capacity, going from an average of 55% starting SOC, to 28% ending SOC. However, the starting state of charge is much lower than the battery electric vehicles, particularly in the case of Toyota Prius Plug-in models. This indicates that the area for improvement with plug-in hybrid vehicles within these fleets is to improve the amount of charging that occurs overnight.

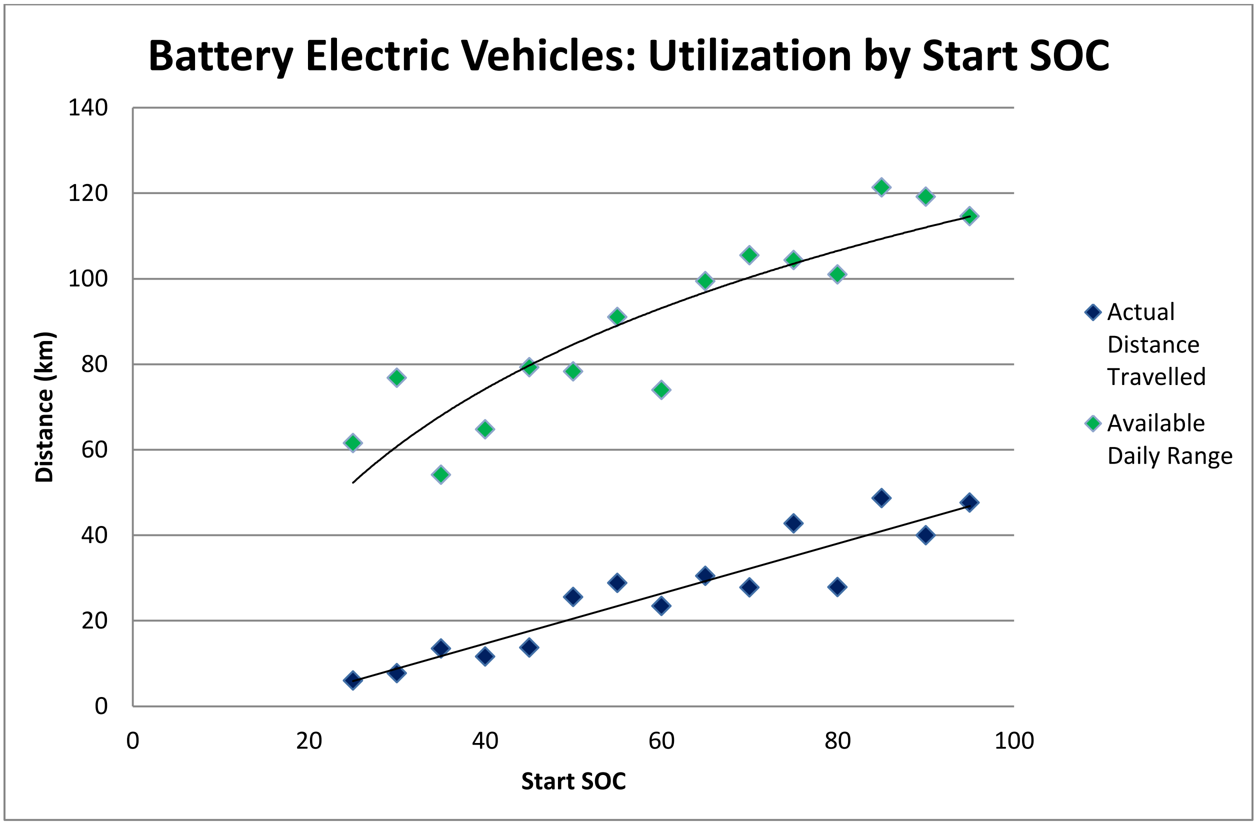
Fleet managers can increase the amount of charging by allowing more access points to chargers at locations that vehicles go to. Fleet managers can also adopt 'Plug-in' policies which require the driver to plug in the vehicle whenever possible. These strategies can aid in seeing greater electric utilization from plug-in hybrid vehicles.

This data suggests that fleets with plug-in hybrids may not be charging the vehicle enough. As it not necessary to charge a plug-in hybrid to continue operating the vehicle it is a facet of ownership that may become overlooked.

6.3.1 Starting State of Charge

The starting state of charge has an effect on the distance travelled throughout the day. This finding may seem obvious, but confirming the effect of a strong relationship between the state of charge at the beginning of each day and vehicle usage provides an actionable tip for fleet managers and organizations. Bulk charging, which occurs either overnight or off regular office hours is essential for increasing electric vehicle utilization.

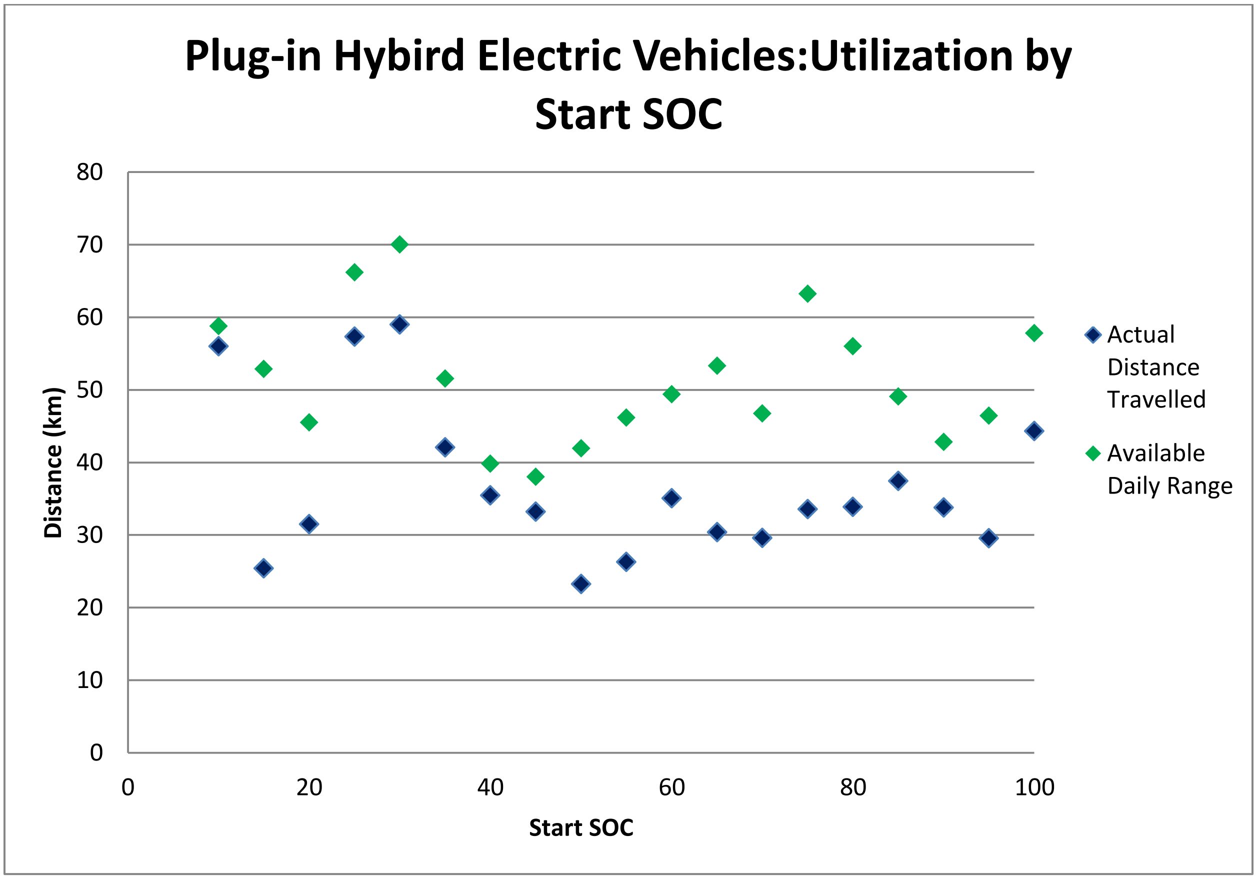
Figure 22: Daily utilization of battery electric vehicles relative to their start of day SOC



Another finding from Figure 24 is that despite bulk charging, battery electric vehicles are only utilized a fraction of their total available range. The average gap between how far a battery electric vehicle travels each day, and the electric range available was found to be approximately 70 km in this sample.

A focus on bulk charging can help address utilization issues by ensuring that at the beginning of a day or shift, the operator has access to a vehicle with a greater state of charge. Not only is that vehicle capable of travelling farther, but the increase in potential range serves to decrease a driver's range anxiety.

Figure 23: Daily utilization of plug-in hybrids relative to their start of day SOC



With plug-in hybrid vehicles there is no significant relationship between the battery state-of-charge at the beginning of the day, and the distance the vehicle travels. This is likely because the vehicle operator is less aware of any diminished all-electric range, and can use the vehicle as much as required.

There is also no significant gap between the distance that is available to be travelled, and the distance actually travelled. This can be attributed to a lack of concern over using all available range. Plug-in hybrid electric vehicles have an increased electric utilization as their operation indicates that drivers are comfortable reducing electric range to 0.

6.3.2 Charging Impact on Grid

Electric vehicles within fleets benefit from regular operational hours and dedicated facilities where infrastructure can be installed. However, fleets also face concerns around reimbursement of charging expenses when the vehicle travels away from fleet infrastructure or is taken home at night. Unlike conventional vehicles, where gas receipts can be purchased, it is difficult for an operator to properly account of the energy spent charging a vehicle. This can lead to reluctance for charging at night if the vehicle is taken home.

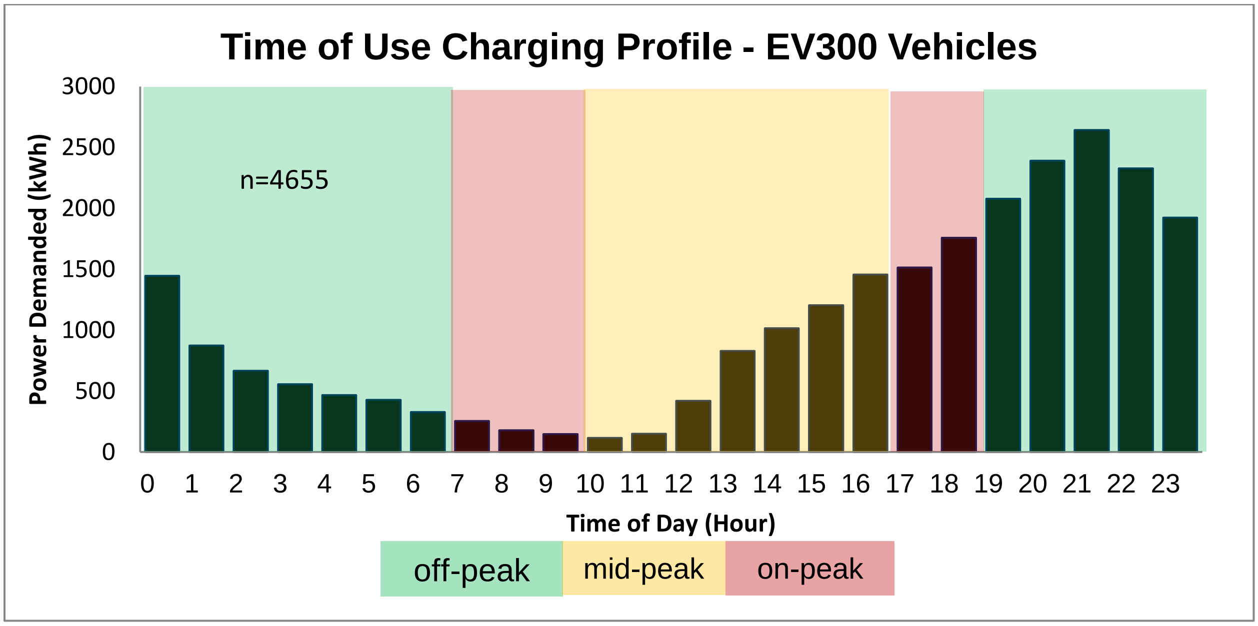
Charging off-peak is important for fleet vehicles. Ontario's time of use rates present an opportunity for fleets to find additional savings, as they shift their energy usage from on-peak daytime hours to off-peak overnight charging.

Table 5: Percentage of charging done in different time of use bands, Ontario Summer and Winter Rates shown.

Time of Use Band	Summer Rate	Winter Rate
Off-Peak	64.0 %	64.0%
Mid-Peak	15.8 %	20.2%
On-Peak	20.2%	15.8%

The fleet vehicles within the EV300 program conducted 64% of their charging off-peak according to the time of use peak periods in the province of Ontario. The time of use charging profile for all the vehicles in the program is shown in Figure 26. Although 64% of charging happened off-peak, there still appeared to be an 'early ramp' of charging during on-peak times at the end of the work day. This profile likely exists as vehicles are plugging in immediately when they are finished operation for the day, rather than delaying the charge events to begin at off-peak times.

Figure 24: Electric vehicle charging profile throughout the day



The charging profile of these vehicles reveals that most charging occurs in the afternoon or evening, with the most frequent charging occurring at 9pm. Charging best practices are to charge off-peak whenever possible, except if on-peak charging is needed to extend the daily electric range of the vehicle. Fleet managers wishing to improve their charging profile to achieve a greater percentage of off-peak charging can schedule charging events to occur later in the evening and install programmable devices to control the vehicle's charging controls or the charge equipment itself.

6.4 Metrics by Vehicle Application

In addition to evaluating the various makes and models within the EV300 program, vehicle utilization and operational metrics were also considered based on the vehicle's application within the fleet portfolio of tasks and jobs. Table 6 provides the key performance metrics by vehicle application, including GHG emissions, fuel usage, daily utilization and eco-driving scores.

Table 6: Key performance metrics of electric vehicles by fleet application

Vehicle Application	GHG emissions (kg CO_2/100km)	Fuel Spend ($/100km)	Average Daily Distance Travelled (km)	Average Eco-driving Score
Car sharing	7.56	5.01	72.00	69.00
Dedicated driver	18.00	7.74	200.00	77.00
Delivery	4.94	5.41	37.75	57.75
Vehicle Pool	8.16	4.78	62.59	69.19
Water / Utilities	3.86	4.70	25.00	62.00

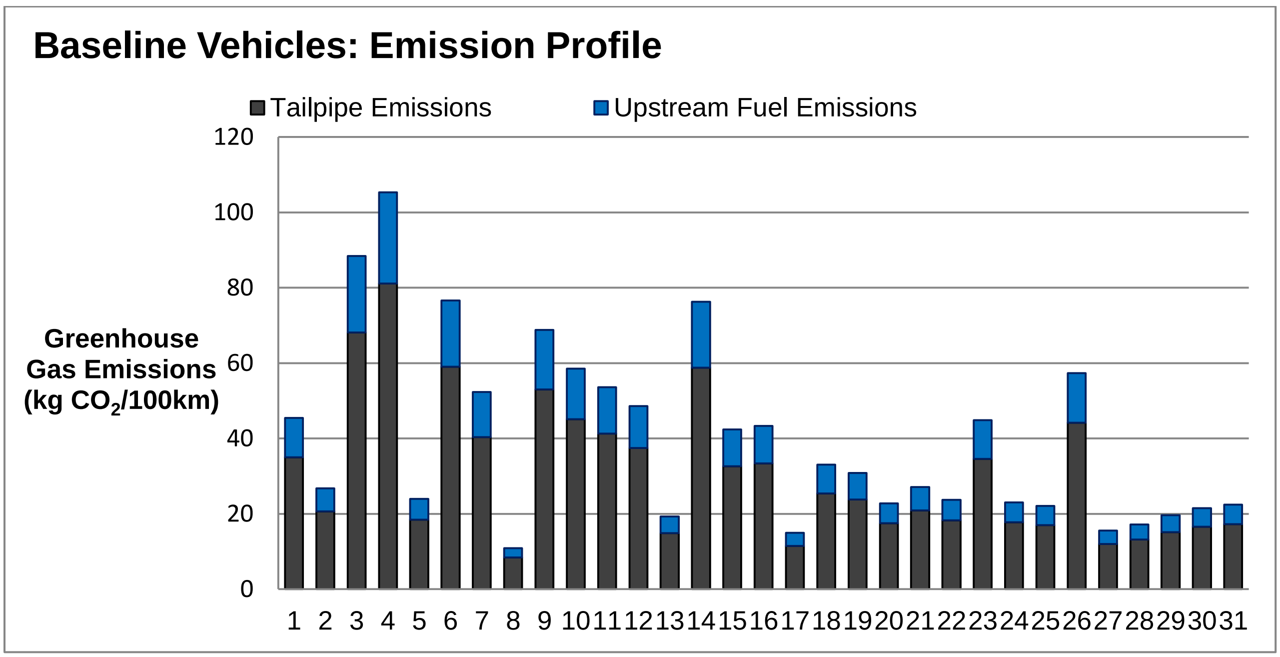
7.0 Greenhouse Gas Emission Impact

7.1 Baseline Vehicle Study

In the early stages of the EV300 program, 31 gasoline-powered vehicles were analyzed to determine baseline greenhouse gas (GHG) emissions before conversion to plug-in electrics. The emissions varied from 10.9 kg CO_2/100km to 106.3 kg CO_2/100km. This large variation can be attributed to the different vehicle models within the baseline fleet, as well as the range of operating conditions and duty cycle parameters. On average, the fleets were emitting 39.1 kg CO_2/100 km across all the 31 baseline vehicles assessed.

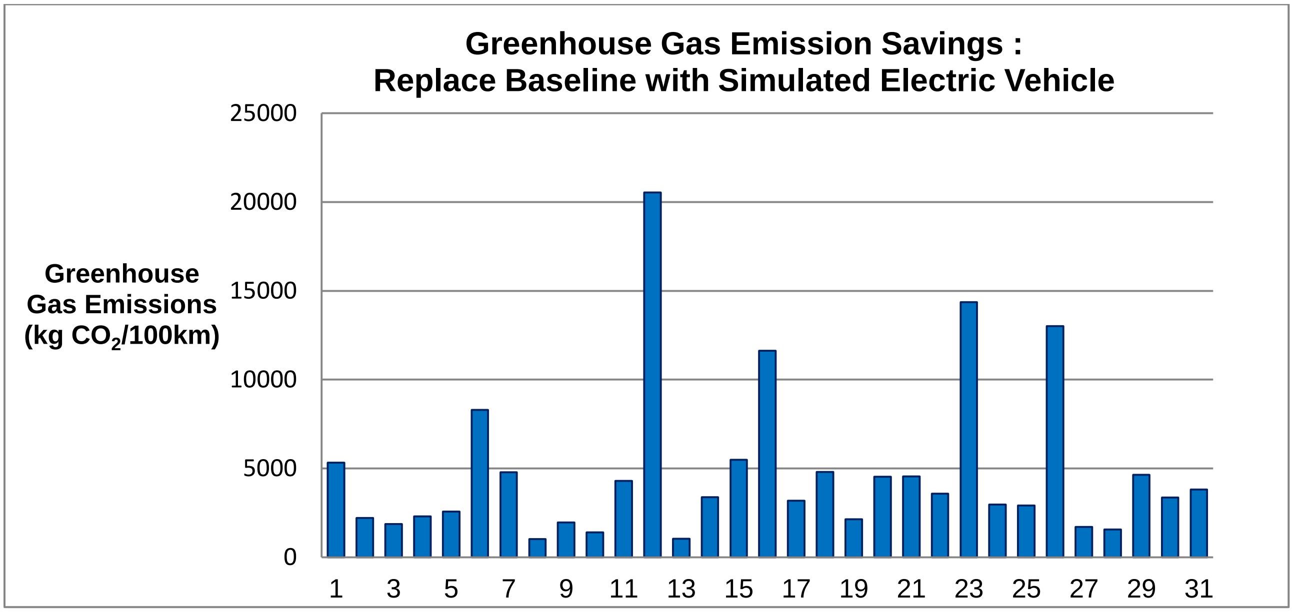
The emissions displayed in this Figure 27 are on a kg CO_2/100km basis which helps assess one vehicle's emissions as compared to another, without the results skewed by the annual mileage of the vehicle. In addition to tailpipe emissions, the graph also provides upstream related fuel emissions associated with the extraction, refinement, and transportation of the fuel before it gets into the vehicles.

Figure 25: Emissions profile of baseline gasoline-powered fleet vehicles



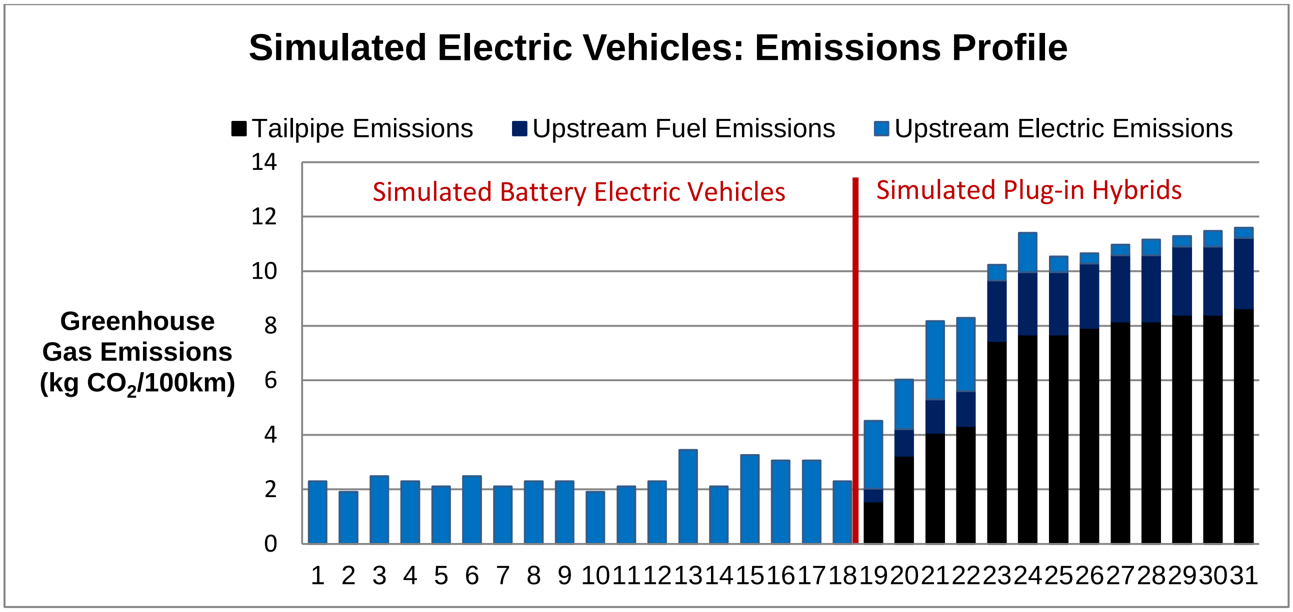
Using the data collected from the 31 baseline vehicles, FleetCarma simulated the performance of five electric vehicles in the same duty cycle. Using the results from these simulations the most appropriate (or 'best-fit') electric vehicle emissions were compared to the baseline emission from the gasoline-powered vehicles and results are shown in Figure 28.

Figure 26: Magnitude of greenhouse gas emission reduction if simulated electric vehicles completed the duty cycle of baseline gasoline-powered vehicles



Looking at total lifecycle emissions of energy consumption we can determine the source of emissions for the simulated vehicles. Battery electric vehicles have greenhouse gas emissions solely due to the emissions found with upstream electrical generation. Plug-in hybrid vehicles must take into account the processing of fuel as well as their tailpipe emissions from its combustion.

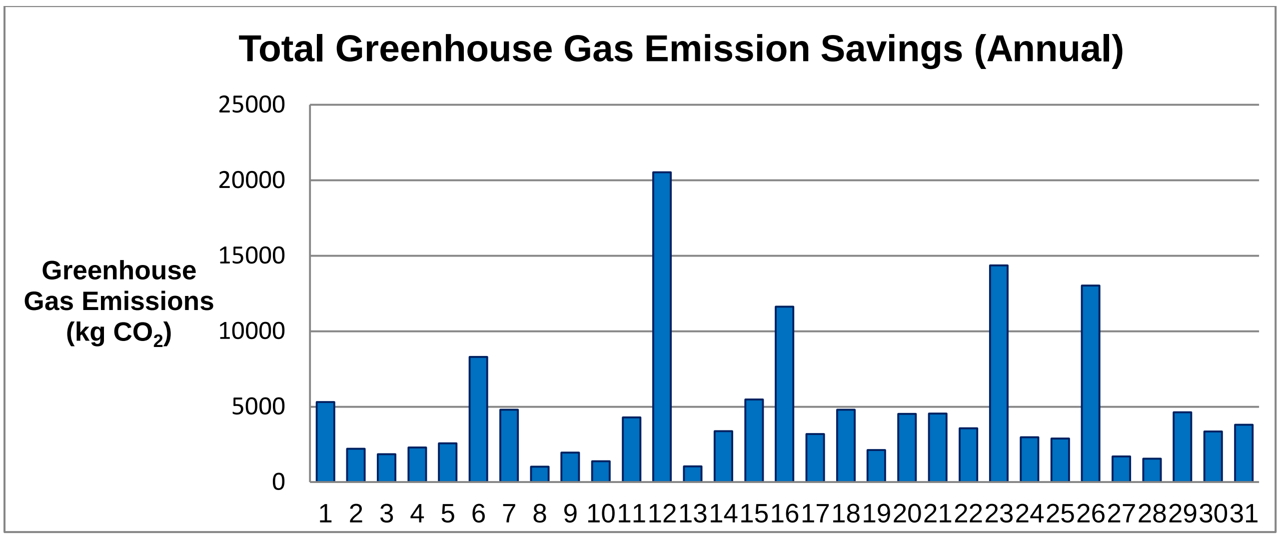
Figure 27: Emissions profile of simulated electric vehicles



The emissions profile of the simulated vehicle fleet can be broken into the emissions from battery-electric vehicles, and those of plug in hybrids. The greenhouse gas emissions from battery electric vehicles are limited to upstream electricity emissions from power generation and distribution. These emissions are comparatively low from electric vehicles due to their efficient powertrains and the relatively clean electricity grid in Ontario.

The emission profile for plug-in hybrid vehicles is larger than battery-electric vehicles. Plug in hybrid vehicles must also account for simulated fuel used to complete the same duty cycle as the baseline vehicle they replace. Emissions from gasoline are not only limited to tailpipe emissions but also include upstream emissions from fuel extraction and processing.

Figure 28: Total annual greenhouse gas emissions savings that electric vehicles would provide relative to the baseline vehicles



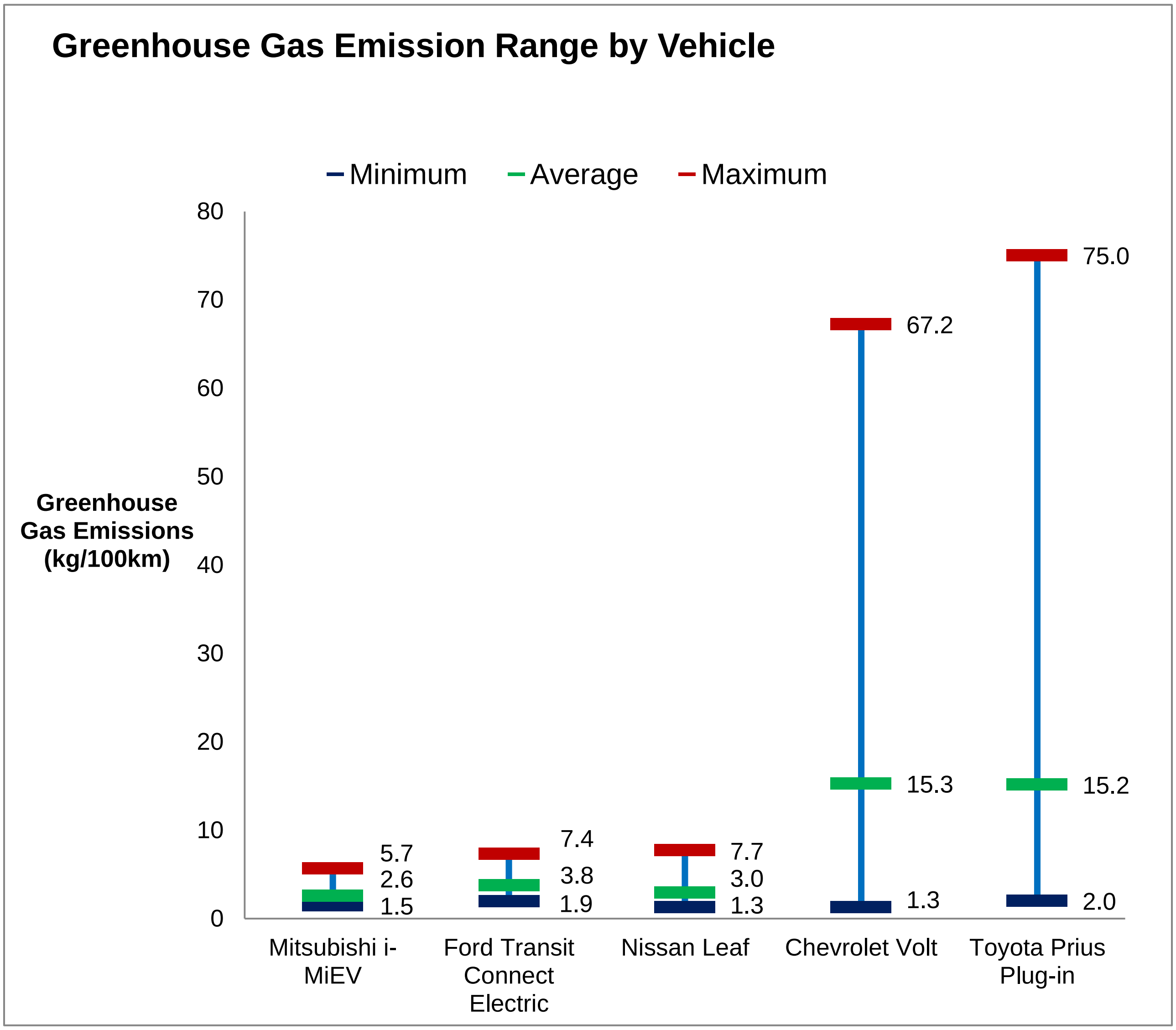
Annual emission savings takes into account the mileage the vehicle travels in a year and gives a perspective on the magnitude making a change to electric vehicles. In some cases the annual GHG emissions savings were as high as 20,540 kg of CO_2 per year and as low as 1,043 kg of CO_2 per year. If all vehicles in monitored in the EV300 program were to be replaced with the simulated electric vehicle counterpart the program overall could realize 149,201 kg (149.201 tonnes) of GHG savings each year.

7.2 Real-World EV Emissions Savings

7.2.1 Fleet-Wide Results

Across the entire EV monitoring program, the average greenhouse gas emissions from electric vehicles was 3.11 kg CO_2/100km for battery electric vehicles and 15.56 kg CO_2/100km for plug-in hybrid vehicles. Compared to the baseline vehicles, this represents an average of a 92% reduction in greenhouse gas emissions for battery electric vehicles, and 60% reduction in greenhouse gas emissions for plug-in hybrid vehicles. The results are summarized in Figure 31.

Figure 29: GHG emissions variation by vehicle make and model



The emissions profile of a plug-in hybrid vehicle is dependent on the breakdown between gas and electric usage. The majority of emissions from plug-in hybrid vehicles are due to tailpipe emissions and upstream fuel emissions.

8.0 The Business Case for Electric Vehicles

8.1 Critical Factors for EV Success

8.1.1 Importance of EV Utilization

In order to realize financial benefits from the use of electric vehicles, fleets must ensure that their use is prioritized. Electric vehicle utilization can be measured in many ways, commonly daily distance travelled, and the percentage of available time in use. As electric vehicle usage increases, the business case for EV success becomes stronger. The fuel used to complete the duty cycle of an electric vehicle is much lower than that of a conventional vehicle and decreasing payback periods follow increasing usage.

8.1.2 Plug-in Hybrids: Shifting Fuel Usage

Plug-in hybrids have a unique opportunity to improve the business case for electric vehicle usage. Not only does utilizing the vehicle offset the usage of a lower efficiency vehicle, but maximizing the electric range of the vehicle serves to shift the fuel spend even further, from gasoline to electricity.

8.2 EV Simulation Analysis Using Baseline ICE Vehicle Data

These operational costs are based on the simulated electric vehicles having the exact duty cycle of the baseline vehicles that were recorded. Greater operational savings could be found by implementing increased utilization strategies for electric vehicles.

Figure 30: Vehicle by vehicle analysis of total fuel cost savings from electric vehicle implementation in baseline vehicle duty cycles.

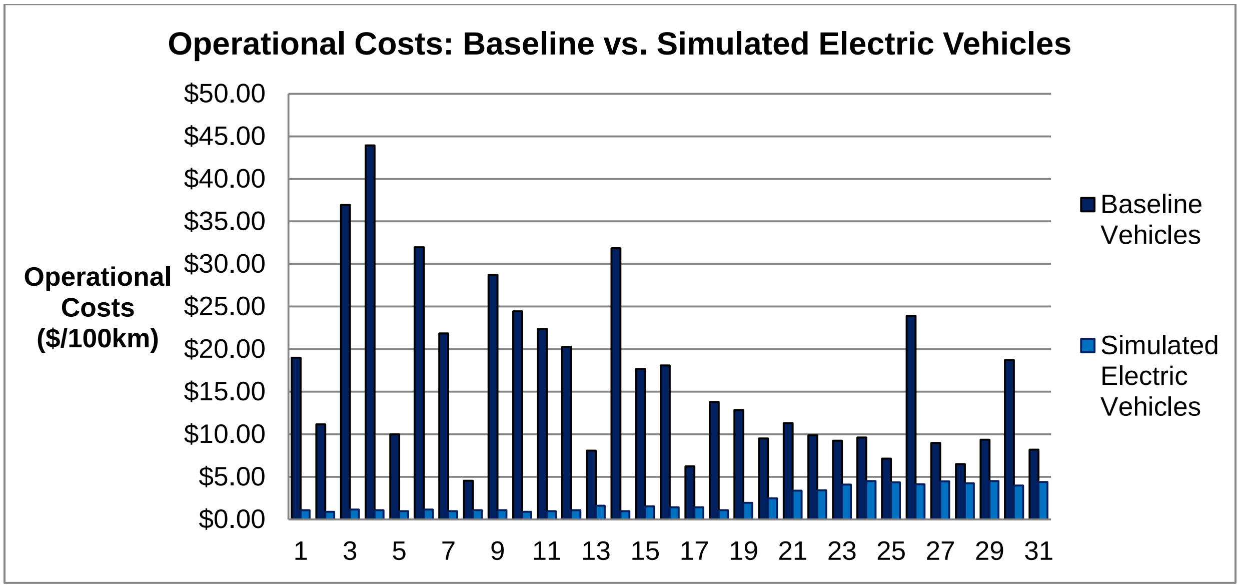
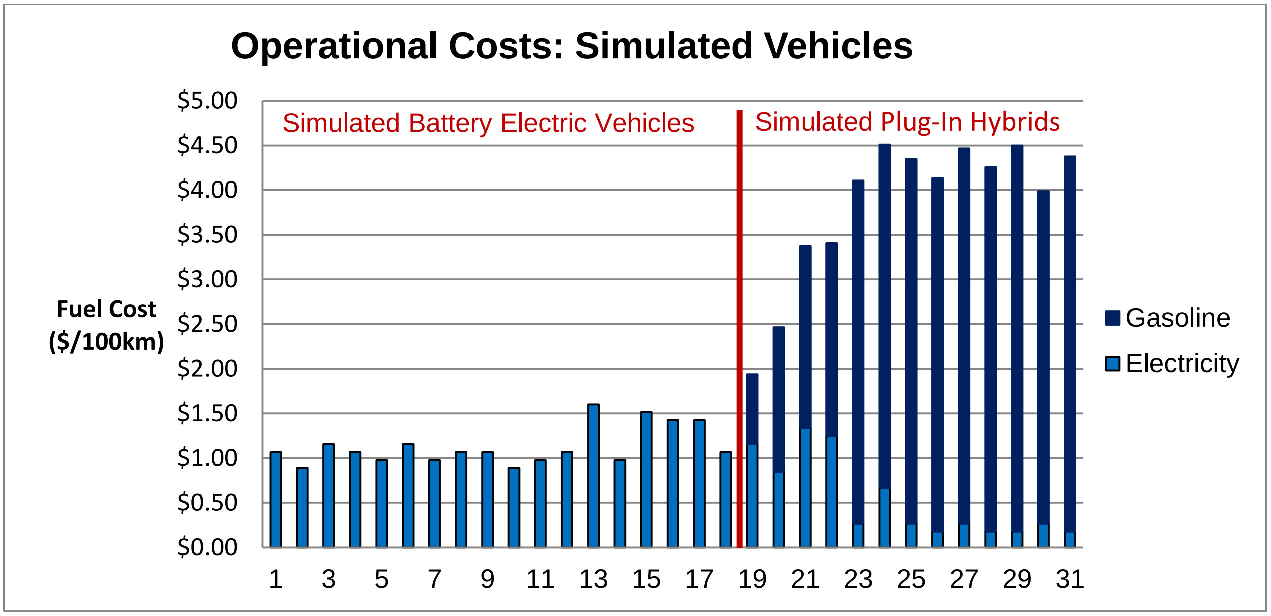
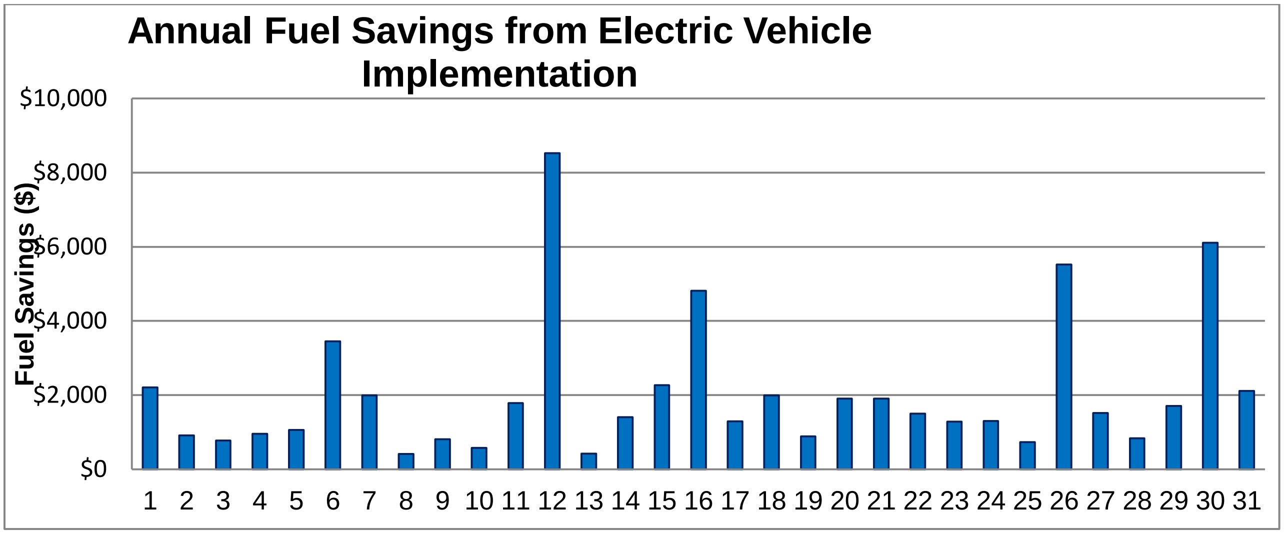


Figure 31: Breakdown of the sources of fuel cost for simulated vehicles



Further investigation of the simulated electric vehicles showed the difference between the operational costs of a battery electric vehicle and a plug-in hybrid.

Figure 32: Vehicle by vehicle analysis of total annual fuel cost savings from electric vehicle implementation in baseline vehicle duty cycles



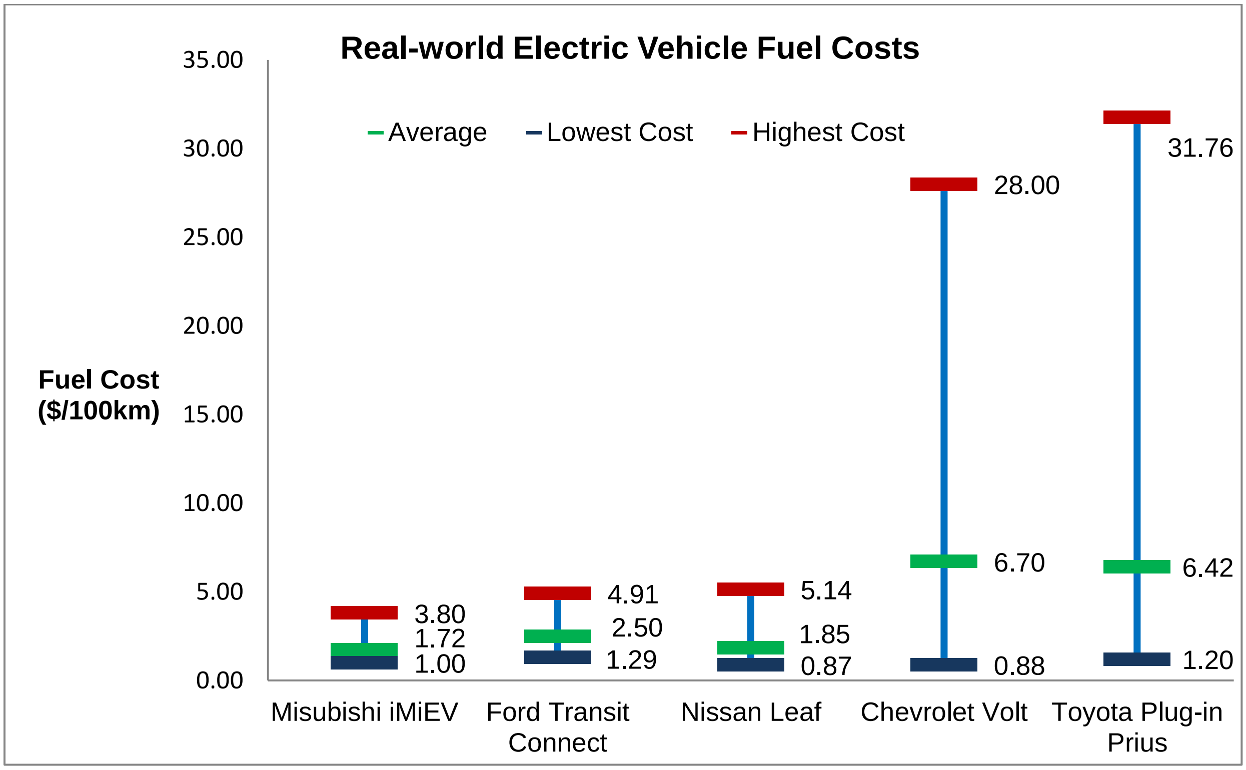
The annual fuel savings demonstrate that depending on the electric vehicle chosen and the application, fleets can save from $424 to $8,524 per year. If all vehicles in monitored in the EV300 program were to be replaced with the simulated electric vehicle counterpart the fleets within the program could realize a cumulative fuel savings of $ 62,978 each year.

8.3 Real-World Business Case Results

Electric vehicles monitored through the EV300 program benefited from low operational costs, as expected.

As with conventional vehicles, the mileage on an electric vehicle also varies. The situation becomes more complex with plug-in hybrid vehicles. As a plug-in hybrid can take trips with power completely from the battery, or can take entire trips where the battery has previously been depleted (charge sustaining mode).

Figure 33: Energy costs for electric vehicles operating in EV300 Program vehicles



With fuel as a major operational cost for fleet operators, a reduction in fuel spend can result in a great impact for a fleet's budget. Figure 34 demonstrates the fuel costs every 100 km the vehicles travelled. Variation exists for all vehicles due to different operating conditions, driver behavior, and duty cycle parameters.

The baseline fleet of conventional vehicles had an average operational cost of $16.67/100km.

For plug in hybrid vehicles, a much larger range existed between the most expensive to operate and least expensive to operate. This variation exists because of the multiple vehicle modes that a plug-in hybrid can operate in.

Due to the large discrepancy between the cost of electricity in Ontario and the cost of gasoline, the trips taken that are powered solely from the battery are considerably less expense than those that are mix or the trips where the battery has been depleted and the vehicle travels in hybrid mode.

Figure 34: A closer look at battery electric vehicle real-world variation in fuel cost

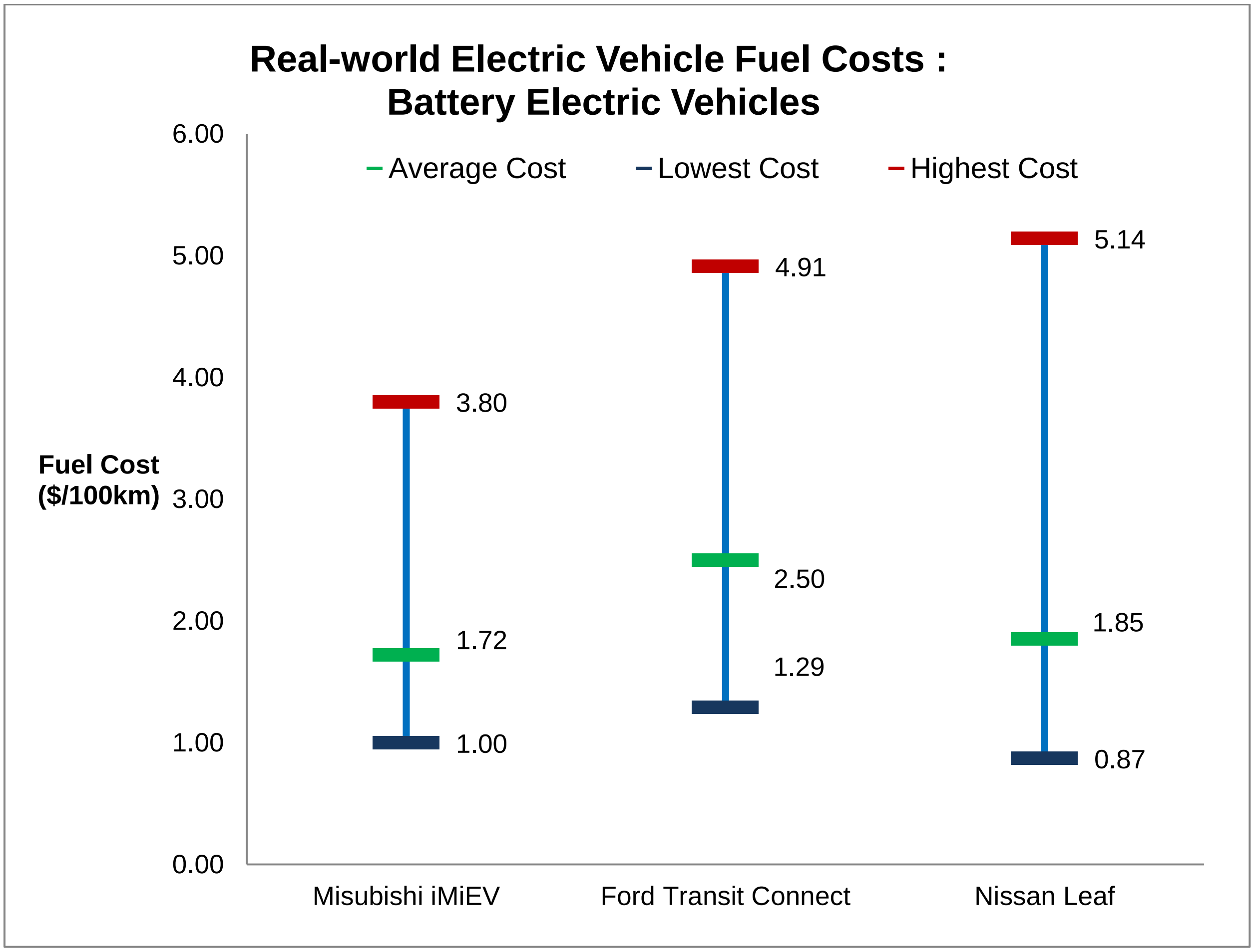
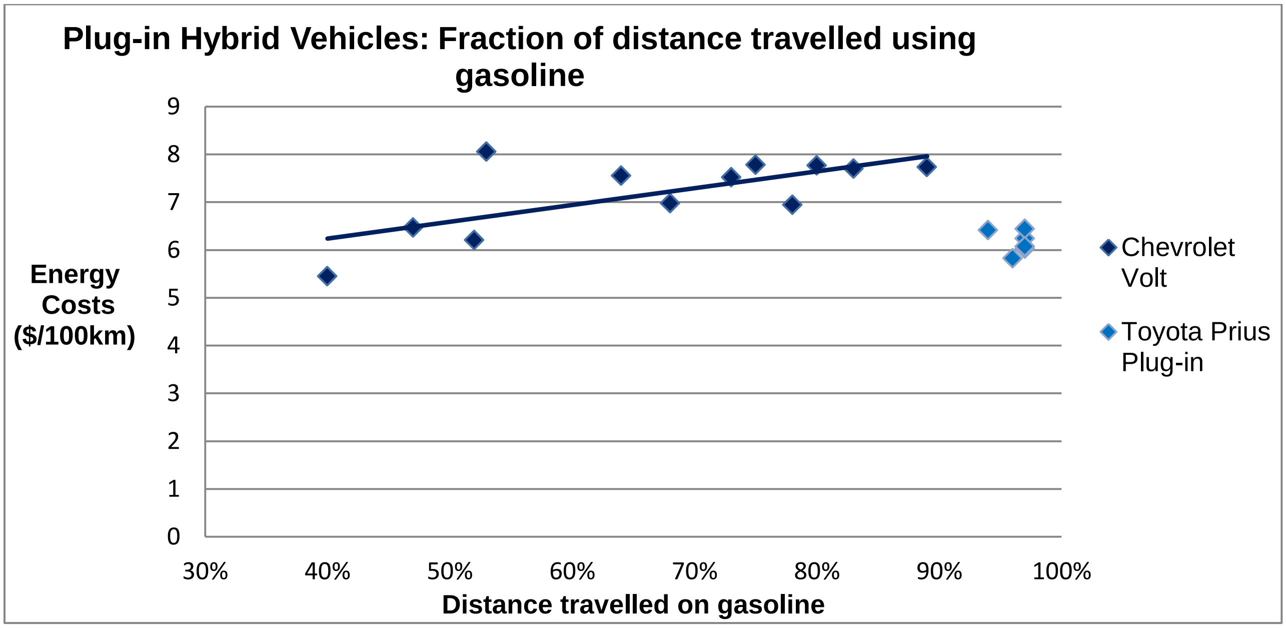


Figure 35 takes a closer look at the range of variation in the energy costs for each electric vehicle. As the cost to power these vehicles is consistent, the differences in operational costs can be attributed to the efficiency in which the vehicles use electrical power. The range within a vehicle model can be attributed to the conditions in which the vehicle was driven, operator preferences, and driver behaviour.

Figure 35: The fuel cost implications of operating plug-in hybrid vehicles without maximizing all-electric range



From data collected from plug-in hybrid vehicles in the EV300 program, we can see that by increasing the distance a plug-in hybrid travels powered by gasoline as opposed to electricity, the costs associated with that distance also increase.

Fleets can reduce operational costs by maximizing both the distance plug-in hybrid vehicles travel, as well as the portion of that distance that is powered by the battery. Fleets can maximize this distance by planning for adequate charging for their vehicles and making use of opportunity charging throughout the day.

9.0 Recommendations & Conclusion

9.1 Thoughts from the Fleet Managers on EVs

“Operating plug-in hybrid electric vehicles in our vehicle pool has been exciting for our employees. Often the plug-in hybrids are the car of choice by our user groups and we’ll be expanding our program from 31 to 60+ plug-in vehicles in the next year. An added benefit many drivers love is the ability to drive as a single occupant in the HOV lanes with green plated vehicles, saving time, reducing costly 407 travel, and reducing fuel and emission levels!”

“All-electric vehicles come with many great opportunities for fleet operators, including the benefit of not needing to pay for fuel ever again – however, they come with their challenges as well. Clearly defined routes with accompanying rapid charge infrastructure are clear enablers, as well as, understanding usage and driving habits in order to match vehicle range capabilities with our utilization requirements.”

-Garry Drouin, Fleet Coordinator at Ministry of Transportation

“On several occasions, the electric vehicle was the only one available for corporate use, many would be reluctant to use it, but by supporting and educating new drivers this would slowly shift their vehicle preference to an EV.”

-Lori Crouse, Administrative Assistant managing EV Program at Metrolinx

“When looking at plug-in vehicles, we knew that we didn't want to add new vehicles to our fleet. Instead we were looking to replace existing gasoline vehicles with plug-in electrics. We started with two all-electric vehicles and will be getting two more this year. The vehicle operators are literally fighting for the right to drive these electric vehicles. They've been a real success for the Town of Oakville.”

-Suzanne Madder, Research Policy Analyst at Town of Oakville

9.2 Thoughts from the Fleet Managers on EV300 Program

“Data logging regular gas vehicles was a good exercise for our fleet; we could see and understand how much mileage was put on the car and some gaps in usage. We experienced firsthand the need for education regarding electric vehicles and their capabilities. The EV300 program was very good at helping us understand the market for electric vehicles and connect to key organizations within that market.”

-Stuart Bustard, Fleet Team Leader at AutoShare Carsharing Network Inc.

“As a result of this project, I went from having concerns about electric vehicles meeting our needs, to greater understanding, and finally promoting electric vehicles within the fleet and elsewhere. The program also provided ongoing and valuable information on the operation of electric vehicles.”

“Seeing the reports on electric vehicles was fascinating, it was good to see details on the vehicle's usage as well as charging data.”

-Lori Crouse, Administrative Assistant managing EV Program, Metrolinx

“Using the FleetCarma system to collect data from our existing fleet helped us model the capabilities of EVs in our applications and to build the business case with our management team. This process help us build the confidence we needed to know that all-electric vehicles could do the job and which make and model was the right fit for our fire prevention department. It was really a no brainer after that.”

-Suzanne Madder, Research Policy Analyst at Town of Oakville

9.2 Conclusions and Lessons Learned

The EV300 program succeeded in integrating electric vehicles into fleets in a targeted way, with real-world evidence to inform and give confidence before purchase. The education available during the purchasing process was critical to increasing familiarity with electric vehicles within fleets. Increased education and familiarity can lead to increased utilization.

Based on the analysis of these vehicle trends we can isolate 6 key ways in which fleet managers can integrate and utilize electric vehicles to have the greatest positive impact on their organization's environmental footprint and budget.

1. **Matching EVs to duty cycle requirements optimizes savings.**
   Since each plug-in vehicle offers unique benefits, fleet managers that leverage EV modeling technology driven by their own duty cycle data, can better match each vehicle option to their fleet needs and to optimize costs and environmental benefits.

2. **GHG savings from EV fleet integration are substantial.**
   The GHG emission savings of EV adoption is substantial. Even with a minority of the fleet converting to electric, more than the majority of GHG emissions could be abated. This impact can be expanded upon through increased utilization of electric vehicles, and an increased portion of electric utilization for plug-in hybrid vehicles.

3. **There are strategies to mitigate the range implications of EVs in cold weather.**
   Although data showed that EVs lose electric driving range when temperatures get cold, the data also showed that this impact can be substantially mitigated by using seat warmers, pre-conditioning vehicles while still on plug, and driving efficiently.

4. **There is an opportunity to use fleet EVs more often.**
   Fleets with plug-in vehicles have not been using them as much as they could be used. Increasing electric vehicle utilization reduces payback periods so that fleets start to save their organization money sooner.

5. **Fleets can increase electric utilization with better charging behaviours**.
   Increasing opportunity charging throughout the day and bulk charging throughout the night enables higher utilization and ensures each day begins with maximum starting state of charge.

6. **Good driving behaviour extends electric driving range.**
   Fleet managers collecting EV utilization data can provide ongoing feedback to drivers to improve and maintain eco-driving performance and to maximize the benefits of EV adoption in their fleet.

10.0 Report Authorship and Acknowledgement

The contents provided in this report for the Toronto Atmospheric Fund (TAF) were made possible by the analysis from FleetCarma Professional Services, a division of CrossChasm Technologies Inc., and data collected using the FleetCarma vehicle monitoring and modelling system.

Authorship credit belongs in part to:

Megan Allen, Vehicle Technology Analyst at FleetCarma

Eric Mallia, General Manager at FleetCarma

A special thanks goes to TAF for providing us with the opportunity work in partnership on collecting these data and to summarize the key findings of this exciting and innovative program. We hope that the work of the past few years contributes to continued growth of electric vehicles and reduced emissions and air pollution in the Greater Toronto and Hamilton Areas and beyond.