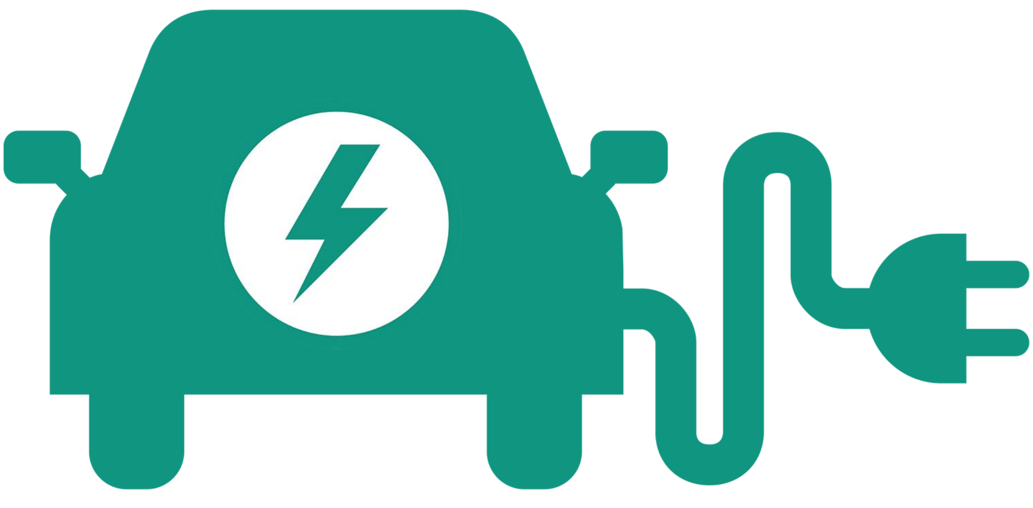
ARCTIC ENERGY ALLIANCE

Electric Vehicle Study

Chevrolet Volt Plug-in Hybrid Electric Vehicle

2015–16



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EXECUTIVE SUMMARY

A study commissioned by the Arctic Energy Alliance (AEA) in 2013 entitled "Electric Vehicle (EV) Update" shows that EVs have potential in the North, especially in hydro-powered communities where electricity generation creates fewer greenhouse gases (GHG).

In the fall of 2014, AEA started its lease of an electric vehicle (EV), a 2015 Chevrolet Volt, to monitor real-world results of driving the vehicle in Yellowknife. At the time of the study, the cost of a new Volt was about $42,000 which puts it in the price range of a full-size sedan such as the Chrysler 300.

From January 2015 to the end of March 2016, AEA used an onboard data logger to monitor the electricity and fuel used by the vehicle. The data logger used is made by FleetCarma and it keeps track of electricity used when driving and charging, as well as fuel consumption. Manufacturers always cold weather test their vehicles; however, the winter testing conditions are often not representative of northern winters, and AEA wanted to get firsthand experience testing this EV in extreme winter conditions. An example of the FleetCarma dashboard is included in the appendix of the report.

The real world results to date suggest that, even with Yellowknife's higher electricity costs, using an electric vehicle costs less than a conventional vehicle of comparable size[1]. Also notable is that the fuel efficiency of the Volt driving on gas alone is still better than a small four-door car, such as the Chevy Cruze. Theoretically, the vehicle should be able to run entirely on electricity for short city trips in the summer; however, data logger results show that the battery accounted for about 90% of the distance driven in the summer and 54% during the winter. The gas generator operated more in the winter to heat the battery and provide supplemental power, and the summer gas usage was mainly due to trips taken when the battery wasn't charged. The Volt runs most efficiently in the summer and there is little difference in cost per kilometer between city and highway driving. The biggest difference is between winter and summer city driving—per-kilometer driving costs double in the winter.

With hydroelectricity being the main source of power in Yellowknife, an EV is able to take advantage of this and generate few to no emissions.

[1] The energy costs used in the report are $0.32/kWh and $1.15/L for gasoline

INTRODUCTION

This report summarizes the findings of 18 months of data collection.

Types of Electric Vehicles (EVs)

Hybrid Electric Vehicles (HEV)

Hybrid EVs use regenerative braking and electricity generated by the gasoline engine to charge their batteries. HEVs can't be plugged in so they are essentially gasoline-powered vehicles that use the battery to help with fuel efficiency.

Plug-in Hybrid Electric Vehicles (PHEV)

PHEVs can be plugged in, and therefore can rely more on the battery to power the vehicle for longer distances. These vehicles still contain a combustion engine or generator to allow for long range driving. PHEVs can be broken down further into two types listed below.

1. *Series PHEVs (e.g. Chevrolet Volt, Cadillac ELR)*

   The internal combustion engine generates electricity for the electric motors and it does not mechanically power the vehicle. The vehicle can drive on stored electricity until the battery is depleted, after that the engine will generate the electricity.

2. *Blended PHEVs (e.g. Toyota Prius Plug-in, Ford Fusion Energi)*

   The internal combustion engine and electric motors work together to power the vehicle. They may be able to run off the battery at low speeds.

Battery Electric Vehicles (BEV)

BEVs can be thought of as true electric vehicles since they do not contain an engine and don't produce emissions. These vehicles will have larger batteries than the other types to allow for longer battery range, but once the battery is depleted it will have to be plugged in.

ELECTRIC VEHICLE TESTED BY AEA

2015 Chevrolet Volt

The Arctic Energy Alliance leased a 2015 Chevrolet Volt. The Volt is a series PHEV so it has a gas generator but is always driven by the electric motor. At the time, the choice of EVs in Yellowknife that were serviceable locally was limited to the Toyota Prius and the Chevy Volt. The Prius is available as an HEV and a plug-in version; the plug-in version is different than the Volt since it is a blended PHEV.

The Volt's lithium-ion battery pack, shaped like a *T*, is mounted in the large tunnel between the front seats and extends underneath the rear seats. The 2015 model Volt has an EPA-rated range of 61.2 km. Once that range depletes the battery, the 1.4 liter four-cylinder engine switches on to power a generator that produces additional electricity to keep the Volt going for another 400 kilometers or more.

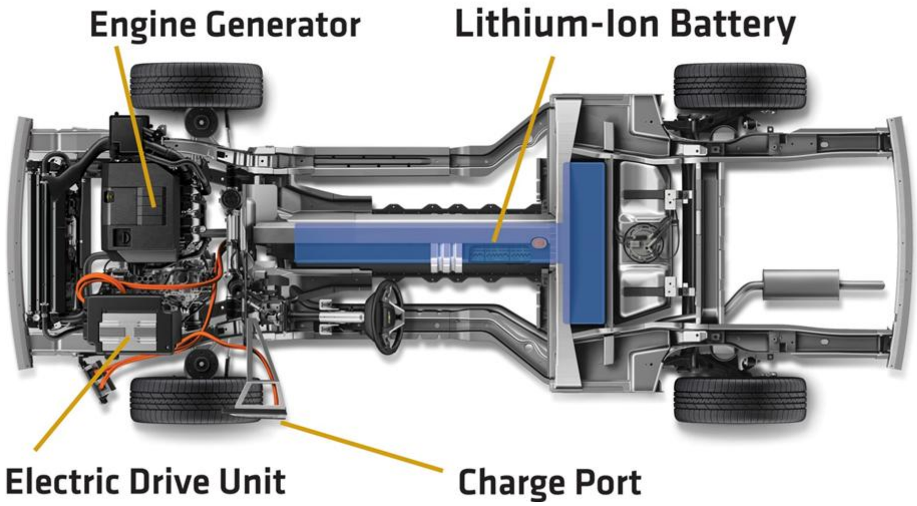


Figure 1

AEA wanted an EV with an extended range to allow trips to the NWT's South Slave and Dehcho regions. It was also required to have plenty of room for the equipment used for home energy evaluations. The Volt suited both of these needs and a series PHEV was the preferred choice for testing since it uses a fully electric drive, which was believed to be the first in the NWT.

AEA Use of the Volt

The Volt was used for both in-town driving and long-distance driving. The in-town driving was based in Yellowknife, where the vehicle was used by AEA's staff for work purposes including travel to clients' homes and businesses.

Long-distance driving of the Volt happened several times throughout the lease period in all seasonal conditions. The Volt was showcased at many community events throughout the North Slave, South Slave and Dehcho regions, and featured prominently at the Yellowknife and Hay River trade shows.

DATA COLLECTION AND REPORTING METHODLOGY

Data Collection

In January 2015, a data logger was installed in the Volt that had the capability to record electricity and fuel usage for every trip the vehicle took. The data logger was made by a Canadian company called FleetCarma, which specializes in monitoring EVs.[2] The system was meant for organizations with multiple vehicles in their fleet, but it also works well for monitoring a single vehicle. This sort of data logging is not limited to EVs: FleetCarma also has a version that monitors fuel usage of gasoline-powered vehicles.

The data logger was plugged into the diagnostic port of the EV and had a GPS sensor mounted on the windshield. The logger connected to the internet so data was available almost immediately. The data logger had the capability

[2] https://www.fleetcarma.com/

of monitoring and recording data on such things as battery usage, charging electricity, fuel consumption and trip distance—the latter being important for establishing efficiency. It also tracked a number of other factors that were interesting to know, such as an ECO SCORE,[3] which is a driving efficiency score. A log book was also maintained to keep track of who was driving the EV, fuel purchases and comments about the vehicle.

FleetCarma features include a Vehicle Report Dashboard of total and daily average distance driven; driving energy broken down into miles per gallon gasoline equivalent (MPGeq); battery kWh and charging loss; time spent driving, idling, charging, and resting; charging energy from Level 1 and Level 2 charging stations; average starting and ending state-of-charge (SOC); and GHG emissions and intensity. In addition FleetCarma provided AEA with the following data:

- Daily summary: A plot of the user's driving, bulk charging, opportunity charging, and resting events. This includes distance driven, available range from bulk charging, and potential range from opportunity charging, starting SOC, ambient temperature, auxiliary load usage, and driver ECO SCORE.
- Trip details: All of the logged trips in one table-including the date, duration, distance, starting and ending state-of-charge (%), and electrical energy consumed.
- Driver feedback: ECO SCORE, number of idle events, average speed, percentage of hard acceleration, and percentage of of hard braking. All these metrics were broken down by trip, and graphed to show their trends over time.
- Charge details: A graph of the charging energy profile, including the ability to set a target time period. This report also includes a table of each charging event, including its duration, EVSE level, charger energy (kWh), charging loss (kWh), starting and ending SOC, and the location.
- Alerts: A summary of alerts for the vehicle, including the date the alert was opened, the day it was closed, the number of days it was/is opened, and the specific diagnostics code. (FleetCarma, 2015)

MONITORED DATA

The following sections presents the "real world" data collected from the Volt's installed FleetCarma data logger.

Volt Driving Data

Summer driving in the city of Yellowknife is predominantly powered by electricity, while in the winter the gas generator operates quite a bit more to heat the battery and provide supplemental power. Figure 2 breaks the data up into city and highway driving, as well as summer and winter driving for both. It takes into consideration both electricity and fuel usage.

[3] **ECO SCORE** is a driving style indicator, i.e. a tool that shows drivers' **ECO** driving performance and, consequently, their efficiency during their trips. **ECO** driving has been gaining in popularity in the transport industry over the past few years.

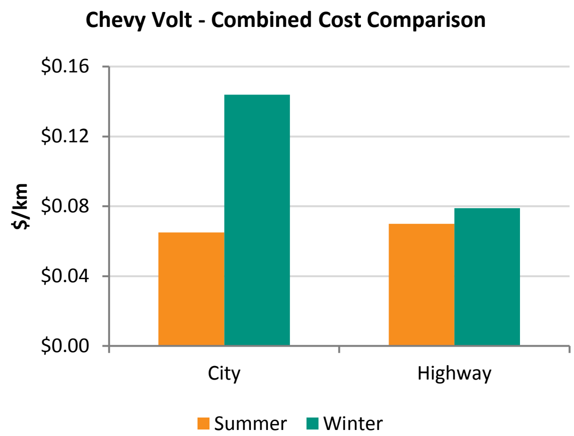


Figure 2

The Volt runs most efficiently in the summer and there is little difference between city and highway driving. Most of the highway driving comprised long trips where the battery was depleted quickly, so the majority of the drive was powered by gasoline regardless of the season. The biggest difference was between winter and summer city driving—per-kilometer driving costs doubled in the winter. The summer city driving data matches the rated fuel economy values derived by Natural Resources Canada (NRCan), which means the NRCan ratings are essentially a best-case scenario.

Fuel usage data was also recorded for three personal vehicles driven by employees of AEA. The three vehicles were a Pontiac Vibe (2003), Ford Ranger (2006) and a Jeep Wrangler four-door (2012). The fuel efficiency of these vehicles was compared against the NRCan ratings and once again, the ratings match closely with the best cases for each vehicle—in other words, summer driving.

Figure 3 compares the cost of city driving between these vehicles in both the summer and winter. The fuel efficiency for all the vehicles dropped off during the winter. This could be due to a number of factors but it happened for both the electric and gas vehicles.

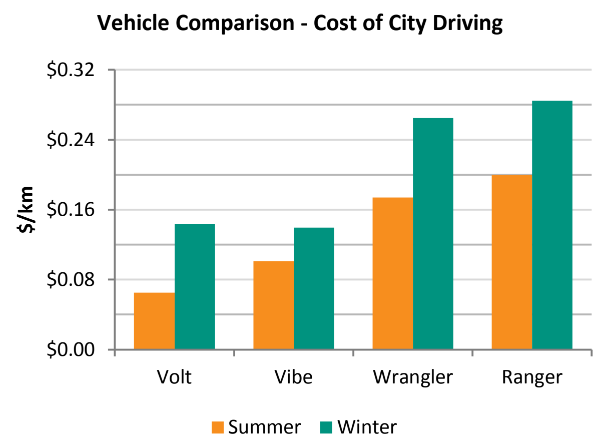


Figure 3

Comparing the measured summer city driving of the Volt and the rated city driving of a Chevy Cruze, the Volt saves almost $0.04 per kilometer. At 10,000 km per year of driving, this is a savings of $400 per year. Another factor that hasn't been included in these numbers is the charging losses of the Volt, which could be compared to using block heaters and battery blankets.

Greenhouse Gases

The Volt is greenhouse gas frugal. The GHG emissions associated with Volt's in-city driving are negligible because most in-city driving would typically done on battery only, and if the batteries were recharged using hydro-electricity, then there would be practically no GHGs created through operation. In actuality, the Volt had a small amount of fuel usage associated with city driving in the summer—with the fuel and electricity combined, the emissions are about 3.8 kg of GHGs per 100 km. The Cruze, on the other hand, has an emissions rating of 22.4 kg/100km. Using the example of

10,000 km per year of driving, this would be a savings of about 1.8 tonnes of GHGs per year.

Charging Losses

During the winter, the Volt will condition the battery while it is plugged in. This means that the EV charger will turn on for about 10 to 15 minutes every hour and a half, even if the battery is fully charged. The conditioning will keep the battery from getting too cold. The conditioning was set to only run when it was colder than −10 °C, and this was the lowest it could be set for.

Figure 4 shows how the electricity usage associated with the battery conditioning increases as the temperature decreases. The monthly temperature is represented as heating degree days (HDD). Heating degree days represent the difference between a balance temperature (18°C in this case) and the ambient (outdoor) temperature.

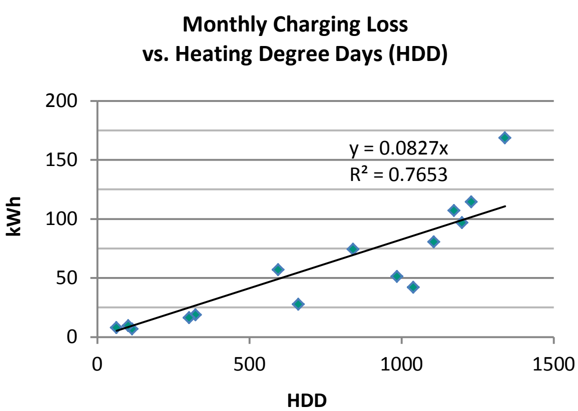


Figure 4

The electricity associated with battery conditioning can be thought of as an additional annual cost rather than being included in the cost per kilometer, similar to block heaters on gasoline vehicles. During this study, the conditioning accounted for about 707 kWh or about $225 worth of additional electricity.

ADDITIONAL FINDINGS

A preliminary report prepared by AEA in early 2015 compared the Volt to several other vehicles using L/100km ratings available from the manufacturers. Natural Resources Canada (NRCan) has started testing vehicles using a more thorough testing procedure that includes cold temperature driving. The results are not representative of driving in the North but are at least a more representative baseline for Canadian driving.

AEA's findings suggest that that even considering Yellowknife's electricity prices during the study period, it was more economical to drive the Volt then a comparably sized vehicle. AEA also noted that the Volt's fuel efficiency driving on gas alone exceeded similar small four-door vehicles such as the Chevy Cruze.

Figure 5 provides a cost per kilometer comparison of four passenger vehicle types as well as the Volt. The graph uses city driving fuel economy taken from NRCan testing. The fuel prices used in this graph are $0.32/kWh and $1.12/L. This cost comparison can obviously vary with changing fuel prices, and EVs become more attractive when gas prices are high and electricity prices are low.

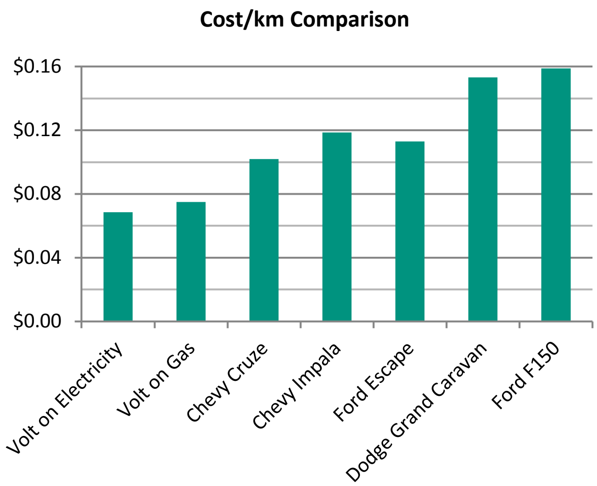


Figure 5

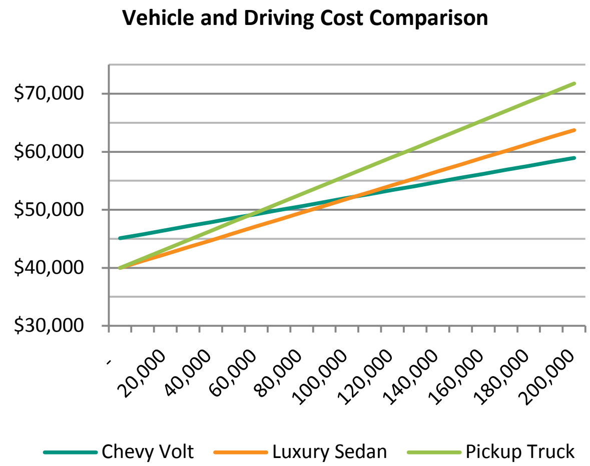


Figure 6

Cost Payback

Electric vehicles cost more than similarly sized non-electric vehicles. For example, the Volt falls into the $35,000-$40,000 purchase price bracket. Add to that the cost of a home charging station, which can cost up to $5,000, and an electric vehicle can cost up to $15,000 more than a comparably sized vehicle.

Presently, non-electric vehicles in the $35,000-$40,000 range provide prospective purchasers “more car for the money”; however, the “in use value” of electric vehicles exceeds that of conventional gasoline vehicles in that they cost less to operate and, as such, are better suited for higher annual mileage vehicles such as taxis.

Figure 6 compares the driving cost of the Volt to two other vehicles: a luxury sedan and a pickup truck, each costing $40,000. Using the electricity and fuel prices stated previously, the additional cost of the vehicle and charging station would be paid off in savings after 100,000 km compared to a luxury sedan, and after 60,000 km compared to a pickup truck.

Figure 7 shows the number of kilometers one would have to drive the Volt to break even compared to the costs to drive the sedan and the pickup. The table also shows the break-even points if the cost of electricity and gasoline were to increase or decrease by 25%.

Chevy Volt – Cost Payback Comparison

	km	
Fuel costs	**Sedan**	**Pickup**
Current	100,000	60,000
25% increase	80,000	50,000
25% decrease	140,000	80,000

Figure 7

ISSUES

A log was kept in the car to keep track of who was driving it, fuel-ups, and any issues that were noticed. Any issues were reported to the GM dealership and the vehicle was taken in to the shop whenever an issue was reported. The EV was kept parked at the AEA office and was always plugged in when not in use. The main issues are listed below in chronological order of when they first occurred.

Range Reduction

A big consideration when driving any electric vehicle in cold weather is that the rated battery range will be reduced. This is due to more electricity being used for passenger comfort as well as a reduced battery capacity. One strategy to preserve battery capacity is to leave the vehicle plugged in while warming the cabin. This will use electricity from the grid to warm the vehicle instead of from the battery. The Volt's dashboard will display the estimated battery range and it will compensate for the reduced range in the winter. FleetCarma has done quite a bit of testing of EV battery range in cold weather.[4]

Charger Drop-off

The car can be programmed to charge at specific times of the day. AEA's car was been set to charge in the night, ensuring the car was ready in the morning. The vehicle will also condition the battery during cold weather, which means a little bit of power gets sent to the battery to ensure it stays warm. On a couple of occasions during January of 2015, the vehicle charger would stop charging during the night and when someone tried to start the car in the morning it was unresponsive. The dashboard would give an alert saying "Battery too cold. Plug in." All that had to be done in these instances was to unplug the charger and plug it back in then wait for about 30 minutes. After this time the battery had received enough power to warm it back up and the car was ready to drive. These instances happened during colder nights so the two situations may be related.

Broken Plug

Plastic and rubber becomes more fragile during cold weather. Even rubber-coated extension cords rated for −40 °C will eventually crack from repeated use. In this case, the cord was bumped by another vehicle which made it pop out of the outlet located on the front driver side. The cord and plug were undamaged but the outlet on the car broke and it was no longer able to lock the plug in place to charge. This is a problem that could happen anywhere but since the plastic is more fragile in cold weather it is more likely to break if something hits it during a period of extreme cold.

Snow in the Vehicle Charge Outlet

Another issue with the outlet is that snow can get packed into it to a point where the plug can't make a connection and the car won't charge. This could happen if the cord is left lying in the snow or from a gradual buildup as the cord is connected.

Oil Level

On a few occasions during longer road trips to the South Slave and Dehcho regions, the oil level was reported as being low and oil had to be added. After this was reported, the vehicle was taken in to the dealership on a monthly basis to monitor the oil consumption. The monitoring hasn't shown any unusual oil usage so this problem is still unanswered.

[4] http://www.fleetcarma.com/nissan-leaf-chevrolet-volt-cold-weather-range-loss-electric-vehicle/

Cold Starting

During the second winter of testing there were a number of instances where the vehicle would not start in the morning. This issue was different than the previous year's problem since the charger still showed that it was working during the night and a different message was displayed: "Propulsion power reduced." This problem was determined to be linked to the 12V auxiliary battery. This battery is needed to start the gas generator but had too low of a charge. A solution to this would be a way to keep this 12V battery charged in the cold weather such as a trickle charger or a battery blanket, both of which require an additional plug to be connected.

FINAL THOUGHTS

This study suggests that PHEVs are viable northern vehicles. While they are more expensive to purchase than a comparable gasoline-only vehicle, they are more economical to operate and produce far fewer greenhouse gases, especially when power is provided by a renewable source. When EVs are running in electric mode they are also very quiet, which improves the driving experience. In other respects they are no different than any other vehicle.

Cabin heating was never a problem during the testing period. The ability to pre-warm the vehicle while still plugged in likely contributed to a satisfactory driving experience, and was especially useful in that warming the vehicle while it was plugged in did not deplete the battery. Reduced winter electric driving efficiency on battery-only power happened because of battery draws to heat the cabin. Notably, many if not all, of the issues noted could be prevented by keeping the vehicle in a heated garage. The warmed vehicle would get better range from the battery since less of the battery power would have to go toward heating the cabin and the engine would turn on less. The garage would also prevent the problems with cold starting.

Many PHEVs have a smaller battery range suitable for city driving, whereas BEVs have ranges of anywhere from 100–500 kms. For BEVs to gain market appeal in NWT there would need to be a network of fast charging stations located along the NWT's highways. PHEVs don't have the same problem since they can always be filled up with gas and continue driving if the battery drains.

APPENDIX

FleetCarma Dashboard

1, (2015 Chevrolet Volt)

Prepared By: nick.walker@aea.nt.ca
Logging Period: 1/1/2015 to 3/31/2016
Fleet: Arctic Energy Alliance
Description: 1

fleetcarma

Driving Summary

DISTANCE

10,796 km

Gas	Electric
70 %	30 %

38 km
0 km — 38 km
Daily Distance Benchmark

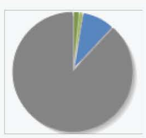
DRIVING ENERGY

6.3 L/100 km$_{eq}$

Fuel Usage	Battery	Charging Loss
602 L	680 kWh	878 kWh

6.3 L/100 km$_{eq}$
0.0 L/100 km$_{eq}$ — 6.3 L/100 km$_{eq}$
Energy Benchmark

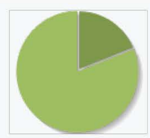
TIME



286 hrs ON		10,613 hrs OFF	
Driving	Idling	Charging	Resting
174 hrs	111 hrs	1,012 hrs	9,601 hrs

1 hrs
0 hrs — 1 hrs
Daily On Hour Benchmark

CHARGING ENERGY



1,571 kWh

Level 1	Level 2	Quick Charge
298 kWh	1,273 kWh	0 kWh

68 % AVG START SOC

54 % AVG END SOC

54 %
0 % — 54 %
Average End SOC Benchmark

GHG EMISSIONS

Total: 1,464 kg

Intensity: 136 g/km

Upstream (Electric)	Upstream (Fuel)	Tailpipe
52 kg	0 kg	1,412 kg

136 g/km
0 g/km — 136 g/km
GHG Emissions Benchmark

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