The Ravina Project

Why Electrify Heating and Transport

using a Dirty Grid?

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2019/11/14

REV 1.3

The Ravina Project - Goals

The Ravina Project consists of several projects all proceeding concurrently. If we were to rename our project today we probably would name it, “The Ravina Projects”.

Our project goals page allows our readers to understand the scope and depth of the various areas of inquiry focused totally on the household.

See the Project Goals page on our WEB site at:

www.theravinaproject.org/Project_Goals.htm

Why Electrify Heating and Transport using a Dirty Grid?

Abstract

As it turns out things are more complicated.

Even if the Grid releases several times more CO_2 per kilowatt-hour (kWh) than the same energy release from a petrol burning Internal Combustion Engine (ICE) car, an Electrical Vehicle (EV) will release less CO_2 per kilometer driven because of its more efficient use of energy per kilometer driven.

Heating is less clear. If the Grid is dirty, that is, the Grid's carbon release is over 180 grams per kilowatt-hour, converting heating to natural gas is preferred. If the Grid's release is less than 180 grams per kWh generated, converting to all electric heating will drop yearly CO_2 release. Here in Ontario with our clean Grid, heating conversion to electric will drop CO_2 production between 450 and 900 percent.

Introduction

Over the years we have read many arguments in favour of electrifying heating and transport. That's nothing new. However, there are many sub-arguments centered upon the state of the Grid that supplies energy for electrified transport and heating.

The first argument: if the Grid is dirty and laden with CO_2 release for every kilowatt-hour generated, the heating and transport can be no cleaner than the dirty Grid supply. The argument concludes with a finding that heating and transport are no better off, that is, they are just as dirty as the Grid and further are not worth the extra resources consumed to make it all happen. The conclusion is that electrified transport and heating plugged into a dirty Grid are more or less, non-starters.

The second argument: is basically the opposite. It argues that even if the Grid is dirty, electrifying heating and transport will reduce the amount of CO_2 released because the EVs at least will not be consuming petrol and thereby not contribute to the ongoing greenhouse gas pollution.

In this paper we want to combine our Ravina Project data with other data from our Tesla Model 3 and crunch the numbers to try to resolve these arguments.

Constants, conversion factors and data we will use

Grid carbon footprint

Usually the Grid's carbon footprint is expressed in grams of CO_2 release for every kilowatt-hour generated. We will continue with this tradition but which Grid carbon footprint will we use in our model? For this paper we will use Germany's Grid's average carbon footprint of 550 grams (0.550 kg) of CO_2 release per kilowatt-hour (kWh) generated. We have heard so much about Germany and their work to reduce their carbon footprint. They have spent many hundreds of billions of Euros on this project so we feel that using their numbers will allow our results to be in line with a country which is working very hard to reduce their Grid's carbon footprint.

Internal combustion engine (ICE) efficiency

What efficiency will we use when we crunch numbers involving ICE cars? How many liters of petrol will a car use every 100 kilometers (km)? There is no one number that captures this metric because it is always changing due to city vs. highway driving and even the kind of traffic one drives through. So the best we can do is to provide a range of petrol usage per 100 km driven. We chose to use a range of 8 liters to 14 liters of petrol consumed per 100 km driven. We think this range will capture most ICE cars' efficiency.

Electric vehicle (EV) efficiency

This number varies from one EV model to another so we will have to use a range. This metric is different than that used in the ICE car world, where the efficiency is tied to the rate of fuel usage. As well, the amount we use per km driven also includes the EV's vampire load. Unlike an ICE car, the EV uses its battery to energize its electronics even while it is sitting unused. So the energy amounts we will use must encompass this vampire load. For the lowest energy use per km driven we will use the low end of our Tesla Model 3's energy usage which is about 120 watt-hours per kilometer driven. In order to account for the vampire load and other models of EVs, we will double that usage to 240 watt-hours used for every km driven.

Home heating energy use

We will use our data from our daily records of cubic meters of natural gas used for these calculations. Our database in this area goes back almost 13 years at this time of writing. We want to use a range of daily natural gas usage but what range to use? We have developed a calculation method that allows us to approximate the average amount of natural gas used per winter day that is only used for heating. In our household, natural gas is used for clothes drying, cooking and domestic hot water so separating out the gas used just for heating is critical to our ability to understand our heating usage and of course, the household heating efficiency.

Natural gas and petrol conversion constants

There are several conversion constants used in this paper.

We will use the common conversion between cubic meters (m^3) of natural gas and kilowatt-hours. One m^3 of natural gas is equal to 10.35 kWh of energy.

One m^3 of natural gas also releases 1.86 kilograms (kg) of CO_2.

One liter of petrol releases 2.3 kg of CO_2.

One liter of petrol is equal to 9.59 kWh of energy.

Efficiencies between ICE and EV vehicles compared

At first glance comparing the efficiency of a car that needs fuel to a car that does not is a problem, or at least a challenge. To help us we will use the conversion constants we listed above.

ICE analysis

The fuel efficiency chosen by us lies between 8 and 14 liters of petrol used for every 100 km driven. Using our conversion factor of one liter of petrol producing 9.59 kWh of energy, an ICE car traveling 100 km will use energy equivalent to 8 x 9.59 = **76.7 kWh** on the low end and 14 x 9.59 = **134.3 kWh** on the high end. Again we stress that these two limits are not written 'in stone'. They are merely there to encompass most of today's ICE cars' efficiencies.

The per km energy usage therefore is between 0.767 and 1.343 kWh or expressed another way, between **767 and 1,343 Watt-hours per km**.

The release is between 8 L x 2300 gm CO_2/L / 100 km = **184 grams of CO_2 per kilometer** traveled at the low end and **322 grams of CO_2 release per km** at the high end.

For a year of driving of say 12,000 km the total release is between 12,000 x 0.184 kg = 2,208 kg and 12,000 x 0.322 = 3,864 kg.

EV analysis

In energy terms the carbon release per kWh of petrol is 1.86 kg CO_2 / 9.59 kWh = 193 grams of CO_2 per kWh of energy used. So here's the challenge. The EV is energized by a Grid that is much dirtier at 550 gm of CO_2 release per kWh. ***On face value, the EV is much more carbon intensive than the ICE car.***

Since the EV is already working on an energy per kilometer metric we don't have to do multiple conversions to get our energy per kilometer usage. What we do need to do, that the ICE analysis did not consider, is to integrate the amount of CO_2 release that comes from the Grid. The calculation is straightforward. The EV uses between 120 and 240 watt-hours per km driven. The Grid produces 550 grams per kWh of electricity generated. Per Watt-hour (W-h) generated, the Grid produces 0.550 grams of CO_2. The EV's per kilometer release of CO_2 is 120 W-h / km x 0.550 gm CO2 per W-h = **66 grams per km on the low end** and 240 W-h used per km x 0.550 gms CO_2 release per W-h = **130 grams per km on the high end**.

We can express these amounts in kilograms as: 0.066 and 0.132 per km driven.

For a year of EV driving that same 12,000 km the total CO_2 release is between 12,000 x 0.066 = 792 kg and 12,000 x 0.132 = 1,584 kg.

So what do these numbers show us?

If we look at the energy use per kilometer we see that the EV uses between 120 and 240 watt-hours. The ICE car uses between 767 and 1,343 Watt-hours per km driven. ***The EV's efficiency more than makes up for the Grid's extra carbon load.***

A change in Grid carbon footprint from 0.550 kg of CO_2 release per kWh

How dirty does the Grid have to be before the EV and ICE cars have the same CO_2 release per km driven?

In a sense we will calculate a top end for Grid carbon footprint. From above, the range of emissions for an ICE car is between 2,208 and 3,864 kg per 12,000 km driven. The EV's release is between 792 and 1,584 kg for the same distance. The ratio is between 2.8 on the bottom end and 2.4 on the bottom end. This tells us that the grid could be about 2.5 times dirtier than the 0.550 kilograms per kilowatt-hour generated. ***The Grid could emit up to approximately 1.4 kilograms of CO_2 per kilowatt-hour generated before the EV and ICE car will reach parity in their carbon release over 12,000 km a year.***

How about using the carbon overhead of our own Grid here in Ontario?

Ontario's nuclear and hydro powered Grid's carbon footprint lies somewhere between 20 and 40 gm per kWh generated or 0.020 and 0.040 gm per watt-hour generated. The EV uses between 120 and 240 watt-hours per km from above. The EV's carbon footprint becomes 2.4 and 4.8 gm per km at 0.020 gm per watt-hour generated and between 4.8 and 9.6 gm per km at 0.040 gm per watt-hour generated.

For a year of driving that same 12,000 km and the Grid emits 20 gm per kilowatt-hour, the total CO_2 release is between 12,000 x 0.0024 = **28.8 kg** and 12,000 x 0.0048 = **57.6 kg**. At 40 gm of CO_2 release per kilowatt-hour the carbon footprints are doubled to **57.6 and 115.2 kg** for 12,000 km driven.

This, in a nutshell, is why electrification is so important. Electric vehicles use energy more efficiently while doing the same work. That means even though they may, on some Grids release more CO_2 per watt-hour of energy expended than an ICE car, their efficiency means over the 12,000 km of driving they release much less CO_2.

But the bonus of transport electrification is also in this nutshell. Notice as the Grid's carbon footprint gets better all electrical appliances … and the EV is an appliance … all have their carbon footprint reduced with no modification. (Note the tinkering and expense to get an ICE car to be just 20% less carbon intensive)

Electrification in general, seen in this light, becomes a major investment in the future.

Heating Analysis

We will use our database located at:

http://www.theravinaproject.org/Ravina%20Data%202007-2019%2001.csv

Our database contains daily household meter readings including the daily natural gas reading.

We will use the last 4 years of data for our calculations. Note that the daily natural gas usage database ends at the end of day on May 31st, 2019. We have from our unpublished records the meter reading for the end of day September 30th, 2019. The January 2020 release of our database will contain the complete 2019 year of data.

Calculating natural gas usage for heating

Calculating the amount of natural gas used for heating is not as straightforward as one would think. The problem is one of use. Natural gas in our household is used for heating, clothes drying, cooking and domestic hot water production. We have a high efficiency gas boiler that both circulates hot water in our radiators (which are original equipment circa 1925) and produces hot water on demand when a hot water tap is opened anywhere in the house. We have no hot water tank nor any type of traditional furnace.

So the question becomes how do we separate out the cubic meters of natural gas used for heating from all other uses? There are no meters that can show us the amounts used for various tasks. We have worked out a method that will give us a close approximation to the amount of natural gas we use for heating.

Every summer the furnace is OFF. That is, all the gas used goes to all the other non heating uses. We reason that this same daily usage for non-heating activities is the same for all the days of the year. Of course this is not an exact accounting for several reasons. We use the gas dryer more in the winter time because we use a clothes line in the summer. We cook hot meals much more often in the winter time and we take hotter showers in the winter time than in the summer. When we crunch the 2007 to 2019 summer usage numbers we get a value of between 1.5 and 1.8 cubic meters used per day. We round this value upwards to 2.0 cubic meters used on average per day to somewhat account for this change in seasonal natural gas usage. We think this is a reasonable modification to the average given the challenges of the situation.

The heating season starts here at the start of day October 1st and ends at the end of day May 31st of the following year. The cooling (non-heating) season starts at the start of day June 1st and ends 4 months later at the end of day September 30th. We notice that Global Warming has changed this slightly. Over the last two years the Fall seasons have been warm with really cold weather and snow not beginning until January.

Meter readings for the 4 seasons

These natural gas readings from our utility meter are all end of day readings. As noted above if you download our database you can find these readings and verify they are correct except for the last reading which has not been posted yet. The data format below is: the date, the gas meter reading at the end of day on that date and a description of the significance of the date.

Date	Meter Reading	Comments
September 30th 2015	34425	Start of heating season 1
May 31st 2016	36291	End of heating season 1 and start of cooling season 1
September 30th 2016	36468	End of cooling season 1 and start of heating season 2
May 31st 2017	38402	End of heating season 2 and start of cooling season 2
September 30th 2017	38610	End of cooling season 2 and start of heating season 3
May 31st 2018	40802	End of heating season 3 and start of cooling season 3
September 30th 2018	40993	End of cooling Season 3 and start of heating season 4
May 31st 2019	43203	End of heating season 4 and start of cooling season 4
September 30th 2019	43396	End of cooling season 4

This chart provides the reader with the crunched data for each season.

Usage in Cubic Meters			
Heating season 1		1866	
Cooling season 1		177	
Heating season 2		1934	
Cooling season 2		208	
Heating season 3		2192	
Cooling season 3		191	
Heating season 4		2210	
Cooling season 4		193	
Total heating	8202	cubic meters over 1,461 days	
Total cooling	769	cubic meters over 484 days	

The plan for calculations from the data

We use the cooling season data to calculate the average non-heating daily gas usage. We have 4 cooling seasons totaling 484 days. We take the average to approximate the amount of daily gas consumption for uses other than heating.

The 4 heating seasons have a total number of days in them of 977 (one leap year). From the meter readings we can calculate the gross amount of gas used. However the amount includes all the gas used for non-heating purposes. In order to calculate the net amount of gas used just for heating we take the average non-heating daily usage and multiply it by 977 to get the total non-heating gas usage for the 4 heating seasons. We subtract this total from the total gas used in all the heating seasons. We are left with as good an approximation as we can get for the number of cubic meters of natural gas used just for heating.

Once we have this net amount of natural gas used for heating, we are able to calculate the amount of CO_2 released over the 4 heating seasons via our conversion constants above. We now know the total CO_2 release across the 4 heating seasons.

The final step is to calculate the household's carbon footprint if the natural gas energy used came from the Grid. We know the cubic meters of natural gas used. We know the conversion factor between cubic meters of natural gas and kilowatt-hours so we can determine the number of kilowatt-hours the house used in gas energy over the 4 heating seasons. We know the carbon footprint above so we can now calculate the carbon footprint if the house was totally Grid powered for heating. We assume in this model that there would be no difference in the total energy used to heat the house, The only difference is the energy source … from the Grid or from natural gas.

Calculations

As you can see from above the total amount of natural gas used over 1,461 days of heating was 8,202 cubic meters.

Over the 4 summers of 484 days we used 769 cubic meters of natural gas. The summertime daily use is 769 cubic meters / 484 days which gives us a average daily usage of 1.6 cubic meters per day. We round this daily total to 2.0 to account for more average daily usage during the winter months.

During 4 years there were 1,461 heating days using a total of 8,202 cubic meters of natural gas. We calculate that 1461 x 2.0 = 2,922 cubic meters of natural gas were used for non-heating purposes. To get the total cubic meters of natural gas used for heating alone we subtract 2,922 cubic meters from the gross total of 8,202 to give us 5,280 cubic meters.

Calculating household energy usage and carbon footprint from heating

From our conversions page above we know that each cubic meter of natural gas produces 10.35 kWh of energy and releases 1.86 kg of CO_2.

5,280 m^3 of natural gas produces 54,648 kWh of energy and releases 9,820.8 kilograms of CO_2. Each kWh of energy used releases 0.180 kg (rounded) of CO_2 or 180 grams per kWh.

The Ontario Grid has a carbon footprint of 20-40 grams of CO_2 per kWh generated. Converting the household to electric heating will reduce the carbon footprint by a factor of between 180 / 20 = 9 times on the low end and 180 / 40 = 4.5 times on the high end of Grid CO_2 release. In other words converting the household to electric heating with the same energy used will drop the household carbon footprint for heating by about 450% to 900%. This is significant.

So how dirty would the Grid have to be before there is no advantage to converting to all electric energy for heating? The Grid would have a carbon footprint of 180 grams of CO_2 (as calculated above) identical to the carbon release for natural gas.

Note that this is a far cry from Germany's grid of 550 gm / kWh generated. So parenthetically, in Germany, the preferred energy source for household heating should be natural gas until the power Grid is cleaned up.

Conclusion

Transport electrification, because of its increased efficiency in using energy, is a transport CO_2 emissions killer even if the grid is dirty.

In general households should use natural gas if the Grid's carbon footprint is substantially greater than 180 gm per kWh generated.

If both transport and heating are electrified, all carbon footprint reductions to the Grid get amplified by all the Grid attached devices. All Grid attached devices drop their carbon footprint at the same time without further modification / expense because they adopt the Grid's carbon footprint no matter what it is.

Note that we have tried our best to get ballpark numbers for energy use and GHG release. There is nothing exact here in the conclusion section of this paper. However, we believe that our data definitely shows trends to the extent that we can make the recommendations we express above.

"If we knew what we were doing, it would not be called research."
- A. Einstein

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