The Ravina Project

Household Carbon Accounting

Calculating our Carbon Credits Including Fugitive Methane Emissions

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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

Household Carbon Accounting

Abstract

We create a carbon accounting model for the household and produce a carbon centric balance sheet of credits and debits for each year from 2007 until 2020. We evaluate the effects of solar panels and an EV on the carbon balance sheet while demonstrating the surprising relationships among: the household carbon budget, solar generation, an EV and the grid's carbon overhead. We also demonstrate that the carbon credit for an EV is inversely proportional to the carbon intensity of the grid while also showing that the carbon credit for solar energy is proportional to the grid's carbon footprint per kWh generated.

Our main conclusions are: the addition of an EV to the household produces an increase in carbon credits only on grids up to a maximum carbon intensity, solar PV deployed on a clean or almost clean grid is useless at displacing carbon dioxide, fugitive Methane released from the natural gas distribution network increases the carbon footprint of the household to such an extent that electrification and insulation become the main drivers of Global Warming Potential reduction.

For decades many, including us, have written about making a dirty grid cleaner. But what happens when the grid is almost clean? Little research has been done on this topic because so few grids are in the 'almost clean' category. We have found that a new set of rules governs Global Warming Potential reduction on an 'almost clean' grid. In short, on such grids, it's a whole new ball game.

Introduction

This paper is our second attempt at a household carbon accounting model and the first to include fugitive emissions of methane. Our energy sources are: natural gas, battery, imported energy from the grid and solar PV. Our energy sinks are the EV, our household electrical loads, the battery, heat and the energy we export to the grid.

In this paper we take into consideration what experts (Howarth 2020) [1] in the field have discovered about fugitive Methane. In the first version of this paper we calculated the CO_2 release from burning a kilowatt-hour (kWh) of natural gas but ignored fugitive Methane, that is, all the Methane that has leaked out of the natural gas distribution system. The 20 year Global Warming Potential (GWP20) of Methane is 86 times greater than the same volume of CO_2. [1]

We record and calculate the number of cubic meters of natural gas used each day. In addition we calculate the CO_2 release equivalent (CO_2e) of the fugitive emissions incurred in getting the natural gas to our house. We add this extra CO_2 emission to our household carbon budget.

The carbon overhead for our grid is set at 40 grams of CO_2 release for every kilowatt-hour (kWh) generated. In comparison with other grids this carbon footprint is very low. We are thankful for the political decisions made decades ago here in Ontario, Canada to invent and produce a whole fleet of CANDU power reactors. Those atomic powered reactors plus our water powered generation at Niagara Falls and other places around the province, allows us to have one of the cleanest grids in the world.

Because we have all the elements working together to make a carbon ecosystem The Ravina Project is set up to develop a comprehensive household carbon accounting model.

1. We have solar panels which harvest clean energy but unlike other households that work on a Feed In Tariff (FIT), we can measure, access and use our solar energy because we have a micro-grid. We have a 17 kWh battery that allows us to store and access the energy we harvest. We measure the daily harvested energy in kWh.
2. We have a bi-directional grid utility meter. It allows us to measure the energy we use from the grid and as a separate total, energy we push to the grid.
3. We have an electric vehicle that is metered. We know how much energy we export to charge its battery.
4. Using these four metered electrical energy flows we can calculate the total amount of clean solar PV energy the household uses each day.
5. We record the metered daily number of cubic meters of natural gas we consume.

With six daily numbers, five metered and one calculated, we have all the elements required to provide data to a comprehensive household carbon accounting model.

Method

Carbon Accounting Model

In order to actually do carbon accounting we need a rulebook for our model … something that spells out the credits and debits. With that in hand we can create a balance sheet for the household. We use the term ‘carbon’ to refer to Carbon Dioxide equivalent (CO_2e) which is the total of immediate CO_2 release from grid electricity usage plus natural gas combustion plus the fugitive release of Methane our combustion caused in the distribution and delivery system.

Our fugitive release amounts and GWP20 calculations rely upon the paper which we will reference as (Howarth 2020) [1].

Credits

A carbon credit increases the carbon credit side of the carbon balance sheet.

Debits

A carbon debit increases the carbon debit side of the carbon balance sheet.

Currency Used

The actual currency we are tracking is the Carbon Dioxide equivalent (CO_2e) we release or displace when we consume energy broken out by kilowatt-hour (kWh). When combined with energy use the metric becomes grams of CO_2e release per kilowatt-hour (kWh) of energy used or g CO_2e per kWh.

Why use kilowatt-hours (kWhs)?

All the energy we use in our accounting system is expressed in kilowatt-hours (kWhs). We use kWh because everyone who pays an electrical utility invoice pays on a per kWh consumed basis. This unit of energy is well known and since all our papers are written for the general public we feel it is the best metric to use.

Data and Calculations

Since we took possession of the EV on May 31st, 2018. We have portioned our data in 365 day segments starting at the beginning of June 1st each year and ending at the end of day May 31st of the next year. In this way can get a real understanding of the effects of adding an EV to our household's carbon balance sheet.

The daily household data we collect are as follows:

Meter Readings / Observations

At sundown, since the start of the project in January 2007, we read the meters to record the daily raw data.

Bi-directional grid energy meter.

This meter allows us to make two readings, kWh coming into the house from the grid and kWh going to the grid. The meter is calibrated in whole number kWhs. The readings are perpetual numbers, always increasing.

Natural Gas meter

This meter provides us with the number of cubic meters of natural gas (m^3 of NG) used by the house. The meter is calibrated in whole numbers that are perpetual, always increasing.

Solar Charge Controller

This device provides us with the number of kWh harvested by our solar panels, a number that is reset to zero every night and calibrated to the tenth of a kWh.

Tesla usage

Each day we record the number of kWh used to energize the Tesla Model 3 battery attached to our household wiring through a 9,500 W level 2 Tesla charging station. These numbers are rounded by us to tenths of a kWh.

Conversions and Constants

The following are used in this paper.

1 cubic meter (m^3) of natural gas (NG) combustion produces 10.6 kilowatt-hours (kWh) of energy.

> A m^3 of NG combustion releases 38.3 Megajoules (MJ) of energy. Since each kWh equals 3.60 MJ, 38.3 MJ of energy equals 38.3 / 3.60 = **10.6 kWh / m^3 NG** [1]

1 cubic meter of natural gas combustion releases 1.920 kg of CO_2.

> A m^3 of NG combustion releases 38.3 MJ of energy and produces CO_2 at the rate of 50 g of CO_2 per MJ. 38.3 MJ of NG energy produces 50.0 g times 38.3 MJ = **1,920 g of CO_2 per m^3 NG** [1]

Release from fugitive Methane emissions per m^3 of NG consumed has a Global Warming Potential over 20 years (GWP20) equal to: **5.94 kg CO_2**. This is expressed as CO_2e, the equivalent amount of CO_2 required to produce the same global warming potential.

1 m^3 of NG consumption promotes the release of 3.6% of one cubic meter of fugitive Methane which has a 20 year equivalent radiative forcing 86 times that of the CO_2 released when NG is combusted (GWP20). From above, 1 m^3 of NG produces 1,920 g of CO_2e. 3.6% of a cubic meter would produce the same GWP20 as: 0.036 times 1,920 = 69.1 g of Methane. The equivalent amount of CO_2e released to match that radiative forcing is 86 times 69.1 g = **5.94 kg**. [1]

Total release of CO_2e for every m^3 of NG used is 1.92 + 5.94 = **7.86 kg**.

Natural gas combustion produces **50 g CO_2/MJ** [1]

1 kWh of grid electrical energy in Ontario on average produces **0.040 kg of CO_2**.

1 kWh NG produces 7.86 kg CO_2e/10.6 kWh per cubic meter = **0.741 kg CO_2e**.

1 liter of petrol has on average **33.5 MJ** of energy density. Note there is a difference between premium (35 MJ/liter) and regular petrol (32 MJ/liter). [4]

1 liter of petrol contains 33.5 MJ / 3.6 MJ/kWh = **9.30 kWh of energy**

One kWh of petrol releases 29 g of CO_2e from fugitive Methane release

1 MJ of petrol releases 0.093 g of fugitive Methane [1]. On average one liter of petrol releases 0.093 g Methane per MJ times 33.5 MJ equals 3.12 g of Methane. Since 1 liter of petrol contains 9.30 kWh, one liter of petrol will release 3.12 g / 9.30 equals 0.335 g of Methane per kWh which has a GWP20 value of 0.335 g times 86 = **29 g of CO_2e per kWh**.

1 liter of petrol combustion releases 2.31 kg of CO_2 [5]

1 US gallon of petrol releases 8.78 kg CO_2. 1 US gallon contains 3.79 liters. 1 liter of petrol releases 8.78 kg per gal / 3.79 liters per gal = **2.31 kg CO_2**

1 kWh of energy from petrol releases 277 g CO_2e

1 kWh of energy from petrol releases 2.31 kg CO_2 per liter / 9.30 kWh per liter = 248 g CO_2 When fugitive Methane is included the total becomes 29 g per kWh plus 248 g per kWh equals **277 g CO_2e**.

Calculating Carbon Credits and Debits

Below are some examples demonstrating how we use our carbon accounting model. We want you to understand our thinking by providing some concrete cases and our analysis of each.

Case 1: Debit

We use a kWh from the grid. The grid's carbon overhead averages 40 g CO_2e per kWh. 40 grams is added to the debit side of our carbon balance sheet.

Case 2: Credit

We harvest one kWh from the sun and consume it on our household micro-grid instead of consuming a grid kWh. The clean kWh does the same amount of work as a grid kWh but no CO_2e is released. We displaced 40 grams of CO_2e by preventing the release of 40 grams. We claim 40 grams of credit. This calculation seems straightforward but it is subtle as we will show below.

Case 3: Credit

We harvest a clean kWh and place it on the grid. Since all kWh on the grid are fungible, we can't ascertain the exact household that uses our kWh. All we can know really is that the grid is cleaner by 40 grams of CO_2e and we are responsible. We claim 40 grams of credit. This credit is well known but there is an issue with it in our view. More below …

Case 4: Credit

We harvest a kWh and place it on the grid. Since all kWhs on the grid are fungible, we can't ascertain the household that uses our kWh. But that doesn't matter because some house uses it. They have a balance sheet and since they are consuming a clean kWh, that clean kWh displaces 40 grams of carbon release they might have incurred. We can add 40 grams of their credit to our balance sheet because we were the source of that energy.

Case 5: Credit

We charge our EV with kWhs from the grid. Without an EV we would consume the energy in the form of petrol at a carbon load of 277 grams of CO_2e per kWh. Since we have an EV we charge its battery with grid kWhs at an average carbon load of 40 grams. The EV does the same amount of work as our old petrol based ICE car however, we do not emit 277 g CO_2e per kWh. The EV emits [sic] 40 grams. The carbon release nets out to a 237 gram credit per kWh of EV battery charge.

Case 6: Debit

We use natural gas to heat our house, cook our food, dry our clothes and provide us with domestic hot water. The carbon debit is 741 grams of CO_2e released for every kWh of natural gas used.

Cases 1 – 4 discussion

Case 1 requires little explanation.

Case 2 this claim for credit requires some thought and calculation. When we push kWhs back to the grid we are harvesting more power than what the household can use plus the battery is fully charged. There really is no place for the harvested power to go except to the grid. Our power flow relationship with the grid is as follows: we can send power to the grid or we can receive power from the grid but we cannot do both at the same time. (logical XOR) So with this logic information we can calculate how much clean energy we use every day.

We have meters to tell us: kWhs we return to the grid, kWhs we use from the grid, kWhs we harvest via the solar panels and kWhs we send to the EV. Our batteries take a very small, unmetered amount because they are being floated at a particular voltage with a very small current drain. We will ignore this trivial energy sink in our accounting model.

For example we harvest 18 kWh of solar energy, we use 5 kWh from the grid, we return 7 kWh to the grid and we put 2 kWh into the EV's battery. How much clean energy did we use to displace grid energy? How big a claim for carbon credits can we make? This calculation, in our view, is central to both this paper and to our efforts as a society to reduce carbon emissions. We also find that this is one of the most confused calculations in the popular media.

So how much carbon displacement can we take credit for? This is the critical question.

We used 5 kWh from the grid, so in order to null this carbon usage we reduce our usable clean energy from 18 kWh to 13 kWh. Together they net out to zero. We can't claim this as a credit because we have a carbon debit of (5 x 40) 200 grams. The best we can do is to dedicate -200 grams of clean electrical energy to make a zero balance. In some analyses this is called 'net zero' carbon emissions. We interpret 'net zero' as a carbon bookkeeping term only … that has no impact upon the world's GWP. Why? We in fact emitted 200 grams of CO_2. No amount of carbon bookkeeping slight-of-hand will alter that fact.

Because we sent 7 clean kWhs back to the grid, we must subtract the 7 kWhs from the remaining 13 to give us 6 kWhs available to be used. Lastly, we place 2 kWhs into the EV's battery. That leaves us with 4 kWhs used by the household.

The 4 kWhs of energy remaining is very special. We use it instead of grid energy … it displaces grid energy. If we didn't have the panels we would have used grid energy. This is not a bookkeeping issue. We, in fact, prevented the consumption of 4 kWh of grid energy with the accompanying release of (4 x 40) 160 grams of CO_2. This is a true carbon credit both as a bookkeeping credit and a negative CO_2 release that, in its small way, will reduce Global Warming Potential (GWP) for a 1000 years.

For those who are enamored with 'net zero' carbon bookkeeping we caution that it appears to be a carbon bookkeeping artifact only … with no real affect on GWP … and that's the whole point, a reduction in GWP via decarbonization, isn't it?

Cases 3 and 4 are interesting or more exactly, provide a challenge to our carbon accounting model. Both are credits. If you take both cases together and look at the result you quickly conclude that double counting has taken place. We strongly suspect that the exported clean kWh suddenly becomes two kWhs of credits.

Note the following: the remote household, in Case 3, credits its balance sheet and in fact has its carbon release reduced by 40 grams because it consumed the clean kWh we harvested. So that household has both a credit and a real world 40 gram CO_2 reduction … this case might be viewed as the carbon bookkeeping agreeing with reality.

What happens in Case 4? The same kWh is claimed by the generator, which is our household, as a credit but it's not available to us. It has been rightly claimed by another balance sheet. And there is, in fact, no reduction in carbon release on our part. It is impossible for us to use the exported kWh given the logic of our bi-directional utility meter.

Case 4 credit does not exist in our carbon accounting model nor in reality. It is a bogus credit.

Case 5 - 6 Discussion

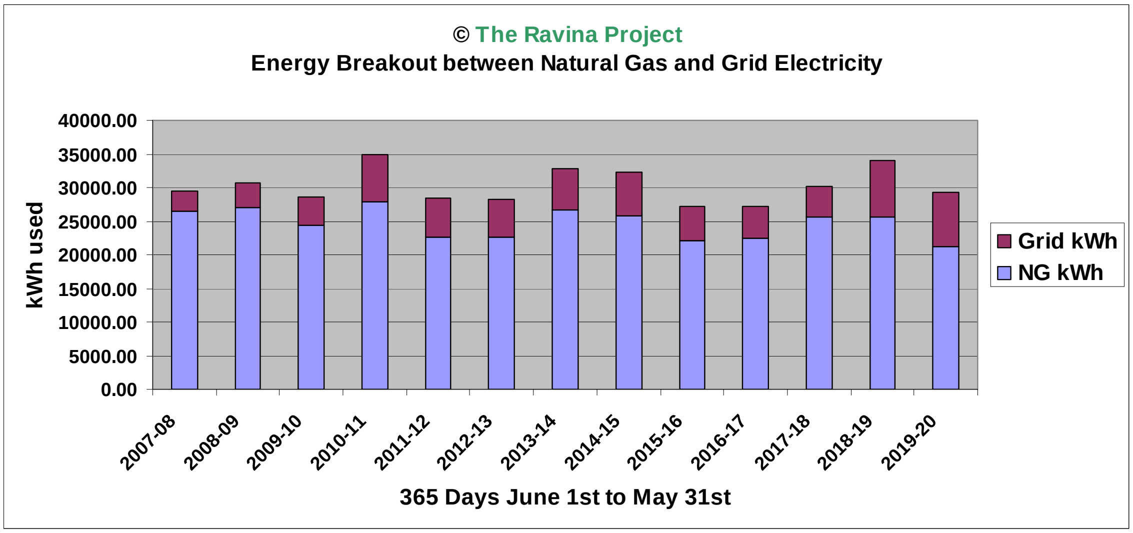
Both these cases are straightforward. No discussion is required.

Data Presentation

In the series of graphics that follow we present our data gathered from June 1st, 2007 until May 31st, 2020 in 365 day blocks. As noted above, the reason for not following the calendar year is the fact that the first day of using our EV is June 1st, 2018. If we used the calendar year, the first and last year's data would only contain about 6 months of EV data. In our view this situation would skew the impact of adding an EV to the household carbon balance sheet.

Total Household Energy Use

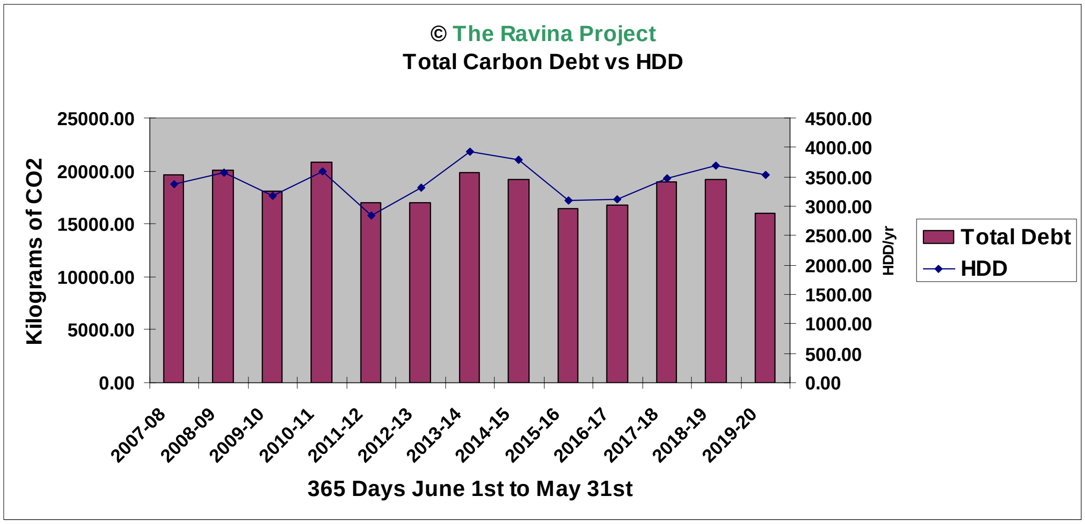
Consider the following graphic. The calculations supporting this graph simply add up, for each 365 day period, all the daily energy consumed in natural gas and grid electricity.



Note the variable amount of electrical usage. What's going on here? Early on in the project after the initial efficiency gains from extra insulation and the like, we tried to reduce our carbon footprint for heating even more by placing electrical space heaters in critical areas of the house. The last two years were the most aggressive and used the latest advanced Dyson heaters.

Total Carbon Debt and Heating Degree Days

Since we heat our house with natural gas, Heating Degree Days tells us how cold our winters have been on a relative basis. The vast majority of our natural gas usage is for heating. On the chart below we plot the total carbon debt by the household against the total heating degree days for each 365 day period. Note that the household carbon debt closely tracks the number of heating degree days in each year.



We include this chart to demonstrate that the last two winters have not been extraordinary. Any changes to our household carbon account balance are not due to weather.

Note again the biggest increases in household heating efficiency due to improved insulation, windows, doors, wrapping the second floor in insulation and the like occurred between 2004 and 2009. Adding heating at a lower carbon overhead (40g vs. 741g CO_2e/kWh) seemed to be another way of decreasing the household carbon release.

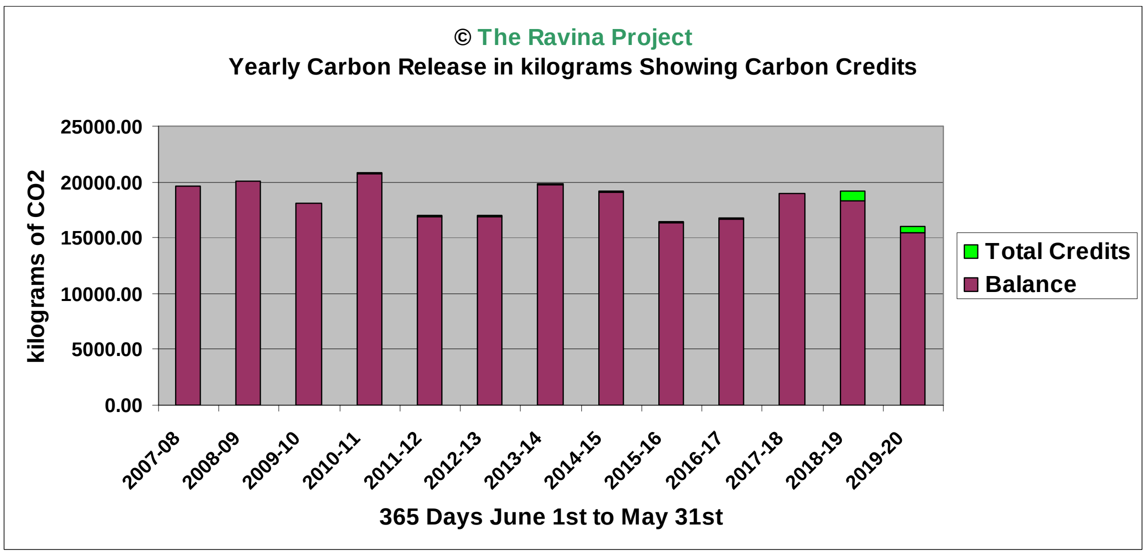
Our total carbon debt is between 16 and 21 tonnes of CO_2e release to the atmosphere a year.

Note we have not accounted for any carbon credits we might calculate.

More below …

Carbon Release including Credits

The following chart shows the effects of our carbon accounting model. Each stacked bar consists of the balance of the carbon release calculated as carbon debits minus carbon credits. It is a measure of the real carbon release each year. The green part represents the total credits for the year based upon our carbon accounting rules.

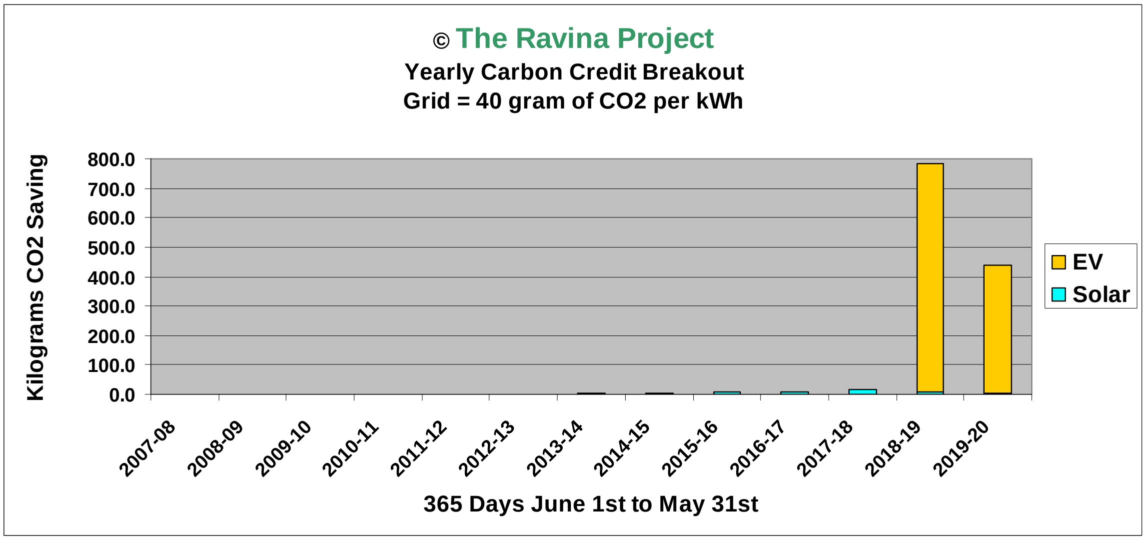


To our surprise we noticed the incredibly small amount of carbon credit we get from solar power. This a brutal chart for those who live on a clean or almost clean grid and want to reduce carbon emissions by the addition of solar PV to a house. Our grid is just too clean for solar PV to make a difference in household carbon footprint. We strongly suspect that wind generation would generate twice as much energy per year as solar PV resulting in the tripling of the amount of displacement for solar PV shown above. But the cruel reality is that tripling a very low number still produces a very low number.

More below …

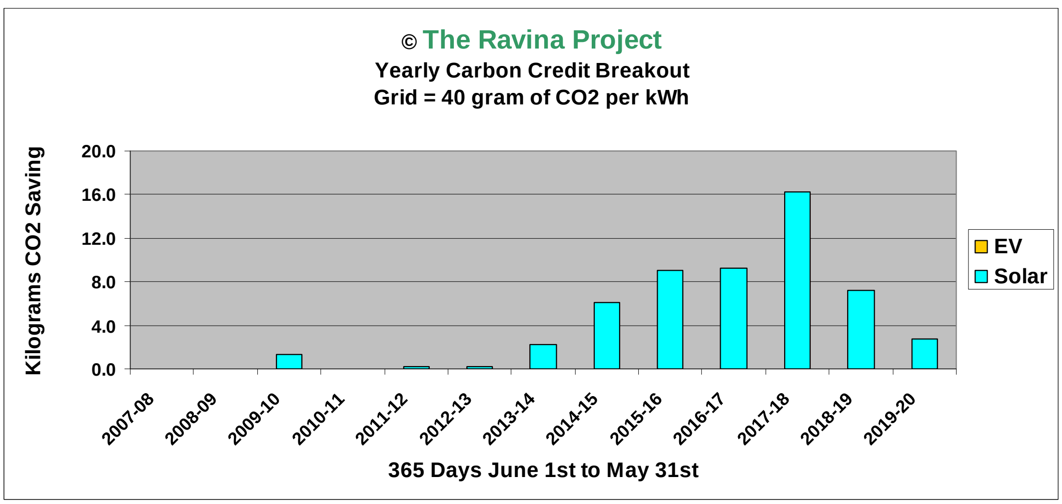
A closer looks at our carbon credits

Let's look at the carbon credits by limiting the chart below to the actual calculated carbon credits we generate each year.



Note that we did not have a bi-directional meter installed on our house until the 2009-10 year. It replaced a mechanical meter that only recorded kWh consumed by the house.

The carbon displaced by the use of solar PV is barely there! Lets eliminate the EV's contribution to the bars so we can see the carbon displacement of solar PV only. Consider the following:



This is another brutal result. All the work we have done and the expense at getting a good database for analysis … all we have to show for it is a lousy 16 kilos of carbon displacement for the whole year of 2017-18? Remember these kilowatt-hours are kWhs we consumed in place of grid kWhs so they are true displacement numbers.

All those solar PV panels were deployed and such a meager reduction in GWP. Our carbon accounting model shows the clay feet of solar PV when deployed on an almost clean grid. Wind is in the same category. There is just so little grid carbon to displace.

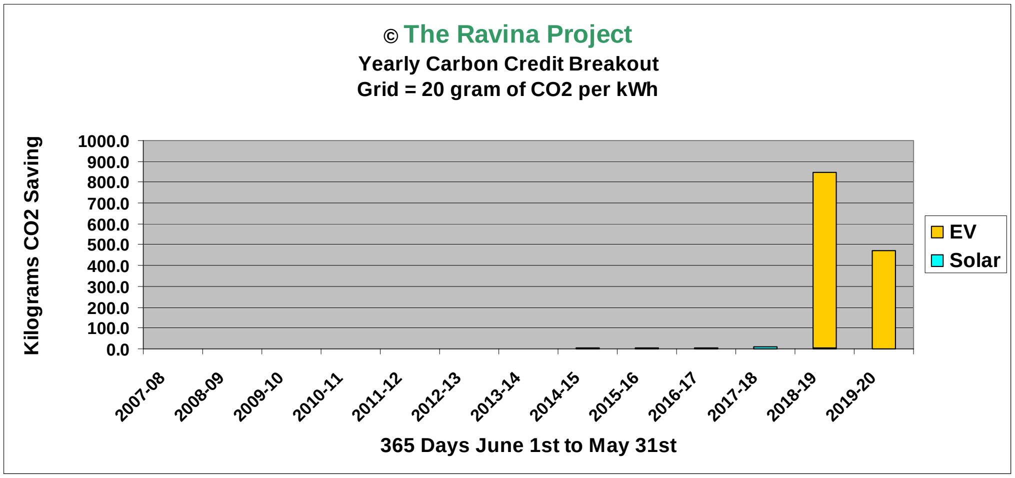
Carbon Credit Calculations with different Grid Carbon Footprints

Footprint of 20 grams per grid kilowatt-hour

Let's play with our numbers and show some interesting effects when our household is transplanted to grids which have different carbon footprints.

On our first chart below we reduce our grid carbon to 20 grams per kWh. We notice immediately that the carbon credit from the solar panels disappears and the credits from the EV are increased.

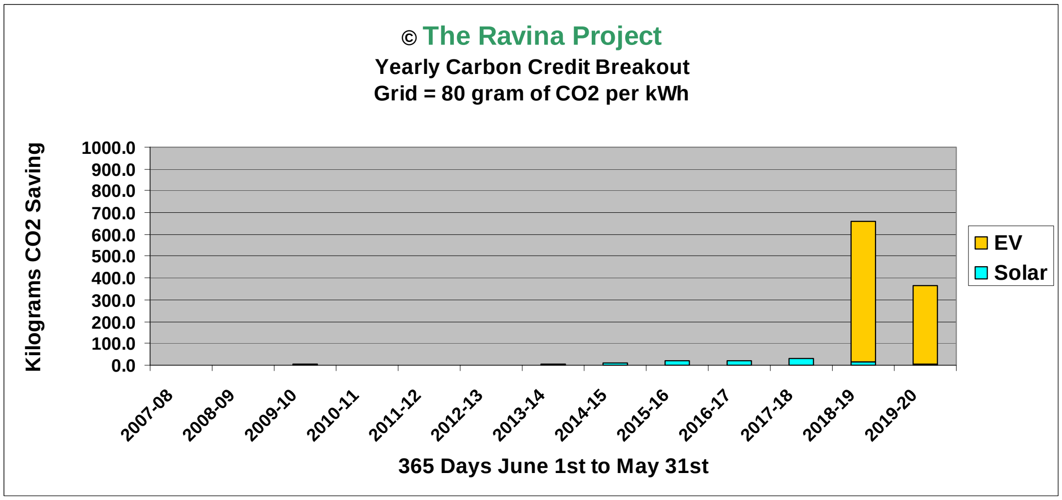
Why does this occur?



Note that we displace 277 grams of CO_2 per kWh from petrol with 20 grams of grid energy producing a credit of 257 grams per kWh placed into the EV's battery … so the EV's total displacement increases. The PV dies.

Footprint of 80 grams per kilowatt-hour

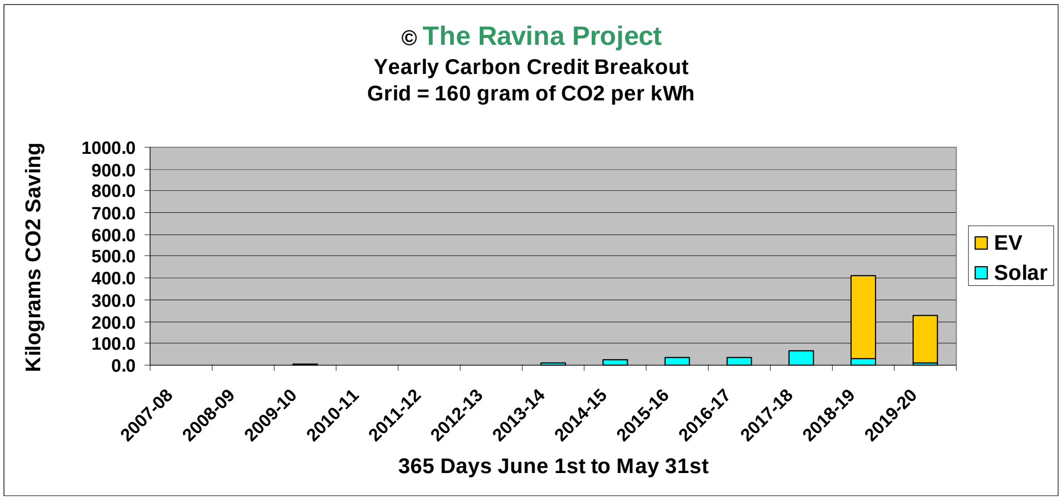
On our next chart below we double our grid's current 40 grams of CO_2 release to 80 grams.



Note the tiny increase in the total displacement of carbon by solar energy. The displacement credit is doubled because the grid is twice as dirty. Note as well, the carbon credit from the EV is reduced in size because 277 grams per kWh is displaced by 80 grams per kWh of grid energy for a reduced 197 gram credit.

Footprint of 160 grams per kilowatt-hour

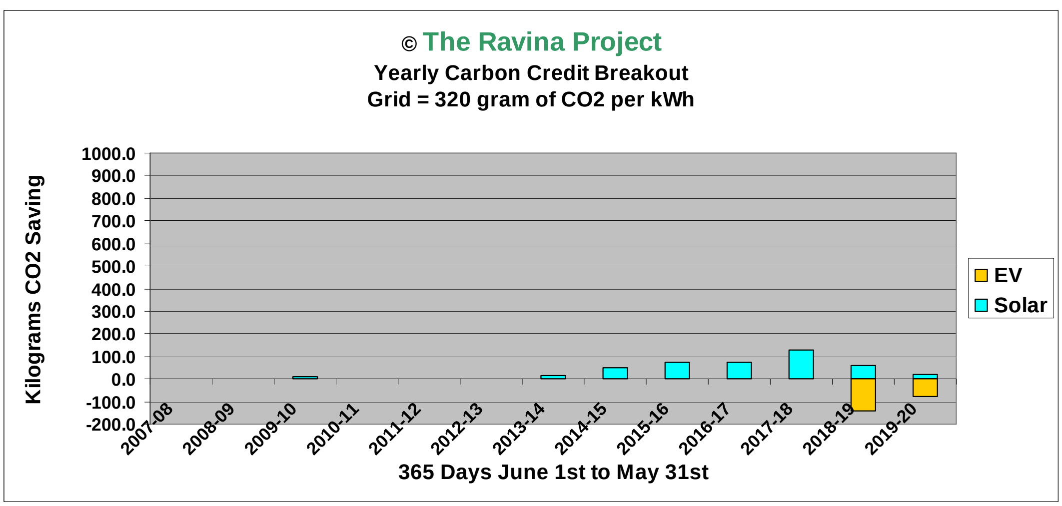
In the chart below we double the grid carbon footprint again from 80 grams to 160 grams of CO_2 per kWh.



We see more of the same … it's a trend. As the grid carbon footprint increases per kWh the carbon credit from solar increases as a bigger displacement is realized. However, as you can see the credit from the EV decreases. The length of the bar for 2018-19 barely reaches over 400 kilos less if the solar is subtracted.

Footprint of 320 grams per kilowatt-hour

On the last chart in this series we double the grid footprint to 320 grams per kWh



Wow … what happened? Let's unpack the chart and see what's going on.

Look at the solar component of our carbon credits. They increase as they should because we are displacing dirtier grid energy with clean energy. So we can account for that increase but what's going on with the EV's carbon credits?

The chart above seems to be telling us that the EV's credit becomes a debit … that is, the EV increases our carbon load by a substantial amount eating into the credits from solar and dramatically dropping the total credits gained from it.

Why does this occur? Let's redo the calculations. The grid energy carbon overhead is 320 grams per kWh. We displace petrol which has an overhead of 277 grams per kWh. Well there it is … we displace cleaner petrol energy with dirtier grid energy to the tune of -43 grams per kWh placed into the EV.

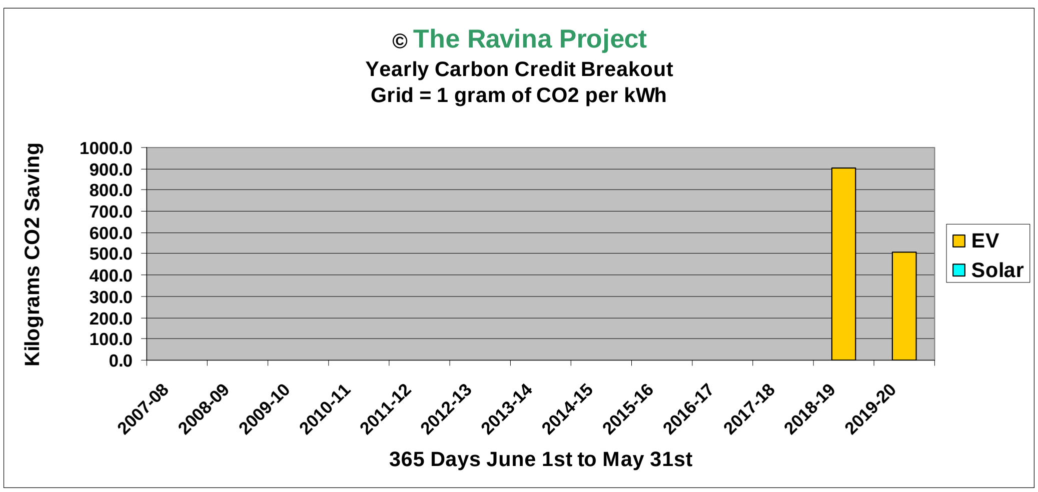
We understand therefore that there is a limit to the carbon credit an EV might provide for a household. The limit is 277 grams which is the carbon footprint per kWh of petrol. If the grid has a larger carbon footprint than 277 the EV becomes a carbon debit on the household carbon release balance sheet.

Footprint of 1 gram per kilowatt-hour

In 2050 the IPCC [2] wants us to have clean grids. So what kinds of saving can solar PV get for us on a clean grid? We see that total drop to zero. They will continue to give us power but they will not displace any carbon. In fact the GWP is larger because the earth will have to suffer from the CO_2 released to make solar PV and other renewables.

The irony is as the grid gets cleaner like here in Ontario, renewable energy generator deployment must die … they are a victim of their own success. On an almost clean grid they are net carbon emitters.

Interesting the carbon savings is still there from displacing petrol.



Note that as the percentage of EVs on the road increases, the carbon displacement of EVs as compared to petrol based cars will decrease until their displacement also approaches zero. That is, there is no carbon credit possible when all vehicles are EVs.

Discussion / Comments

1. As the grid's carbon overhead decreases, the carbon offset value of solar panels decreases. Solar panel carbon offsets are proportional to the grid's carbon overhead. From a carbon point-of-view, if the grid is clean there is no carbon displacement possible when producing or deploying the next (marginal) solar panel.
2. For example the lifecycle emissions of solar PV is between 45 and 55 g CO_2e kWh^{-1}. This is a NREL number [3]. As you can see there is no carbon displacement benefit for installing solar panels on our almost clean grid … in fact today on our average 40 g CO_2/kWh release grid solar panels are a net carbon source over their lifetime.
3. As the grid's carbon overhead decreases, the carbon displacement value of an EV increases. An EV's carbon displacement varies inversely to the grid's carbon footprint.
4. If the grid is dirty enough (over 277 grams of carbon per kWh generated) an EV becomes a carbon liability. Note to those who want to use this argument to call for the reduced use of EVs on a dirty grid … the EV adopts the carbon footprint of the grid that charges it. This is a feature that petrol based cars do not have. They have a fixed carbon footprint of 277 grams whereas the EV's footprint varies. As grids get cleaner going into the future, every EV energized by the grid will get cleaner with no modifications to its hardware. This fact provides huge leverage for efforts at reducing carbon emissions. In addition to the grid's generators efforts in reducing carbon emissions, which are significant in themselves, all attached electrical appliances also become cleaner including the electrified transportation sector of the economy. This is huge leverage.
5. Solar may last 25 years and wind 20 years before replacement. That is, solar needs to be deployed once and replaced 3 times a century. With wind it needs to be replaced 4 times after the initial rollout. Seen in this light wind and solar seem to be large, never ending, make-work projects that accumulate huge associated carbon debts on a clean grid. In short our green renewables become dirty renewables … carbon drenched technologies we need to eliminate.
6. These results show how cleaning up the grid is more important than the short term offsets from EV, wind or solar production. A clean grid eliminates the energy used, waste products and recycling issues with existing green generation technologies. Why? In the longer term (30-50 years), clean power generators with 80-100 year lifespan should replace all wind and solar generators. This effort will finish humanity's epic decarbonization project and eliminate the final vestiges of the carbon overhead incurred by the current renewable energy revolution. We call this cleansing process the **Second Green Revolution**.
7. Nuclear power and hydro dams are the reason for our 40 grams of carbon average per kWh generated. Both these means of clean generation are not short lifespan generators. If they were built today with today's technologies they would be good for at least 80 - 100 years. In some ways the renewable energy revolution is becoming victim of its own success. The push by advocates for the environment has always been the adoption of renewable technologies everywhere and at anytime. Up to a point they have been correct in their efforts. However, as we have demonstrated in this paper, there are limits which if crossed, transform these clean technologies into net carbon sources. This is a new area of analysis because of course most grids are dirty.

Policy Implications

How does our data and our simple, almost trivial, household model inform any policy we may make? One metric overshadows these recommendations … the GWP20 7.9 kg of CO_2e released per cubic meter of natural gas consumed.

1. **Don't subsidize renewables on a clean or almost clean grid**. As the marginal carbon displacement realized by the next renewable installation approaches zero, the real cost in dollars of subsidy per unit of carbon displacement approaches infinity. It's a mugs game.
2. **Don't deploy new renewables on a clean or almost clean grid**. As above they will never be able to displace enough carbon to cover the carbon debt they have accumulated. They will be a carbon source.
3. **Encourage electric vehicle sales**. As the grid gets cleaner each EV will become a more powerful carbon displacement device.
4. **Encourage insulation to reduce household natural gas usage**. Every cubic meter of natural gas saved reduces CO_2e release by 7.9 kilograms. If we are seeking monster savings in greenhouse gas emissions and want a low tech, easy solution, this is it. It's cheap and incredibly effective plus it's labour intensive. It really does not get any better than this and everyone gets their cut of the action: home owners, installers, manufacturers, supply chain and the tax man.
5. **Encourage the building of long life, clean grid generation like nuclear, hydro dams and utility grade geothermal** on clean or almost clean grids. The purpose of building them on an almost clean or clean grid is to **remove** the currently deployed short lifespan solar and wind generators. The carbon release required for the renewables' manufacture, deployment and recycling will finally be ended. Doing so will give the final boost to our carbon reduction efforts.
6. **Encourage heat pumps to augment home heating** to depress carbon fuel usage for home heating. As the grid gets cleaner they will get cleaner. This is more leverage for our decarbonization efforts.
7. **Encourage solar hot water**. This technology reduces reliance on carbon fuel for domestic hot water if natural gas is used to heat water. As we have seen, any technology that displaces natural gas has a huge carbon offset.
8. **Encourage replacement of fossil fueled generation with long lifetime generation** like utility grade geothermal, hydro dams and nuclear in areas which currently have a dirty grid. *Eliminate the wind and solar intermediate step* towards grid clean up because a rapid, successful decarbonization over 15 – 30 years will quickly make these renewable technologies into net carbon emitters.

Notes and References:

The Main and Summary databases can be downloaded in .CSV format at:

www.theravinaproject.org/raw_data.htm

[1] https://www.tandfonline.com/doi/full/10.1080/1943815X.2020.1789666

[2] https://www.ipcc.ch/sr15/chapter/spm

[3] https://www.nrel.gov/docs/fy13osti/56487.pdf

[4] https://www.extension.iastate.edu/agdm/wholefarm/pdf/c6-87.pdf

[5] https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

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

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