Electric car: 697,612 km to become green! True or false?

Author: Prof. Damien Ernst, University of Liège

Very recently, the RTBF, a Belgian media outlet, published an article titled "Electric car: 697.612 km to become green!" I had given an interview to the journalist Gérald Wéry about this article, and I made some calculations. So yes, under certain hypotheses, I found that when we took into account the CO2 emitted for the manufacture of the battery of an electric vehicle, it was only after that car had travelled 697612 km that we could consider that the electric vehicle emitted less CO2 than a petrol-driven car. Here we are talking about an electric vehicle with an 80 kWh battery. Note that some high-end electric vehicles can come with even larger batteries. As examples, the Audi E-Tron has a 95 kWh battery. And the new Tesla Roadster a 200 kWh battery. Gérald Wéry and I were lambasted following the publication of this article which was badly misunderstood. I tweeted about it to explain, quite directly, what was the basis for my coming up with this number during the interview: https://twitter.com/DamienERNST1/status/1104060419897991168 (Sorry for those who do not understand French. You can still use the translation service of Twitter).

To avoid any controversy and attacks on social media, the RTBF decided to remove it from its website. It should be noted that apart from its provocative title, the article did not attack the electric vehicle industry in any way. The article mentioned, for example, that electric vehicles, unlike current petrol-driven vehicles, do not emit NOx and emit significantly fewer fine particles, which has a very beneficial effect on human health.

The methodology used to calculate this number of kilometres has been heavily attacked on social media by, let's say somewhat ironically, that group of people who think that buying a huge electric car weighing more than two tons - like the Jaguar I-Pace (2200 kg) for example - makes them fine examples in the fight against global warming. The attacks on Twitter were often demonstrating a lack of class. We will skip over the details. Nevertheless, some of these attacks were also instructive and, as I am a scientist, I never hesitate to question anything I had asserted when presented with new information. Such an attitude is at the very core of scientific thought. So, I have redone my calculations below, but integrating the information collected from these 'attacks' to expand upon the hypotheses that I used to make my calculations, and even to change one that needs to be changed. I have no problem recognizing this fact. To calculate the number of kilometres covered whereby an electric car with an 80 kWh battery became "green", it was assumed that the total energy required for its manufacture was 296 GJ. This figure comes from the article "Manufacturing energy analysis of lithium ion battery pack for electric vehicles". The article is available here: https://bit.ly/2VMa4hA

Since this figure of 296 GJ refers to a small manufacturing facility, it is reasonable to expect that economies of scale can be achieved with industrial battery manufacturing facilities, which the article mentions. It even proposes a figure of a 72% energy saving, but without citing any source behind it. I did not take it into account in my previous calculations. It was a mistake. So, we will now take this into account. It should be noted that this reduction of 72% in energy used on the manufacturing side does not mean a 72% reduction in the 296 GJ of energy necessary to manufacture the battery which I had taken into account during my calculations made for the RTBF. Indeed, to manufacture a battery there are two major stages that consume considerable energy: the manufacture of raw materials (about 100 GJ according to the article) and the manufacture of the battery from these raw materials (196 GJ according to the article). This reduction of 72% applies only to the 196 GJ, which gives the total energy needed to manufacture the battery of 80 kWh equal to 100 + 54.88 = 154.88 GJ, instead of the 296 GJ on which the original calculation was based. Subsequently, we will no longer use the GJ as a unit of energy, but the kWh, a unit of energy that seems to me to be more user-friendly. Expressed in kWh, this amount of energy equals 43022 kWh. In comparison, an average household in Belgium consumes around 3500 kWh of electricity per year.

Our first working hypothesis will therefore be the following:

Hypothesis 1 [energy to make a battery]. *The amount of energy required to make a battery of 80 kWh is equal to 43022 kWh.*

Note that this is the only hypothesis that I have changed when compared to the article published by the RTBF. I will come back with a new set of hypotheses later on.

The following are calculations and associated assumptions. These hypotheses are also discussed.

Hypothesis 2 [CO2 emitted per kWh of battery manufactured]. *1 kWh of energy used to manufacture a battery emits the same amount of CO2 as the combustion of 1 kWh of gasoline.*

Remember that with 1 litre of gasoline, there is 9.63 kWh of energy, and that the combustion of a litre of gasoline produces 2.28 kg of CO2. The kWh of energy consumed in manufacturing our battery is equivalent to 0.236 kg of emitted CO2.

The manufacture of the battery therefore emits 0.236 [kg / kWh] x 43022 [kWh] = 10153 kg of CO2, a little more than ten tons.

Discussion Hypothesis 2: Assuming that only 236 gr of CO2 are emitted per kWh of energy used to manufacture the battery is, in fact, very little. Take, for example, the stage of manufacturing the battery from raw materials. This stage mainly consumes electrical energy. In the US, producing 1 kWh of electricity leads to the production of about 500 grams of CO2. In China, it's even more, there we are closer to 1kg of CO2. One third of the energy used to make our battery is related to the manufacturing part. This manufacturing part could therefore be associated with four-times greater CO2 emissions than previously considered. This would double the number of tons of CO2 emitted for the manufacture of the battery. It is therefore likely that the manufacture of an 80 kWh battery in China will actually lead to the production of 20 tons of CO2 if we adapt Hypothesis 2, taking into account the specificities of the Chinese electricity mix. Long live ‘Made in China’! It should be noted that greenhouse gas emissions in Belgium are of the order of 8.5 tons of CO2 per person, per year.

Hypothesis 3 [energy consumption of vehicles]. *The electric vehicle consumes 20 kWh per 100 km and a petrol-driven car consumes 6 litres of fuel per 100 kilometres*.

Discussion Hypothesis 3: For a Tesla S, 20 kWh per 100 km seems to be more or less valid even if, on social media, the biggest defenders of the electric car put forward a figure of 23 kWh per 100 km. A friend who has a Tesla X tells me that he gets around 26-27 kWh per 100 km through having an energy-conscious driving style. A small electric vehicle of the Nissan Leaf type will consume 15 kWh per 100km. For a Jaguar I-Pace, the figure would be above 30 kWh per 100 km. The journalist Gerald Wery informed me that during his tests, he obtained a value of 28 kWh for the Audi E-Tron without the air conditioning on, and 34 kWh for the Jaguar I-Pace with the air conditioned on. He also told me that these values were obtained by opting for the "efficiency" mode of the cars, with, I quote, “a very light foot”. The 6 litres per 100 km is probably low for a high-end car such as the Tesla S or Jaguar I-Pace. We could be around 8 litres per 100 kilometres for a high-end car. For my car, a Citroën C1, I consume roughly 5.5 litres per 100 km. Note also that a diesel-driven car emits about 10% less CO2 than a petrol-driven car of the same size. We must not forget to mention that for cars running on compressed natural gas (CNG), there is talk of a more-than-10% reduction in CO2 emissions compared to diesel when considering also the “production and transport part” of the fossil fuel. And perhaps even better in terms of CO_2 emissions: the hybrid car running on natural gas! With small batteries of less than 5 kWh, hybrid cars manage to show impressive performances. The first generation of Toyota Prius was for example fitted with a small battery of 4.4 kWh and had a consumption below 5 litres per 100 km. We also note that a person who wants to be able to travel 400 km with his electric vehicle is obliged to opt for one with a battery of the order of 80 kWh, which we only currently find in the premium models. It's a safe bet that in two to three years, a more modest car with an 80 kWh battery will also be available. In this respect, it is worth noting that the Nissan Leaf e + coming out in June 2019 will have a 62 kWh battery.

Hypothesis 4 [grams of CO2 per kWh electric]. *Every kWh stored in the battery - and therefore usable by the electric vehicle - is associated with 550 grams of emitted CO2.*

With this new hypothesis, we can calculate that driving 100 km with our electric vehicle produces 20 x 0.55 = 11 kg of CO2.

Discussion Hypothesis 4: The figure of 550 grams is the CO2 weight associated with the production of 1 kWh of electricity with the German electricity mix. At the European level, the average is around 300 gr per kWh, or perhaps a little more. At the beginning of the 2000s, it was around 400 gr per kWh in Europe. It should be noted that these figures are sometimes controversial, in particular because it is difficult to exactly quantify the CO2 emissions of a power-generation system over its entire life cycle. We often tend to underestimate these emissions. For the nuclear industry, estimates can vary from 15 to ... 140 grams of CO2 emitted per kWh produced. For renewable sectors such as solar, wind and hydro, we often talk about values ranging between 10 and 40 grams of CO2 emitted per kWh over their life cycle. Note that for a photovoltaic panel installed in northern Europe, this could be significantly more than 40 grams. It should also be noticed that there are energy losses associated with recharging the battery of an electric vehicle. Here we are talking about 5% and it depends on the speed of charging. The higher the speed, the greater the losses are. There are also losses in the battery during the discharge and these are higher when the power withdrawn from the batteries is large. This is the reason why the “energy performance” of a battery drops when you drive at high speeds. There are also losses in the electricity grid to get this electricity from its source of production to the car. They are of the order of 10% in France when routing the current to a user connected to the low-voltage network. By taking these losses into account, every kWh of electricity stored into a car powered by the German electricity mix would therefore lead to the production of more than 630 grams of CO2.

Hypothesis 5 [grams of CO2 per litre of gasoline consumed by the car]. *One litre of gasoline consumed by a car corresponds to the emission of 2.28 kg of CO2*

With this hypothesis, our gasoline-driven vehicle will emit 6 x 2.28 kg = 13.68 kg of CO2 per 100 km traveled.

Discussion Hypothesis 5 (and a little bit of 4): 2.28 kg is the amount of CO2 produced by the combustion of 1 litre of gasoline. However, oil extraction, transportation and refining also emit CO2. A number was given to me several times: burning a litre of gasoline in your car would actually in terms of CO2 emissions equate to the combustion of 1.4 litres of gasoline. Our figure should therefore be 1.4 x 13.68 = 19.15 kg of CO2 per 100 km traveled. It should be noted that the gas used to produce electricity must also be extracted and transported. In addition, the extraction of gas, especially shale gas, also emits CH4 into the atmosphere, a powerful greenhouse gas. This has not been taken into account in assessing the greenhouse gas emissions of our electric car. Nor has it been taken into account that building and maintaining an electricity grid has a significant CO2 cost.

Hypothesis 6 [CO2 emitted by car manufacturing]. *The manufacturing of an electric car emits a quantity of CO2 equal to the amount of CO2 used to produce a petrol-driven car, plus the volume of CO2 emitted to manufacture the battery.*

Discussion Hypothesis 6: It would fair to consider that with this hypothesis, an electric car is at a disadvantage, in particular due to the fact that an electric motor is simpler than a petrol engine and therefore that the manufacture of the latter emits less CO2. It is very difficult to see all this clearly; it lacks numbers. We will, however, emphasize that the bigger the car (petrol, diesel or electric), the greater the associated CO2 emission levels will be with their manufacture.

And now the calculation!

Based on the above assumptions, we calculate the number of kilometres traveled from which an electric car starts to emit less CO2 than a petrol-driven car.

Per 100 km traveled, our electric vehicle will produce 13.68 [kg CO2 / 100 km] - 11 [kg CO2 / 100 km] = 2.68 kg of CO2 less than a petrol-driven vehicle. We remind that the manufacturing of the battery was producing 10153 kg of CO2. The vehicle will therefore have to travel 10153 [kg CO2] /2.68 [kg CO2] x 100 [km] = 378843 km to reach parity. That's less than the originally announced 697612 km.

A new set of hypotheses

Let's arrive at a new set of hypotheses that I find very interesting, and which are more favorable to electric vehicles. I will first revisit Hypothesis 3, which now becomes:

Hypothesis 3 [consumption of vehicles]. *An electric vehicle consumes 23 kWh per 100 km and a gasoline-driven car 6 litres per 100 km*

The 20 kWh per 100 km was much too optimistic for a big electric car. It is probably closer to 30 kWh than 23 kWh in reality.

I am also revisiting Hypothesis 4. The new Hypothesis 4 is as follows:

Hypothesis 4 [grams of CO2 per electric kWh]. *Every kWh stored in the battery - and therefore usable by the electric vehicle - is associated with 317 grams of emitted CO2.*

To arrive at this new figure of 317 grams per kWh, I am actually making two sub-hypotheses. First, I have chosen an electricity mix with a carbon intensity of 275 grams per kWh, which is half the carbon intensity of the current German electricity mix. I believe that the average carbon intensity of the European electricity mix over the next ten years, a period of time compatible with the lifetime of an electric car, could revolve around this value. The renewable energy sector is growing well, but we will also lose a lot of nuclear capacity in Europe in the next 7-8 years, about 15 GW. In my opinion, it will be quite difficult to get below this carbon intensity of 275 grams of CO2 per kWh generated for the European electricity mix before 2025. Secondly, I consider that for 1 kWh stored in the battery, it is necessary to generate 1.15 kWh of electricity to take into account the losses in the electricity network and the losses during recharging of the battery. Once again, this sub-hypothesis seems to me to be quite optimistic for the electricity industry.

The last hypothesis I will change is Hypothesis 5. The new Hypothesis 5 is:

Hypothesis 5 [grams of CO2 per litre of gasoline consumed by the car]. One litre of petrol consumed by a car corresponds to the emission of 3.2 kg of CO2.

I consider with this new hypothesis that consuming 1 litre of gasoline equals, in terms of CO2 emissions, to actually burning 1.4 litres of gasoline. This makes it possible to take into account the CO2 emissions associated with the extraction, refining and transport of petroleum products. Note that I should probably also be fair to the gasoline sector and consider that there is a hidden CO2 cost behind the construction, maintenance and operation of electricity networks, but which I have not.

With this new set of assumptions, we can see that per 100 km traveled, our electric vehicle will now produce 6 x 3.2 - 23 x 0.317 = 19.2 - 7.291 = 11.90 kg less CO2 than a petrol-driven vehicle. It will have to travel 10153/11.90 x 100 = 85319 km to become greener than a petrol-driven vehicle. It should be noted that if I had taken a consumption of 28 kWh per 100 km travelled for the electric vehicle, as Gérald Wery observed during his tests with the Audi E-Tron, I would have obtained a value equal to 10153/ (6 x3.2 - 28 x 0.317) = 98343 km.

Let's try to discuss Hypothesis 1 and Hypothesis 2 again. These two hypotheses lead us to CO2 emissions of the order of 10,153 kg for the manufacture of an 80 kWh battery. As discussed previously, the CO2 emissions associated with battery manufacture can vary quite a bit, depending on where the battery is manufactured. It's very difficult to get an entirely clear picture of this. I have the impression that, in 2019, we must be somewhere in the range of 8000 kg - 18000 kg of CO2 emitted for the manufacture of 80 kWh batteries. With our new set of assumptions, an electric vehicle with a battery of 80 kWh would begin to have a lower carbon footprint than a petrol-driven vehicle somewhere between 67226 km and 151259 km traveled. With the old set of assumptions, this would be in the range of 298507 km - 671641 km.

What can we conclude from these figures?

I'll let you conclude what you want from these numbers, but there is certainly a lot to say. As the assumptions are perfectly detailed and the calculations well explained, you will be able to generate different results by varying the assumptions. Note that an interesting case to study is the hybrid car running on natural gas or on hydrogen. It implies probably a “revisit” of Hypothesis 6.

I just want to finish this article by discussing the rise of EVs in China. China is witnessing a massive development of its electric vehicle sector, mainly for reasons of public health. The air quality is appalling major Chinese cities. Replacing old petrol-driven vehicles with electric vehicles means reducing NOx and fine particulate emissions that are toxic, thus improving air quality. In China, with an electricity mix that is close to 1 kg of CO2 emitted per kWh produced and which, in my opinion, will remain well above 600 grams per kWh for the next 10 years, even the substitution of the petrol-driven vehicles with electric vehicles with a modest battery size of about 40 kWh, may be accompanied by an increase in CO2 emissions. Given the size of the Chinese market, this is not reassuring when we bear in mind that the IPCC tells us that it is imperative we rapidly reduce our CO2 emissions to avoid a global catastrophe.

Another important point about China: Chinese companies that manufacture batteries are not subject to a CO2 tax in the way European companies that enter the ETS system are. From the point of view of the fight against global warming, this is ridiculous, because it is an incentive to manufacture batteries for electric vehicles in China where the carbon intensity is higher than in Europe. It is crucial that Europe introduces a carbon tax on imports as soon as is feasibly possible. I'm not the only one saying this, but nothing seems to be happening.

Epilogue

A great friend of mine, who could be described as a radical ecologist, told me, with a touch of ironic humour: "It is totally outrageous that the title of this article published on the RTBF website suggests that an electric vehicle can be green!" It’s a sobering thought.