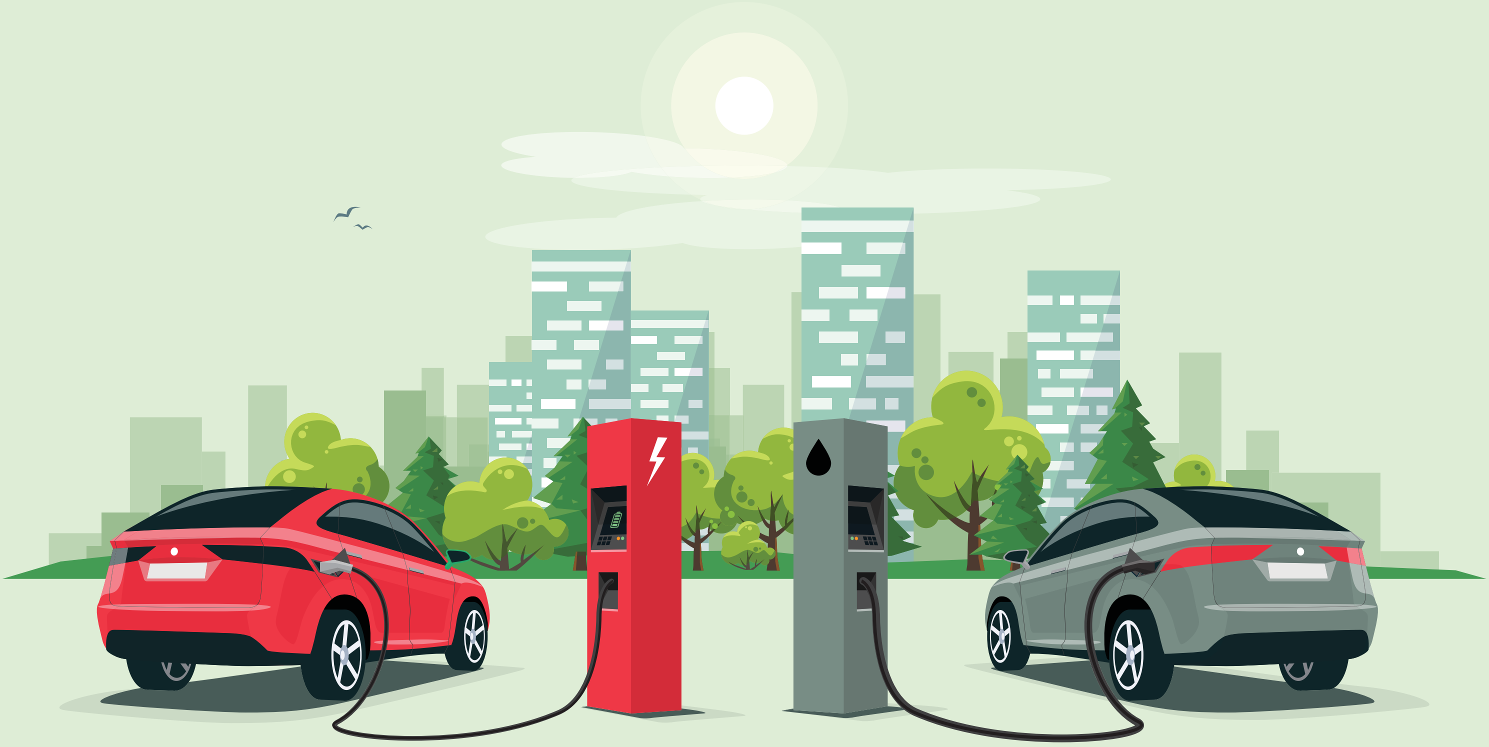
HOW GREEN ARE ELECTRIC CARS?

Gautam Kalghatgi versus Auke Hoekstra



The Global Warming Policy Foundation
Open debate 1

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Open debate 1, The Global Warming Policy Foundation

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About the debaters

Gautam Kalghatgi

Gautam Kalghatgi is a fellow of the Royal Academy of Engineering, the Institute of Mechanical Engineers and the Society of Automotive Engineers. He is currently a visiting professor at Oxford University, and has held similar professorial appointments at Imperial College, Sheffield University, KTH Stockholm and TU Eindhoven. He has 39 years of experience in combustion, fuels, engine and energy research; 31 years with Shell and 8 years with Saudi Aramco.

Auke Hoekstra

Auke Hoekstra is founder and director of the NEON research program, which compares the climate impact of fossil and renewable technologies at the Eindhoven University of Technology. His firm Zenmo Simulations models zero-emission energy and mobility. He wrote his first book on electric cars in 2008 and has been researching and writing about them ever since. Calculating the CO_2 emission of electric vehicles versus combustion engine vehicles is his speciality.

Foreword

How green are battery electric cars? Are they really greener and more environmentally friendly than the cleanest conventional cars? That's a question that is dividing opinion, even among environmentalists. In a recent *Guardian* column, environmental activist George Monbiot warned that electric cars won't solve the problems of car pollution:

> If, as a forecast by the National Grid proposes, the current fleet is replaced by 35m electric cars, we'll simply create another environmental disaster.

In early September, Thomas Ingenlath, the chief executive of electric car company Polestar, acknowledged that electric cars are not clean, but that they are the future and will become cleaner:

> Electric cars are not clean. As the chief executive of an electric car company I am not supposed to say that. Let me be clear, electric cars are the future. Electric cars offer a genuine route to zero carbon impact, but it is time for honest analysis, tough questions and some even tougher answers to ensure we achieve this goal. That is what I want to address today, calling for the entire industry to become more transparent.

Ingenlath warned that the public has been misled by policy makers and the car industry before, when diesel cars were promoted as a green alternative to petrol:

> The fraudulent abuse of public trust in order to maximise profitability must rank as one of the most immoral actions ever perpetrated by the automotive industry. Families bought diesel cars because they wanted to help protect the environment. They were lied to. That must never happen again.

Lifecycle CO_2 analysis of the environmental impact of electric vehicles – from the moment metals are mined, and materials produced for their manufacture, to the end of their lives and the recycling and disposal of batteries and components – and comparisons to conventional cars remain highly contentious. Thanks to their batteries, electric cars don't need to burn any fuel and therefore they emit no CO_2 while driving. However, if the source of energy to power electric cars doesn't come from renewable or nuclear energy, their indirect CO_2 emissions will be much higher. In other words, if the electricity used to charge battery cars comes from coal or gas-fired power plants, as it does in most countries around the world, it doesn't matter if electric cars are not emitting CO_2 directly because this already happened, and in large amounts, in a conventional power plant.

The process of producing a car includes the extraction and refinement of raw materials, which are then transported and manufactured into numerous components, which are fi-

nally assembled in a car factory. While this process is more or less the same in both conventional and electric cars, the production of electric cars generate significant CO_2 emissions due to the production of the batteries. These use materials such as lithium, nickel, cobalt or graphite, the mining and extraction of which can be energy-intensive and highly polluting. The number of battery electric cars needs to increase at least 300-fold to replace all conventional cars. As their number increases, can the world continue to ignore their impacts on human health, water requirements and eco-toxicity just because these environmental impacts are exported to countries where the mining takes place?

That's one of the reasons why the question of whether electric cars are greener or not remains contentious.

Recently Auke Hoekstra and Professor Maarten Steinbuch published a study that claims electric vehicles already emit less than half the CO_2 of combustion engine vehicles.* Professor Gautam Kalghatgi wrote a critique of this new study, claiming that the advantages of electric vehicles were smaller. We approached Mr Hoekstra with a request to react to this criticism. Professor Kalghatgi in turn reacted to that and we gave Mr Hoekstra the final word.

Auke Hoekstra thinks the report he wrote simply presents straightforward facts and calculations that represent the findings of most academic research in this area and that he rebutted all of Gautham Kalghatgi's criticisms. Gautam Kalghatgi sees this differently and thinks Auke Hoekstra paints the electric vehicle in much too positive a light. At the Global Warming Policy Foundation we encourage robust academic discussion and in that light we present the entire exchange so readers can draw their own conclusions.

The GWPF has no collective view on this question, but we are keen to encourage and foster a culture of open and fact-based discussions on all aspects of climate and energy policy. This is why we are very pleased to be publishing the following exchange between two eminent researchers and hope readers will find the discussion informative, enlightening and encouraging.

Benny Peiser
Director, Global Warming Policy Foundation

* Hoekstra A and Steinbuch M, *Comparing the Lifetime Greenhouse Gas Emissions of Electric Cars with the Emissions of Cars using Gasoline or Diesel*. Technical report, Technical University of Eindhoven, 2020. https://static.arkku.datadesk.hs.fi/arkku/files/26649046englisch_StudieEAutoversusVerbrenner_CO2.pdf

A critique of Hoekstra and Steinbuch

Gautam Kalghatgi

Introduction

A report by Hoekstra and Steinbuch (hereafter 'the authors'), commissioned by the German Green Party, bends over backwards to show battery electric vehicles (BEVs) in the best possible light.[1] It is full of criticisms of other studies for being 'unscientific' or 'influenced by outside sources'.[2] However, the authors do not seem to recognise that their own views are prejudiced and not very objective; they have, perhaps, been doing their very best to please their sponsors! In fact, all available technologies, including BEVs, need to be used sensibly to improve the sustainability of the transport sector. Hyping up one technology – BEVs – while ignoring the very serious barriers to its unlimited expansion and exaggerating the shortcomings of internal combustion engine vehicles (ICEVs) to get to the answer they seem to want, is not very helpful.

This note outlines some of the problematic assumptions in the Hoekstra and Steinbuch paper, focusing on their comparison of the Mercedes C220d with the Tesla Model 3. The final section outlines alternative calculations, using perfectly plausible assumptions, which show that the difference between BEVs and ICEVs is very much smaller than claimed by the authors.

Emissions from battery production

The authors assume battery production is responsible for greenhouse gas emissions of 75 kg CO_2eq/kWh of capacity. However, their source,[3] which they quote approvingly elsewhere, actually suggests a range of 61–106 kg CO_2eq/kWh. Note, however, that these figures are for the future, when electricity generation, and hence the energy used for battery manufacture, is assumed to be free of fossil fuels. Currently, battery manufacture, and mining and refining of the materials involved,[4] takes place in countries such as China and the Democratic Republic of Congo, which are not going to decarbonise their energy systems anytime soon. For example, China accounts for 70% of global battery production, and most of the processing of lithium and cobalt salts needed for lithium-ion batteries. And even if batteries were manufactured with CO_2-free energy in Europe, the embedded emissions would still be much higher than assumed by the authors – perhaps as high as 106 kg CO_2eq/kWh – because of the emissions from the mineral extraction and processing in developing countries.

Overestimating battery life

The authors criticise an earlier paper by Buchal and Sinn, who had assumed a battery life of 150,000 km, suggesting that a figure of 250,000 km should be used. However, Tesla guarantee the battery for a Model 3 BEV for 8 years.[5] Let us assume that the average Tesla Model 3 does 10,000 miles annually, like the average British car.[6,7] This is an overestimate because the average BEV would do less mileage because it will drive shorter distances than the average ICEV. So in 8 years, we should expect the average Tesla Model 3 to do little more than 80,000 miles or 129,000 km. This is the practical, realistic battery life, over which the embedded CO_2 emissions should be distributed. In other words, Buchal and Sinn are much nearer the mark than the authors, who seem to expect the average BEV to last over 15 years, driving 16,000 km annually.

Carbon intensity of electricity

Even if the electricity used by BEVs is generated from renewables, so that the carbon intensity is very low, the extra electricity demand from BEVs has to be met with marginal (backup) electricity generation, which can quickly respond to changing demand. This usually relies on fossil fuels, especially if nuclear power is not in favour. The authors accept this fact, but then later dismiss it[8] because it is 'subjective' and launch into a long, subjective defence of their decision. However, this does not make them right. Notably, the average carbon intensity of the German grid, which uses a high proportion of renewables, is 469 g/kWh.[9] Despite this, the authors use a value of 250 g/kWh on the assumption that electricity grids will decarbonise in future. By the same argument, ICEVs will also get better over the years!

Fuel consumption of ICEVs

The authors reject standard industry numbers for fuel economy and carbon dioxide emissions, preferring to use figures they say are from the US Environmental Protection Agency, although they do not give a direct reference to the figures used, only citing a website, www.fueleconomy.gov. However, the vehicle they use as a comparator for the Tesla Model 3, the Mercedes C220d, is not listed on that website. For the Mercedes C220d, they assign a value of 228 gCO_2eq/km for driving emissions,[10] compared to a maximum WLTP figure quoted by Mercedes of 151 gCO_2eq/km.[11] So the total emissions – i.e. manufacture *and* driving – for the C220d should be only 183 gCO_2eq/km rather than 260 gCO_2eq/km.

Ignoring wider impacts and costs

While criticising others for 'ignoring the larger system', the authors ignore or gloss over many issues that will become increasingly important as the number of BEVs increases.

These include in particular, the significant environmental and human-health issues – worse for BEVs than for ICEVs – associated with mining and processing of materials.[12,13] Just because these problems are exported from where BEVs are used does not mean that they are not important environmental issues.

Then there are the large requirements for infrastructure, in terms of charging, electricity generation and distribution. As the number of BEVs increases, there are significant issues with electricity distribution at both micro and macro levels and existing distribution infrastructure will need to be rebuilt.[14,15]

The authors also gloss over the challenges posed by recycling the batteries from EVs, which are considerable because of the weight and complexity of batteries. Currently, it is difficult to recover commercially useful material from spent batteries, although the technology might improve.

Fossil fuel production emissions

There is a big push in the oil industry to improve energy efficiency and reduce/eliminate flaring. For instance, Saudi Aramco have been steadily reducing flaring for at least two decades. The result is that their upstream carbon intensity is now only 4.6 gCO_2eq/MJ, less than half the world average.[16] Using this best current value, the total CO_2 emission for diesel comes to 3091 gCO_2eq/litre, about 7% lower than the figure quoted by the authors.[17]

Ignoring electrical losses

If fossil fuel production efficiencies are to be considered for ICEVs, the following must also be taken into account for BEVs

- transmission and distribution losses for electricity, which vary from 16% in low-income countries to 6% in high-income countries[18]
- losses while charging the BEV battery, which amount to about 16%.[19]

So the total efficiency for BEVs, from electricity production to charging, is only around 79% in rich countries, an overall efficiency less than for diesel, including crude oil production and refining, even using the authors' figures.[20]

Future developments

Hoekstra and Steinbuch seem to think that there is no scope to improve ICEVs. However, there is little doubt that with better combustion, control and after-treatment systems, and with partial electrification and weight reduction, fuel consumption of gasoline engines can be reduced, perhaps by as much as 50%.[21] Similarly, as discussed above, crude production and refining can be expected to become more efficient. Why do the authors assume such improvements will not happen?

And as an aside, ICEVs may soon be seen as preferable to BEVs in terms of their non-greenhouse pollution standards. Modern (Euro VI) diesels can meet or beat the most stringent NOx standards and have negligible particulate emissions in real driving conditions.[21] And as ICEV exhaust management systems improve, particulates such as those released from tyre wear become more important contributors to pollution. BEVs, because of their greater weight (because of the battery), will be worse for particulates.

An alternative calculation

On what basis did the authors select the Tesla Model 3 and Mercedes C220d for making their comparison? In this section, we show that it is easy enough to draw different conclusions by making other plausible assumptions. In other words, the authors' results are subjective.

Table 1 reworks the calculations using the Mercedes A220d Saloon and the Tesla Model 3 Long Range (75 kW). These two vehicles are used because they have comparable dimensions and the range of the Tesla, quoted at 320 miles, is more in line with that of the A220d. However, the kerb weight of the A220d is 1484 kg compared to 1847 kg for the Tesla Model 3 Long Range. This is primarily because the Tesla's battery weighs 480 kg.[22]

Reasonable assumptions – different to those of Hoekstra and Steinbuch – are made about the emissions involved in manufacture and use. These assumptions are as follows.

For the battery, we assume 106 kg CO_2eq/kWh of battery capacity to account for the fact that, in the future, mining and processing of metals will continue to take place in countries with high carbon intensity, even if final battery assembly/manufacture takes place in Europe, with fossil-free electricity. Tesla guarantees the Model 3 Long Range battery for eight years or 120,000 miles (192,000 km). We assume a ten-year battery life and 16,000 km annual distance covered. So, the realistic, practical distance over which the embedded battery manufacture emissions can be distributed is taken to be 160,000 km. Thus, emissions associated with battery manufacture component is 49.7 gCO_2 eq/km.

We assume for this exercise that the manufacturing emissions, excluding those for the battery, are the same for both vehicles.

For driving emissions, we take the maximum WLTP figure quoted by Mercedes Benz of 143 g CO_2 eq/km for the A220d Saloon.[10]

As noted above, BEVs on average will be charged by marginal (backup) electricity generation, which can quickly respond to changing demand. It is not credible that millions of BEVs will charge only when they detect the electricity coming down the cable to be zero-carbon! This will probably be fossil-fuel based for many years in Germany, because nuclear energy is being phased out and ways to store renewable electricity at scale are not viable. So, a more credible number (probably an underestimate) for the carbon intensity of the BEV charging grid is 500 g CO_2 eq/kWh, slightly higher than the current average figure for Germany of 469 gCO_2 eq/kWh.

The combined city and motorway driving energy use for the Tesla Model 3 is 240 Wh/mile or 149 Wh/km.[23] Hence the driving contribution is 74.5 gCO_2 eq/km.

We can also add end-of-life GHG emissions – the emissions associated with recycling and/or disposing of the materials used. For BEVs a figure of around 15 g CO_2 eq/kWh is used,[24] while for ICEVs, a figure for end-of-life emission of 400–800 kg,[25] and an assumption of a 200,000 km lifetime for the Mercedes A220d, gives a result of 2–4 g CO_2 eq/km.

Table 1: Results of the alternative calculation

	ICEV	BEV
	Mercedes A220d Saloon g CO_2 eq/km	Tesla Model 3 Long Range g CO_2 eq/km
Manufacturing ex-battery	32	32
Battery	—	49
Driving	143	75
Recycling	4	15
Total	179	171

The results are shown in Table 1.

There are other very serious environmental and health impacts of BEVs which cannot be ignored as their number increases, as explained above. BEVs also require the development of significant new infrastructure for charging and electricity generation and distribution. In the UK, the Tesla Model 3 Long Range is listed at around £47,000 and the Mercedes A220d Saloon, which can be refuelled in about five minutes using existing infrastructure, at around £31,000.

Notes

1. Hoekstra A and Steinbuch M, *Comparing the Lifetime Greenhouse Gas Emissions of Electric Cars with the Emissions of Cars using Gasoline or Diesel*. Technical report, Technical University of Eindhoven, 2020.

2. See, for example, their p. 7.

3. Emilsson E and Dahllöf L. *Lithium-Ion Vehicle Battery Production*. Technical report C 444, IVL Swedish Environmental Research Institute, 2019. https://www.ivl.se/download/18.14d7b12e16e3c5c36271070/1574923989017/C444.pdf.

4. Notably lithium, cobalt and graphite.

5. Dow J. 'Tesla now covers degradation in Model S/X warranty — but leaves software loophole'. Electrek, 2 February 2020. https://electrek.co/2020/02/02/tesla-model-s-x-warranty-70-capacity-150k-mile/.

6. Statista. Distribution of the average annual mileage of all motorists in the United Kingdom (UK) in 2017 and 2018. Statista, September 2018. https://www.statista.com/statistics/513456/annual-mileage-of-motorists-in-the-united-kingdom-uk.

7. Although the authors quote on p. 12 that the average European car does 13,202 km, or 8200 miles, annually.

8. See p. 16.

9. Country specific electricity grid greenhouse gas emission factors. Carbonfootprint.com, June 2019.

10. See table on p. 5.

11. Mercedes. WLTP fuel consumption and emission values. https://www.mercedes-benz.com/en/vehicles/wltp/wltp-fuel-consumption-and-emission-values/. WLTP refers to the Worldwide Harmonised Light Vehicle Test Procedure, a standardise way of measuring fuel economy.

12. *Electric Vehicles from Life Cycle and Circular Economy Perspectives*. Report No 13/2018, European Environment Agency. https://www.emobility-svizzera.ch/pdf/TH-AL-18-012-EN-N%20TERM%202018.pdf.

13. Commodities at a Glance: Special issue on strategic battery raw materials.

14. Muratori M. Impact of uncoordinated plug-in electric vehicle charging on residential power demand. *Nature Energy* 3(3).

15. Travers M. *The Hidden Cost of Net Zero: Rewiring the UK*. Briefing 48, The Global Warming Policy Foundation, 2020.

16. The figure is shown on p. 23 of the report, presumably taken from the ref. 44.

17. See their p. 22.

18. Electric power transmission and distribution losses (% of output). World Bank. https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS.

19. DOE: 77%-82% of energy put into an electric car is used to move the car down the road. Green Car Congress website, 5 September 2018. https://www.greencarcongress.com/2018/09/20180905-fotw.html

20. 2670/3310. See p. 22.

21. Leach F et al. The scope for improving the efficiency and environmental impact of internal combustion engines. *Transportation Engineering* 2020;1: 100005.

22. Incidentally, on average, 500 times this weight or 240 tons, of rock will have to be removed to extract the materials needed to make the battery. See Mills M. Mines, minerals, and "green" energy: a reality check. Manhattan Institute, 9 July 2020. https://www.manhattan-institute.org/mines-minerals-and-green-energy-reality-check.

23. The Worldwide Harmonised Light Vehicle Test Procedure. https://ev-database.uk/car/1060/Tesla-Model-3-Standard-Range#:~:text=The%20estimated%20combined%20(motorway%20and,in%20a%20traditional%20petrol%20car.

24. Romare M and Dahllöf L. *The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithi-*

um-Ion Batteries. Technical report, C 243, IVL Swedish Environmental Research Institute, 2017.

25. Nakano K and Shibahara N. Comparative assessment on greenhouse gas emissions of end-of-life vehicles recycling methods. *Journal of Material Cycles and Waste Management* 2017; 19: 505–515.

Rebuttal by Hoekstra

Auke Hoekstra

Summary

Mr Kalghatgi challenges our scientific integrity and assumptions but ignores that we published this information before without sponsoring and that each of our assumptions is well supported by multiple sources. He on the other hand forgets to include entire emission categories and makes up assumptions with little or no sourcing.

I will react to Mr Kalghatgi's response using his section titles and will refer to him as GK. I will summarise first (in italics), followed by a quote from GK and rebuttal from me.

Introduction

We did not bend over backward to please our sponsor as evidenced by the fact that I had already published almost exactly the same results before in a scientific journal.

Regarding GK's suggestion that 'they have, perhaps, been doing their very best to please their sponsors!', I would like to point out that before I wrote this study, I had been making exactly the same points for years on Twitter and that I wrote an unsponsored article for the scientific journal *Joule* – requested by the editor at the start of 2019 – in which I pointed out exactly the same errors and came to the same conclusions (with some minor updates due to new studies appearing in 2020).[1] Figure 1 shows the title and abstract, and Figure 2 the table, with the main conclusions, so you can judge for yourself.

Figure 1: Abstract from my paper in *Joule*.

Preview

The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions

Auke Hoekstra[1,2,*]

Greenhouse gas (GHG) emission reductions possible with battery electric vehicles (BEVs) are underestimated in the scientific literature. The following causes are identified and illustrated: overestimating battery manufacturing, underestimating battery lifetime, assuming an unchanged electricity mix over the lifetime of the BEV, using unrealistic tests for energy use, excluding fuel production emissions, and lack of system thinking. In an example calculation, BEVs reduce emissions from 244 to 98 g/km. In a fully renewable system, BEV emission could decrease to 10 g/km.

Now that we have conclusively established that we reached almost the same results before we were sponsored to do this study, making the entire accusation of changing them to suit our sponsors baseless, I would like to make two further points.

Figure 2: Key emissions data from my paper in *Joule*.

Joule

Table 1. Life Cycle GHG Emissions in g/km of a Diesel Car and BEV

	Buchal et al.[5]	Hoekstra et al.[9]	Renewable Future
Diesel Car Total	170	244	153
Driving	143	217	150
Manufacturing	27	27	3
BEV Total	189–214	95	10
Driving	73	55	6
Manufacturing	100–125	40	4
(Battery)	(73–98)	(16)	(2)

Analogous to Buchal et al.,[5] this scenario assumes comparing a Mercedes C 220 d as the diesel car and a Tesla Model 3 with 74 kWh NCA battery as the electric vehicle. To make Buchal et al. relevant to a wider audience, the German electricity mix was replaced with the average European electricity mix. The German mix would result in increased driving emissions of 16 g/km for Buchal et al. and 18 g/km for Hoekstra et al.[9] The Renewable Future scenario is speculative but illustrates the impact of the integral system approach.

- First: we were asked to reformat our existing research in a way better suited to the discussion on the topic in Germany. Never were we asked to reach a certain conclusion, only to present our earlier research. This we did.
- Second: GK joined Saudi Aramco in 2010 after 31 years with Shell and all his publications are on combustion engines. If anyone is vulnerable to ad-hominem attacks that imply his standpoints are due to 'bending over backwards' for sponsors instead of having scientific integrity, it would be him. That someone with such a fossil-fuel background implies that it is *our* scientific integrity that is lacking, without even taking the trouble of establishing that we had previously reported similar results (which would have been obvious after a quick Google search) is not smart in my opinion.

But let's forego any more mudslinging and concentrate on the facts and arguments.

Emissions from battery production

GK misunderstands the one source he claims we use, and ignores the other seventeen. He then picks the highest value of that one source, without supporting this choice by sources.

Statement by GK

> 'However, their source,[2] which they quote approvingly elsewhere, actually suggests a range of 61–106 kg CO_2eq/kWh.'

Rebuttal

We cite that range of 61–106 ourselves. So, the use of the word 'actually' seems out of place here. Furthermore, we discuss a total of 18 sources in some depth,[2–19] not one. We criticise many of them (mostly by pointing out that the values used are based on outdated manufacturing practices), but we cite at least six of them approvingly (to use the term adoped by GK)[2,4,5,17–19] and point out that even sources we criticise agree that most of the carbon reduction stems from improved production processes in larger factories.[15] GK only points to emissions from the electricity generating system, but if you do the maths, scaling up is even more important.

Statement by GK

> 'Note, however, that these figures are for the future, when electricity generation, and hence the energy used for battery manufacture, is assumed to be free of fossil fuels.'

Rebuttal

This is simply wrong. As Emilsson and Dähllof state in their summary: 'Based on the new and transparent data, an estimate of 61–106 kgCO_2eq/kWh battery capacity was calculated for the most common type, the NMC chemistry. The difference in the range depends mainly on varying the electricity mix for cell production.'[2]

So only the lower end of the scale (the value of 61 kgCO_2eq/kWh) is for a future where the factory uses renewable energy. And this fact was clearly communicated in the summary.

Furthermore, we are actually pretty critical of Emilsson and Dähllof (since it is the follow up to a study that was broadly maligned as being unrealistically pessimistic), which is why we take so much time to explain how it differs from other studies and why we supplement it with five other sources that we consider more thorough and which use more recent data.

Statement by GK

> 'Currently, battery manufacture, and mining and refining of the materials involved, takes place in countries such as China and the Democratic Republic of Congo, which are not going to decarbonise their energy systems anytime soon. For example, China accounts for 70% of global battery production, and most of the processing of lithium and cobalt salts needed for lithium-ion batteries.'

Rebuttal

GK seems to be confusing battery production with mining, since Congo is only relevant for cobalt mining. The artisan mines in Congo, the working conditions of which are rightly criticised, hardly have a problem in being fossil-fuel powered, since they use human muscle, pickaxes, and buckets.

Furthermore, GK and I were both comparing the diesel vehicle to the Tesla Model 3, and Tesla actually published battery manufacturing emissions for their battery production plant. So it is encouraging that the value we use for 2020 (based on multiple sources) comes very close to the value Tesla reported for 2019.

Anticipating this 'but China' argument – which we have heard often before – we included two sources in our study that looked at battery production in China specifically and they underscore our point,[4,5] not GK's. It's a shame he seems to have missed that.

Statement by GK

> 'And even if batteries were manufactured with CO_2-free energy in Europe, the embedded emissions would still be much higher than assumed by the authors – perhaps as high as 106 kgCO_2eq/kWh – because of the emissions from the mineral extraction and processing in developing countries.'

Rebuttal

GK seems to misunderstand the one source that he uses.[2] He seems to think that the entire range of 61–106 kgCO_2eq/kWh pertains to production with emission free energy. Instead this is just the case for the lowest number. Apart from that, GK does also not defend taking the highest value from this range of one source. All in all I think that he should study the topic more closely before attacking others.

Overestimating battery life

GK confuses warranty with lifetime, and makes up an example instead of using reliable sources as we did.

Statement by GK

> 'The authors criticize an earlier paper by Buchal and Sinn, who had assumed a battery life of 150,000 km, suggesting that a figure of 250,000 km should be used. However, Tesla guarantee the battery for a Model 3 BEV for 8 years.[5] Let us assume that the average Tesla Model 3 does 10,000 miles annually, like the average British car.[6,7] This is an overestimate because the average BEV would do less mileage because it will drive shorter distances than the average ICEV. So in 8 years, we should expect the average Tesla Model 3 to do little more than 80,000 miles or 129,000 km. This is the practical, realistic battery life, over which the embedded CO_2 emissions should be distributed. In other words, Buchal and Sinn are much nearer the mark than the authors, who seem to expect the average BEV to last over 15 years, driving 16,000 km annually.'

Rebuttal

That the Tesla guarantee is less than the assumed lifetime is irrelevant. No car gives a guarantee on any part (e.g. the motor) that is anywhere close to the lifetime. GK simply assumes an electric vehicle drives less than average and will fail once the guarantee is up. This is laughingly simplistic. We quote multiple sources to back up our claim that modern batteries easily outlast the lifetime of the car.[20–23] GK only has his 'but that can't be true because they would last longer than the warranty' argument. We showed a detailed analysis of European data to come up with an average car lifetime (something GK doesn't even attempt to improve or comment upon), an approach that was groundbreaking the first time we published about it,[1] and which has now been corroborated by a new and very extensive study by Ricardo for the European Commission[24] (although the report conservatively stops at 225,000 km instead of our 250,000 km).

Carbon intensity of electricity

GK assumes EVs are powered by marginal electricity, without explaining why demand from other uses does not use it instead. He also ignores time of day, which is a must when using marginal electricity.

Statement by GK

> 'Even if the electricity used by BEVs is generated from renewables, so that the carbon intensity is very low, the extra electricity demand from BEVs has to be met with marginal (backup) electricity generation, which can quickly respond to changing demand. This usually relies on fossil fuels, especially if nuclear power is not in favour. The authors accept this fact, but then later dismiss it because it is 'subjective' and launch into a long, subjective defense of their decision. However, this does not make them right. Notably, the average carbon intensity of the German grid, which uses a high proportion of renewables, is 469 g/kWh. Despite this, the authors use a value of 250 g/kWh on the assumption that electricity grids will decarbonize in future. By the same argument, ICEVs will also get better over the years!'

Rebuttal

This is now the go-to argument of EV sceptics: 'electric vehicles will use the marginal mix'. The argument goes like this: 'Coal fired power plants are the first to be turned off due to them being last in the merit order as their marginal cost is highest. So, the added demand of the electric vehicle leads to them being run on coal.'

We call this 'subjective' for the following reason. Who determined that electric vehicles are last in the demand merit order? Might not the electricity that is no longer needed to refine oil be considered marginal demand too once we go down that route? Why would heat pumps and factories producing solar panels not be considered marginal demand? And once we start: why is simply using less energy not something that we subtract from marginal demand?

So, you can not simply take one form of electricity demand and say 'this one will use all the coal'. When you go down that route you have to rank all electricity demand and defend your ranking. Some blogposts have tried (and failed in my opinion) but we know of no serious publication that has attempted this.

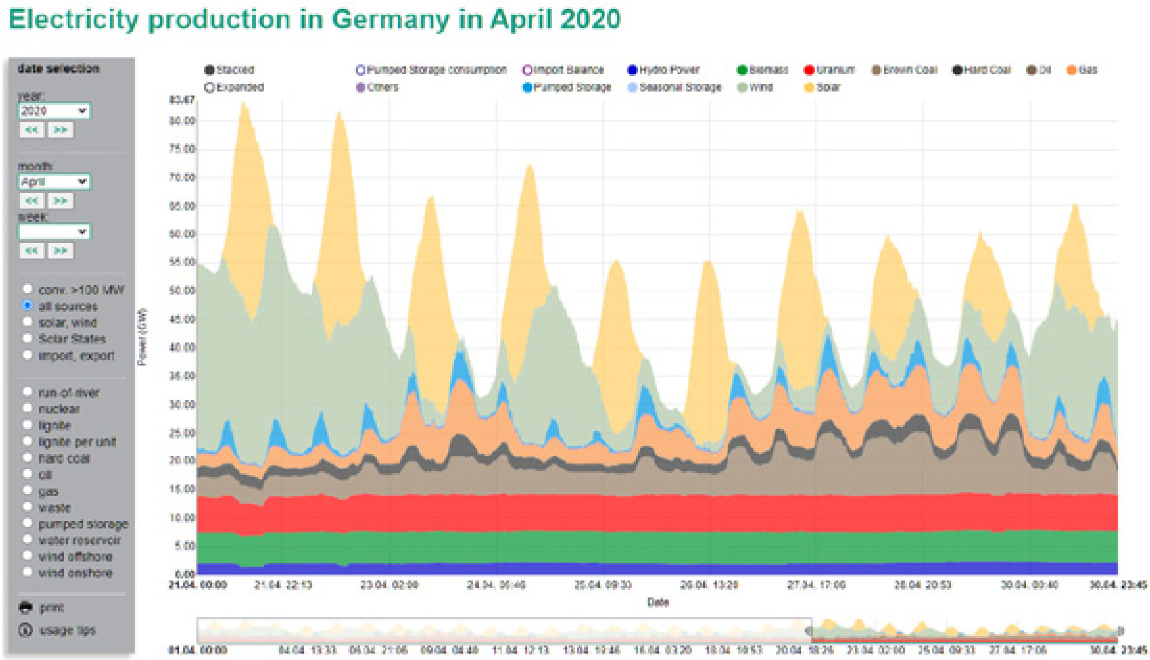


Figure 3: Electricity production in Germany, April 2020.

https://www.energy-charts.de/power.htm. See also my Twitter discussion on the same subject at https://twitter.com/Auke-Hoekstra/status/1300718012304064512.

Furthermore, you have to take the time of consumption into account. Because over the lifetime of electric vehicles they will often charge on moments during the day when they generate no demand for coal at all.

We can already see a reduction in the amount of coal being burned in Europe and Germany, with days entirely without coal use expected within a few years (Figure 3). So, referring to marginal demand without simulating it and taking time of day into account is another sign of someone trying to do down electric vehicles without understanding exactly how electricity markets work.

Finally, electric vehicles are actually unique in terms of potentially supporting renewable energy. As renewable energy system researchers - which GK clearly isn't - we are excited about the prospect of 'smart charging'.[25–27] This basically means that charging will be shifted automatically to times when energy is cheaper. On those times it is also greener. Car owners will still find their car full when they use it again, but they will charge cheaper and greener. This is not an elusive idea, but something I helped to implement (and use) in multiple places in the Netherlands without a problem. Government, car manufacturers and users are all in favour and we have received delegations with German experts that where about to implement it in Germany too. It is also part of the IEC 15118 standard that is already implemented by German car manufacturers. With smart charging, the electric vehicle would be the cleanest form of marginal demand, not the arbitrarily dirtiest.

Basically this 'marginal demand' argument is just a way to allocate the dirtiest form of electricity available on the market to the type of innovation you want to criticize, while still appearing somewhat scientific. That's why we don't use it for electric vehicles. But when we ask electric vehicle critics to rank the sources of demand mentioned above, using a rational basis that shows why electric vehicles come after all the other ones, we never get a coherent reply.

Fuel consumption of ICEVs

GK ignores both diesel production (one of our six cardinal mistakes) and the fact that WLTP is not realistic without a correction factor.

Statement by GK

> 'The authors reject standard industry numbers for fuel economy and carbon dioxide emissions, preferring to use figures they say are from the US Environmental Protection Agency, although they do not give a direct reference to the figures used, only citing a website, www.fueleconomy.gov. However, the vehicle they use as a comparator for the Tesla Model 3, the Mercedes C220d, is not listed on that website. For the Mercedes C220d, they assign a value of 228 gCO_2eq/km for driving emissions, compared to a maximum WLTP figure quoted by Mercedes of 151 gCO_2eq/km. So, the total emissions – i.e. manufacture and driving – for the C220d should be only 183 gCO_2eq/km rather than 260 gCO_2eq/km.'

Rebuttal

First of all GK simply forgets to add the emissions from fossil fuel production to the number he uses. We list six errors many studies make, and this is one of them. That he has read our report and still makes one of those six errors while criticising our numbers (which do incorporate them), beggars belief. So, this error immediately makes GK's statement wrong by 24% (in the case of diesel production).

Taking the WLTP, according to the quick-and-easy but unrealistic approach we discuss directly below, brings the emissions to 183 $gCO_2eq \times 1.24$ (because of diesel production) = 227 gCO_2eq.

But we explain what is wrong with the WLTP in detail. Basically, it is still a test paid for and influenced by the manufacturer and we know (this is not debatable, but factually established, as we document) the fuel economy figures under the NECD (the precursor to the WLTP) ended up being 40% lower than in real-world use. By the way, the other study of the European Commission we mentioned[24] takes another approach that yields the same result: it takes the WLTP but multiplies by a factor to bring it in line with real-world use.

Regarding the usage data for the Mercedes, we state in our study: 'If measurements are not available from the EPA (which happens for some diesel cars not sold in the US), we recommend finding another independent source, preferably doing tests of many vehicles. A good option is spritmonitor.de where there are often thousands of measurements for popular diesel cars and one could argue that it is hard to come closer to real world use.' So, we took our usage data for the Mercedes from spritmonitor.de.

Ignoring wider impacts and costs

GK assumes ICEVs are better for the environment without providing sources that actually say this. Although we did not mention this topic because it was out of scope for the study, here we point to a source that compares ICEVs and EVs, showing that EVs are better for the environment and have lower human toxicity.

Statement by GK

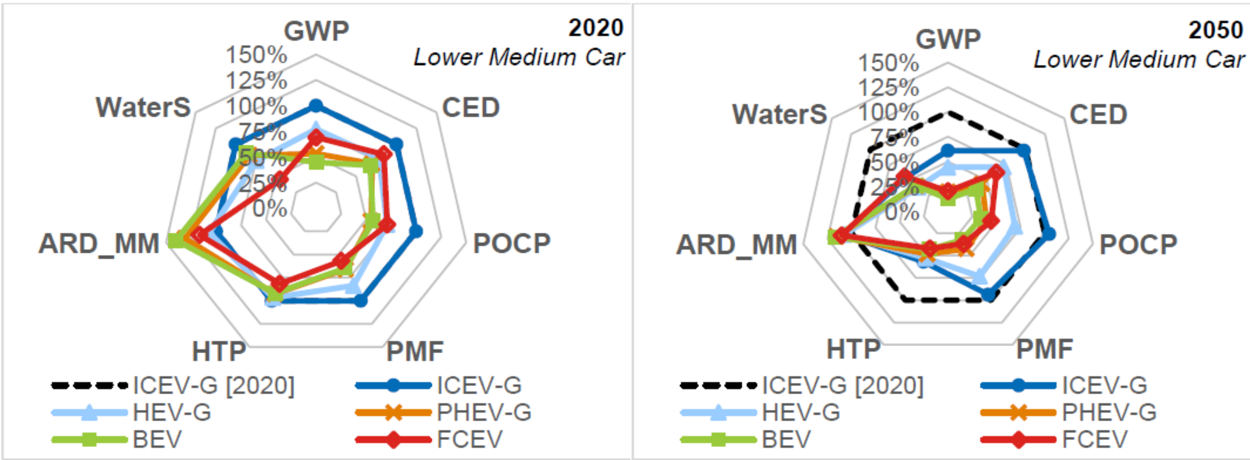
> 'While criticising others for 'ignoring the larger system', the authors ignore or gloss over many issues that will become increasingly important as the number of BEVs increases. These include in particular, the significant environmental and human-health issues – worse for BEVs than for ICEVs – associated with mining and processing of materials. Just because these problems are exported from where BEVs are used does not mean that they are not important environmental issues.
>
> Then there are the large requirements for infrastructure, in terms of charging, electricity generation and distribution. As the number of BEVs increases, there are significant issues with electricity distribution at both micro and macro levels and existing distribution infrastructure will need to be rebuilt.
>
> The authors also gloss over the challenges posed by recycling the batteries from EVs, which are considerable because of the weight and complexity of batteries. Currently, it is difficult to recover commercially useful material from spent batteries, although the technology might improve.'

Rebuttal

This study is about CO_2 emissions, so the criticism that we 'gloss over' other aspects is true. We also gloss over the health impacts of oil because that is not the subject of our study either. But if GK claims that the environmental impacts are worse for BEVs than for ICEVs he is flat out wrong. Moreover, his sources just point to potential problems with EVs without saying they are worse than the ICEVs.

To communicate this I would like to use the latest and most extensive report on this subject again (Figure 4).[24] What we see here is that EVs score better on human toxicity, water scarcity, ozone creation, PM formation, etc. The only area in which they score worse is the depletion of minerals and metals. But this problem is really one of long-term depletion, which can be countered using recycling (we point to reports

Figure ES4: Summary of the relative impacts for Lower Medium Cars for the most significant mid-point impacts for road transport, by powertrain for 2020 and 2050 (Tech1.5 Scenario)



Notes: Total emissions are presented relative to a 2020 conventional gasoline ICEV = 100%.
Powertrain types: G- = Gasoline; ICEV = conventional Internal Combustion Engine Vehicle; HEV = Hybrid Electric Vehicle; PHEV = Plug-in Hybrid Electric Vehicle; BEV = Battery Electric Vehicle; FCEV = Fuel Cell Electric Vehicle.
LCA impacts: GWP = Global Warming Potential, CED = Cumulative Energy Demand, POCP = Photochemical Ozone Creation Potential, PMF = Particulate Matter Formation, HTP = Human Toxicity Potential, ARD_MM = Abiotic Resource Depletion, minerals and metals, WaterS = Water Scarcity.

Figure 4: Environmental impacts of different vehicle types.

showing this area is developing quickly). Fossil oil depletion will happen sooner, and recycling is of course impossible.

Fossil-fuel production emissions

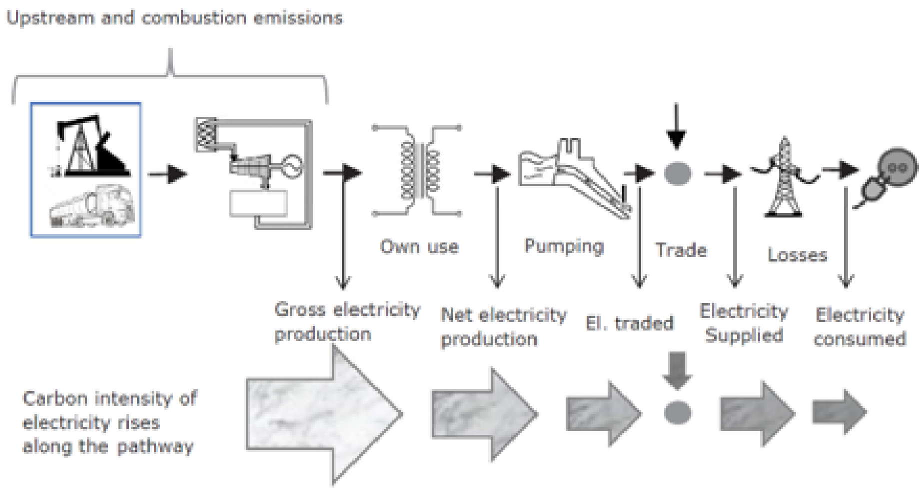
GK claims that oil from his employer, Saudi Aramco, emits less CO_2 per kWh than average. This is true but irrelevant.

Statement by GK

> 'There is a big push in the oil industry to improve energy efficiency and reduce/eliminate flaring. For instance, Saudi Aramco have been steadily reducing flaring for at least two decades. The result is that their upstream carbon intensity is now only 4.6 gCO_2eq/MJ, less than half the world average. Using this best current value, the total CO_2 emission for diesel comes to 3091 gCO_2eq/litre, about 7% lower than the figure quoted by the authors.'

Rebuttal

We understand GK wants to paint his employer, Saudi Aramco, in a positive light and indeed their emissions are a bit lower than average. But we assume ICEVs drive on an *average* mix; not an unrealistic assumption, we think.



Generation	Add upstream	Add self use	Add pumping	Add trade	Add HV losses	Add MV losses	Add LV losses	Total increase
100%	14%	5%	1%	1%	3%	1%	3%	31%

Figure 5: Extract from our paper, showing that we do consider electrical losses.

Ignoring electrical losses

GK claims we ignore electrical losses. We actually include more losses than he proposes.

Statement by GK

> 'If fossil fuel production efficiencies are to be considered for ICEVs, the following must also be taken into account for BEVs
>
> - transmission and distribution losses for electricity, which vary from 16% in low income countries to 6% in high-income countries
> - losses while charging the BEV battery, which amount to about 16%.'

Rebuttal

We add not 16% but 31% due to upstream emissions, trading and grid losses. It is unclear to us how GK could have overlooked the figure in our paper, reproduced here as Figure 5. As for charging losses: they are included in the EPA measurements, as anyone familiar with the methodology would have known.

Future developments

GK claims we ignore future developments for ICEVs. We simply did not consider the future in this study, but our previous study, where such a comparison was in scope, shows we do not ignore this but use assumptions similar to what GK is proposing. However, adding the future perspective only underscores that the advantages of BEVs relative to diesel and gasoline will strongly increase in the future.

Statement by GK

> 'Hoekstra and Steinbuch seem to think that there is no scope to improve ICEVs. However, there is little doubt that with better combustion, control and after-treatment systems, and with partial electrification and weight reduction, fuel consumption of gasoline engines can be reduced, perhaps by as much as 50%. Similarly, as discussed above, crude production and refining can be expected to become more efficient. Why do the authors assume such improvements will not happen?
>
> And as an aside, ICEVs may soon be seen as preferable to BEVs in terms of their non greenhouse pollution standards. Modern (Euro VI) diesels can meet or beat the most stringent NOx standards and have negligible particulate emissions in real driving conditions.[21] And as ICEV exhaust management systems improve, particulates such as those released from tyre wear become more important contributors to pollution. BEVs, because of their greater weight (because of the battery), will be worse for particulates.'

Rebuttal

It is simply wrong that we assume there is no scope to improve ICEVs. We did not consider future developments in this study, so we didn't touch on the topic of technological advances. However, in my earlier report, I assumed improvements of 30% (see Figure 2). Interestingly, this is same value given in the publication GK refers to as the improvement possible from advances to ICEV drivetrains.[28]

A figure of 50% can only be reached by adding weight reductions (which would also improve the efficiency of the electric vehicle if done to both vehicles) and hybridisation (adding a battery and more powerful electric motor to the conventional motor). Since GK is fulminating against electric drivetrains and batteries, it seems questionable to include them in the potential efficiency gains for ICEVs.

However, if we start fantasising about such a utopian future in terms of combustion drivetrains, we should compare the results with an equally utopian future for electric drivetrains. And since electric drivetrains can be produced and used entirely with renewable electricity that itself can be produced using renewable electricity, the efficiency gains of EVs can been argued to come close to emitting no CO_2 at all, not just 30% less. So, if we start fantasising about a perfect future, the advantages of the electric vehicles increase instead of decrease.

Regarding diesels being seen as preferable to BEVs in terms of non-greenhouse pollution standards: it is true that NOx emissions can be very low for trucks, and they could be very low for cars too if they adopted measures common in trucks, such as the use of 'ad blue' in the exhaust system.* However, this will not make diesels better, as it only shifts the problem elsewhere: less NOx leads to more O_3.

Regarding the weight of electric vehicles: with batteries and drivetrains getting lighter in a very predictable way, it is my assumption that most new BEVs will become *lighter* than their ICEV counterparts between 2025 and 2030.

An alternative calculation

GK makes an alternative calculation that is almost completely off.

As discussed above, GK is wrong in every single attack on us. I had expected him to find some small mistakes (I am certainly fallible), but none of his points are correct.

Unsurprisingly, I think his alternative calculation is utterly wrong. My reasons have already been set out, but let me summarise:

- He assumes 106 kgCO_2eq/kWh for battery production instead of 75 kgCO_2eq/kWh.
- He uses the highest value of one arbitrary source without supporting this decision. We would like to refer him to our detailed discussion of 18 sources.
- He assumes a battery will fail the moment the warrantee runs out.
- Does he also assume a VW Golf will fail as soon as its 4-year/50,000 mile warranty[29] runs out?
- We would like to stick to our long list of more thorough sources that actually document battery degradation timescales instead of warranties.
- He assumes diesel does not have to be manufactured. Our document is all about 'the top six errors in EV critical studies' and this is one of them. To make this mistake in an attack on our publication is not very smart, to put it mildly. By the way: GK doesn't seem to dispute that diesel production needs to be included, because he does address the issue when he defends his employer Saudi Aramco as having lower emissions than average. He just forgets to add it in his calculations.
- He assumes WLTP is more realistic than road tests. We discussed this at length above.
- He takes a marginal mix of 500 gCO_2eq/kWh. We discussed why taking the marginal mix is subjective and unsuitable. He is wrong to claim that we assumed EVs would drive on fully renewable electricity.

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* Ad blue is a fluid that can be injected in small quantities into exhaust gases to reduce NOx emissions.

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Response from Kalghatgi

Gautam Kalghatgi

I thank Mr Hoekstra for engaging in this discussion. I apologise if the German Green Party did not commission or sponsor their report. It is quite clear that AH believes in what he says. I was not aware that AH had published these views before and I am sorry to have questioned the authors' scientific integrity.

The views I express are my own and sincerely held. Though the number of BEVs is growing fast, they start from a very low base and the technology faces very significant environmental and economic barriers to unlimited growth; ignoring or downplaying these barriers will lead to bad policy decisions. All available technologies, *including BEVs*, ICEVs and fuels need to be continuously improved and used sensibly to improve the sustainability of the transport sector. I am not 'against' BEVs and if I am 'fulminating' against anything at all, it is against the belief that BEVs are the *only* solution for transport and that ICEVs can and should be eliminated. Also, I am not an employee of Saudi Aramco – I retired more than two years ago and I don't get a pension from that company. I am currently a Visiting Professor at Oxford University. In the past, I have also been a Visiting Professor at Imperial College and Sheffield University, part-time Professor at TUE and Adjunct Professor at KTH Stockholm for various durations. I hope AH and his co-author extend me the courtesy of not questioning my technical integrity.

My main point is the obvious one, namely that there is a great deal of leeway in the assumptions one can make. AH obviously thinks their assumptions are objective and correct while those of others are not. I think their report overstates CO_2 emissions from the ICEV, Mercedes C220d, and understates those from the Tesla Model 3 and shows the Tesla in a far more favourable light than is probably the case. In my remarks below, I'll focus on this broad point rather than address every remark made by AH (some of them quite snide!) in his rebuttal, unless it is necessary.

Overstating CO_2 emissions of Mercedes C220d

The authors assign a value (183 g CO_2eq/km) that is 21% higher than the maximum WLTP figure for combined driving and then multiply it by a factor of 1.24 to account for emissions from crude oil production, refining and transport of fuel. However, I pointed out that the current best figure for crude oil production from a major producer is only 45% of the figure they use. I did so because all major oil producers are striving to reach such a figure in the future, not because I am an employee of Saudi Aramco (I am not). If AH feels it is right to extrapolate to use future reduced emissions from electricity generation (see next section), it should be acceptable to use what is demonstrably possible for upstream emissions. Using this figure (4.6 gCO_2/MJ), the multiplication factor becomes 1.15. So, the authors are overstating the emissions of the ICEV by 30%. I did not include these upstream emissions in my table at the end, but discussed it under a separate heading. So, for the Mercedes C220d, a figure of 174 (151 × 1.15) CO_2eq/km is justified. Taking the WLTP figure is also justified because it is compared with the combined driving energy use for the Tesla in the next section.

Incidentally, AH makes the following remark:

> First of all GK simply forgets to add the fossil fuel production to the number he uses. We list six errors many studies make, and this is one of them. That he has read our report and still makes one of those six errors while criticising our numbers that do contain them, beggars belief.

I did not make this error. I addressed these issues under two separate headings. The percentage losses are similar.

Understating CO_2 emissions from Tesla Model 3

I was comparing the cars in Germany because the report by AH seems to have gained a lot of traction there and they explicitly rebut the work of Buchal and Sinn, which was also much discussed in Germany. Germany has a current carbon intensity of 469 gCO_2/kWh for power generation. In their analysis, AH starts with 267 gCO_2/kWh for the EU average and ends up with 251 gCO_2/kWh over the lifetime of the Tesla. So, for Germany, this figure would be 441 gCO_2/kWh. It should actually be much higher because BEVs charge on marginal electricity, the carbon intensity for which in Germany is 555–1360 gCO_2/kWh,[†] but let us ignore this point and take 441 gCO_2/kWh. We then take the US EPA figure of 28 kWh/100 miles for energy use by the Tesla – by the way, I know that this includes charging losses; I had used 24 kWh/100 miles in my alternative calculation and addressed the charging losses separately – or 0.175 kWh/km. So, the driving emissions for Tesla would be 77 gCO_2eq/km for Germany.

Though I think the figure for battery manufacture in their table should be greater than 23 gCO_2eq/km for the reasons I have given, I won't try to convince AH of this anymore! We will also use 28 gCO_2eq/km contribution from manufacture ex battery. The only change we will make in the table in HK's report is to use 77 gCO_2eq/km for driving the Tesla in Germany and add 15 gCO_2eq/km for end-of-life emissions, giving a total of 143 gCO_2eq/km instead of 91 gCO_2eq/km for the Tesla.

For the Mercedes C220d, we add 4 gCO_2eq/km for end-of-life emissions and take driving emissions as 174 gCO_2eq/km (for the Mercedes A220d these will be 164 gCO_2eq/km).

† Buchal and Sinn *Eur. Phys. J. Plus* (2019) 134: 599.

The total for the C220d will then be 210 gCO_2eq/km and for the A220d, 200 gCO_2eq/km. So, with these assumptions, the Tesla Model 3 Long Range is 32% better than the Mercedes C220d, not 65% better.

Incidentally, AH says of my statement that the numbers for CO_2 emissions from battery production are for the future:

> This is simply wrong. As Emilsson and Dähllof state in the summary: 'Based on the new and transparent data, an estimate of 61-106kg CO_2-eq/kWh battery capacity was calculated for the most common type, the NMC chemistry. The difference in the range depends mainly on varying the electricity mix for cell production.'

The preceding sentence in the summary referred to, explaining the low values for GHG emissions from battery production, says:

> One important reason is that this report includes battery manufacturing with close-to 100 percent fossil free electricity in the range, which is not common yet, but likely will be in the future.

So what is 'simply wrong' about my statement that the numbers in the report by AH are 'for the future'?

The above discussion simply highlights the very obvious point that the results depend on the assumptions one makes. My assumptions above are 'not almost completely off'. I think the assumptions AH makes are biased towards making a BEV look as good as possible for GHG emissions.

Other issues

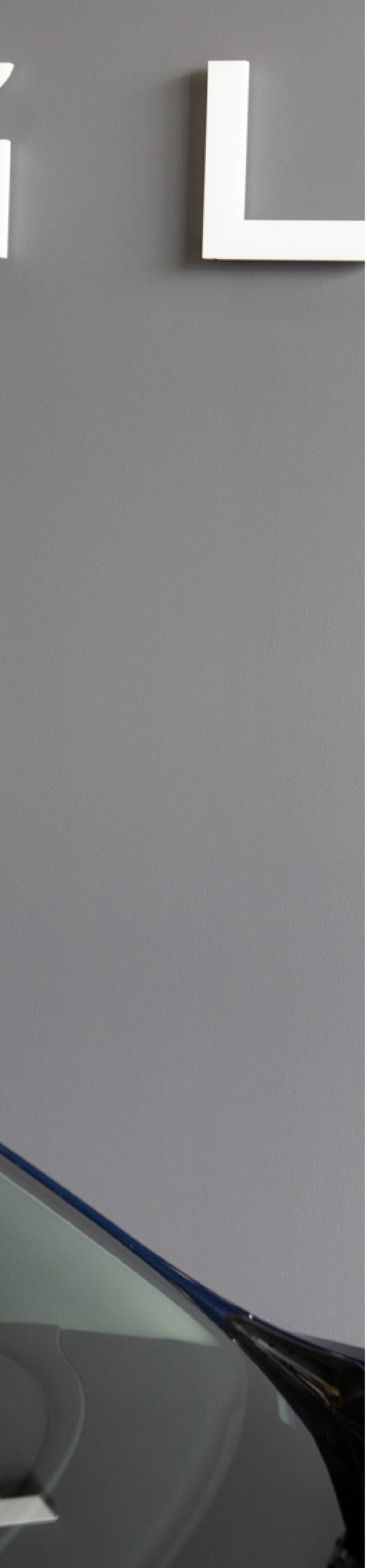
The environmental and economic issues cannot be ignored as the number of BEVs increases. BEVs currently account for around 0.33% of global light duty vehicle (LDV) numbers and LDVs account for only 45% of global transport energy use. If all LDVs, including large SUVs, are to be replaced by BEVs, the required battery capacity has to increase by well over a factor of 300. Such an enormous increase in materials required for battery production will have problems associated with human health and water and eco-toxicity. It will lead to an appreciable reduction in global greenhouse gases only if all the energy used for manufacture of batteries and use is GHG-free.

In response to one of AH's challenges, Hawkins et al. state that 'The different EV options have 180% to 290% greater [human toxicity potential] impacts compared to the ICEV alternatives'.[‡] I have not had a chance to study the report, which I think is from Ricardo, and from which AH takes Fig. ES4, which seems to show otherwise. Also, in the figure

‡ *J. Ind. Ecology*, vol 23 pp 53–60 , 2013. Also see, Brennan, J.W. and Barder, T. *Battery Electric Vehicles vs. Internal Combustion Engine Vehicles*', 2016, Arthur D Little.

shown by AH, the base car is a gasoline car. But these environmental issues undoubtedly exist. Also, there are huge costs, material requirements and environmental problems associated with new infrastructure required for a significant increase in BEV numbers which will inhibit such an increase.

I am confident that BEVs cannot and, in fact, should not replace ICEVs completely. All available technologies including BEVs, ICEVs and fuels should be continuously improved and used to reduce the GHG and other environmental impacts of transport while ensuring adequate availability of societies' needs for transport.



Concluding comments from Hoekstra

Auke Hoekstra

I'm glad Mr Gautam Kalghatgi (GK) no longer suggests the outcomes of our research are influenced by the organisation that asked for the research (since we published them earlier).

I concede that I erroneously assumed GK forgot to take diesel production into account. In fact, he took theoretical WLTP values instead of real-world numbers for energy use and best-in-class instead of average diesel production numbers. Together this produces almost the same result as forgetting diesel production, hence my confusion. The magnitude of his error does not change materially but I erroneously attributed it to the wrong cause. My apologies for that.

I discussed at length why taking the marginal electricity mix, in the way GK does, makes no sense. GK is free to take the average German electricity mix instead of the average EU mix and indeed this increases the Model 3's driving emissions over its lifetime by around 33% (as I mention in my *Joule* article).

I'm glad that our use of many sources pointing out lower battery production emissions has had an effect. I would like to point out again that the 100% renewable scenario in Emilsson and Dähllof pertains to the lower value in their range of emissions, not to the whole emission range. Adding end-of-life emissions specifically for batteries is fine, if second lives and recycling are also considered and if a source is given. I'm missing GK's source for end of life emissions and in our report we explain how second lives and recycling actually lower the carbon footprint of battery production.

All in all, I see no reason to change my assumption that the Tesla Model 3 emits 64% less CO2 in Europe than the Mercedes C220d. And although I think GK is still too negative about EVs for aforementioned reasons, I'm glad he has moved from 4% better to 32% better in Germany.

As a closing remark, I don't want to claim electric vehicles are unproblematic. On the contrary, I have often said that if all of humanity had the same level of car ownership as currently seen in developed countries, this would be highly problematic. But whether in terms of human toxicity or environmental damage, electric vehicles are simply *less bad*. The faster combustion vehicles are retired in favour of electric ones, the better. I'm confident that anybody who studies our exchange in detail and with an open mind will come to that same conclusion.

About the Global Warming Policy Foundation

The Global Warming Policy Foundation is an all-party and non-party think tank and a registered educational charity which, while openminded on the contested science of global warming, is deeply concerned about the costs and other implications of many of the policies currently being advocated.

Our main focus is to analyse global warming policies and their economic and other implications. Our aim is to provide the most robust and reliable economic analysis and advice. Above all we seek to inform the media, politicians and the public, in a newsworthy way, on the subject in general and on the misinformation to which they are all too frequently being subjected at the present time.

The key to the success of the GWPF is the trust and credibility that we have earned in the eyes of a growing number of policy makers, journalists and the interested public. The GWPF is funded overwhelmingly by voluntary donations from a number of private individuals and charitable trusts. In order to make clear its complete independence, it does not accept gifts from either energy companies or anyone with a significant interest in an energy company.

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GWPF DEBATES