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Who will bell the cat? On the environmental and sustainability risks of electric vehicles: A comment

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In Transportation Research A 133:79–81, Francisco Bahamonde-Birke (B-B) asks “Who will bell the cat? ... [and presumably discloses] … the fact that, under current conditions and with flat energy prices, a substantial increase in the number of EVs [electric vehicles] in many countries would necessarily result in an increase of CO_2 emissions”. B-B wants to … “raise awareness among authors and reviewers regarding the risks associated with replacing conventional vehicles – especially those highly efficient in terms of CO_2 emissions, such as Diesel and LPG vehicles – by electric vehicles”.

1. Combustion engines are not energy efficient

Unfortunately, there is no such thing as a highly efficient diesel vehicle. In the best of cases (i.e. when the engine load is optimal), diesel engines convert something like 35–40% of the energy contained in the fuel into kinetic energy, i.e. propulsion. At low speed, typical of city driving, the energy efficiency is much lower – occasionally as low as 10%. On average, the energy efficiency of a diesel vehicle hardly exceeds 20–25%.

This contrasts sharply with the battery electric vehicle (BEV), in which 80 to 90% of the electricity stored in the battery is converted into propulsion – not only when the load is optimal, but throughout the range of speed. On average, diesel cars consume 3–4 times more energy than BEVs, as reckoned per kilometer driven. For city driving under congested conditions, the internal combustion engine (ICE) vehicle easily consumes 5–10 times more energy than the BEV. In this perspective, it makes little sense to speak of any type of ICE vehicle as “highly efficient”. On a global scale, the use of fossil fuel for vehicle propulsion amounts, in fact, to a massive waste of energy.

Even more seriously, ICE vehicles emit large amounts of greenhouse gases (GHG). With the global motor vehicle fleet set to reach 2 billion units around 2030, there is hardly any sector more in need of drastic GHG abatement. According to Sperling & Gordon (2009) … “The principal solution is electric-drive technology”. Marginal improvement in ICE efficiency will not do, nor will sweeping enhancements in mass transit supply or large-scale substitution of biofuel for fossil fuel.

2. Life-cycle assessment

In a very thorough life-cycle analysis of specific diesel, gasoline, hybrid and battery electric passenger car models, Miotti et al. (2016) calculate comparable CO_2 emission intensities on the assumption of a US energy mix, by which electricity is generated with a climate footprint of 623 g of CO_2 equivalents per kilowatt hour (gCO_2e/kWh). This translates into per km life-cycle emission rates between 110 and 200 gCO_2e/km for BEVs, between 130 and 270 gCO_2e/km for hybrid electric cars, and between 200 and 430 gCO_2e/km for gasoline and diesel driven cars. Thus, there is little doubt that, even under unfavorable conditions (i.e. a large share of fossil-based, thermal power generation), electric vehicles leave a much smaller climate footprint than do ICE vehicles.

As the power sector becomes decarbonized, through the substitution of solar, wind, or nuclear power for thermal plants, the difference between ICE and battery electric vehicles is bound to increase. This is exactly what is now happening in the USA. Coal fired plants are being outcompeted by wind turbines and photo-voltaic (PV) installations (i.e., solar panels). Paradoxically, hardly any

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country is currently exhibiting an equally fast reduction in GHG emissions as the one nation that has announced its withdrawal from the Paris agreement (Jackson et al., 2019).

Lithium-ion battery production is energy intensive, especially if it takes place in a humid climate, since the manufacturing must be done in ultra-low humidity 'dry rooms'. Life-cycle analyses based on the present location of battery manufacturing facilities typically exhibit twice as high a climate footprint from BEV manufacturing as for similar ICE vehicles. This is so because many battery factories are located in China, where the air humidity may be high and the power generation is based to a large extent on coal fired plants. It does not have to be that way. When production takes place in the Nevada desert, based on wind, solar or geothermal energy, like in the Tesla Gigafactory 1 near Reno, the climate footprint from battery and vehicle manufacturing becomes fairly small.

3. Cap-and-trade: The EU ETS waterbed

Another way, beside power sector decarbonization, to ensure that vehicle electrification translates into large-scale greenhouse gas mitigation, is cap-and-trade. The European Union's Emissions Trading System (EU ETS) puts a cap on the total amount of GHG emissions within the economic sectors covered. Included among these sectors are all electricity generating plants with a capacity above 20 MW. To emit GHG, all enterprises covered by the EU ETS must possess emission allowances. The allowances are tradable across all countries and all sectors covered. The EU ETS extends geographically to the entire European Economic Area (EEA, i.e. EU + Norway, Iceland and Liechtenstein).

The EU ETS has been compared to a waterbed: When you sit on the bed, the distribution of the water in the bed changes, but the total amount of water held by the bed remains constant. By analogy, any reduced use of emission allowances gives room for more emissions from other sources within the ETS sector, while increased emissions from any one source are necessarily counterbalanced by reduced emissions elsewhere. A somewhat discomforting implication of the waterbed cap-and-trade system is that no other GHG abatement effort within the ETS sector is worthwhile. This fact might stifle certain national climate policy initiatives or clean energy investments.

Vehicle electrification is a much more effective and uncompromising strategy than extending the ETS so as to cover the combustion of fossil fuel in vehicles, as suggested by B-B. This is so because the latter strategy would hardly be feasible without simultaneously raising the cap, through the issuance of additional emission allowances, in much the same way as when intra-EEA aviation was included in the ETS from January 1, 2012. In contrast, since electrically driven means of transportation receive their energy from power plants covered by the ETS, vehicle electrification means moving important sources of emissions from the non-ETS into the ETS sector – *without raising the cap*. In principle, CO_2 emissions are therefore reduced by the full amount of gasoline and diesel combustion avoided when an ICE vehicle is replaced by a BEV.

A massive electrification of the European vehicle fleet would significantly affect the price of emission allowances, making energy conservation and decarbonization more profitable throughout the ETS sector. From a climate policy angle, electrification and cap-and-trade are perfect complements.

4. From waterbed to bathtub: The market stability reserve (MSR)

In 2015, in response to low allowance prices and a large surplus of allowances, the EU introduced a 'market stability reserve' (MSR), whereby parts of next year's allowances are set aside ('banked') rather than auctioned, reducing the short-term supply of allowances. Since 2018, certain revised MSR rules are in place, so that when the MSR exceeds a certain threshold, some surplus allowances are permanently canceled. In the words of Perino (2018), the waterbed has been punctured. Otherwise put, the waterbed has been replaced by a bathtub (Graichen et al. 2018), where spillover of water may occur, reducing the total volume contained in the tub.

With the new MSR rules, the emissions cap has become endogenous, dependent on the amount of surplus allowances and on future GHG abatement costs. This introduces uncertainty regarding cumulative emissions reductions. On the whole, the new MSR rules seem to imply a reduced long-term supply of allowances. Rosendahl (2019) concludes that … "the cancellation rule is likely to reduce cumulative emissions by several gigatons of carbon dioxide". By comparison, the ETS cap for 2020 is of the order of 1.8 gigatons of CO_2 equivalents.

It is worth noting that when the cap is no longer carved in stone, it does matter what other mitigation efforts are made even within the ETS sector. New wind and solar power installations will, for example, increase the probability of ETS allowances becoming redundant and eventually canceled. The large-scale introduction of electric vehicles will, on the other hand, presumably result in fewer allowances being banked and canceled. Thus, the final mitigation effect of vehicle electrification will likely be somewhat smaller than the full amount of gasoline and diesel combustion avoided.

5. Political risks

Between June 2017 and December 2019, the price of ETS allowances increased almost five-fold, from about € 5 to around € 25 per ton CO_2. The MSR rules no doubt contributed to this. Between 2021 and 2030, the cap is due to be reduced by 2.2% annually, probably resulting in another steep price increase. But the present ETS price of carbon is considerably lower than the average 2030 prices implicit in the 1.5 °C mitigation pathway of IPCC – the United Nations' Intergovernmental Panel on Climate Change (Rogelj et al. 2018: 153).

There is an interesting line of reasoning implicit in B-B's remark that … "a large increase in CO_2 emissions would put a lot of pressure on the system, as steep increases in the price of emissions permits have been observed every time the EU ETS has expanded". The EU EUTS being a politically instituted mechanism, one cannot rule out the possibility that with increased market pressure and allowance prices, the EU ETS may lose political support and eventually break down. Also, large-scale carbon leakage and reduced employment and economic growth may occur if major manufacturing sources of emission choose to relocate outside the EEA, or simply stop investing inside the EEA.

But the present MSR mechanism most probably reduces the risk of EU ETS collapse. In the worst of cases, MSR and privately banked allowances may be reintroduced into the market, easing the market pressure. The MSR can thus be seen as a safety valve – an insurance against the political risks surrounding the European cap-and-trade system.

6. Increased electricity demand, reduced energy demand

Obviously, large-scale vehicle electrification will boost the demand for electricity. In some countries with abundant power supply, like Norway and Iceland, this increase can likely be accommodated without much difficulty. Fridstrøm (2019a) calculates that a full battery electrification of the light duty vehicle fleet and an 80% fuel cell or battery electrification of the heavy duty vehicle fleet at the 2050 horizon, would increase the annual electricity demand in Norway by no more than 15%, or 21 TWh, assuming that all hydrogen be produced through water electrolysis. At the same time, the annual consumption of gasoline and diesel would decrease by around 35 TWh compared to the 2018 level, implying considerable (37%) energy savings in road transportation as a whole, despite a 45% projected traffic growth.

In most other countries, with a lower per capita electricity output, the required relative increase in power generation will be more challenging. The approximate per capita electricity output in 2018 was 27,600 kWh in Norway, 13,300 kWh in the USA, and 7800 kWh in Germany. Thus, the 15% growth in electricity production calculated for Norway would translate, roughly speaking, into a 31% demand growth in the USA and a 53% boost in Germany. Buchal et al. (2019) optimistically estimate the added electricity demand under full electrification of the German vehicle fleet at 300 TWh per annum, corresponding to a 47% surge from the current output.

7. The German predicament

The German predicament is compounded by the country's self-inflicted electricity shortage, brought about by the decision to shut down all nuclear power plants. Almost 100 TWh of annual nuclear electricity supply have already been withdrawn from the market, and the last 76 TWh will be phased out by 2022. The idea of the '*Energiewende*' is to replenish the energy supply by electricity produced from renewable sources, primarily wind and sunlight. But these sources have the distinct disadvantage of being weather dependent and hence volatile and practically unmanageable by humans. A power supply system based exclusively on such sources will entail unacceptably high risks. There is thus a need for a network of supplementary or parallel power plants that can ensure a minimum supply of electricity in times of reduced PV and wind power production. Facilities for storing and retrieving energy, such as battery parks or hydrogen production and storage, with reconversion into electricity by means of fuel cells, may have to be developed.

The challenge is not only technological, but also economic, institutional and legal. There is, for example, an obvious need for more sophisticated electricity pricing and demand response systems than the present single bidding zone in effect in Germany (Egerer et al. 2016), which provides few incentives for power transfer between areas of temporary shortage and areas of ample production.

8. Barriers to electrification

B-B may be right in pointing out that the marginal kWh produced may have a higher carbon intensity than the average energy mix. Typically, coal fired power plants play the role of buffer capacity, cushioning variations in demand or in wind and solar power supply.

But when the question is whether to electrify the whole or large parts of the vehicle fleet, we no longer talk about marginal changes. As argued above, large-scale vehicle electrification presupposes, in most countries, sizeable expansions in power generation. If all or most new power added is emission free, so will the electric vehicles be.

In many cases, massive enhancements to the distribution grid will be needed as well, for millions of BEV owners to be able to recharge their vehicle at home. Smart demand response systems of vehicle recharging will have to be introduced, inducing households to recharge in the dead of the night rather than during the morning or afternoon peak hours. Rooftop solar panels may allow some households to become electricity 'prosumers', i.e. self-reliant power producers and consumers.

The likelihood of opting for an electric vehicle increases substantially if the owner is able to recharge the car at home. But in densely populated cities, many car owners do not have a designated parking space or driveway. This is likely to limit electric vehicle demand.

Although the typical range of electric vehicles has improved substantially over the last few years, it still falls far short of ICE vehicle range. Another BEV handicap, compared to ICE vehicles, is the time needed to replenish energy. While these drawbacks may not be decisive in the context of short-haul urban trips, they severely limit the attractiveness of BEVs for high-speed long-distance traveling. For large-scale automobile electrification to take place, there is a need to develop recharging infrastructure with massive capacity along the highways. If users experience long queues at the charging stations, BEV demand will be effectively curbed.

9. The Norwegian experience

In 2019, 42.4% of all new passenger cars sold in Norway were BEVs. The market share of BEVs and plug-in hybrid electric vehicles taken together was 55.9% (Fridstrøm, 2020).

Behind this development are strong government incentives. A widespread misconception is that these incentives have something to do with the country's petroleum wealth. Only a rich government – so it goes – can afford the degree of subsidization necessary for an immature technology like electric cars to exhibit such an accelerated market uptake.

But this news is fake. The fact of the matter is that vehicle electrification in Norway is brought about, not by generous subsidization, but – quite the contrary – by stiff taxation of ICE vehicles and fossil fuel. The stick works better than the carrot.

Hence, any country – rich or poor – could, in principle, copy the Norwegian recipe, introducing some or all of the vehicle taxes and regulations applied (see the list given by Fridstrøm (2019b)), with exemptions for battery and fuel cell electric cars. Far from draining the public treasury, such a policy would generate considerable government revenue, strengthening public finance in whatever country implements the scheme.

10. Summary and conclusions

In summary, there is nothing wrong with the climate and environmental characteristics of electric vehicles *per se*. Under unfavorable assumptions, all-out vehicle electrification may be expected to reduce the climate footprint of road transportation by around one half. Up to 100% reduction may be achieved if the added electricity output is produced in a decarbonized way, that is, without GHG emissions, or if power generation is encompassed by an effective emissions trading system, be it in the form of waterbed or bathtub. Energy consumption will be cut, and tailpipe emissions of local pollutants will be eliminated.

The challenges and obstacles to large-scale vehicle electrification are, nevertheless, daunting. In a market economy with consumer sovereignty, it is unlikely to happen unless the government decides to tax fossil fuel and ICE vehicles rather sharply. Here, the petroleum and auto industry lobbies, whether representing capital or labor, might be powerful adversaries – or perhaps allies? To avoid the Kodak fallacy, some automakers may see it in their interest to work *with* environmental stakeholders or activists and invest heavily in battery, hybrid and/or fuel cell electric technology.

Vehicle electrification presupposes pervasive changes even outside the transportation domain, most notably in the energy sector. Decarbonized electricity output must be increased and the local and regional grids must be enhanced. Closing down nuclear plants is a step in the wrong direction. Charging infrastructure with massive capacity must be developed along highways and in the cities, with government support if necessary. To ensure efficient electricity production, transfer and consumption, sound economic incentives must be in place.

The path to sustainable road transportation is ridden with hurdles and risks. There are plenty of mean cats lurking around. I am afraid Bahamonde-Birke (2020) has belled the wrong cat.

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