The Next Generation Policies Project

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Current and future environmental performance of passenger cars

Brian Cox, Christian Bauer, Chris Mutel

Key Points

- Current BEV (see Table 1 for abbreviations) charged with European average electricity already provide lower life cycle Greenhouse Gas (GHG) emissions than conventional ICEV and have climate impacts comparable to HEV.
- In the future BEV will likely have lower greenhouse gas emissions than hybrid vehicles (Figure 2).
- Full decarbonization of passenger transport, in line with 1.5°C targets, will also need clean upstream processes such as raw material production and manufacturing.
- Vehicle electrification via BEV and FCEV will shift burdens from areas with high traffic density to other regions where power generation and industrial processes are located. The associated impacts on human health require further analysis.
- Life cycle GHG emissions of BEV and FCEV strongly depend on the CO_2 intensity of the electricity used to charge the battery or produce hydrogen. When BEV and FCEV are powered by electricity or hydrogen from sources with low CO_2 emissions, they cause substantially lower greenhouse gas emissions than fossil ICEV and HEV (Figure 3).
- The increased greenhouse gas emissions from current BEV production compared to ICEV are compensated for by lower operating emissions after roughly 40’000 kilometers when BEV are charged with average European electricity in the current case. Compared to HEV this currently takes roughly 120’000 kilometers. Vehicle production impacts are expected to decrease in the future.
- In addition to switching to electric powertrains, large reductions in environmental burdens can be achieved by reducing vehicle size and mass.

Scope

This policy brief describes the environmental burdens of current (2017) and future (2040) passenger cars on the basis of Life Cycle Assessment (LCA). The assessment includes the entire life cycle of vehicles: manufacturing, operation and end-of-life. It also includes the production chains of fuels, whether petrol, diesel, gas, electricity or hydrogen and the entire fuel chain infrastructure. This life cycle perspective is important because, although battery and fuel cell vehicles do not emit any tailpipe pollutants, the environmental burdens of producing these vehicles and the electricity and hydrogen that they consume can be substantial. Total costs of vehicle ownership are also included, though based on less detailed analysis.

Vehicle technologies and fuels

We consider seven popular powertrain configurations.

Conventional vehicles with combustion engines (ICEV) can be operated using petrol (p), diesel (d) or compressed natural gas (g). Alternatively, vehicles can be powered by electric motors, such as battery or fuel cell electric vehicles (BEV and FCEV). The “fuel“ for these vehicles is electricity that is either stored directly in batteries, or in the form of hydrogen that is converted into electricity using fuel cells as needed. Hybrid vehicles (HEV-p) have a small battery that assists the petrol fueled combustion motor to improve efficiency, but cannot be charged from the electricity grid. Plug-in hybrid vehicles (PHEV) have a combustion motor and a slightly larger onboard battery that be charged from the electricity grid. They can operate either in electric or combustion mode. Results for PHEV are shown here for average usage shares of combustion and electric mode operation [1].

Table 1: Powertrain abbreviations.

Abbreviation	Description
ICEV	Internal combustion engine vehicle
-p	Petrol
-d	Diesel
-g	Compressed natural gas
HEV	Hybrid electric vehicle
PHEV	Plug-in hybrid electric vehicle
BEV	Battery electric vehicle
FCEV	Fuel cell electric vehicle

Main assumptions

We model current and future vehicle performance and calibrate current performance based on measurements of real vehicles.

This policy brief focuses on the performance of lower-medium sized vehicles (similar to a VW Golf) in average European conditions. Vehicles have an assumed average lifetime of 200'000 km; replacing the battery of BEV is not required. The calculations consider uncertainties in car specifications and operating conditions such as differing vehicle aerodynamic properties, energy battery sizes, or total distance driven over the vehicle's lifetime (with a specific sensitivity analysis in Figure 4). Error bars in Figure 2 visualize these uncertainties, while the columns show the most likely results. A complete description of the model and extended results can be found in the background paper accompanying this policy brief [2]. Current combustion vehicles meet Euro 6 emission standards. Pollutant emissions of future vehicles are assumed to be 50% lower than those of current vehicles. In general, our assumptions regarding vehicle specification are in line with recent literature [1, 2, 4, 8-10]. Most sensitive in terms of impact on the results are assumptions regarding vehicle and BEV battery lifetime, BEV battery size determining its range, vehicle fuel consumption and burdens associated with electricity supply for BEV and hydrogen supply for FCEV, respectively [1, 2, 4, 8-10].

Future energy scenarios

We consider two future energy scenarios: "BAU" and "Climate".

In our prospective analysis, we use scenario results from the REMIND model [3] to capture future developments to the energy system which influence the environmental burdens of building and operating future passenger cars. We limit the selection to two future scenarios, which can roughly be interpreted as worst and best cases: "BAU" represents a business as usual scenario, while "Climate" represents a very ambitious climate policy that is in line with targets to limit climate change to 1°C in 2100 (RCP26). Figure 1 shows European electricity mixes and life cycle greenhouse gas emissions per average kilowatt-hour of electricity for each of these scenarios.

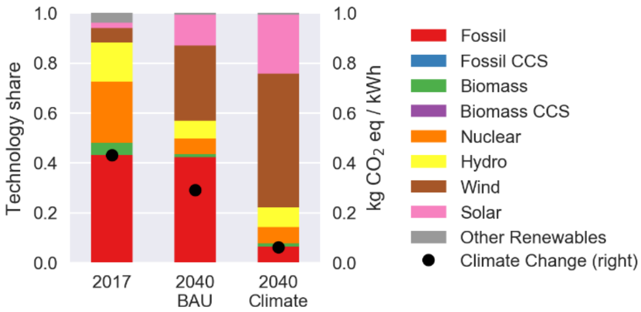

Figure 1: Current and future European average electricity mixes and their life cycle GHG emissions. For reference: hydro and wind electricity in Europe have CO_2 intensities of ca. 10-30 g CO_{2eq}/kWh; photovoltaic systems cause roughly 50-100 g CO_{2eq}/kWh; natural gas power plants reach levels around 400-500 g CO_{2eq}/kWh.

Results

Future vehicle performance improvements are substantial, but the largest improvement potential for electric vehicles is only reached when the energy system used to build and operate the vehicles is also "clean".

Figure 2 shows selected life cycle environmental burdens of lower-medium sized passenger cars in 2017 and 2040 for two different future energy scenarios. The colored bars represent the most likely results. The uncertainty bars consider variability and model uncertainty in vehicle performance and operation. The improvements in 2040 vehicle life cycle emissions are partially due to expected technological improvements (engine efficiency increases, vehicle weight reductions, exhaust emissions reductions and improved battery and fuel cell technology), but are mostly due to improvements in the energy system used to build and operate the vehicles. The cleaner energy supply in the climate scenario results in a more substantial reduction of impacts.

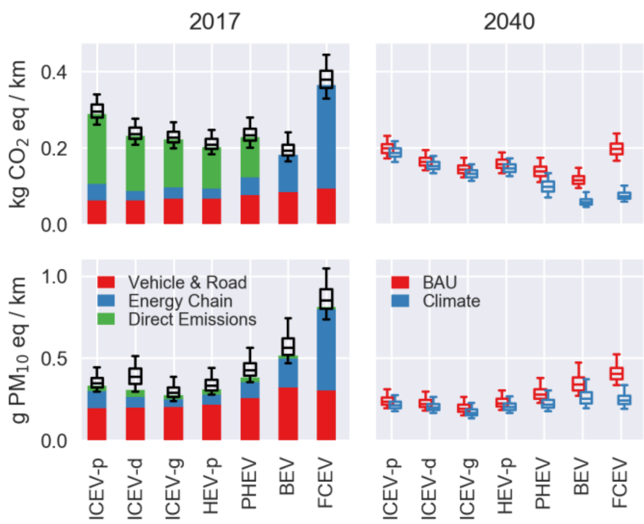

Figure 2: Life cycle burdens of lower medium size passenger vehicles. Climate change impacts (top), particulate matter formation (bottom).

Battery and fuel cell electric vehicles can reduce local air pollution in high traffic areas. However, their total air pollutant emissions are currently similar or even higher than those of ICEV – mostly due to coal power in the upstream energy chain. This will improve as coal will be phased out as an electricity supplier.

The bottom panels of Figure 2 shows particulate matter formation potential. Results for most air pollution impact categories look similar. A substantial portion of the air pollution due to electric vehicles is caused by the use of coal in the electricity mix used to charge the batteries or produce hydrogen. There also are substantial emissions due to the battery production chain. However, these emissions are often released in less populated areas where fewer people can be affected, for example, in mines where raw metals are produced or from power plants outside of urban centers. The resulting health impacts are likely much lower than those of emissions that occur in densely populated areas with high transport demand. Quantifying these effects will require further analysis.

Sensitivity Analysis – Carbon intensity of the electricity grid

BEV and FCEV have the best performance when powered by clean electricity. BEV are generally preferable to HEV if the electricity comes from sources better than or equal to a modern natural gas power plant.

Figure 3 shows the sensitivity of vehicle life cycle GHG emissions to the carbon intensity of the electricity grid used for battery charging and hydrogen production. The solid lines show the best fit result and indicate the general trend, while the shaded regions show the standard deviations of the results.

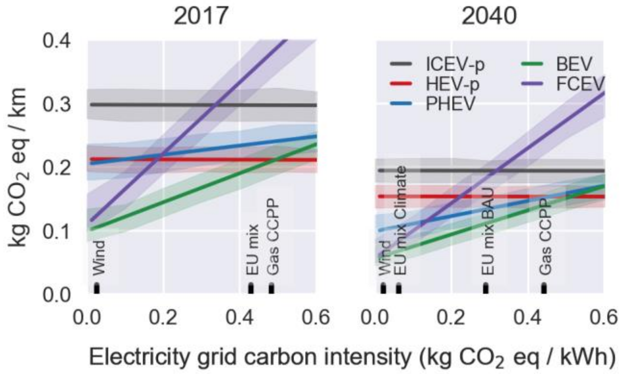

Figure 3: Life cycle GHG emission dependency on the CO_2 intensity of the electricity used to charge batteries for BEV and produce hydrogen for FCEV. The higher the CO_2 intensity of this electricity, the higher are life cycle GHG emissions of BEV and FCEV. The 2040 panel shows results calculated with both the BAU and the Climate scenarios. CO_2 intensities of specific electricity sources (wind and natural gas power) and mixes are indicated on the x-axes. CCPP: Combined Cycle power plant.

Sensitivity Analysis – Vehicle lifetime distance

Increasing vehicle lifetime distance travelled reduces the average environmental burdens per kilometer. Electric vehicles are more sensitive than combustion cars to lifetime distance due to higher burdens from vehicle production, but this difference will get smaller in the future.

Figure 4 shows the life cycle climate change result sensitivity to the lifetime distance travelled by the vehicle. Future vehicles are less sensitive to this parameter than current vehicles, because vehicle production will become cleaner in the future.

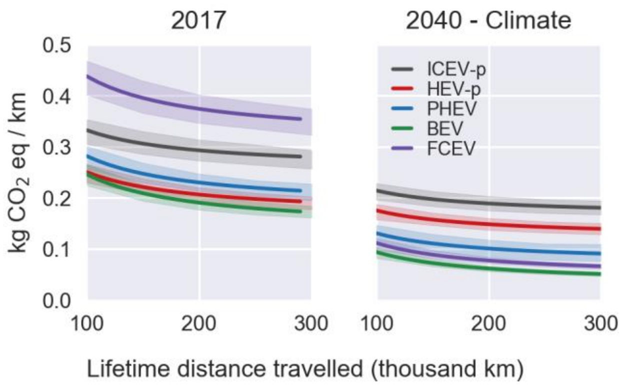

Figure 4: Greenhouse gas emission dependency on the lifetime distance travelled by the vehicles.

Sensitivity Analysis – Vehicle mass

Smaller vehicles cause much lower environmental burdens than larger vehicles. The benefits of moving from a large to a small car are similar to switching from an ICEV to a BEV. Sensitivity to vehicle mass will be lower over time due to increased efficiency.

Figure 5 shows the life cycle climate change result sensitivity to vehicle mass. Results for all powertrains are highly sensitive to this parameter – large reductions in environmental burdens can be achieved by reducing vehicle sizes and lightweighting. Future vehicles, especially future electric vehicles operating with clean energy sources, are less sensitive to this parameter.

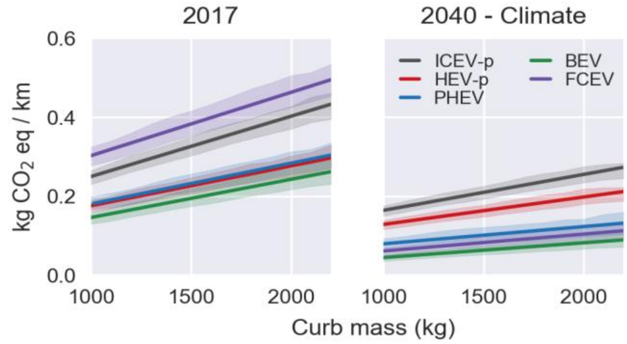

Figure 5: Greenhouse gas emission dependency on vehicle mass.

Comparing results with other recent publications

Our outcomes are within the range of results of other recent LCA studies. Differences are usually due to specific assumptions regarding important vehicle parameters.

Figure 6 shows life cycle GHG emissions of petrol ICEV and BEV charged with the EU or US electricity mixes, which are similar in terms of GHG intensity, according to various studies. Assumptions in [9] can be considered as biased, favoring BEV.

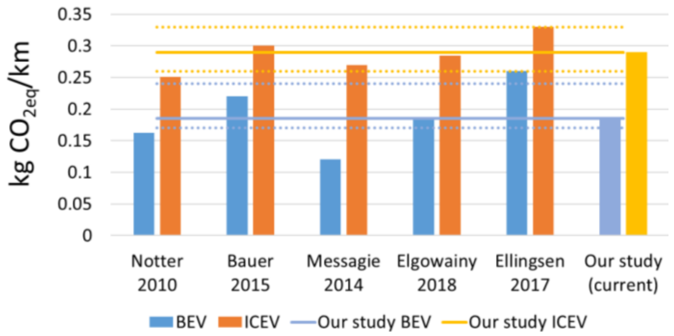

Figure 6: Life cycle GHG emissions per km according to various sources [4, 7-10]. Dotted lines indicate the ranges of our results.

Total ownership costs: benefits of powertrain electrification

Electric vehicles will provide cost benefits in the future.

Figure 6 compares the total ownership costs of current and future vehicles to their life cycle GHG emissions. BEV are expected to provide not only climate benefits, but also cost savings in the future. These will strongly depend on future developments of fuel and electricity prices.

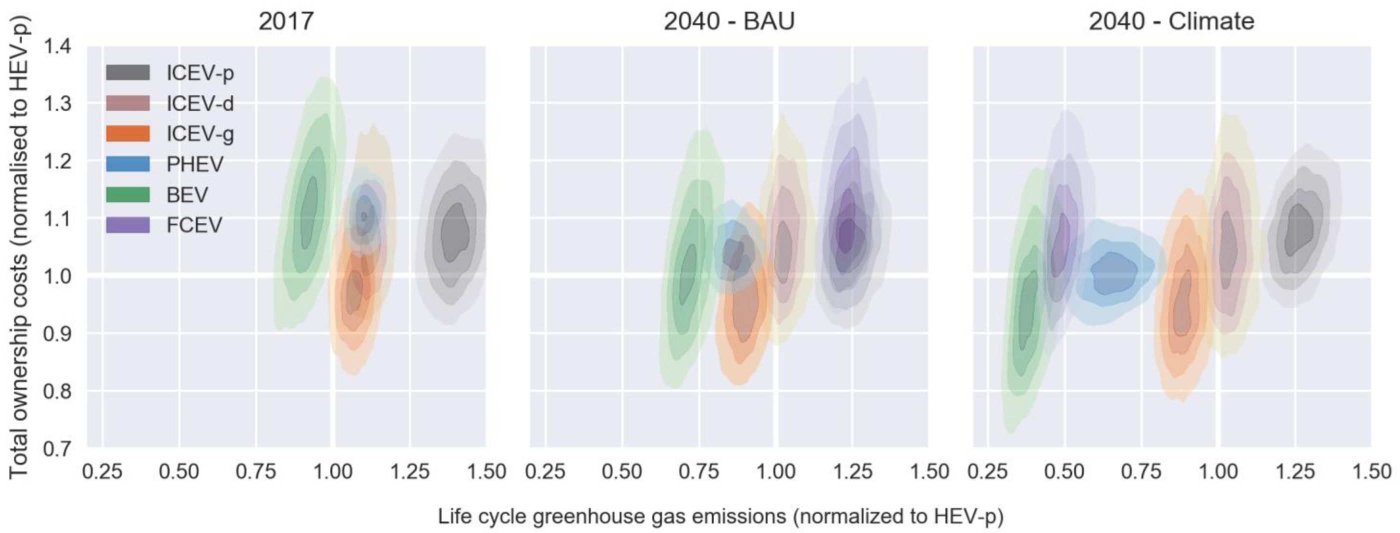

Figure 7: Total ownership costs versus life cycle GHG emissions. Values are normalized to the performance of a hybrid vehicle. Thus, a score of less than one indicates better performance than a hybrid vehicle and vice versa.

The environmental impacts of battery production

Batteries will get smaller, store more energy and cause less impacts on the environment in the future, mostly due to increased energy density.

Lithium-ion batteries are the current standard for battery electric vehicles. Battery production results in substantial environmental burdens, mainly due to raw material supply and manufacturing energy demand [1, 4-6]. Therefore, vehicles with larger batteries, and thus larger ranges, cause more environmental burdens. The current battery system in our analysis weighing 300 kg has a storage capacity of 36 kWh – thanks to improving energy density of batteries, a future battery system weighing only 200 kg will store roughly 55 kWh in the year 2040. Both current and future batteries are assumed to be replaced after roughly 200'000 km, which is the average lifetime of the vehicle.

If current batteries were produced with renewable energy, their production impacts would be reduced by roughly 20%.

One of the most important factors for the environmental burdens of battery production is the energy consumed for the production of battery cells. The two determining factors are how much energy this process consumes and where that energy comes from. We assume global average heat and electricity supply mixes, and 8 kWh/kg battery cell, which is in line with current best-in-class battery production facilities [4-6]. If clean electricity such as solar or wind power were to be used, GHG emissions due to current battery production would decrease by up to 20%.

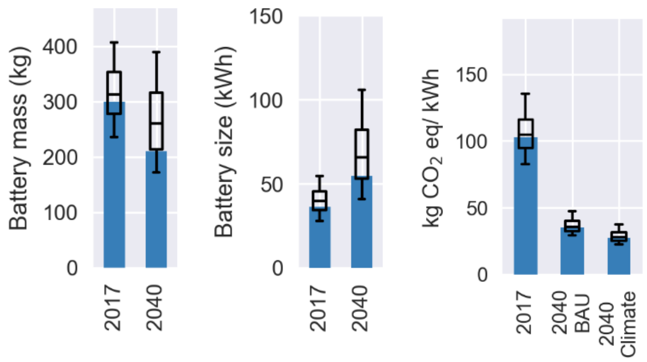

Figure 8: BEV energy storage battery mass, energy capacity and life cycle greenhouse gas emissions due to battery production.

Cited references are available at [add link]

For more information

https://www.mcc-berlin.net/next-generation-policies

Project coordination:

Mercator Research Institute on Global Commons and Climate Change (MCC) GmbH | Berlin

Dr. Nicolas Koch | koch@mcc-berlin.net

MCC Mercator Research Institute on Global Commons and Climate Change

PIK Potsdam Institute for Climate Impact Research

Paul Scherrer Institut PSI

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