

How clean are electric cars?

T&E's analysis of electric car lifecycle CO₂ emissions

April 2020

Summary

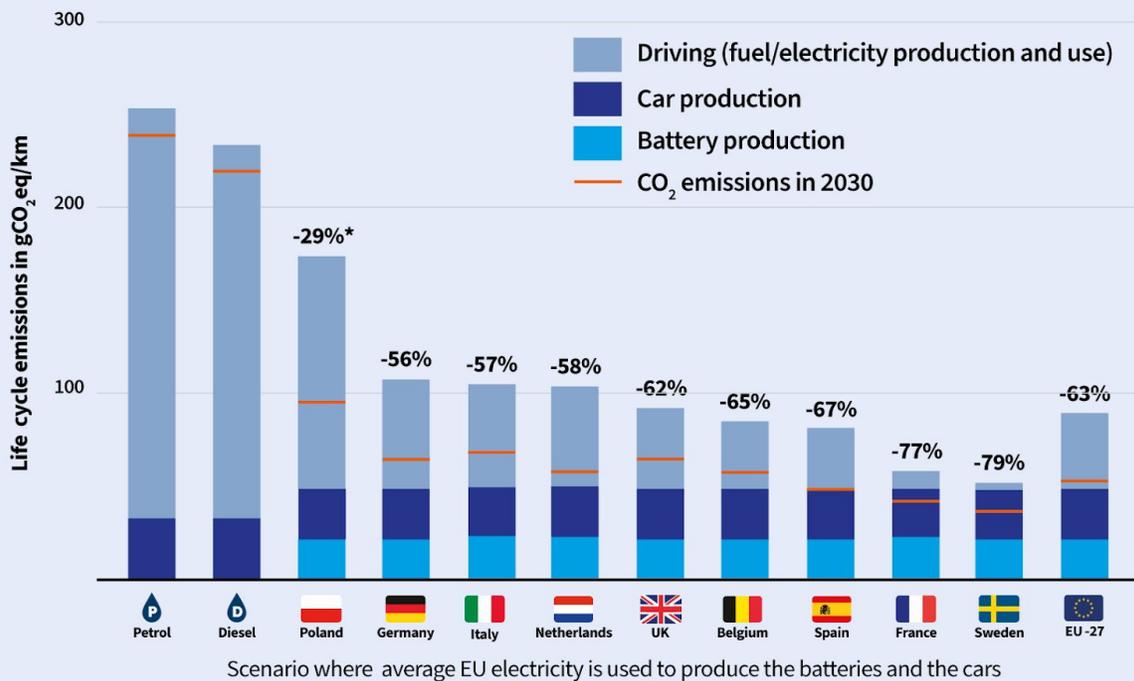
As carmakers rush to reduce CO₂ emissions from their vehicles to comply with EU car regulations in 2020 and 2021, the offer and sales of electric vehicles (EVs) are rapidly growing. In the 2020s, electric car sales will reach the mass market with the total number of EVs on the road expected to increase by more than 30 times across Europe by 2030. This means that 97% of the electric cars that will be on the road in 2030 have not yet been sold (from 1.3 million EVs in the end of 2019 to 44 million in 2030¹).

The arrival of the electric car has brought with it an array of lifecycle analyses estimating CO₂ emissions of electric cars including battery and charging, and comparing those to conventional cars. While many researchers have to rely on outdated data or evidence, some LCAs (or their interpretation) are deliberately misleading. A lot of these rely on outdated data to compare fast developing EVs with mature petrol or diesel technology that has little room for improvement. To bring clarity and transparency to this debate, T&E has produced a comprehensive and forward-looking comparison of electric, diesel and petrol engines in different car sizes for 2020 and 2030. The [online tool](#), published alongside this paper, is based on the latest evidence that shows that an average EU electric car is already **close to three times better than an equivalent conventional car** today². Crucially, electric cars will get considerably cleaner in the next few years as the EU economy decarbonises, with average EVs more than four times cleaner than conventional equivalents in 2030.

¹ Transport & Environment (2020), Recharge EU: How many charge points will EU countries need by 2030. [Link](#)

² 2.6 times less than diesel and 2.8 times less than gasoline. EVs are on average at 90gCO₂e/km.

Today petrol and diesel cars emit almost 3 times more CO₂ than the average EU electric car



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*CO₂ savings compared to the average of both diesel and petrol emissions Source: transenv.eu/lca

Electric cars outperform diesels and petrols in all scenarios, even on carbon intensive grids such as Poland, where they are about 30% better than conventional cars. In the best case scenario (an EV running on clean electricity with a battery produced with clean electricity), EVs are already about five times cleaner than conventional equivalents. Crucially, the evidence shows that electric cars - powered with the average electricity - repay their “carbon debt” from the production of the battery after slightly more than a year and save more than 30 tons of CO₂ over their lifetime compared to a conventional equivalent. Electric vehicles that do high mileages (e.g. shared vehicles, taxis or Uber-like services) save up to 85 tons over their lifetime (compared to diesel).

T&E’s assessment is more granular, accurate and forward looking than any other existing LCA as it includes up-to-date evidence on key aspects on the lifecycle performance of EVs, i.e.:

- **Electricity for EV charging:** Scenarios for electricity grid decarbonisation are in line with the current and expected uptake of renewables to 2040s.
- **Battery footprint:** More recent and industrial scale battery manufacturing resulting in values two to three times lower than previous commonly used estimates.

- **Real-world emissions** of conventional cars (instead of unrepresentative laboratory test values), as well as updated indirect fuel emissions from the production, refining and transportation.
- **Realistic lifetime mileages** for electric cars adjusted to the performance of the latest generation of electric cars and batteries.
- Importantly, T&E's tool allows to compare emissions of **future EVs bought in 2030** and shows they would reduce CO₂ emissions further by about a third compared to an EV bought in 2020.

The LCA emissions of electric cars are bound to reduce even further compared to what is presented in this the case as new evidence builds up on: the longer lifetime of batteries thanks to innovation, the ramping up of battery reuse, repurpose and recycling, and the accelerating uptake of renewables. Battery recycling couldn't be fully incorporated due to the lack of any reliable data; however the scarce data available shows its impact to be between negligible to beneficial, so would leave the lifecycle EV results unchanged in the worst case.

But one cannot use LCA methodology in regulations covering one specific sector, e.g. vehicle CO₂ standards. Lifecycle analyses point to where emissions occur but include actors as varied as individuals charging their cars, power companies, Chinese battery makers, EU carmakers and eastern European governments. There's no way an LCA regulation could properly address all those actors all at once. Rather we need tailored policies to each of the areas identified as problematic, e.g. increasing renewables power across Europe and mandating batteries longer life and recycling.

The potential of electric cars to reduce CO₂ emissions is crystal clear and the EU should accelerate the transition to zero emission mobility and phase out diesel and petrol cars by 2035 at the latest, in line with its Green Deal climate ambition.

Introduction

Although recent metastudies³ supports that the lifetime emissions of electric cars are much less than their diesel or petrol counterparts, many, often biased, studies continue to claim otherwise. Often these life-cycle assessments (LCA⁴), rely on very conservative assumptions and methodological choices for electric cars that are either outdated or misleading and do not reflect the current state of the technology and its recent or future improvements.

The most common outdated assumption used for LCAs is the climate impact of the production of electric vehicle (EV) batteries. According to data published in 2019 by battery researchers at IVL Sweden⁵, EV batteries have become 2-3 times cleaner compared to two years ago (chiefly thanks to the scaling up of battery production). Nonetheless, the previous study from 2017 has been widely used to discredit the climate performance of EVs despite the evidence supporting much lower values. Other misleading assumptions commonly used are to suppose that the electricity grid does not decarbonise during the use phase of the electric cars, to use the very optimistic and non-representative laboratory test emission values for diesel and petrol emissions or to assume that electric car batteries would not last long distances.

T&E has put together a tool to compare the life-cycle performance of electric cars with diesel and petrol models based on a forward-looking analysis for EVs bought in 2020 and 2030 in Europe. By using reliable assumptions and data for the next decade, we are able to analyse the performances of EVs sold in the 2020s which is when most of them will be hitting the road.

This prospective LCA analysis should be used to support robust policy decisions and inform the wider debate on the contribution of EVs to reducing CO₂ emissions. It can also shed light on what are the key factors that influence the carbon footprint of EVs to focus future policy on improving those (e.g. the location of the battery cell production).

T&E will regularly update this tool based on new evidence and will widen the scope of the tool to include fuel cell electric cars (FCEV) and gas cars (CNG) in due course.

³ Selection of three authoritative sources:

EEA (2018). Electric vehicles from life cycle and circular economy perspectives. [Link](#)

ICCT (2018). Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions. [Link](#)

IEA (2019). Global EV Outlook 2019. [Link](#)

⁴ Life cycle assessment (LCA) is a methodology, commonly used for the environmental assessment of vehicle technologies (or any other product/system). LCA studies consider all the environmentally significant processes throughout the life cycle of vehicles, from raw material extraction, production of components, assembly, transport, vehicle use to the end-of-life treatment. (i.e. cradle-to-grave)

⁵ Transport & Environment (2018). EV batteries are getting cleaner and cleaner. [Link](#)

2. T&E assumptions for forward-looking LCA

This section presents the assumptions and methodology used in the tool and explains how they are forward looking. The tool is based on balanced, recent, real-world assumptions that allows us to provide an up-to-date picture of how electric cars and internal combustion engines (i.e. ICEs or diesel and gasoline cars) compare on life-cycle CO₂ emissions. Importantly, T&E's tool can model the lifecycle emissions of vehicles bought in 2030. This prospective analysis is virtually never included in LCA comparisons.

Electricity

T&E's calculation of the carbon intensity of a country's electricity grid is done on the basis of a bottom-up calculation based on realistic electricity generation mix evolution, IPCC emission factors for different energy sources and IEA country-specific electricity transmission and distribution losses (see electricity losses below).

To model the decarbonisation of the electricity over the lifetime of the EV and the future trends in EV's impacts, electricity production mixes in EU countries are based on ENTSOEs' (European Network of Transmission System Operators for Electricity)⁶ 2020 TYNDP (Ten Year Network Development Plan) scenarios⁷ which describe European energy futures up to 2050. The scenarios used are the following: 'National Trends' for 2025 and 'Global Ambition' for 2030 and 2040. As the official European network of Transmission System Operator (TSOs), ENTSO-E's scenarios and in particular the 'Global Ambition' scenarios are the most credible pathways which best reflect the European net-zero carbon ambition for 2050.

The scope for the European Union average values has been adjusted post-Brexit and covers the EU27 in this paper (EU and EU27 will be used interchangeably in this paper). Renewable electricity generation is expected to increase from 35% in 2019 to 43% in 2025, 55% in 2030 and 74% in 2040 (see Figure 1). This rapid uptake in renewables has an important consequence: an EV bought today will keep getting cleaner throughout its lifetime, which is usually not considered in LCAs.

⁶ ENTSOE is the European Network of Transmission System Operators (TSO) for Electricity and represents 43 electricity TSOs from 36 countries across Europe. ENTSO-E was established and given legal mandates by the EU's Third Package for the Internal energy market in 2009 and produces generation outlooks as well as a long-term system adequacy forecast (the Scenario Outlook).

https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/scenario_report.pdf

⁷ ENTSO-E (2019), TYNDP 2020 – Scenario Report, Download data. [Link](#)

Because no official Eurostat data for 2018 or 2019 was yet available, T&E used the data recently compiled by Agora Energiewende⁸ from different sources (e.g. AG-Energiebilanzen in Germany, Carbon Brief in the UK, or ENTSO-E data verified with TSO's data), which was found to be the most up to date.

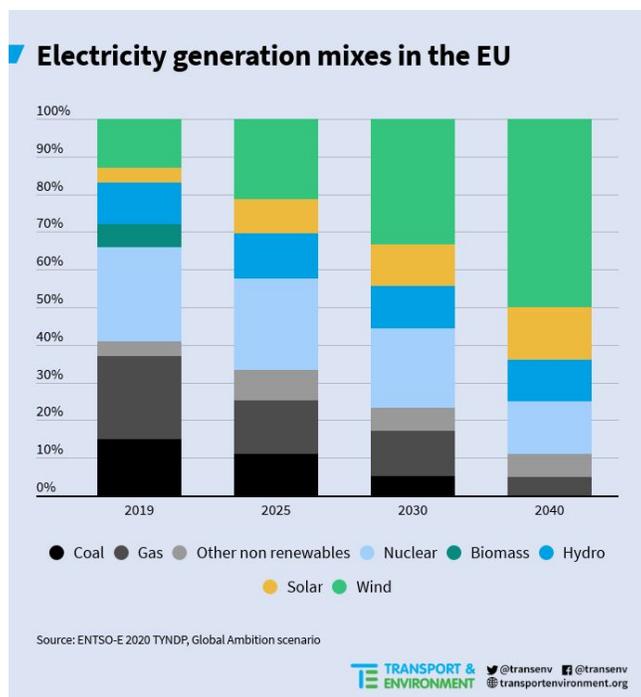


Figure 1: Electricity generation mixes in the EU (ENTSO-E 2020 TYNDP)

Finally, the carbon intensity of the grid was calculated based on the total life cycle CO₂ emissions for each electricity supply technology based IPCC's Fifth Assessment Report⁹, more details, see Annex I. To give an example, the calculated EU27 average carbon intensity of the electricity grid is 319 gCO₂e/kWh in 2020 and 168 gCO₂e/kWh in 2030 and 84 gCO₂e/kWh in 2040. Most studies do not rely on such dynamic data and rather use static, constant values for the carbon intensity of the electricity grid. For example one of the main studies used by anti-EV commentators, Buchal et al. 2019, uses 576 g/kWh (based on the German electricity mix from a couple of years ago)¹⁰ which compares to our estimate of 428 g/kWh for Germany in 2020.

⁸ Agora Energiewende (2020), The European Power Sector in 2019. [Link](#)

⁹ Intergovernmental Panel on Climate Change, IPCC (2014), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the IPCC - Annex III. [Link](#). Median values assumed

¹⁰ C. Buchal, H.-D. Karl, H.-W. SinnKohleMotoren, Windmotoren und Dieselmotoren: Was zeigt die CO₂-Bilanz? Ifo Schnelldienst, 72 (2019), pp. 40-54. [Link](#)

Carbon footprint of battery production

T&E's methodology for battery production emissions is forward looking for several reasons: it relies on updated carbon values for the electricity grid (see above), it is based on the scientific evidence from recent battery plants and it allows for the user to select the location of the battery production as well as the year of production of the battery (2020 or 2030).

This latest evidence shows that the **carbon impact of production of batteries** ranges from 61 to 106 kgCO₂e/kWh (maximum of 77 kgCO₂e/kWh when the heating source is optimised, see Section 5 - Impact of battery production) according to the 2019 updated study from IVL Sweden¹¹. Their previous estimate - from 2017 - ranged from 150 to 200 kgCO₂e/kWh and relied on scarce data from small scale production, with some dating back to 2010.

Production location: T&E has calculated the carbon footprint of the battery production based on the carbon intensity of the electricity used for manufacturing processes. The different locations for the battery production are the following: EU average (EU average electricity grid), EU low carbon (based Sweden's on high renewable electricity), EU high carbon (based on Poland's coal-rich electricity grid) and China (based on China's electricity grid). Both 2020 and 2030 electricity mix are considered for each of the locations.

The upstream part of the battery production (mainly **mining and refining**) is the same in all scenarios and only improves to a limited extent between 2020 and 2030. This is a conservative assumption and the improvement here could be significant thanks to the use of clean energy sources and relocating the battery value chain (including mining) within Europe (see Section 5. Future Outlook for more).

The **chemistries** considered for new battery cells are NMC (Nickel-Manganese-Cobalt) li-ion batteries - now used in most new EVs coming to market - for which the composition is shifting to lower cobalt content compared to previous NMC111 batteries which have dominated the market until recently (30% in 2016 according to BNEF, see Annex 1¹²). In 2020, we use NMC622 or NMC532 (2 out of 10 part of the cathode material is cobalt) batteries, which are effectively from the same generation of li-ion cells¹³ and represent together 45% of the market according to BNEF, while NMC811 (1 out of 10 part of the cathode material is cobalt) was selected for 2030 as it would make up 57% of the market in 2030.

¹¹ Transport & Environment (2018). EV batteries are getting cleaner and cleaner. [Link](#)

¹² The NCA batteries used in Tesla EV are not considered in this analysis for reasons: it's not the most representative chemistry (the relative share of NCA batteries decreases from 2020 where it's at 41%) and more importantly the literature consensus focuses on NMC.

¹³ NMC532 and NMC622 are effectively from the same generation of li-ion NMC batteries. NMC532 has the same content in cobalt and one share of nickel is substituted for one share of manganese.

Fuel and energy consumption

Fuel and energy consumption is based on real-world consumption declared values from millions of drivers, taken from the spritmonitor.de database¹⁴. Given the large sample, these have been proven to be representative of the overall gap of real-world CO₂ emissions compared to laboratory tests¹⁵. Unlike other studies, regulatory laboratory test protocols (WLTP or NEDC) are not used here because they seriously underrepresent the real-world fuel consumption (hence CO₂ emissions) due to the significant gap between laboratory and real-world emissions. This gap between real-world emissions and laboratory tests was around 39% in 2018 compared to NEDC according to ICCT¹⁶ (T&E has also published reports to expose this difference¹⁷). For conventional cars, the average real-world consumption of the 2018 top 10 most-sold vehicles¹⁸ for each category was considered (weighted average) as it was deemed representative of the fleet of new car sales in the next years. Similarly, a combination of spritmonitor and ev-database¹⁹ has been used to estimate the real-world energy consumption of electric cars. Energy consumption for electric cars and ICE cars was assumed constant within each vehicle category from 2020²⁰.

Vehicle characteristics

The vehicles types considered in this analysis are the common types found among EU drivers, i.e. :

- Small car or segment B car: e.g. Ford Fiesta, Peugeot 208 or Renault Zoe
- Medium car or segment C car: e.g. Volkswagen Golf, Nissan Qashqai and Leaf or the upcoming Volkswagen I.D. 3.
- Large car or segment D car: e.g. Volkswagen Passat, BMW 3-series, Tesla Model 3 and (upcoming) Y or Mercedes EQC.
- Executive car or segment E car: Audi A6 or A7, Volvo XC90 or Tesla Model S and X.
- High mileage cars (e.g. taxi, Uber) are large cars that travelled much longer distances. This corresponds to vehicles with a mileage of at least 30,000 - 40,000 km per year like taxis, ride-hailing vehicles or other shared vehicles.

¹⁴ Spritmonitor.de is a German website that collects and delivers information about the fuel consumption of vehicles under real-life conditions. The data base is provided by the users of the website themselves who log the fuel ups of their vehicles in the system.

¹⁵ ICCT (2019), Real-world vehicle fuel consumption gap in Europe is stabilizing. [Link](#)

¹⁶ ICCT (2019). From laboratory to road: A 2018 update. [Link](#)

¹⁷ Transport & Environment (2016). Mind the gap. [Link](#)

¹⁸ European Environmental Agency (EEA), Monitoring of CO₂ emissions from passenger cars – Regulation (EC) No 443/2009. Data from 2018.

¹⁹ Ev-database.org is an independant website that aims to gather as much real-world data as possible on electric cars on the market. The website relies on a series of real world tests and a model that calculates the real world energy consumption.

²⁰ Improvements in efficiency of diesel and gasoline cars is expected to be very small since carmakers will rely mostly on electrification to reduce their CO₂ emissions and reach their targets (this excludes hybridisation). Improvements in EV efficiency are not well addressed in literature and were conservatively assumed negligible.

Emissions from production of glider and powertrain

The emissions from production of glider and powertrain are extrapolated from the average weight of the vehicles in each category, which is calculated based on the Spritmonitor data (i.e. the average weight from Spritmonitor of the top vehicle models in each category). Based on the study (Ellingsen et al., 2016)²¹ -which relies on average European electricity- we have used the value of 4.8 tCO₂ released per kilogram of vehicle produced (battery excluded) in 2020, and 2.9 tCO₂/kg in 2030 (reduction in line with the average ‘greening’ of the EU electricity grid). Finally, because the conventional powertrain is much heavier and work intensive than the electric powertrain, we estimate based on a Ricardo study²² that the production of electric cars (excluding the battery) is about 10.7% less carbon intensive than for conventional equivalents. For more details, see Annex I.

Lifetime mileage

T&E’s analysis relies on latest evidence which shows that new electric cars will last long mileages and would even outlast diesel and gasoline cars (for more see Annex II, Longer vehicle lifetime for EVs). Therefore no battery replaced was assumed and the total distance travelled was assumed the same for EVs and ICEs (split over 15 years). Annual distance driven is assumed to reduce by 3% every year to take into account decreasing vehicle usage as vehicles age²³. The total lifetime distance travelled (or mileage) assumed is different per vehicle category, which is supported by the evidence that larger cars drive more than smaller ones. T&E makes the following assumptions for the lifetime mileage of cars: Small: 170,000 km, Medium: 225,000 km, Large: 280,000 km, Executive: 335,000 km and High mileage car: 500,000 km²⁴.

Upstream emissions from diesel and gasoline production

Often the Well-to-Tank (WTT) CO₂ emissions, also known as upstream or indirect emissions (extraction, processing, transportation and refining) of gasoline and diesel are omitted and only tailpipe combustion emissions are considered. In this tool we use the latest results from the Knobloch et al. (2020)²⁵ LCA analysis of EVs published in Nature in February 2020. They authors calculate that the

²¹ Ellingsen et al., 2016: The size and range effect: lifecycle greenhouse gas emissions of electric vehicles.

[Link](#)

²² Ricardo, Preparing for a Life Cycle CO₂ Measure, 2011. slide 53: emissions from vehicle production (excluding the battery for BEV) are 10.7% lower for BEV vs. total emissions from ICEV production (5t vs. 5.6t)

²³ Calculated based on Table 4-8 – Passenger car average annual mileages by age of vehicle from Ricardo (2015). Improvements to the definition of lifetime mileage of light duty vehicles. [Link](#)
Average annual rate for petrol: 3% and for diesel: 4%

²⁴ See Annex II where we show that the limit of half a million kilometers is probably already reached today with batteries lasting about 3,000 cycles over their lifetime. The comparison for shared vehicles assumes that the two large cars compared can last 500,000 km, which might not be the case for all cars.

²⁵ Knobloch et al. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time. [Link](#)

indirect (WTT) emissions increase the tailpipe emissions (TTW) by 28% for diesel and 26% for gasoline. This is equivalent to an additional 735 gCO₂e/L for diesel and 614 gCO₂e/L for gasoline.

Emissions considered here do not account for emissions related to the use of **biofuels** (biodiesel and ethanol), including indirect land use change (ILUC) emissions. Biofuels use is driven by policy and member states have different shares of blended biofuels in their fuel mix and rely on varying biofuels feedstocks with varying GHG emissions. This creates a highly complex and evolving framework which is out of scope here (see Section 5. Future outlook for more).

Electricity losses

Electricity grid transmission and distribution losses are applied to each country based on IEA statistics²⁶. On average at EU level transmission and distribution losses increase the carbon intensity of the grid by about 7%. On top of this, 10% efficiency losses were added: 5% from the charger equipment and 5% from the battery charging efficiency²⁷.

Several key factors like battery recycling, smart charging, vehicle-to-grid (V2G) and others will further improve the overall carbon footprint of electric cars but are not included in this version of the tool because of the current lack of methodology and data.

²⁶ Worldbank (2018). Electric power transmission and distribution losses (% of output). [Link](#)

²⁷ Transport & Environment (2018), Roadmap to decarbonise European cars. [Link](#)

3. Results: EVs better in all scenarios

For cars sold in 2020, a medium-sized EU-average electric car emits about 90 gCO₂e/km over its lifetime, while a diesel counterpart emits 234 gCO₂e/km and a gasoline car 253 g/km, including upstream emissions. Over the lifetime this is respectively 20 tons, 53 tons and 57 tons of CO₂. In other words, on average in the EU, the EV emits about 2.7 times less CO₂ than the conventional car in 2020 (2.6 times less than diesel and 2.8 times less than gasoline²⁸). When the battery is produced with clean electricity, the impact of electric cars decreases to 86 g/km or 2.7-3.0 times less than ICE. In the **best case**, if the electric car is run on clean renewable electricity (e.g. Sweden hydro power), then the GHG impact decreases to 11 tons of CO₂ (47 g/km) which is 5.0 and 5.4 times less than diesel and gasoline equivalents (see Figure 2 below). For large and executive categories, average EU electric cars are between 2.8 and 3.1 times better than conventional equivalents.

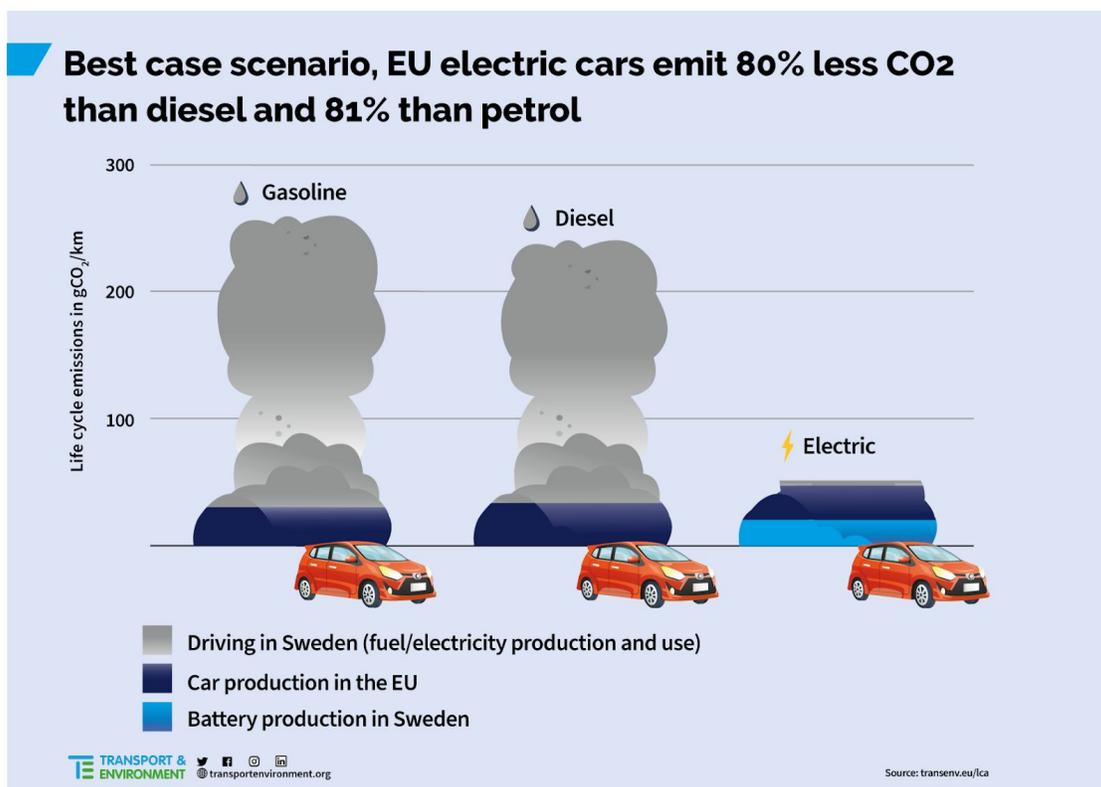


Figure 2: Lifetime CO₂ emission savings from EVs in the best case scenario

²⁸ Here diesel performs slightly better than gasoline thanks to better efficiency (L/100km) in real-world operations of most vehicles. If ILUC emissions of biodiesel were included, emissions from diesel would increase which would reduce or close the gap. It should be noted that this comparison is done for vehicles of the main segment and driving the same distance over their lifetime. In practice, diesel vehicles are typically bigger and heavier vehicles and drive longer during their lifetime, which would also play against diesel cars.

If the battery is produced in China, the impact of an average medium-sized EU EV increases to 22 tons (99 g/km) although this can be reduced to 21 tons (93 g/km) if optimised energy source is used for the heating and drying processes (see Section 5 - Impact of battery production). In this case, electric cars are still 2.5 to 2.7 times cleaner over their lifetime compared to diesel and gasoline counterparts.

In the **worse-case scenario**, the battery would be produced in China and the EV would run on one of the EU's most carbon intensive grids (e.g. Poland). In this situation, the lifetime impact increases to 41 tons of CO₂ (182 g/km) and EVs would still be 22% cleaner than the diesel counterpart and 28% cleaner than the gasoline counterpart (see Figure 3 below). Per EU member state comparison can be undertaken in the tool.

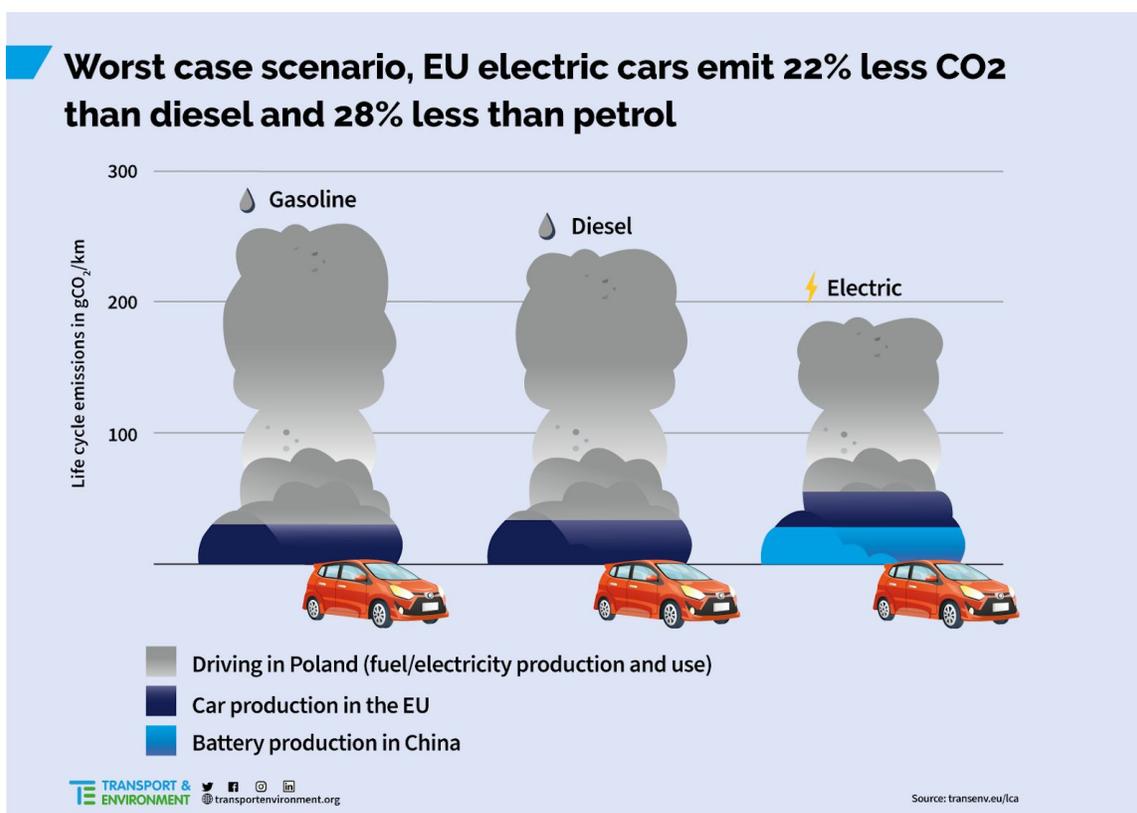


Figure 3: Lifetime CO₂ emission savings from EVs in the worst case scenario

Influence of national electricity grid over the use phase

The carbon intensity of the electricity used to charge the vehicle over its life has the highest impact over the lifecycle CO₂ emissions of electric cars. The results in this section correspond to a situation where the battery is produced with EU average electricity, so only the electricity used to charge the

vehicle changes. If an EV is recharged in Poland, which has one of the most carbon intensive electricity grids in Europe, an EV is still 26% cleaner than a diesel car (31% cleaner than a gasoline car, see Figure 4 below). In the Netherlands, Germany and Italy an electric car is slightly more than two times cleaner than a conventional car while in low carbon France and Sweden the impact is four to five times smaller (around 50g/km)²⁹.

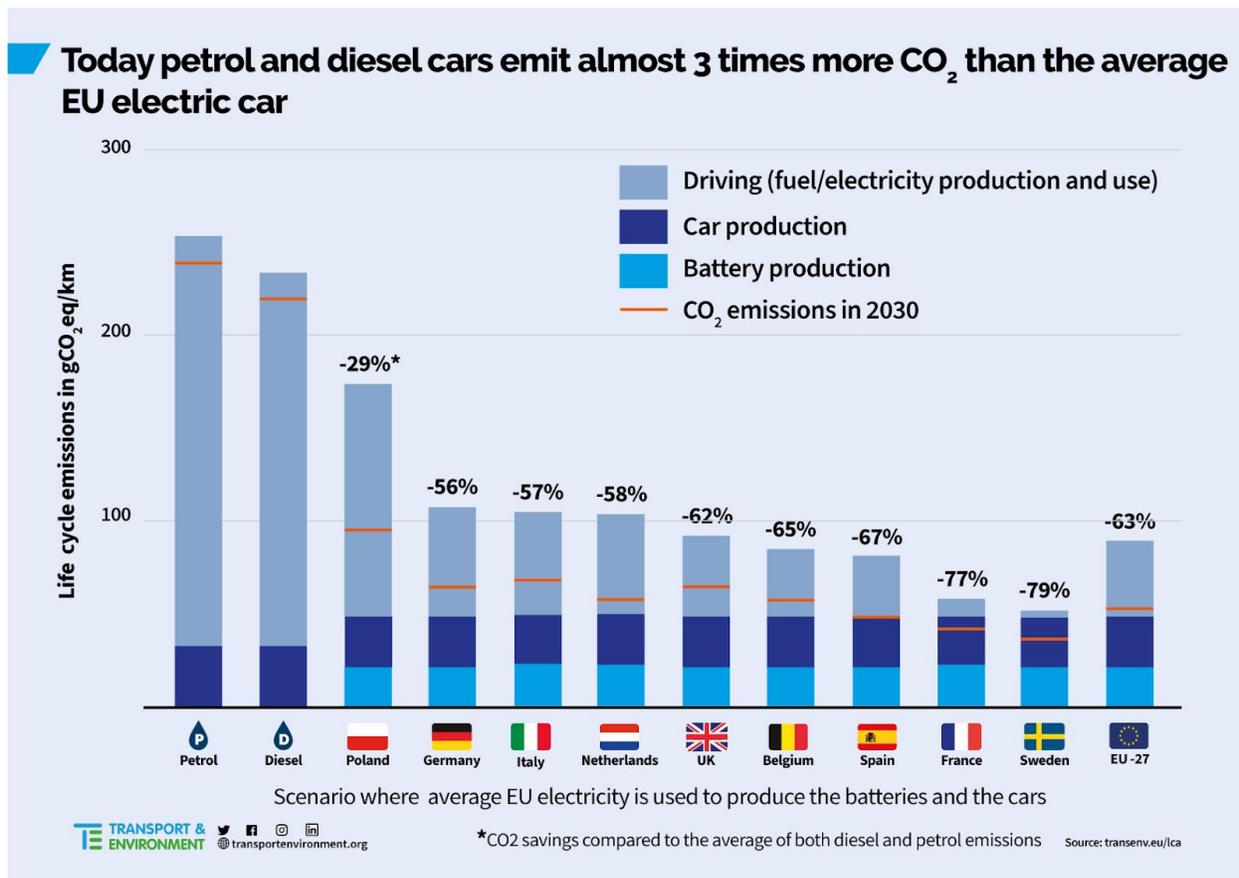


Figure 4: Lifetime CO₂ emission savings from electric cars in key EU countries

Displaced emissions per vehicle segment

If we replace the purchase of a conventional diesel or petrol car with the purchase of an electric car - while assuming the same segment and unchanged driving patterns (same distance driven over the lifetime) - we can note that, larger electric cars are able to displace more CO₂ than smaller ones, because they drive longer distances and consume more energy. On the other hand, if a small urban

²⁹ Only a selection of Member States were represented in the Figure for visibility purposes. These countries are deemed representative of the variability between Member States. However in the tool, all Member States are available and it is possible to compare any two EU countries.

gasoline car is replaced with a small electric car, the amount of CO₂ displaced is smaller even though the battery of the EV is much smaller. For example a small electric car displaces 24 tons of CO₂ while a medium, large and executive EVs displace respectively 32-37 tons, 45-54 tons and 63-68 tons (depending if compared to a gasoline or diesel car, see Figure 5 below).

Importantly, the amount of CO₂ saved is lower if a conventional car is replaced with a larger electric car while on the other hand, switching from a large conventional car to a smaller one driving lower distance (all the rest being unchanged) would generate even higher savings.

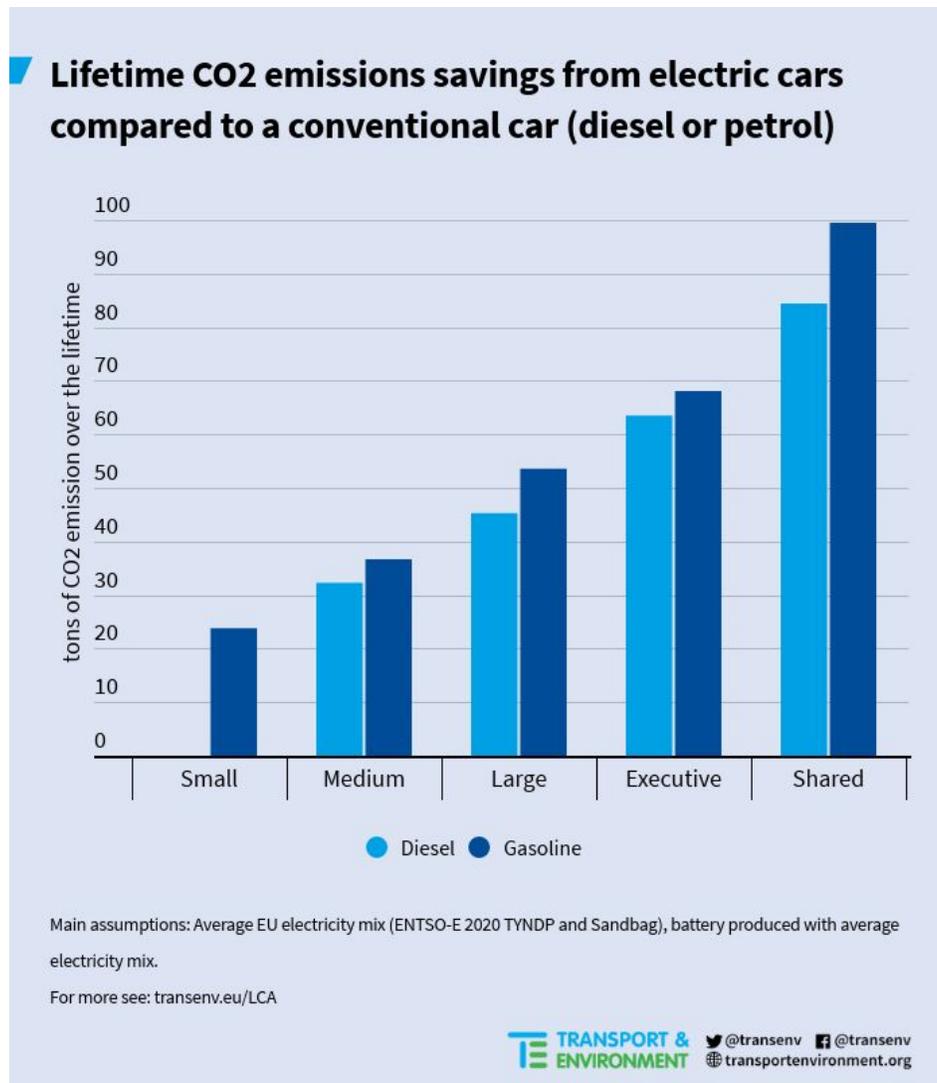


Figure 5: Lifetime CO₂ emission savings from electric cars in 2020

Shared vehicles

Vehicles that travel long distances and thus make intensive use of the battery have a better overall climate impact per kilometer driven (called 'high mileage' vehicles). T&E calculates that vehicles shared vehicles displace up to 84 to 99 tons of CO₂ over their lifetime and benefit from the lowest CO₂ impact per kilometer compared to other categories: 72 gCO₂e/km for the average EV and down to 30 gCO₂e/km for an electric car running on renewable electricity (E.g. Sweden electricity) and with a battery produced with clean electricity.

EVs reach carbon parity in one or two years

After production, electric cars quickly 'repay' their carbon debt' compared to equivalent conventional cars. It takes about one to two years of driving an electric cars to reach parity with diesel and gasoline (after approximately 23,000 km, see Figure 6 below). For electric cars with a battery produced on clean electricity and running on clean electricity, the excess carbon debt would be paid back after less than one year of driving (about 13,000 km).

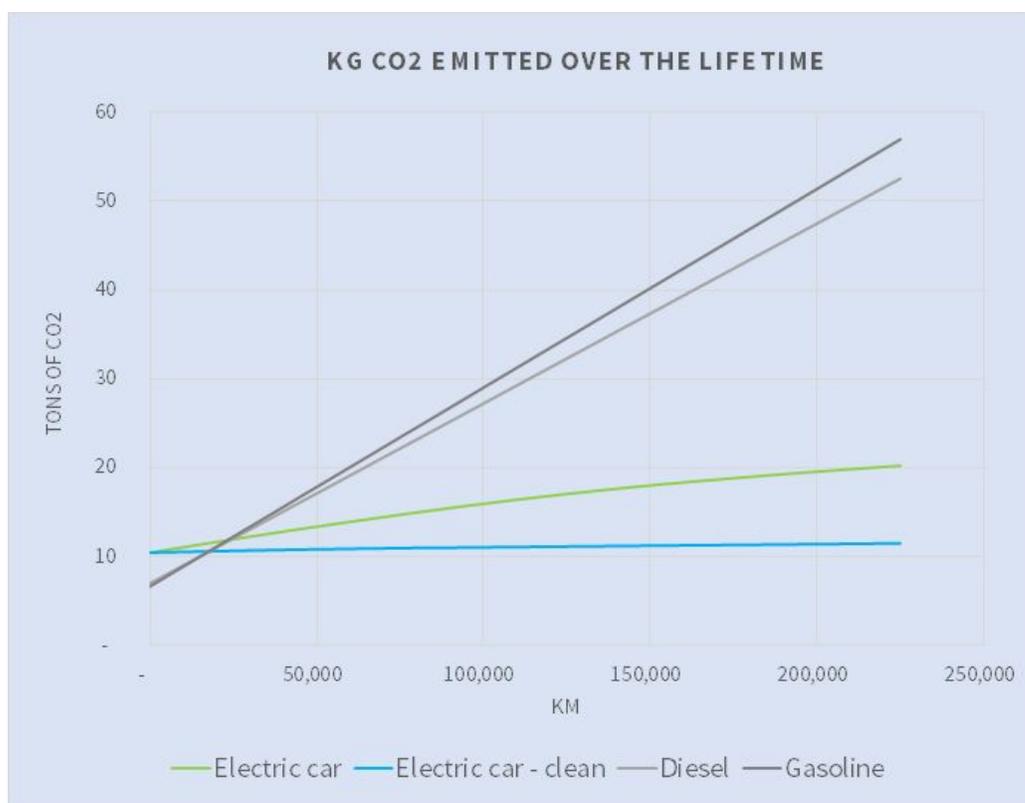


Figure 6: Evolution of lifetime CO₂ emissions of an average and clean EV

Comparison for EVs sold in 2030

The lifecycle emissions of EVs sold in 2030 are considerably better than those in 2020. The lifecycle emissions are reduced by about 41% on average for electric cars (medium category). Thanks to rapidly decarbonising electricity, the impact decreases down to 53 gCO₂e/km for an average EU medium electric car (4.2 times cleaner than a diesel car and 4.5 times cleaner than a gasoline car, see Figure 7 below). This increases to about 4.5-5.1 times the advantage over ICE cars for large and executive categories, and between 5.8 and 6.5 cleaner for shared EVs (40 gCO₂e/km).

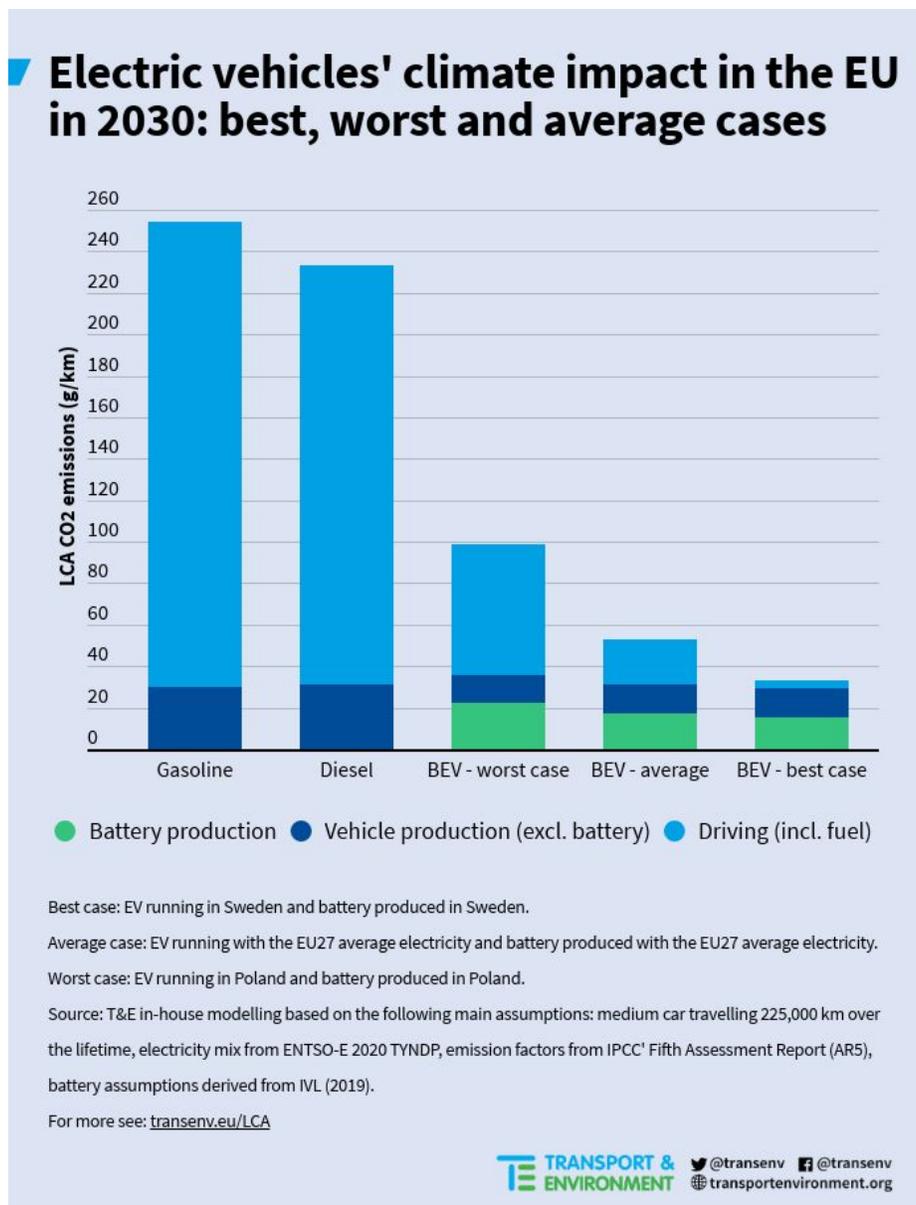


Figure 7: Lifetime CO₂ emissions of an electric car in 2030

4. LCA use in regulations

Lifecycle analyses cover the economy-wide array of actors and processes, as well as being a snapshot comparison depending heavily on the available evidence, methodology and assumptions. These two factors make them impossible to use in regulations, especially in those covering one industry part, e.g. car manufacturers.

First, LCA is an inadequate tool for vehicle emission standards. Any regulation based on LCA would create **many loopholes because of the shared responsibility** between the different actors of the wide value chain. It is of paramount importance to keep separate responsibilities for separate actors: the fuel suppliers have the responsibility to decarbonise the fuels while OEMs have the responsibility for the vehicles. We cannot hold EU carmakers responsible for the choices over energy mix in Poland or the battery manufacturing techniques in China.

As such, parameters included in LCA are already regulated in different EU directives and regulations. For example renewable fuels blended in diesel or gasoline, or the increase in renewable electricity generation is covered within EU renewable energy targets in the Renewable Energy Directive (RED II), while much of industrial emissions within the EU are covered by the EU Emissions Trading System (ETS). The European Commission is currently working on battery regulations that would cover aspects such as cell manufacturing, refining and reuse & recycling. Finally, today's EU vehicle CO₂ emissions standards based on tailpipe emissions cover the areas where the carmakers' responsibility lies (i.e. engines, motors, powertrain technology and overall vehicle efficiency) and should remain being based on tailpipe for regulatory purposes.

Second, LCAs are **inherently uncertain**. Each value calculated by the tool should be considered as a range given the uncertainties and variabilities underlying the assessment.

In some situations, where little previous evidence is available, uncertainties can be very high, especially when looking into the future. The biggest uncertainties exist for certain vehicles (e.g. heavy duty) and fuels (e.g. synthetic fuels and hydrogen) where the lack of data creates uncertainties that are today still too high to carry out a robust analysis. Moreover, precise individual LCA for each carmaker's model would not be feasible in practice because of the complexity of the supply chain and the level of information that would be needed on the specific production processes and composition of the vehicle. Therefore LCA results are for generic types of vehicles (e.g. segment C) and the validity for specific single vehicle models is naturally limited. It does not allow the level of detail needed to capture differences between models and OEMs. Another key uncertainty is the type of fuel or electricity that would be used by the vehicle during its lifetime as its driving patterns cannot be controlled or predicted with certainty. In particular the share and the content of biofuels (ethanol and biodiesel) varies greatly from one location to another and information on European blend average is

very scarce and uncertain, although the emissions from the fuel chain and the ILUC emissions could have a very high impact. The same could be said for the carbon content of the electricity used to charge the vehicle (e.g. solar PV vs. high-coal Poland electricity grid).

Nonetheless, the LCA is a good tool to **assess different policy options, to compare technologies or understand trends and emission hotspots**. T&E has developed this tool for those exact informative purposes to inform the debate in the media, academia and policy worlds as to the overall emissions of electric cars.

5. Future outlook: How EVs would become even cleaner

Some of our current assumptions used are likely to become outdated quickly compared to future literature. For this reason, T&E will keep the tool updated based on the most recent scientific evidence in the field and will document the changes made in Annex of this document. Below are key examples of assumptions and performance indicators which are likely to improve the LCA of EVs in the near future (more details provided in Annex II).

Recycling

Today, the amount of EV batteries that have reached the recycling stage is very small and is only available in pilot projects³⁰. However, the scale of EV battery recycling will significantly increase in the next few years as EU and national authorities will set recycling targets for these batteries once they have reached their end of life. According to Circular Energy Storage, there will be more than 400,000 tons of batteries reaching end of life in the EU in 2030. While several battery recycling processes exist (pyrometallurgical recycling, hydrometallurgical recycling, and direct cathode recycling), the greenhouse gas emissions impacts and economic prospects of these processes differ, and could vary by specific battery chemistry. According to (Ciez, R.E. et al., 2019)³¹, “while pyrometallurgical and hydrometallurgical processes do not significantly reduce life-cycle greenhouse gas emissions, direct cathode recycling has the potential to reduce emissions and be economically competitive”. Based on the authors’ research, CO₂ emissions avoided by using direct recycling with NMC battery cells could be around 1 to 2 kgCO₂e/kg battery. To correctly account for these benefits, further research on end-of-life recycling is needed to improve the methodology and availability of data.

Grid integration: smart charging and second life

Electric vehicles can contribute to the electricity grid in two ways during their lifetime: first, they could provide flexible electricity demand by charging at the right time (smart charging); second, EVs can

³⁰ Element Energy (2019), Batteries on wheels: the role of battery electric cars in the EU power system and beyond. [Link](#)

³¹ Rebecca E. Ciez & J. F. Whitacre (2019). Examining different recycling processes for lithium-ion batteries

provide electricity back to the grid (vehicle-to-grid or V2G). Both would increase the uptake of renewables (e.g. reduce curtailment rates) and minimise the need for peak fossil plants³². In particular, the charging of the car would be aligned with the wind or solar generation, which allows EVs to be charged with electricity that is on average greener than the average generation electricity.

Once the battery has reached around 80% of its original capacity, the electric car battery would either be recycled (see above) or be used for second life. During its second life, the battery is used for stationary electricity storage to support the electricity system, to facilitate the integration of renewable electricity sources and help stabilise the grid.

Both smart charging (including V2G) and second life of batteries represent an efficient use of resources to provide services to the grid and displace the production of new batteries and extraction of raw materials, which could otherwise be necessary to fulfil the same service. However, currently, there is very little research on the methodology and little data available to integrate smart charging and the second life of batteries in the assessment of the carbon impact of batteries, it was therefore excluded from the current scope of this assessment. On the other hand, this study doesn't account for the potential effect of fast charging and frequent cycling on the durability of the battery.

Impact of battery production

Some studies (presented in Annex II) suggest that the carbon emissions embedded in the production of the battery might be much lower in the future than our central estimate of 86 kgCO₂e/kWh, with values down to 40.5 kgCO₂e/kWh for battery cell production. Factors that are likely to have an influence and lower further the impact of battery cell production include (more details are presented in Annex II):

- Technological progress or breakthroughs in battery chemistry. Energy density of batteries increases constantly, which reduces the amount of material needed for one kWh and thus reduces in the same proportion the impact per kWh of battery. New chemistries will reduce the usage of the most impactful materials such as cobalt.
- Efficiency and scale of battery production. As the scale of battery production factories increased in recent years, the overall factory energy efficiency to produce one unit of battery capacity (kWh) has greatly improved. As more large battery production plants are deployed in the near future, data on this would need to be updated regularly .
- Battery producers can choose to rely on natural gas boilers for the energy-intensive heating and drying processes in places where the high-coal electricity increases significantly the footprint of the battery. This optimised heating is feasible today and would in some cases

³² Element Energy (2019), Batteries on wheels: the role of battery electric cars in the EU power system and beyond. [Link](#)

provide significant benefits on the carbon footprint of the battery production (therefore only affects battery production in location where the grid is very carbon intensive)³³. We estimate that the impact of batteries currently produced in China would decrease by 24% with this method (from 114 kgCO₂/kWh to 87 kgCO₂/kWh). For batteries produced in Poland, this would reduce from 95 kgCO₂/kWh down to 80 kgCO₂/kWh (-16%)

- Decarbonisation of the upstream supply chain of battery production: as the global and European economy decarbonise further, all applications along the value chain will see their CO₂ emissions reduce. Cleaner machinery will be used in the mines, refining plants will rely on cleaner electricity and transportation of materials will also decarbonise.
- Cleaner electricity: Thanks to the upcoming EU rules on the production of batteries, battery factories are expected to incorporate higher rates of renewable electricity in their production. Placing the battery factory in areas with high renewable energy production - like Northvolt is doing in Sweden - or adding on-site renewable electricity production will drive down emissions of battery production. This trend will be amplified by the expected increased EU ambition on the deployment of renewable energy in the 2020s (see below).

Increasing climate ambition for electricity generation

The European Green Deal sets the ambition for a decarbonised European Union by mid-century. In the next few years, European laws and regulations are expected to enshrine this and are likely to increase emissions reduction targets for 2030 down to 50% or 55% compared to the 1990 levels, necessitating a much faster deployment of renewables. ENTSO-E 2020 TYNDP scenarios were published in October 2019 and thus preceded the new European Commission's climate ambition (EU Green Deal communication was presented on the 11th of December 2019). The decarbonisation of the wider economy would also have a positive impact on the whole vehicle value chain, including the production of the glider and powertrain, and the upstream and end-of-life emissions of the battery value chain. According to Eurelectric, it is possible to fully decarbonise the European power sector by 2045 (and electric cars will play a significant role in achieving that goal thanks to synergies between the two sectors)³⁴.

Longer vehicle lifetime for EVs

In 2030, it is likely that EVs will outlast ICEs for two reasons. Firstly, electric motors last much longer than combustion engines as they are more robust and have less moving parts. Secondly, battery lifetime will enable electric cars to drive distances up to half a million kilometers (and possibly even more) before the battery has to be replaced (see Annex II). In the Annex, we show that the limit of half a million kilometers is probably already reached today with batteries lasting about 3,000 cycles over

³³ The assessment of natural gas boilers as an energy source for heating and drying does not seem to take into account methane leakage which could have the potential to balance off the benefits of using this energy source.

³⁴ Eurelectric (2018), Europe's power sector can decarbonise by 2045. [Link](#)

their lifetime. Conservatively, batteries are assumed to last 1,500 cycles (e.g. European Commission Ecodesign preparatory studies), which already allows the EV to drive more than 300,000 km for most vehicles categories (i.e. more than what was assumed in our current assumptions).

Biofuels

A full biofuels LCA includes estimates about direct emissions linked to biofuels production (cultivation, processing, transportation) and the indirect land use change (ILUC) impacts of biofuels demand. ILUC emissions refer to the additional CO₂ emissions due to land-use changes (e.g. deforestation) caused by the expansion of croplands for ethanol or biodiesel production (which are then blended in gasoline and biodiesel). The majority of biofuels used in Europe today are crop biofuels and ILUC emissions vary depending on the biofuels feedstocks. Crop biodiesel -which still represents the majority of biodiesel in Europe- is worse for the climate than fossil diesel because of these LUC impacts³⁵. Overall, the use of crops for fuels is not an efficient, scalable and sustainable way of decarbonising transport fuels.

This briefing does not include emissions linked to biofuels for the following reasons:

- The share of biofuels blended in petrol and diesel varies from one country to another . For example, not all countries allow for E10 (petrol blend with up to 10% bioethanol) and, even if they do, E5 (5% blend of ethanol) may continue to dominate these markets³⁶.
- Life-cycle emissions per biofuels' feedstocks vary a lot and there is no uniform data for the split between feedstocks at EU level. In some countries (e.g. Netherlands) biofuels are mostly based on waste with low or no ILUC impact and some others like Spain rely mainly on palm oil (which is the feedstock with the worse ILUC impact).

Short conclusion

The potential of electric cars to mitigate CO₂ emissions is crystal clear: on average EVs are close to three times cleaner than diesel and petrol cars today. Discussing whether or not coal-fuelled electric cars are better or worse for the climate than conventional cars is no longer relevant (EVs are 30% cleaner even then). The urgency should be placed on accelerating the transition to electric mobility while at the same time decarbonising the electricity grid. Awaiting for the grid to decarbonise before shifting to zero emission mobility would increase further CO₂ emissions and would seriously compromise any chances of reaching the Paris Agreement. Given the already significant lifetime benefit of electric cars, the EU should put in place an **EU-wide phase out of ICE cars by 2035 at the latest** (only zero emission vehicle sales) with a higher intermediate CO₂ emission reduction targets after 2025.

³⁵ Transport & Environment (2016). Globiom: the basis for biofuel policy post-2020. [Link](#)

³⁶ European Commission (2017). Evaluation report of the fuel quality directive. [Link](#)

Furthermore, T&E calls for a wider use of updated data and further research on key topics. In particular, there's today little research to correctly account for the environmental gains from li-ion battery recycling (or energy/chemical penalty of some processes) and second life. New LCAs should be carefully peer-reviewed and should be assessed with regard to the added value they provide, the amount of new primary research that is included and to what extent the data used is outdated with regards to technological progress and latest scientific evidence. Uncertainties should be explicitly communicated for better understanding and robust policy support.

Further information

Lucien Mathieu
Transport & Emobility Analyst
Transport & Environment
lucien.mathieu@transportenvironment.org
Mobile: +32(0) 83 08 48 91

Annex I - Supplementary material on main assumptions

Life-cycle carbon intensity of electricity sources

The carbon intensity of the electricity grid was calculated including total lifecycle CO₂ for each selected electricity supply technology based on IPCC (median value, see Figure 8 below)³⁷.

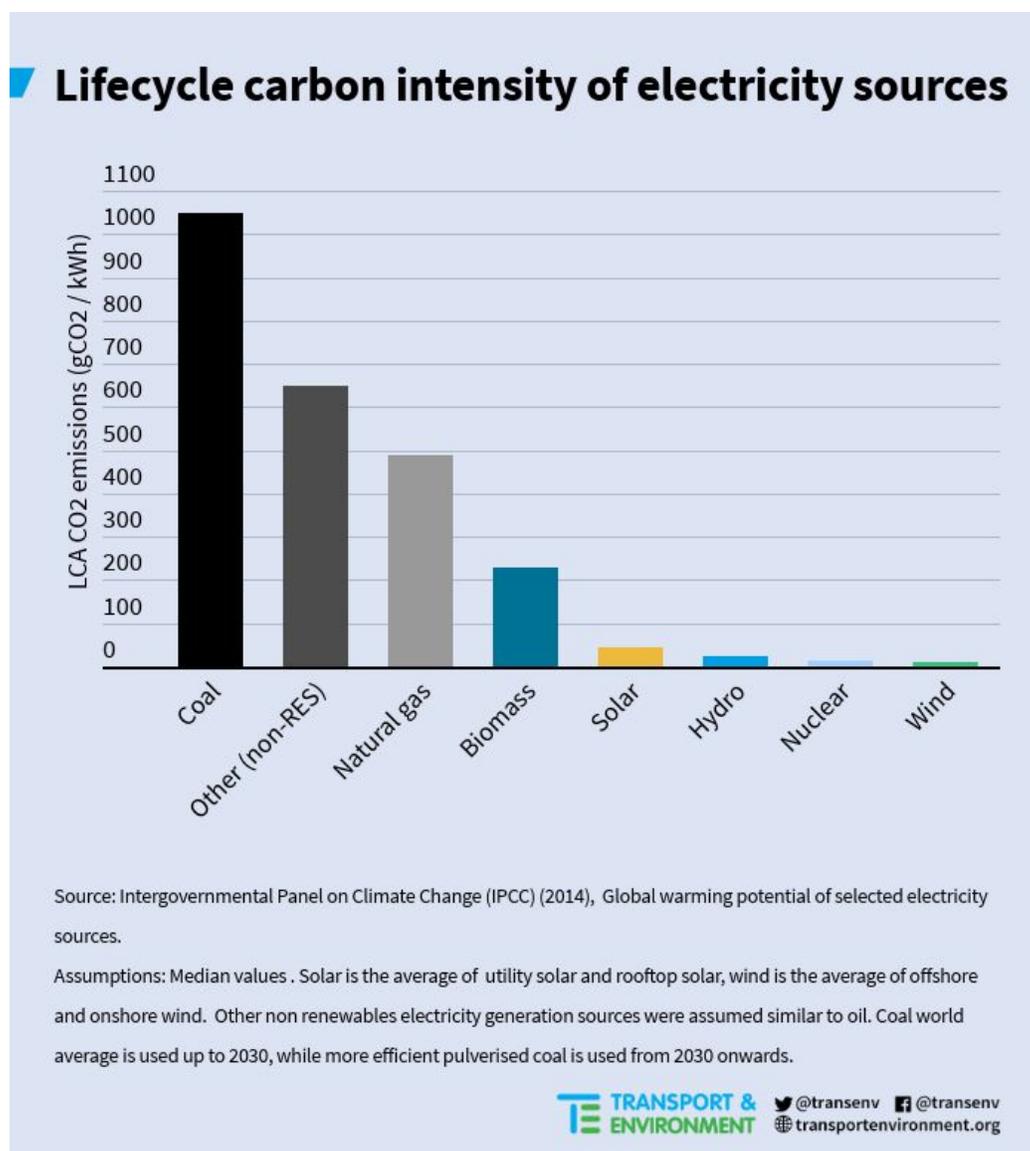


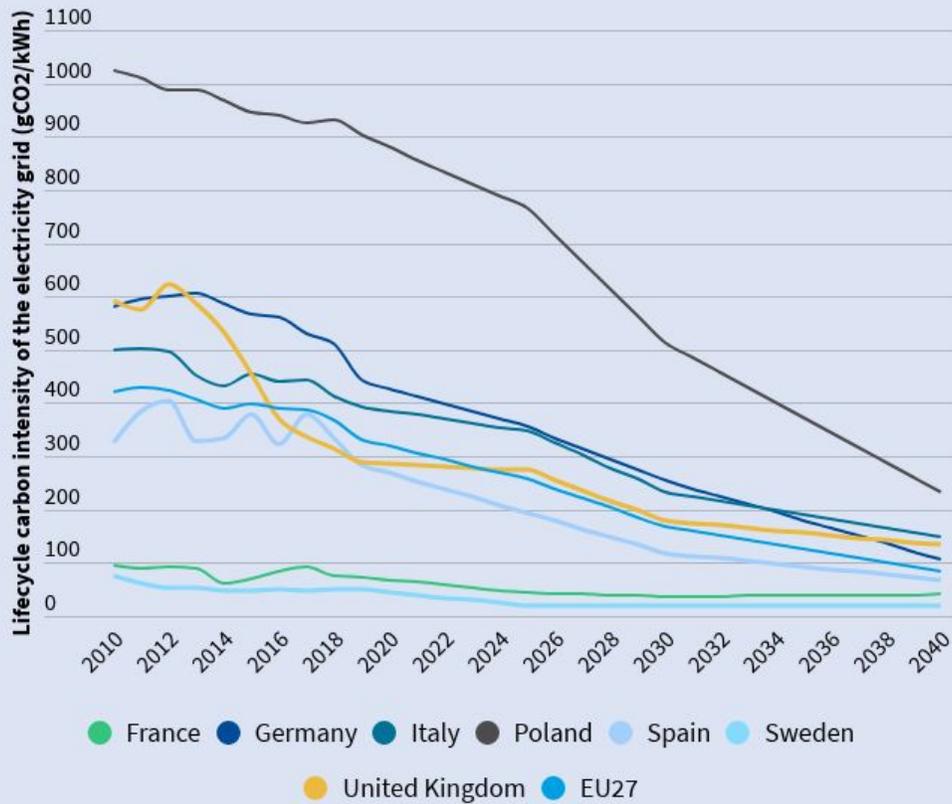
Figure 8: Lifecycle carbon intensity of electricity sources (IPCC)

³⁷ 2014 IPCC, Global warming potential of selected electricity sources.
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7

For each country the lifecycle carbon intensity of the electricity was assumed to evolve linearly between 2019 and 2025, between 2025 and 2030 and between 2030 and 2040. Data from 2010 to 2019 are historic data from Sandbag (which is Eurostat official up to 2017) while forecasted data are from ENTSO-E 2020 TYNDP (beyond 2020). Electricity grid transmission and distribution losses are applied to each country based on IEA statistics³⁸. On average at EU level transmission and distribution losses increase the carbon intensity of the grid by about 7%. The final carbon intensity in some key EU countries is shown in Figure 9 below.

³⁸ Worldbank (2018). Electric power transmission and distribution losses (% of output). [Link](#)

Lifecycle carbon intensity of the electricity grid in key EU countries



Source: Future electricity generation from ENTSO-E (Global Action scenario) from the 2020 TYNDP, Historic data from Sandbag and Eurostat (up to 2019), lifecycle emissions factors from IPCC Fifth Assessment Report 2016 and transmission & distribution losses from IEA.

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transportenvironment.org

Figure 9: Lifecycle carbon intensity of the electricity grid in key EU countries

For Belgium and Spain, the carbon intensity in 2025 was not in line with current trends (2019) or not compatible with 2030 levels, therefore the carbon intensity was assumed to decrease linearly between 2020 and 2030.

This bottom-up approach differs from other top-down approaches where the total annual emissions are divided by the amount of electricity produced. Top-down methods account for country-specific

efficiencies in the generation of the electricity (for example, the fleet of coal power plants might be more or less efficient than the IPCC generic value) and can yield higher carbon intensity values in some cases.

Carbon footprint of battery production

The GHG impact of the production of batteries was adjusted based on the electricity used for the production of cells and assembly of the battery. The assumptions and evidence for the modelling of the emissions from battery production are to a large extent based on this IVL study from November '2019 Lithium-Ion Vehicle Battery Production³⁹. More details are provided in the Annex I.

The Table below summarises the key results, where the upstream part of the battery production (mining, refining etc) is responsible for 59 kgCO₂e/kWh while the cell production and pack assembly are responsible for 2 kg/kWh to 47 kg/kWh based on the carbon intensity of the grid. In our model, upstream emissions from battery production are slightly lower because of chemistry and density improvements (see below).

Table 8. The sum of the results of the two scenarios for cell production and pack assembly from Table 7 and the upstream material GWP from Dai et al. (2019) which was 59kg CO₂-eq/kWh consumed.

Scenario	Energy sources of cell and pack manufacture	Sum GWP from cell and pack manufacture [kg CO ₂ -eq/kWh]	Total GWP [kg CO ₂ -eq /kWh capacity]
Scenario 1	Electricity: Renewable mix – fossil-fuel rich mix Heat: Electricity, Renewable mix – fossil-fuel rich mix	2-47	61-106
Scenario 2	Electricity: Renewable mix – fossil-fuel rich mix Heat: Natural gas with boiler efficiency 80%.	11-18	70-77

Table 1: Results for carbon footprint of battery production (IVL, 2019)

If the electricity grid is very carbon intensive, the impact can be reduced by using natural gas boiler for the heating and drying (responsible for a large majority of the emissions). According to (Dai et al. 2019), 140 MJ of energy is required for the heating and drying with a gas boiler per kWh of battery produced (which translates into 10.1 kg/kWh with 80% boiler efficiency).

Location for battery production

The available options for the location of production of the battery cell and pack manufacturing are the following:

³⁹ IVL (2019), 2019 Lithium-Ion Vehicle Battery Production. [Link](#)

- EU average: the electricity used has the (life cycle) carbon intensity of the average European grid
- EU low: the electricity used has the (life cycle) carbon intensity of Poland
- EU high: the electricity used has the (life cycle) carbon intensity of Sweden
- China: the electricity used has the (life cycle) carbon intensity of 919 g/kWh in 2020 and 810 g/kWh which is based on Knobloch et al. (2020)⁴⁰

Battery chemistries

The following chemistries were assumed:

- NMC622 chemistry is the default option in 2020 as it is more representative of the 2020s li-ion battery market than NMC111. According to BNEF (see image below), NMC622 and the similar NMC532 account for 45% of the market in 2020. IVL (2019) calculates that NMC622 requires 4% less energy to produce than NMC111 (11% less CO₂ emissions).
- NMC811 chemistry is the default option in 2030 as BNEF assumes that it will make 57% of the market by then (see below). IVL (2019) calculates that NMC811 requires 7% less energy to produce than NMC111 (14% less CO₂ emissions).

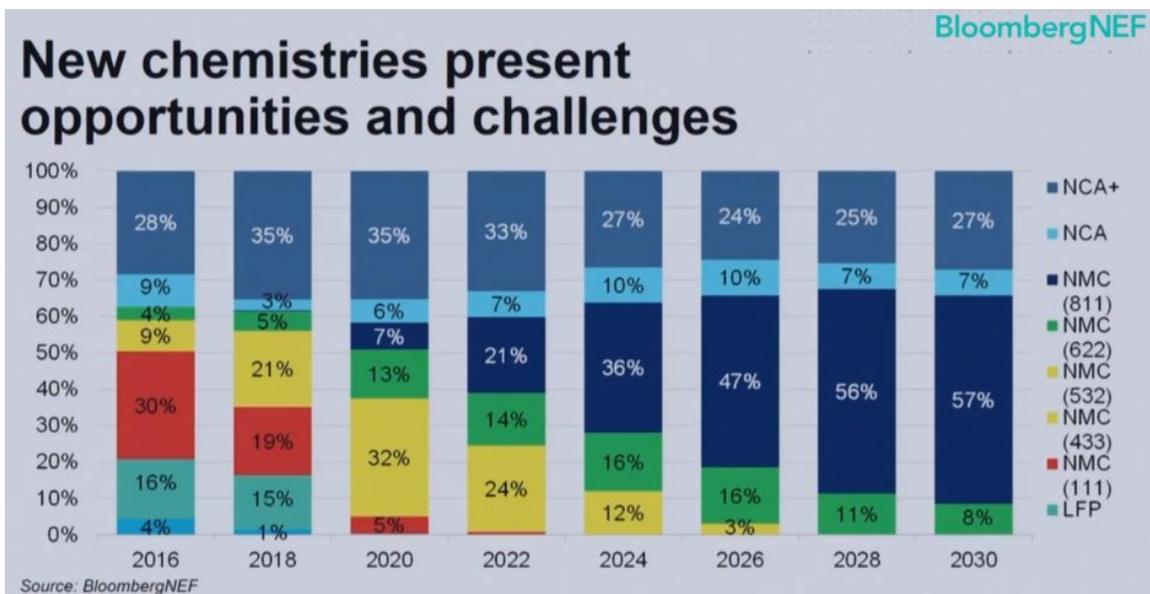


Figure 10: Li-ion battery chemistries up to 2030 (BNEF)

These density and chemistry improvements of battery cells are taken into account based on the above. As a result the emissions for upstream production of one kWh of battery decreases from 59 kgCO₂e/kWh with NMC111 batteries in the late 2010s to 57 kg/kWh for NMC622 in 2020 and 55 kg/kWh for NMC811 in 2030. Conservatively we assumed here that the upstream emissions from battery

⁴⁰ Knobloch et al. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time. [Link](#)

production only decrease thanks to battery cell density improvements and not from decarbonisation of the upstream processes in mining, refining and transportation of materials. Emissions for transport of the finished battery product from China is not considered here.

Carbon content of battery production (including upstream)

Production region	2020 (kgCO ₂ /kWh)	2030 (kgCO ₂ /kWh)
EU average	75	64
EU low	59	56
EU high	107	84
China	110	100

Table 2: Carbon content of battery production

Vehicle characteristics

Emissions from production of glider and powertrain is extrapolated from the average weight of the vehicles in each category which is calculated based on spritmonitor information (i.e. the average weight from spritmonitor of the top vehicle models in each category). The study (Ellingsen et al., 2016)⁴¹ has researched values for CO₂ emissions per kg of vehicle produced (between 3.9 and 5.7 tCO₂/kg), we’ve used the median value of 4.8 tCO₂/kg in 2020. The carbon intensity of the vehicle production in 2030 was estimated by adjusting the 2020 value linearly based on the average EU reduction of the carbon intensity of the electricity grid from 2020 to 2030: 2.9 tCO₂/kg of vehicle produced. Electric drivetrains are lighter and composed of less parts than diesel or gasoline powertrains, therefore

⁴¹ Ellingsen et al., 2016: The size and range effect: lifecycle greenhouse gas emissions of electric vehicles

emissions from the production of the glider and powertrain of electric cars is expected to be smaller than their fossil fuelled counterparts. Based on results from a Ricardo⁴² study we estimate that the production is about 10.7% less carbon intensive for electric cars (in 2020 and 2030). This result is aligned -although slightly more conservative- with (Hoekstra A., 2019)⁴³, which estimates that production of electric cars requires one to two tons less CO₂ (excluding the battery). T&E calculates 7.8t CO₂ for the production of a large diesel car where (Hoekstra A., 2019) uses 8 tons.

The size of the battery or total capacity in kWh for electric cars was assessed based on the most recent trends and market benchmarks. The same values were used for 2020 and 2030.⁴⁴

Segment	GHG emissions from glider & powertrain (t)				Efficiency			Battery capacity (kWh)
	ICE 2020	ICE 2030	EV 2020	EV 2030	Gasoline (L/100 km)	Diesel (L/100 km)	BEV (kWh/100km)	
Small	5.5	2.9	5.0	2.6	6.6	N.A.	16	45
Medium	6.7	3.5	6.0	3.1	7.5	6.0	17.5	60
Large	7.8	4.1	7.0	3.7	8.6	6.7	19	75
Executive	9.4	5.0	8.4	4.4	9.1	7.6	20.5	90
Shared	7.8	4.1	7.0	3.7	8.6	6.7	19	75

Table 3: Vehicle details: glider production and efficiency

⁴² Ricardo, Preparing for a Life Cycle CO₂ Measure, 2011. slide 53: emissions from vehicle production (excluding the battery for BEV) are 10.7% lower for BEV vs. total emissions from ICEV production (5t vs. 5.6t)

⁴³ A. Hoestra. The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions. Joule, 3 (2019), pp. 1412-1414

⁴⁴ T&E has shown that the average size of batteries produced in Europe in 2025 will be 60 kWh. Transport & Environment. Electric surge: Carmakers' electric car plans across Europe 2019- 2025. July 2019

Annex II - Improvement potential based on available evidence

In this section we present several pieces of available evidence that show that EVs are likely to become cleaner in 2030 than what is presented in the tool. Currently, not taken into included, these improvements could be taken into account at a later stage.

Impact of battery production dropping further

Some studies suggest that the carbon emissions embedded in the production of the battery might be much lower in the future than our minimum estimate of 58 kgCO₂e/kWh.

The 2019 study ‘Eco-Efficiency of a Lithium-Ion Battery for Electric Vehicles: Influence of Manufacturing Country and Commodity Prices on GHG Emissions and Costs’ from authors Philippot et al.⁴⁵ shows that battery emissions from battery manufacturing could decrease down to 40.5 kgCO₂e/kWh once four criterias are met (see Figure 11 below): production volume reach a high level (e.g. today’s plans for factories producing several dozens of GWh per year), processes are optimised, low carbon electricity is used (e.g. in Sweden, with renewable electricity generated on site) and increase in energy density of batteries produced. No dates are provided as to when these criteria would be met, but it is expected that large factories planned in Europe for the early 2020s could meet these performances if they relied on renewable electricity.

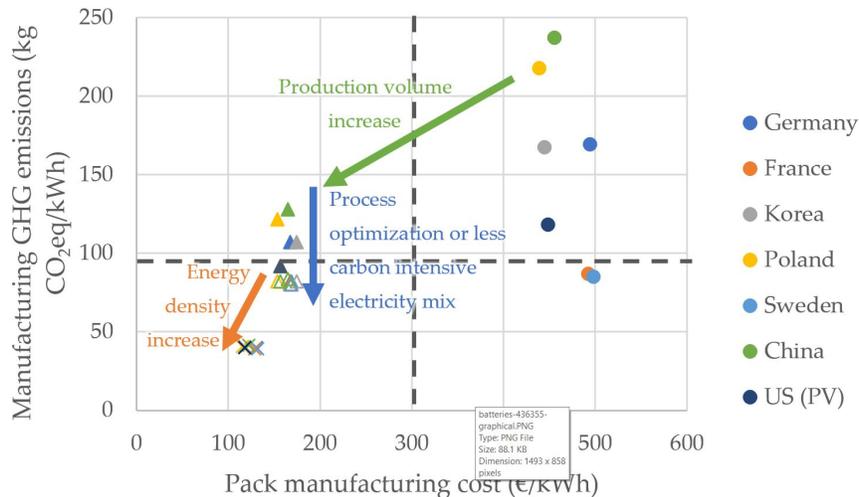


Figure 11: Manufacturing GHG emissions (Philippot, M. et al, 2019)

⁴⁵ Philippot, M.; Alvarez, G.; Ayerbe, E.; Van Mierlo, J.; Messagie, M. Eco-Efficiency of a Lithium-Ion Battery for Electric Vehicles: Influence of Manufacturing Country and Commodity Prices on GHG Emissions and Costs. Batteries 2019, 5, 23.

In the 2019 study ‘The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions’⁴⁶, author A. Hoekstra makes the case that the environmental and climate impact of electric cars will greatly reduce in the future. This study assumes that 65 kg of CO₂ is emitted for every kWh of battery produced which is between our ‘EU average’ and ‘EU low’ scenarios. Author claims that ‘it is not an exaggeration to say that in such a scenario, the GHG emissions of batteries could be further reduced by a factor of ten or more’. The author justifies this reduction by the fact that though an integral system approach based almost exclusively on renewable energy, the potential of batteries and EVs to reduce CO₂ emissions would be much further improved. If the EU reaches climate neutrality by 2050 as it is targeted by the European Green Deal, the entire automotive supply chain as well as the production of steel and aluminum, mining, refining and recycling of metals and the transportation of products would all run on renewable electricity.

Longer vehicle lifetime for EVs

According to (Hoekstra A., 2019) current batteries are estimated to last at least 1,500 to 3,000 cycles, while the Ecodesign preparatory study uses 1,500 cycles over the lifetime of an EV⁴⁷. According to another study from 2018 that surveyed a panel of experts from academia and industry on the prospective improvements in cost and cycle life of batteries⁴⁸, the cycle life of batteries would increase to between 5,000 and more than 10,000 cycles are expected in 2030 (as reported by Hoekstra A.). Advances like solid-state electrolyte could further increase the lifetime while making batteries non-flammable. The Table 4 below shows how the cycle life of batteries impacts the lifetime distance that can be driven by battery electric vehicles (rounded figures). The results assume a generous 20% DoD and 20% safety margin to account for the capacity fade over the lifetime of the battery. It should be noted that assumptions used in this publication are more conservative than what is presented below. As more evidence of the real-world durability of batteries is brought forward, this analysis will be updated accordingly.

⁴⁶ A. Hoekstra. The Underestimated Potential of Battery Electric Vehicles to Reduce Emissions. Joule, 3 (2019), pp. 1412-1414

⁴⁷

https://ecodesignbatteries.eu/sites/ecodesignbatteries.eu/files/attachments/ED_Battery_Task%207_V45_final_corrected.pdf

⁴⁸ S. Few, O. Schmidt, G.J. Offer, N. Brandon, J. Nelson, A. Gambhir. Prospective improvements in cost and cycle life of off-grid lithium-ion battery packs: An analysis informed by expert elicitations. Energy Policy, 114 (2018), pp. 578-590

Segment	Range (km)	2020		2030	
		Lifetime distance @ 1,500 cycles (in km)	Lifetime distance @ 3,000 cycles (in km)	Lifetime distance @ 5,000 cycles (in km)	Lifetime distance @ 10,000 cycles (in km)
Small	281	270,000	540,000	900,000	1,800,000
Medium	353	340,000	680,000	1,130,000	2,260,000
Large	395	380,000	760,000	1,260,000	2,530,000
Executive	439	420,000	840,000	1,400,000	2,810,000

Table 4: Scenarios for lifetime durability of EV batteries

According to the (Buchal et al. 2019)⁴⁹ study in which Hans-Werner Sinn participated⁵⁰, large ICEVs last 300,000 km which is slightly less conservative than what we've assumed for both EVs and ICEs. Ricardo's LCA methodology uses 225,000 km driven over 15 years for medium cars, which is in line with our assumption.

Researchers which have recently tested batteries for three years have concluded that li-ion cells (in this case NMC532) should be able to power an electric car for over 1.6 million kilometers and last at least two decades in grid storage⁵¹. The lifetime of these cells far exceeds that of other NMC/graphite cells reported in the literature and are more representative of modern Li-ion cells according to researchers. The paper finds that thermal management of the battery cells is crucial to ensure these long lifetimes.

⁴⁹ C. Buchal, H.-D. Karl, H.-W. Sinn Kohlemotoren, Windmotoren und Dieselmotoren: Was zeigt die CO₂-Bilanz? Ifo Schnelldienst, 72 (2019), pp. 40-54. [Link](#)

⁵⁰ The Guardian. Yes, electric vehicles really are better than fossil fuel burners, November 2019. [Link](#)

⁵¹ J.E. Harlow et al. (2019). A Wide Range of Testing Results on an Excellent Lithium-Ion Cell Chemistry to be used as Benchmarks for New Battery Technologies. [Link](#)