FARADAY INSIGHTS - ISSUE 12: NOVEMBER 2021

THE FARADAY INSTITUTION

The UK: A Low Carbon Location to Manufacture, Drive and Recycle Electric Vehicles

Stephen Gifford,
Chief Economist, Faraday Institution

Electric vehicles (EVs) have much lower life cycle carbon emissions than petrol and diesel vehicles using internal combustion engines (ICE). Carbon emissions[1] over the EV life cycle are falling fast as the UK electricity grid is decarbonised and the UK moves towards Net Zero. Total life cycle carbon emissions of a medium-sized battery EV will be about one-quarter of a petrol car sold in 2025, with UK-manufactured EV batteries 12% greener than the European average.

Introduction

Battery electric vehicles (BEVs) are often referred to as zero emission vehicles, but this definition only captures tailpipe emissions – the gas and particles emitted during the operation of the vehicle. Carbon emissions[1] will also arise from the manufacture of the EV and the battery, from the generation of electricity used to charge the EV, and the energy used for recycling once the vehicle and battery reaches its end of life. Our conclusion is clear that the shift to BEVs from petrol vehicles will bring about a substantial reduction in UK greenhouse gas emissions.

The availability of renewable energy in the UK will be a big draw for global battery manufacturers considering building gigafactories in the UK. EV batteries manufactured in the UK could easily be advertised as 'greener' given that they will generate 12% lower emissions than the European average and 24% lower than Germany in 2025.

Quantifying the total carbon emissions generated across each of the manufacturing, usage and recycling stages is referred to as a life cycle assessment (LCA). The LCA makes sure that a comparison of emissions from EVs and ICE vehicles are conducted on a consistent basis. This Faraday Insight provides an assessment across the full 'cradle-to-grave' life cycle (Figure 1) from the mining of the raw minerals required to manufacture the EV and battery (the 'cradle') to end-of-life recycling of the battery (the 'grave'). Other life cycle assessments are also illustrated and include cradle-to-gate, well-to-tank, tank-to-wheel and well-to-wheel.

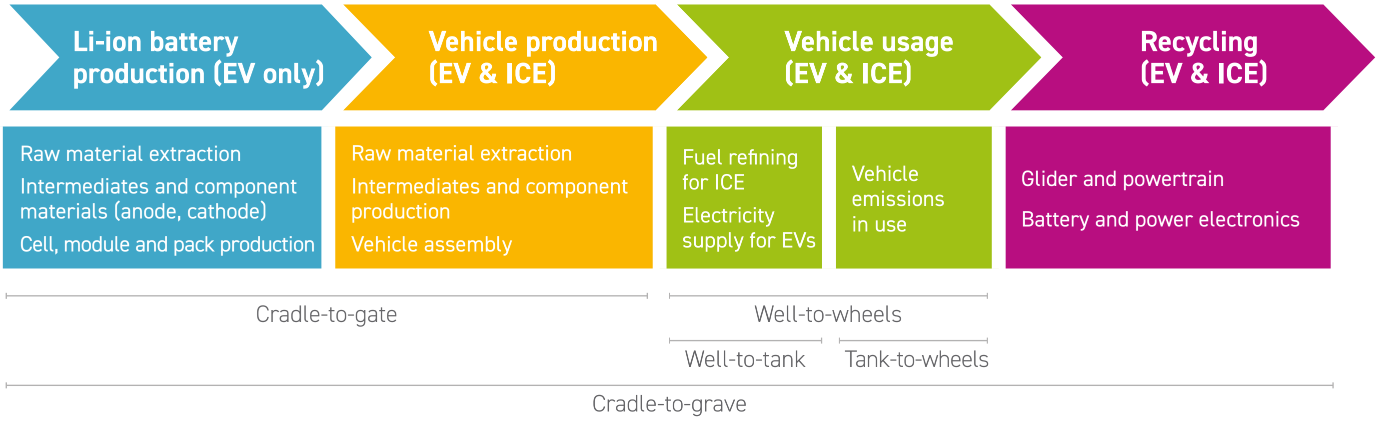
Life Cycle Carbon Emissions: BEVs versus ICE

Small, medium and large[2] BEVs sold in the UK in 2025 are estimated to generate around one-quarter the amount of carbon emissions of an equivalent-sized petrol or diesel[3] vehicle over the full life cycle including raw mineral extraction, vehicle production, battery manufacturing, usage/charging, and battery recycling.

A medium-sized BEV (typically a small family car) sold in 2025 is estimated to emit a life cycle total of 10.7 tonnes of carbon dioxide equivalent (CO_2e) compared to 38.5 tonnes from an equivalent-sized ICE vehicle. Around 40% of BEV carbon emissions are generated from usage/charging followed by vehicle production (32%), battery manufacturing (25%) and

[1] Carbon emissions' is used as short form to define greenhouse gases (GHG), with carbon dioxide being the most significant GHG. 'Carbon dioxide equivalent' or 'CO_2e' is used throughout this Insight to describe GHG in a common unit of measurement.
[2] Three vehicle sizes are modelled. These are defined as small (Category A / city car), medium (Category C / small family car) and large (Category E / executive car).
[3] Total carbon emissions from diesel vehicles are estimated to be 8% lower than from petrol vehicles, largely due to better efficiency in real world situations. Sales of diesel are, however, falling fast due to concerns about impacts on air quality. The results of the modelling in this Insight are therefore focused on petrol vehicles.

Figure 1: Life cycle assessments

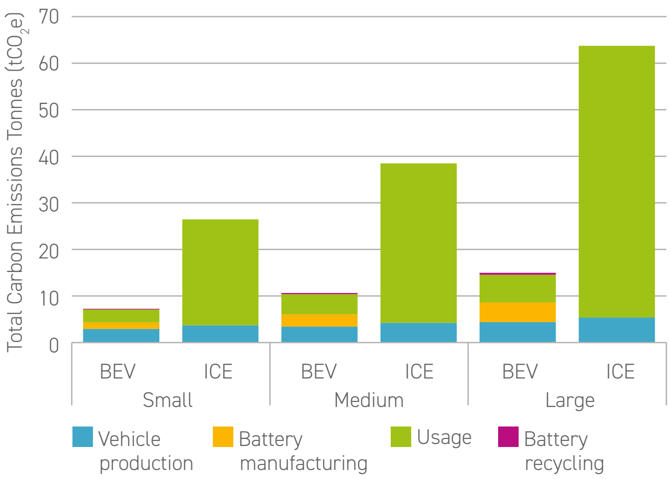


The extent to which EVs reduce carbon emissions is the subject of a confusing debate, largely caused by analysis looking at discrete and incomplete parts of the EV and ICE vehicle life cycle. This Insight has tackled this issue by examining carbon emissions generated across the full 'cradle-to-grave' life cycle of petrol vehicles and EVs.

recycling (3%). Estimates for different sized BEV and ICE vehicles across each part of the life cycle are shown in Figure 2.

At current levels, BEVs are already responsible for substantially lower carbon emissions than petrol vehicles during the use phase, but BEV emissions will reduce further still as the UK electricity grid decarbonises. For medium-sized vehicles sold in 2025, just 4.3 tonnes of CO_2e are

Figure 2: Total life cycle carbon emissions from EVs and ICE sold in 2025



Source: Faraday Institution estimates, based on various sources including Global EV Outlook, ICCT, EEA, IVL and T&E.

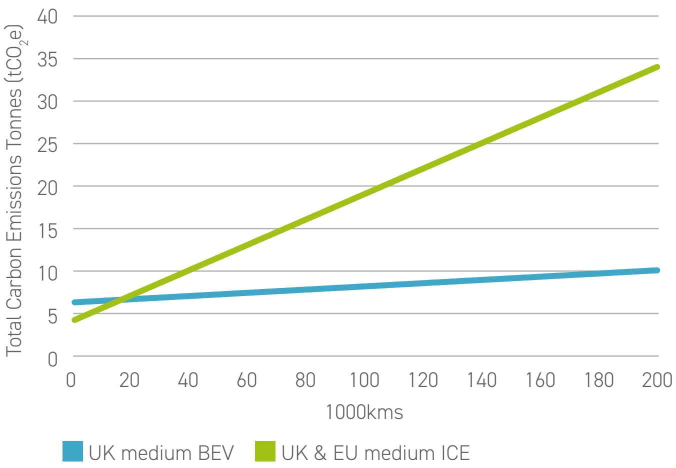
generated from driving and charging a BEV, compared to 34.2 tonnes from using a petrol vehicle over the same estimated lifetime mileage of 230,000 km. Electricity is needed to recharge EV batteries and the extent to which this electricity is generated from renewables or fossil fuels determines the extent of the success of BEVs in reducing carbon emissions. The carbon intensity of the UK electricity grid is therefore the most important determinant of the level of carbon emissions from BEVs.

The carbon intensity of the UK electricity grid is projected to fall (see Appendix A) as the UK Government implements policies to achieve Net Zero by 2050, which will result in BEVs generating lower and lower carbon emissions in the coming years. Total life cycle carbon emissions of a BEV vehicle in the UK is estimated to fall from 14.5 tonnes of CO_2e for a medium-sized BEV sold in 2020 to 10.7 tonnes and 7.8 tonnes for BEVs sold in 2025 and 2030 respectively. The UK Government's recent policy announcement[4] to cut total UK emissions by 78% by 2035 means these reductions could well be exceeded if the new policy leads to the acceleration of grid decarbonisation.

Carbon emissions from a BEV are initially greater than a petrol vehicle as a battery needs to be manufactured alongside the production of the vehicle chassis and body. However, charging and driving a BEV generates much less carbon on a per kilometre basis than an ICE vehicle. The longer a BEV is driven during its lifetime the greater the carbon benefit over an ICE vehicle with the crossover point of about 16,000 kilometres (or 10,000 miles) for medium-sized vehicles sold in 2025. By 230,000 kilometres[5] BEVs have an overwhelming total carbon emissions advantage over ICE vehicles (Figure 3). On average, EVs in the UK in 2025 emit around 46 gCO_2e per km compared to 167 gCO_2e per km for a petrol vehicle, although carbon emissions efficiency is likely to deteriorate with distance travelled for both types of vehicle.

[4] UK enshrines new target in law to slash emissions by 78% by 2035 compared to 1990 levels.
[5] The lifetime range of batteries in BEVs is increasing each year. By 2025, the Faraday Institution expects EVs to achieve this distance without replacing the EV battery. This lifetime range is more conservative than other studies such as T&E 'How clean are electric cars?' (170,000 km to 500,000km), Ricardo (225,000 km) and BNEF (250,000 km).

Figure 3: Total life cycle carbon emissions for EVs and ICE sold in 2025 by kilometres driven



Source: Faraday Institution estimates, based on various sources including Global EV Outlook, ICCT, EEA, IVL and T&E.

Carbon Benefits from UK Gigafactories

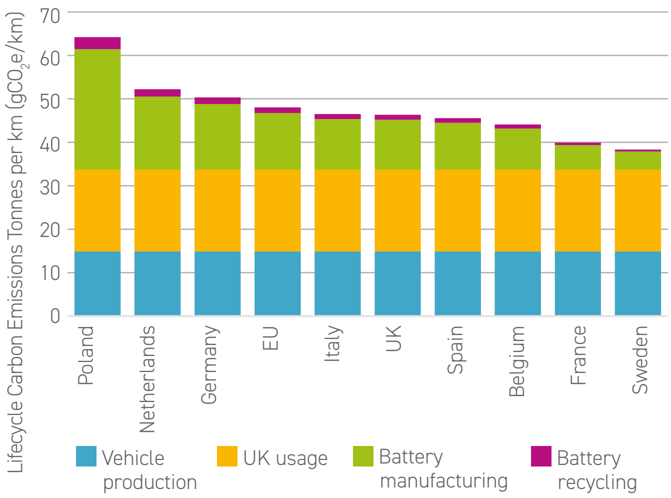
Battery cell manufacturing is energy-intensive with even large-scale state-of-the-art facilities requiring at least 30 kWh of electricity to produce 1 kWh of cells.[6] The capacity of the battery (the amount of charge able to be stored in the battery) is therefore a key determinant of carbon emissions, with battery capacity worldwide estimated to be 49 kWh for small BEV rising to 65 kWh (medium BEV) and 81 kWh (large BEV) in 2025.[7]

The carbon footprint of a BEV is also heavily influenced by where the EV battery is manufactured. A battery manufactured in Poland produces approximately 2.4 times more carbon emissions than the same EV battery manufactured in the UK. Over the full 'cradle-to-grave' life cycle this means the carbon emissions of an EV driven in the UK but with a battery manufactured in Poland would be 39% higher than the same EV driven in the UK but with a UK manufactured battery (Figure 4).

The 'cradle-to-grave' carbon emissions of an EV driven in the UK but with a battery manufactured in Poland are 39% higher than the same EV driven in the UK but with a UK manufactured battery. The rate of decarbonisation of the UK grid and the ability to manufacture EV batteries with 'cleaner energy' will be very attractive to global battery manufacturers considering the UK as a place to locate new gigafactories.

The UK boasts one of the greenest electricity grids in Europe. Battery manufacturers have access to electricity that not only already has a below average carbon intensity but is also expected to decline much faster than other European countries as the UK moves towards Net Zero. In 2025, batteries manufactured in the UK would generate 12% lower emissions than the European average. Emissions are sourced from European Environment Agency projections to 2030[8], which take into account the European Commission's 'Fit for 55' framework to deliver a 55% reduction in greenhouse gas emissions by 2030.[9] The ability to market UK EV batteries as batteries manufactured with 'cleaner energy' will be very attractive to global battery manufacturers considering the UK as a place to locate new gigafactories.

Figure 4: Total life cycle carbon emissions from UK EVs sold in 2025, by location of manufactured EV battery



Source: Faraday Institution estimates, based on various sources including Global EV Outlook, EEA, IVL and T&E.

Decarbonising the electricity grid in the UK will not completely remove carbon emissions from battery manufacturing, as carbon emissions will still be created from mining of the raw materials outside the UK. For example, mining activities in countries such as Australia for lithium and the Democratic Republic of the Congo for cobalt.

The above carbon emission estimates assume that 70% of the battery manufacturing process is undertaken in the country where the EV is used with the remaining from imports (largely mining activities). This is based on the following estimates of the proportion of the different parts of the battery manufacturing value chain undertaken domestically or abroad:

- 20% of mining and refining activities to source the raw materials required to produce EV batteries (e.g., lithium, nickel and cobalt) is undertaken domestically with 80% imported.
- 80% of the value chain involved in the manufacturing of active materials (e.g., complex chemical production processes for making cathode and anode materials requiring large amounts of energy) is undertaken domestically with 20% imported.
- 80% of the activities involved in the manufacturing of

[6] C. Yuan, Y. Deng, T. Li and F. Yang, 'Manufacturing energy analysis of lithium-ion battery pack for electric vehicles', CIRP Annals - Manufacturing Technology, vol. 66, pp. 53-56, 2017.
[7] BNEF (May 2020). Electric Vehicle Outlook 2020.
[8] Greenhouse gas emission intensity of electricity generation, European Environment Agency (June 2021).
[9] 2030 Climate Target Plan, European Commission.

battery cells and packs (e.g., activities typically taking place in a gigafactory) is undertaken domestically.

- 100% of recycling activities, including re-use and re-purposing, is undertaken domestically.

There may be opportunities to locate a greater share of the battery manufacturing value chain in the UK than 70% if companies like Cornish Lithium are successful in identifying and extracting high-quality mineral resources and in increasing mining volumes, and if the Clydach nickel refinery in South Wales predominantly supplies its nickel to UK gigafactories.

Carbon Emissions by Each Lifecyle Element

Comparing EV carbon emissions with ICE vehicles involves separate modelling of the carbon emissions generated from each of the following parts of the life cycle: (1) battery manufacturing (2) charging and driving an EV (3) vehicle production (4) end-of-life recycling. These are explored in greater depth below.

(1) Carbon Emissions Generated from Battery Manufacturing

Carbon emissions from battery manufacturing depend on the capacity of the battery, battery chemistry and the carbon intensity of the electricity grid in the country where the manufacturing takes place. Economies of scale of the manufacturing plant is also important with low-throughput facilities having higher energy intensity and carbon emissions per unit of output than larger and near-capacity facilities.[10]

Battery capacity is expected to slowly increase from 2020 to 2030 and then plateau as larger-sized batteries deliver an EV range close to existing ICE vehicles. Some BEV models will continue to house batteries with larger and larger capacity after 2030, but these are expected to be for niche and specialist markets rather than the mass market. These average assumptions mask a wide range of differences by models. For example, the Tesla Model X Long Range has a capacity of 90 kWh[11] compared to 85 kWh[12] for the Jaguar iPACE and 56 kWh[13] for the Nissan Leaf+ 2019 model.

The Faraday Institution modelling uses an estimate of 55 kgCO_2e of carbon emissions generated per 1 kWh of battery capacity manufactured. This is based on an estimate by the International Council of Clean Transport (ICCT)[14] using a latest and revised version of the GREET model[15] developed by the Argonne National Laboratory (see table below). These latest estimates from the GREET model are lower than previous versions due to lower estimates of energy consumption. Other sources include IVL & the Swedish Energy Agency, which estimate that carbon emissions range from 61 to 106 kg CO_2e/kWh for an NMC (lithium nickel manganese cobalt oxide) battery chemistry depending on whether renewable energy or fossil fuels are used. Studies using the older version of the GREET model and the EU Product Environmental Footprint Category Rules (PEFCRs) range from 65 to 86 kg CO_2e/kWh. Carbon emissions are also expected to fall rapidly as battery manufacturing techniques become more efficient and economies of scale take hold. Ricardo estimates that carbon emissions from battery manufacturing fall from 90kg CO_2e/kWh in 2020 to around 35kg CO_2e/kWh in 2030.[16]

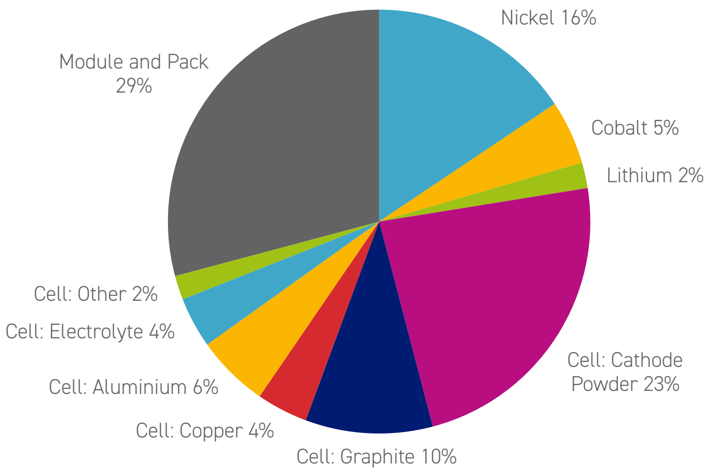
Table 1: Carbon intensity of battery manufacturing, kg CO_2e/kWh of battery capacity

	Europe	US	China	S Korea	Japan
NMC111-graphite	56	60	77	69	73
NMC622-graphite	54	57	69	64	68
NMC811-graphite	53	55	68	63	67
NCA-graphite	57	59	72	67	70
LFP-graphite	34-39	37-42	51-56	46-50	50-55

Source: International Council of Clean Transport (July 2021)[17]

The mining and purification of the raw materials, and then their synthesis into lithium carbonate or lithium hydroxide for use in the cathode active material generates the largest amount of carbon emissions and about 45% of total carbon emissions from battery manufacturing. Around 23% is generated from lithium, cobalt and nickel mining and refining operations and 22% from the energy needed to manufacture the cathode material (see Figure 5).

Figure 5: Carbon emissions by component of the EV battery manufacturing process



Source: Faraday Institution estimates based on EV 2019 Outlook, Lithium-Ion Vehicle Battery Production (2019) and Element Energy (unpublished).

[10] J. B. Dunn, L. Gaines, J. C. Kelly, C. James and K. G. Gallagher. 'The significance of Li-ion batteries in electric vehicle life-cycle energy and emissions and recycling's role in its reduction', Energy Environ. Sci., 2015, 8, 158-168.
[11] www.ev-database.uk/car/1407/Tesla-Model-X-Long-Range
[12] www.ev-database.uk/car/1287/Jaguar-I-Pace-EV400
[13] www.ev-database.uk/car/1144/Nissan-Leaf-eplus. The February 2018 Nissan Leaf model version had a battery capacity of 36 kWh.
[14] A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars, ICCT (2021).
[15] The Greenhouse Gases, Regulated Emissions, and Energy use in Transportation Model, Argonne National Laboratory (2018).
[16] See Figure 4.9b, Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Ricardo Energy & Environment (July 2020).
[17] A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars, ICCT (2021).

The remaining parts of the cell manufacturing process, including the production of graphite, copper and aluminium, contributes around another quarter of emissions (26%) and assembly of the battery pack and module 29%. Carbon emissions from production of NMC 622 batteries, NMC 811 and lithium nickel cobalt aluminium oxide (NCA) chemistries per kWh are similar.[18]

Battery production (excluding raw material extraction and mining) is estimated to consume between 17%[19] and 40%[20] of energy from electricity with the remaining energy supplied by fuels. Going forward to 2025 and 2030, the carbon emissions generated is assumed to fall in line with the general decline in the decarbonisation of the electricity grid, which requires either a move towards battery manufacturing to be driven solely by electricity or energy to be sourced from new and more efficient natural gas power plants.

(2) Carbon Emissions Generated from Charging and Using BEV and ICE Vehicles

Carbon emissions from charging and driving an EV are determined by energy consumption per kilometre, the total kilometres driven and the carbon intensity of the UK electricity grid.

Fuel economy for EVs is assumed to be 13 kWh per 100 km (city car), 16 kWh per 100 km (small family) and 18 kWh per 100 km (executive car).[21] Total distance travelled is assumed to be 230,000 km for a medium-sized vehicle, 180,000 km for a small vehicle and 280,000 km for a large vehicle.[22] This translates into an lifetime average of 19 gCO_2e/km of carbon emissions for a medium-sized BEV sold in 2025.

The carbon intensity of the UK's electricity generation is falling (see Appendix A) as the UK shifts to renewable sources, reaching a record high of 37.1% in 2019 compared to 2.7% in 2000.[23] This trend is expected to continue with large increases in offshore wind and solar anticipated in the coming decades with renewables potentially reaching between 72% to 96% by 2030 and between 91% and 99% by 2050.[24] The emission intensity of the UK electricity grid is currently around 17% below the EU average (Appendix B). Differences between European countries in the profile of EV charging and the location of charging combined with the effects of national electricity mixes will influence the extent to which UK retains this emission advantage going forward.[25]

Petrol and diesel engine cars are getting more carbon-efficient, driven by consumer demands and regulation. European Union (EU) regulations require emissions of 95 gCO_2 per kilometre for the 2020-24 period, which is a fleet-wide target.[26] Stricter targets are set over time with a further 15% reduction by 2025 and 37.5% by 2030 relative to the 2020-24 baseline, translating into values of 81 g/km in 2025 and 59 g/km in 2030.[27] Emissions targets are specific to the automotive manufacturer and are dependent on the weight of the vehicle. Our modelling assumptions are set out below dependent on different weight or vehicle classes.

Table 2: Carbon intensity for ICE vehicles, gCO_2e/km

ICE vehicle class	2020	2025	2030
Class A (city car)	85	72	53
Class C (small family)	100	85	63
Class E (executive)	140	119	88

Source: Faraday Institution assumptions based on ICCT and European Environment Agency database.[28]

In addition, these figures are uprated by 39% to reflect real-world fuel and energy consumption being higher than laboratory tests[29] and 26% for upstream or indirect emissions generated from extraction, processing, transportation and refining of petrol.[30]

(3) Carbon Emissions from Vehicle Production

The elements of vehicle production that generate carbon emissions include the manufacture of the powertrain, power electronics and vehicle glider (non-powertrain components). Carbon emissions generated by the manufacture of each of these elements depends on the materials used, geographic location of materials, manufacturing processes, manufacturing efficiency of the plant, the composition of the supply chain and waste produced. Overall, carbon emissions generated from vehicle manufacturing is approximately in proportion to the weight of the vehicle.

Table 3 summarises low and high range carbon emissions estimates with a medium value of 4.2 kg of CO_2e per kg of vehicle weight for EVs (excluding the battery) compared to 4.8 kg CO_2e per kg for ICE vehicles.

[18] Box 4.1, Global EV Outlook 2019: Scaling-up the transition to electric mobility, International Energy Agency (2019).
[19] Dai, Dunn, Kelly, and Elgowainy (2017). Update of Lifecycle Analysis of Lithium-Ion Batteries in the GREET Model, Argonne National Laboratory.
[20] Circular Energy Storage (July 2019). Analysis of the climate impact of lithium-ion batteries and how to measure it.
[21] See Figure 10 in 'A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation', World Economic Forum (September 2019).
[22] Kilometre range assumptions based on a variety of sources including T&E, Ricardo, BNEF and World Economic Forum.
[23] Digest of UK Energy Statistics (DUKES) 2020, Chapter 5: Electricity.
[24] National Grid's Future Energy Scenarios 2050 Data Workbook. The range represents the high and low range of the Net Zero scenarios defined as 'System Transformation' and 'Leading the Way' scenarios.
[25] Noussan M. and Neirotti F., (May 2020), Cross-Country Comparison of Hourly Electricity Mixes for EV Charging Profiles, Energies 2020, 13(10), 2527.
[26] European Commission CO_2 emission performance standards for cars and vans (2020 onwards).
[27] ICCT (January 2019). CO_2 Emission Standards for Passenger Cars and Light-Commercial Vehicles in the European Union.
[28] CO_2 emissions from new passenger cars, European Environment Agency.
[29] ICCT (2019), Real-world vehicle fuel consumption gap in Europe is stabilizing.
[30] Knobloch et al. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time.

Table 3: Carbon intensity of vehicle manufacturing, kg CO_2e per kg

	Carbon emissions per kg weight of the vehicle		
Source of data	Low	Average	High
BEV without battery manufacturing	3.4	4.2	4.9
ICE vehicle	3.9	4.8	5.7

Source: Ellingsen, Singh and Hammer Strømman (May 2016), The size and range effect: life cycle greenhouse gas emissions of electric vehicles.

The kerb weight[31] of a BEV (excluding the battery) is about 10% lighter than an ICE vehicle but is higher than an ICE vehicle once the weight of the battery, ranging from 300kg to 500kg, is added.[32] Given average emissions of CO_2e per kg in Table 3, total carbon emissions for a city, small family and executive BEV and ICE vehicle are given in the table below.[33]

Table 4: Carbon emissions from vehicle production by BEV and ICE vehicle types

	Kerb weight (kg)	Total emissions (tonnes CO_2e)	Lifetime range (km)	Carbon emissions (gCO_2e/km)
ICE vehicle				
Class A (city car)	1,300	3.7	180,000	20.4
Class C (small family)	1,500	4.2	230,000	18.4
Class E (executive)	1,900	5.4	280,000	19.2
BEV (excluding battery)				
Class A (city car)	1,200	2.9	180,000	16.3
Class C (small family)	1,400	3.4	230,000	14.9
Class E (executive)	1,800	4.4	280,000	15.7

Source: Faraday Institution, Ellingsen (2016), easyelectriccars.com, ICCT[34] and European Environment Agency.

(4) Carbon Emissions from Recycling

The recycling of EV batteries is a requirement in law as the Waste Batteries and Accumulators Regulations[35] prohibits the disposal of batteries in landfill or incineration within the UK. Substantial amounts of energy, water and materials are used in the recycling process, which produces carbon emissions. In Europe, 12% of carbon emissions are estimated to be created at the end-of-life battery pack and battery cell recycling stage in 2018 through the dismantling of components, conversion into recycled materials and shredding processes.[36] Lithium-ion battery recycling is in its infancy and efficiencies and economies of scale are expected to reduce the amount of energy and heat used from recycling with carbon emissions assumed to fall to 10% of the total battery manufacturing emissions by 2025 and 8% by 2030.

Direct cathode recycling involving the recovery and reconditioning of the active cathode material is one economically competitive method for recycling NMC and NCA cells.[37] Estimates of carbon emissions avoided in the recycling process compared to the creation of a new lithium-ion battery range from around 0.75 to 2.0 kg CO_2e per kg for an NMC battery with cylindrical or pouch cell format respectively.[38] Hydrometallurgical recycling and pyrometallurgical technology are other options suitable for recycling lithium-ion batteries.

Whilst lithium-ion battery recycling currently produces significant carbon emissions, largely from the energy required, it is expected that in the coming years recycling will lead to avoided emissions compared to manufacturing new batteries. The overall objective is to create a circular economy where recycled materials are used to manufacture EV batteries rather than requiring the mining of new raw materials.[39] Preliminary battery recycling methods use pilot manufacturing plants with small volumes. However, as manufacturing processes become more efficient and take advantage of economies of scale, recycling will be able to be undertaken at both a competitive cost and at lower levels of emissions.

Recycling is just one action that can occur at the end of a battery's useful life, along with re-use and repurposing. Re-use is using the battery for the same purpose it was originally designed for after remanufacturing, refurbishment or repair. Repurposing is utilising the battery for a different purpose from which it was originally designed. Second life applications, such as domestic and industrial energy storage are likely to be key uses. The Faraday Institution ReLiB[40] research programme is developing the technological, economic and legal infrastructure to allow close to 100% of the materials in lithium-ion batteries at the end of their first life to be reused or recycled. Recycling is likely to become a substantive market in its own right in a decade or so with global revenues of US$ 11 billion by 2030.[41]

[31] The mass of a vehicle in a resting state with all standard equipment including fuel but without passengers.
[32] Comparison of different battery types for electric vehicles (Iclodean et al 2017).
[33] Vehicle weights based on www.easyelectriccars.com/how-much-do-electric-cars-weigh-with-10-examples/
[34] European Vehicle Market Statistics, Pocketbook (2020-21), ICCT.
[35] The Waste Batteries and Accumulators Regulations 2009.
[36] Product Environmental Footprint Category Rules for High Specific Energy Rechargeable Batteries for Mobile Applications, Advanced Rechargeable & Lithium Batteries Association (February 2018).
[37] Ciez, R.E., Whitacre, J.F. Examining different recycling processes for lithium-ion batteries. Nat Sustain 2, 148–156 (2019).
[38] For a summarised discussion see: https://arstechnica.com/science/2019/02/electric-car-batteries-might-be-worth-recycling-but-bus-batteries-arent-yet/
[39] Baars, J., Domenech, T., Bleischwitz, R., Melin, H. E., & Heidrich, O. (2021). Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. Nature Sustainability, 4(1), 71–79.
[40] See the Faraday Institution ReLiB project.
[41] See Figure 7 in 'A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation', World Economic Forum (September 2019).

Conclusions and Implications

The UK's ambition to achieve Net Zero emissions by 2050 requires substantial decarbonisation across all sectors of the economy, but particularly the transport sector, which is one of the highest emitting sectors representing about a quarter of the UK's carbon emissions. The shift to EVs is at the heart of the plan to decarbonise transport, with the recent Government announcement accelerating the transition by ending the sale of diesel and petrol vehicles by 2030. How successful the shift to BEVs will be in removing carbon emissions from transport will largely depend on the pace of decarbonising the UK electricity grid and the ability to establish battery manufacturing within the UK territories as it significantly affects the carbon emissions from BEVs across their life cycle.

The extent to which EVs reduce carbon emissions is the subject of a confusing debate, largely caused by analysis looking at discrete and incomplete parts of the EV and ICE vehicle life cycle. For example, it is often cited that EVs are zero emissions, but this does not consider the electricity needed to charge a battery or the hidden emissions from the recycling stage. Others point to the carbon emissions embedded in batteries and that manufacture of EVs (including the battery) generates more carbon emissions than an ICE vehicle, but this fails to compare the emissions from using and driving the car as a result of the carbon emissions per km difference between petrol and EVs. This Insight has tackled this issue by examining carbon emissions generated across the full 'cradle-to-grave' life cycle of petrol vehicles and EVs.

All major car manufacturers now have EV models planned or already for sale and demand is currently outstripping supply. Whilst the transition to EVs is certain and already underway, it is useful to assess and quantify the benefit in carbon emission terms of an EV over an ICE vehicle. The conclusion of this Insight is clear - that the shift to BEVs will bring about a three-quarters reduction in UK greenhouse gas emissions from moving away from petrol- and diesel-powered vehicles. This benefit will only increase further as the carbon intensity of the electricity grid reduces further resulting in lower carbon generated. The difference in life cycle carbon emissions between BEVs and ICE vehicles depends on lifetime range and, as batteries emerge with longer lifetime range, BEVs will become even less carbon producing by comparison.[42]

A BEV sold in 2025 will bring about a three-quarters reduction in UK greenhouse gas emissions compared to an equivalent ICE vehicle. This benefit will only increase further as the carbon intensity of the electricity grid further reduces.

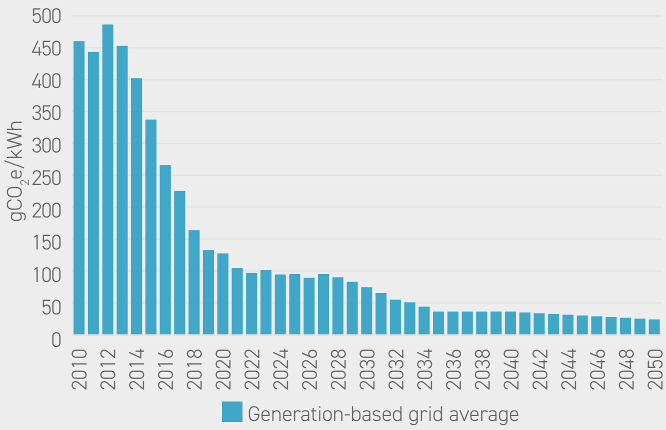
As well as differences between EVs and ICE vehicles, there are also country differences driven by whether the EV batteries are charged using electricity generated from renewable energy or fossil fuels. Compared to other European countries, the UK boasts one of the lowest grid carbon intensities at 33% lower than that of Germany. A manufacturing facility in the UK would allow auto manufacturers sourcing batteries from the UK to advertise their products as having lower life cycle emissions compared with those from elsewhere in Europe. This point will become increasingly relevant as the EU is considering the use of whole life carbon reporting for vehicle CO_2 emissions.

Appendix A: Carbon Intensity of UK Generation

The HM Treasury Green Book anticipated the carbon intensity of electricity generation falling significantly from the current 141 gCO_2e/kWh in 2020 to 25 gCO_2e/kWh by 2050 as shown in the figure below. The Climate Change Committee's Carbon Balanced Net Zero Pathway scenario projects a faster fall with carbon intensity of electricity generation falling to 50 g CO_2e/kWh in 2030, 10 g CO_2e/kWh in 2035 and 2 gCO_2/kWh in 2050.[43]

National Grid expects at least 60% of all road transport to be electrified by 2050, which will be "critical in providing flexibility to the electricity system, facilitating integration of renewables and helping to manage peak demand".[44] Improvements in technology and the falling cost of renewable energy is driving the energy transition.

Figure A-1: Electricity emissions factors (gCO2e/kWh) in the UK to 2050



Source: BEIS Green Book supplementary guidance: Valuation of energy use and greenhouse gas emissions.

The chart shows carbon emissions for the grid average, but for small changes in consumption and generation it may be more accurate to use marginal emissions factors. These are different to grid averages as small changes in consumption demand are more likely to be delivered by coal and gas power plants rather than renewable energy. Over the next decade or so as more BEVs are being bought and charged at any one time, BEVs will no longer be the marginal user and energy use and therefore carbon emissions will be more reflective of the grid average.

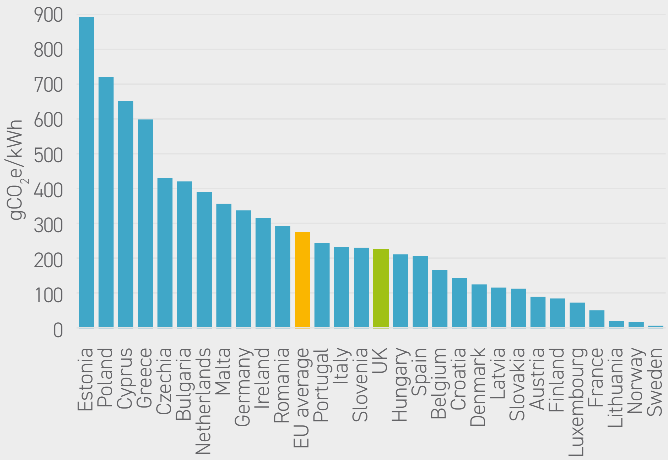
[42] See Faraday Insight 10, 'Why Batteries Fail and How to Improve Them: Understanding Degradation to Advance Lithium-ion Battery Performance' for an exploration of research into extending battery life.
[43] Climate Change Committee (December 2020). The Sixth Carbon Budget – the UK's Path to Net Zero (Figure 3.4b).
[44] National Grid's Future Energy Scenarios 2050 (July 2020).

Appendix B: European Country Comparison of Carbon Intensity of Electricity Generation

In the EU, the share of renewables for electricity generation reached 32%[45] in 2018 and is expected to increase to 55% in 2030 and 74% in 2040.[46] This downtrend and rate of reduction masks huge differences across Europe. For example, the greenhouse gas emission intensity of electricity generation in the EU averaged 275 gCO_2e/kWh in 2019 compared to a high in Estonia of 891 gCO_2e/kWh and low in Sweden of 8 gCO_2e/kWh. The UK's emission intensity of 228 gCO_2e/kWh is 17% below the EU average.

The UK will continue to maintain its position below the EU average, as the EU's carbon intensity average is set to decline at a similar pace to the UK. The EU also has an advantage over the rest of the world, with the EU's carbon intensity of power generation at 270 gCO_2e/kWh in 2018 much lower than the USA (400 gCO_2e/kWh) and China (600 gCO_2e/kWh).[45]

Figure B-1: Carbon intensity of the electricity grids in Europe, 2019



Source: European Environment Agency

About the Faraday Institution and Faraday Insights

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis, and early-stage commercialisation. We bring together academics and industry partners in a way that is fundamentally changing how basic research is carried out at scale to address industry-defined goals.

Our 'Faraday Insights' provide an evidence-based assessment of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government. If you would like to discuss any issues raised by this "Faraday Insight" or suggest a subject for a future Insight, please contact Stephen Gifford.

Sign up today to be added to the distribution list for future Faraday Insights www.faraday.ac.uk/subscribe

[45] IEA European Union Energy Policy Review, 2020.
[46] How clean are electric cars? T&E's analysis of electric car lifecycle CO_2 emissions (April 2020).

CONTACT
Stephen Gifford
Chief Economist
stephen.gifford@faraday.ac.uk
www.faraday.ac.uk
01235 425125
07741 853068

THE FARADAY INSTITUTION

UK Research and Innovation