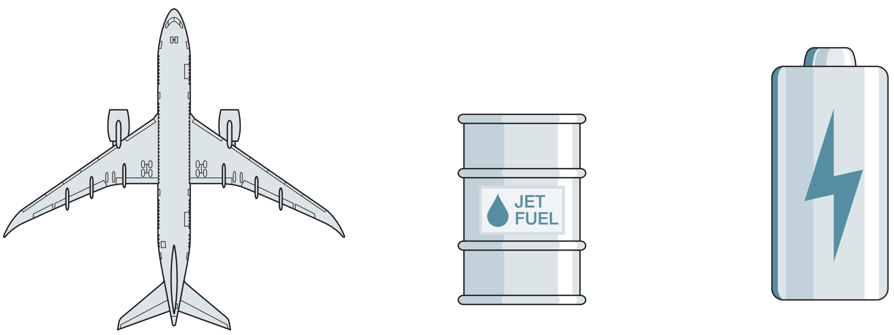
Impact analysis of mass EV adoption and low-carbon intensity fuels scenarios

Introduction

It is widely accepted that low-carbon liquid fuels will be essential in the long-term for sectors that have limitations in using electricity directly, such as the long-distance heavy road transport, aviation, maritime, and petrochemicals sectors. There is, however, a view that all light-duty road transport, and many of the other transport sectors, should be electrified in order to meet the European Union's climate objectives. There is also a growing awareness that achieving this level of electrification will be challenging (Figure 1), and that there is no single solution to building a low-carbon transport system, not least for the heavy-duty transport, marine and aviation sectors, but even for the passenger car segment.

A Concawe study examined several options for achieving a low-carbon transport system in the EU by 2050. Significantly, a mass EV adoption scenario and a low-carbon fuels scenario both achieve similar reductions in total parc greenhouse gas emissions, at similar cost.

Figure 1: Battery weight versus fuel tank volume (e.g. for aviation)



Boeing 787
230 tonnes at take-off

Jet fuel
100 tonnes*

Electric battery
2,000 tonnes*

* The jet fuel capacity of a Boeing 787 Dreamliner is about 223,000 pounds, [...]. The estimated weight of a battery pack with equivalent energy would be 4.5 million pounds, [...]. (Los Angeles Times, 9 September 2016, http://www.latimes.com/business/la-fi-electric-aircraft-20160830-snap-story.html)

This article discusses a study,[1] carried out by Ricardo on behalf of Concawe, to investigate various scenarios associated with future passenger car transportation, and to improve the understanding of the possibilities and potential outcomes of different options for the segment.

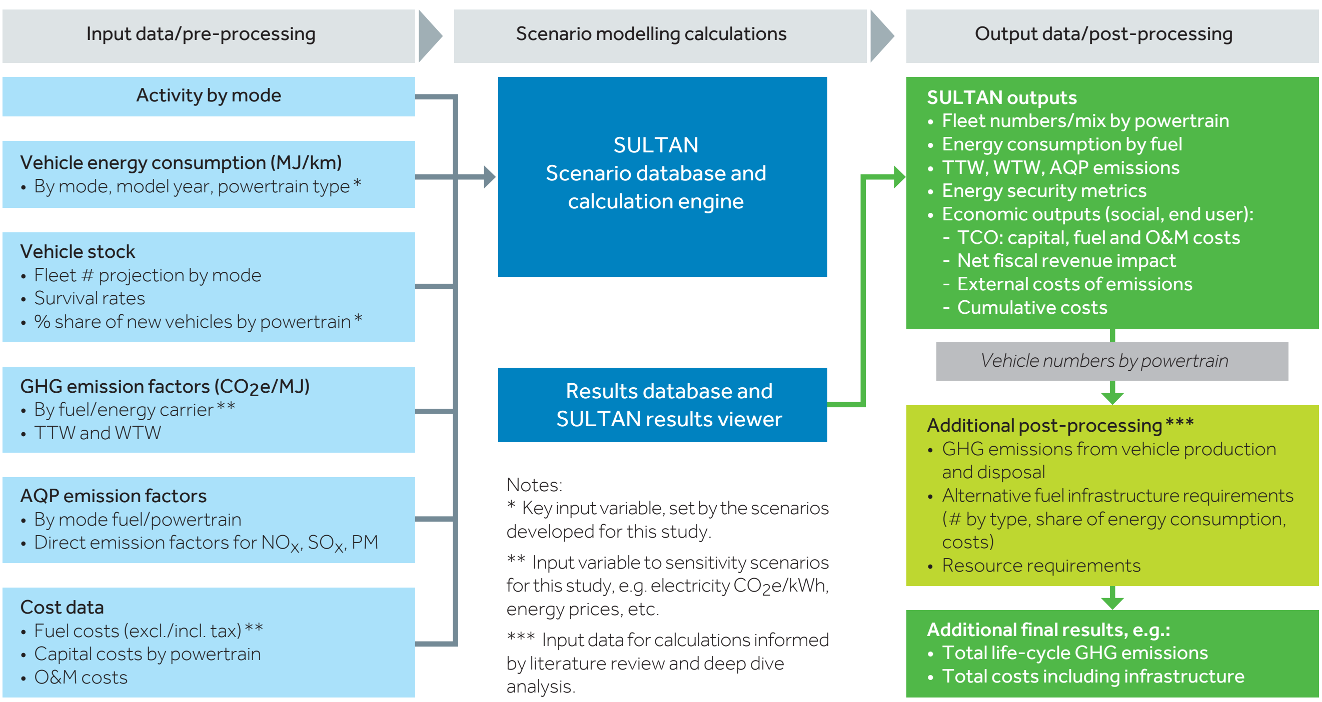
The Ricardo study

Ricardo were commissioned by Concawe to carry out an extensive study to examine a scenario involving the near-complete electrification of passenger cars and light commercial vehicles in the EU by 2050 (the 'High EV scenario'), and to compare this scenario with the combined use of electrification and low-carbon liquid fuels (e-fuels and sustainable biofuels) in highly efficient internal combustion engine (ICE)-based vehicles (the 'Low Carbon Fuels scenario'). These two scenarios were compared with a business-as-usual (BAU) scenario, as well as with an alternative scenario based on a higher proportion of plug-in hybrid electric vehicles (PHEVs) and an increased use of e-fuels and biofuels.

This in-depth study includes the quantification of greenhouse gas (GHG) reductions (in terms of CO_2 equivalent), total parc annual cost, and total cost of ownership for final users as well as the cost of infrastructure, materials, resources and power requirements. The study also sets out the challenges and opportunities associated with such a range of alternative options.

The main tool used to conduct the scenario modelling part of the study was Ricardo's SULTAN model (originally developed by Ricardo for the European Commission's Directorate-General for Climate Action — DG CLIMA). The functions of the model are shown in Figure 2 along with the inputs and outputs. In addition, an extensive literature review was carried out as input for some of the post-processing calculations including several deep dives into a number of areas of interest including life-cycle analysis, battery resources, and materials and infrastructure.

Figure 2: Overview of the SULTAN model



A number of sensitivity cases were also included, covering: GHG emissions, e.g. the sensitivity of GHG intensity with respect to electricity use (baseline trajectory equivalent to 0.1 kg CO_2/kWh GWP); the degree of improvement of battery energy density (average battery pack size of 82 kWh with 800 Wh/kg energy density in 2050 for an EV passenger car); embedded emissions from vehicle production and disposal; and the availability of biofuels. Cost analyses included low/high cost sensitivities relating to future battery costs (assuming a battery pack cost of $60/kWh by 2050 in the central case, based on a learning-based cost analysis developed by Ricardo as part of the work undertaken for the European Commission) and recharging infrastructure requirements (and costs) for EVs (home vs grazing, managed vs unmanaged network). A sensitivity analysis of a potential 'high-cost' scenario for low-carbon fuel prices (equivalent to ~20% increase on the base prices) was also carried out.

The High EV scenario

The High EV scenario in the study assumes that full electrification of transport for passenger cars and light-duty vans in 2050 will reach 90% of the vehicle parc on the basis of 100% registration of battery-electric vehicles from 2040 onward. The full breakdown of registrations and vehicle parc is shown in Figure 3. The carbon reduction trajectory is consistent with the upper limit of the percentage improvement in emissions from light-duty vehicles proposed by the European Commission in November 2018 in their post-2020 emissions targets through to 2030 (i.e. at least a 30% improvement in 2021 tailpipe gCO_2/km by 2030). The energy mix in the High EV scenario (see Figure 4 on page 24) shows a rapid decline in the use of fossil fuel from 2030, a rapid rise in electricity use and an end to biofuel use by 2050. In addition to this requirement, a lower level of improvements in the efficiency of internal combustion engines is assumed, due to the high uptake of electric vehicles and the resultant lack of incentives to improve ICE technology beyond 2025+.

Figure 3: High EV scenario — new registrations and vehicle parc

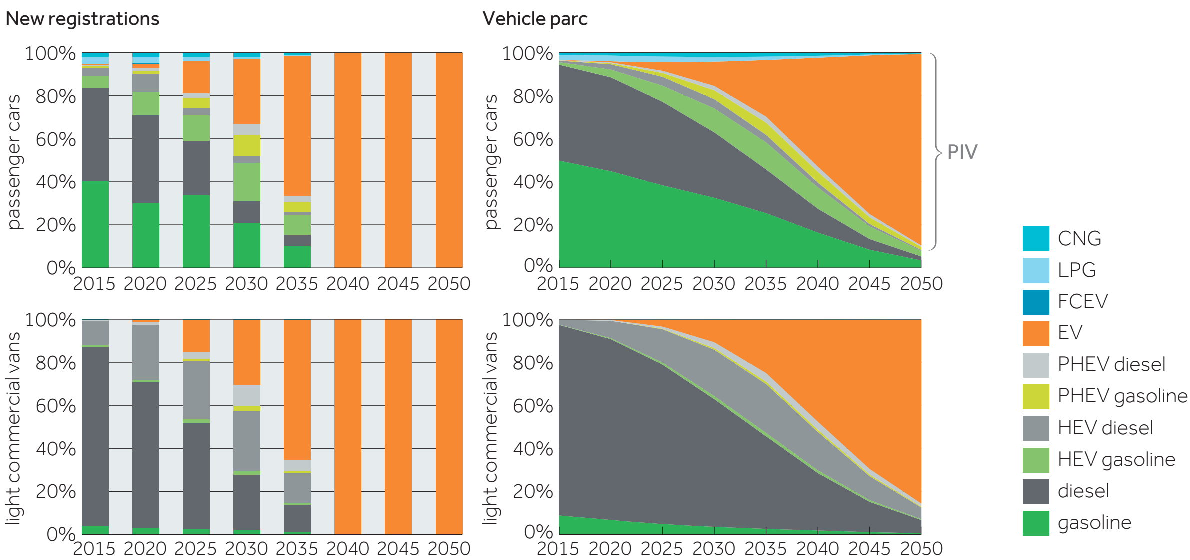
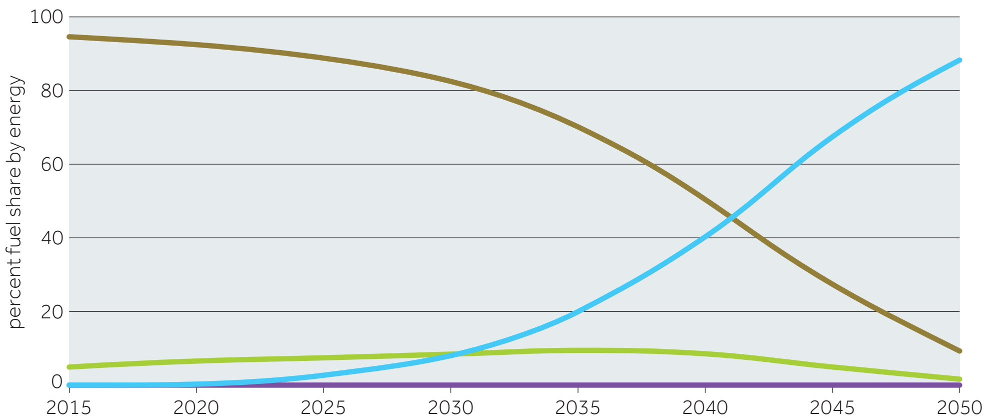


Figure 4: Fuel share for the High EV scenario



The Low Carbon Fuels scenario

The Low Carbon Fuels scenario assumes that, in 2050, the vehicle parc will consist of highly efficient ICE vehicles, with a high penetration of low-carbon fuels (68% fuel share by energy) complemented by 23% electricity and a minor quota of fossil fuels (Figure 5). The biofuel/e-fuel share is higher in 2020–2030 compared with the High EV scenario, and increases rapidly post-2025 with 100% substitution for diesel in 2050 as shown in Figure 6 (page 25). The carbon reduction trajectory (tailpipe gCO_2/km) is set at a slightly lower percentage improvement versus the High EV scenario. The tailpipe CO_2 trajectory is further extrapolated using the same percentage improvement out to 2050. There are also increased improvements in the efficiency of ICE and hybrid electric vehicle (HEV) passenger cars compared to the High EV scenario.

Figure 5: Low Carbon Fuels scenario — new registrations and vehicle parc

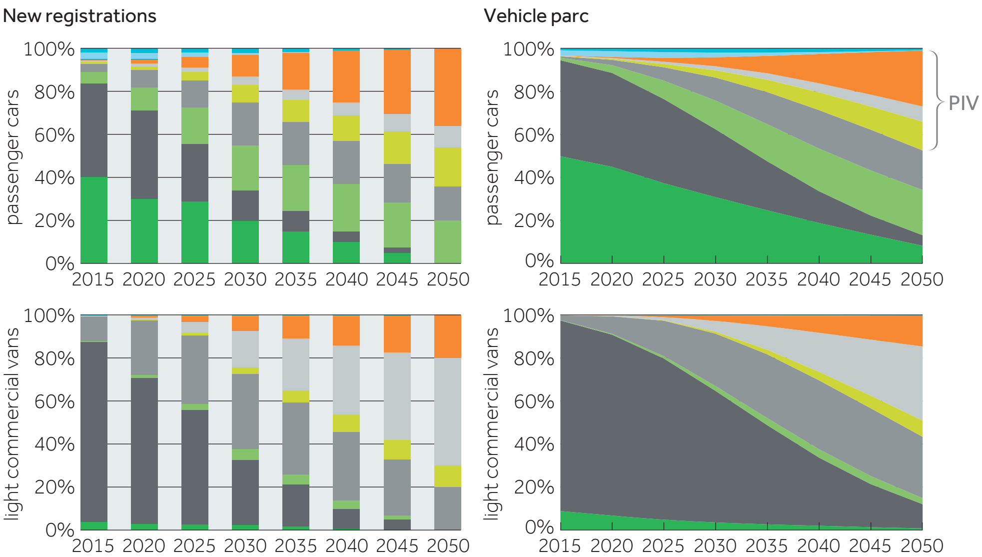
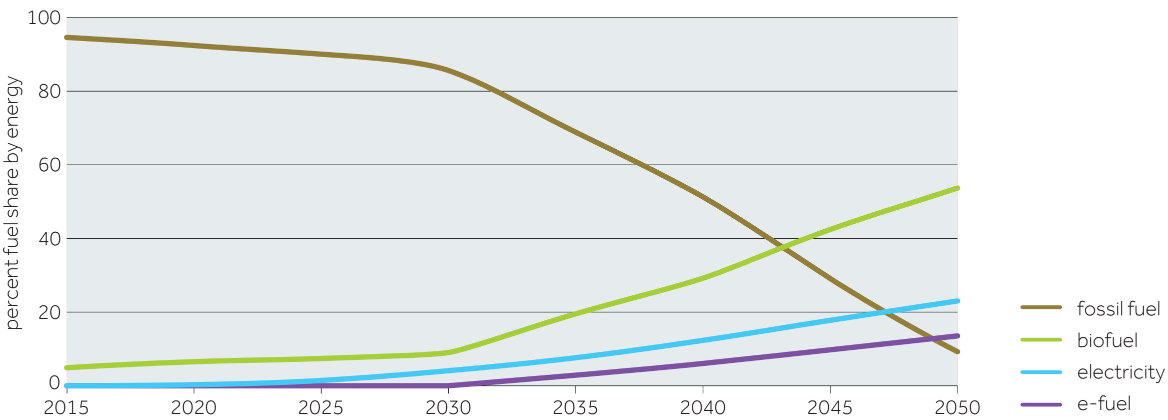


Figure 6: Low Carbon Fuels scenario — fuel share by energy



Results: comparison of life-cycle GHG emissions and energy consumption

Life-cycle GHG emissions, including well-to-tank (WTT) and tank-to-wheels (TTW) emissions as well as annual vehicle disposal and annual vehicle production emissions, were compared with the business-as-usual scenario and with each other. The results for the High EV scenario and the Low Carbon Fuel scenarios are shown in Figure 7 on page 26. All scenarios demonstrate broadly similar reductions in total GHG emissions by 2050. Embedded emissions from production and disposal of vehicles account for around 8% of total emissions in 2015 (including accounting/reduction for end-of-life vehicle recycling). This share rises to ~25% by 2050 for both the Low Carbon Fuels and High EV scenarios.

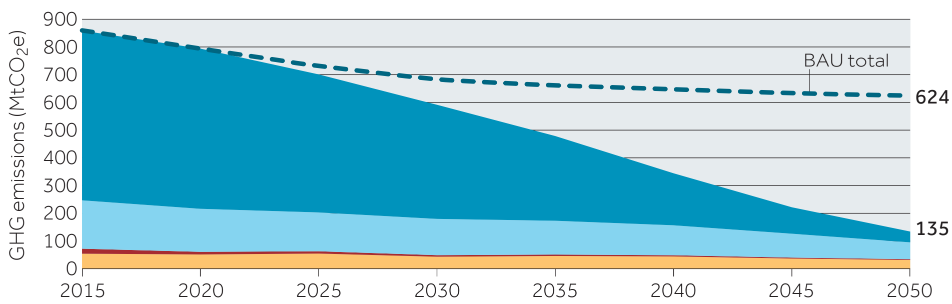
When energy consumption in these two scenarios is compared (Figure 8), it can be seen that there is a significant reduction in overall energy consumption resulting from both scenarios, with 550 TWh (1980 PJ/year) of electricity consumption for the High EV scenario.

The High EV scenario shows a reduction of more than 74% in overall energy consumption by 2050 versus 2015, and a 97% reduction in liquid fuel use in the same period. Electricity consumption is almost 90% of total energy use by 2050, at ~550 TWh (1980 PJ/year). This demand, excluding additional potential requirements across other sectors such as industry or for buildings, represents ≈17.5% of the EUs' electricity generation in 2015.

The Low Carbon Fuels scenario shows a 49% reduction in overall energy consumption, comprising of a 60% reduction in liquid fuel use which would be equivalent to a 96% reduction in oil-based liquid fuels (excluding low-carbon fuels). Low-carbon fuel accounts for an 88% share of liquid fuel use in 2050, equivalent to almost 3,000 PJ/year or 70 Mtoe for the whole light-duty segment. It should be noted that EU production of e-fuels will add +17% to the electricity use shown (and overseas electricity consumption would add a further +108%).

Figure 7: Comparison of GHG emissions on a life-cycle basis for the EU light-duty fleet

a) High EV scenario



b) Low Carbon Fuels scenario

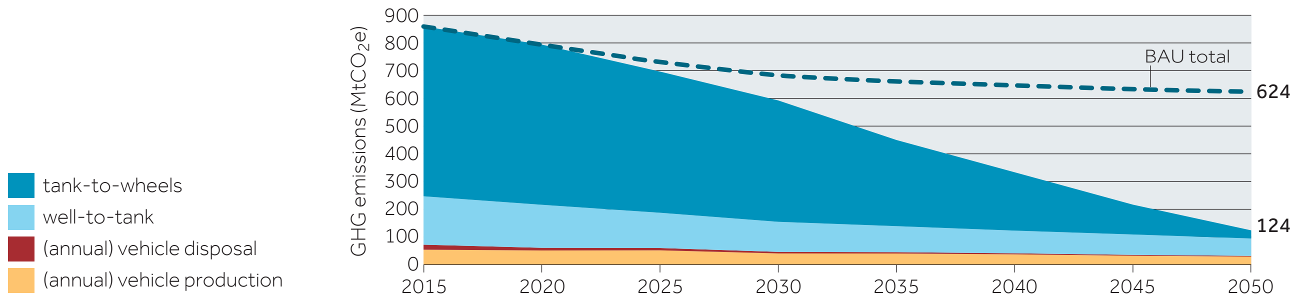
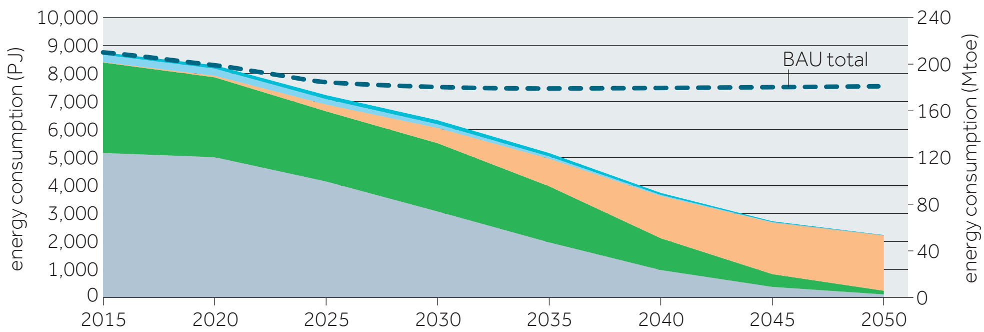
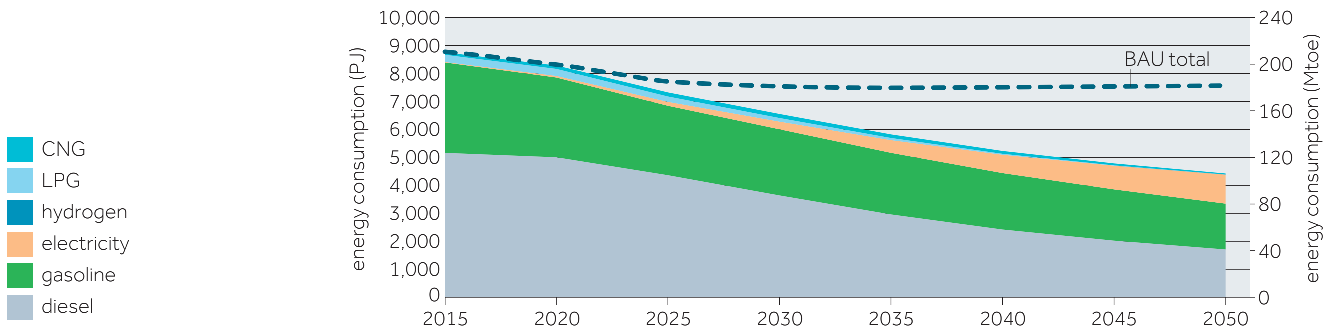


Figure 8: Comparison of energy consumption (TTW) of the EU light-duty fleet

a) High EV scenario

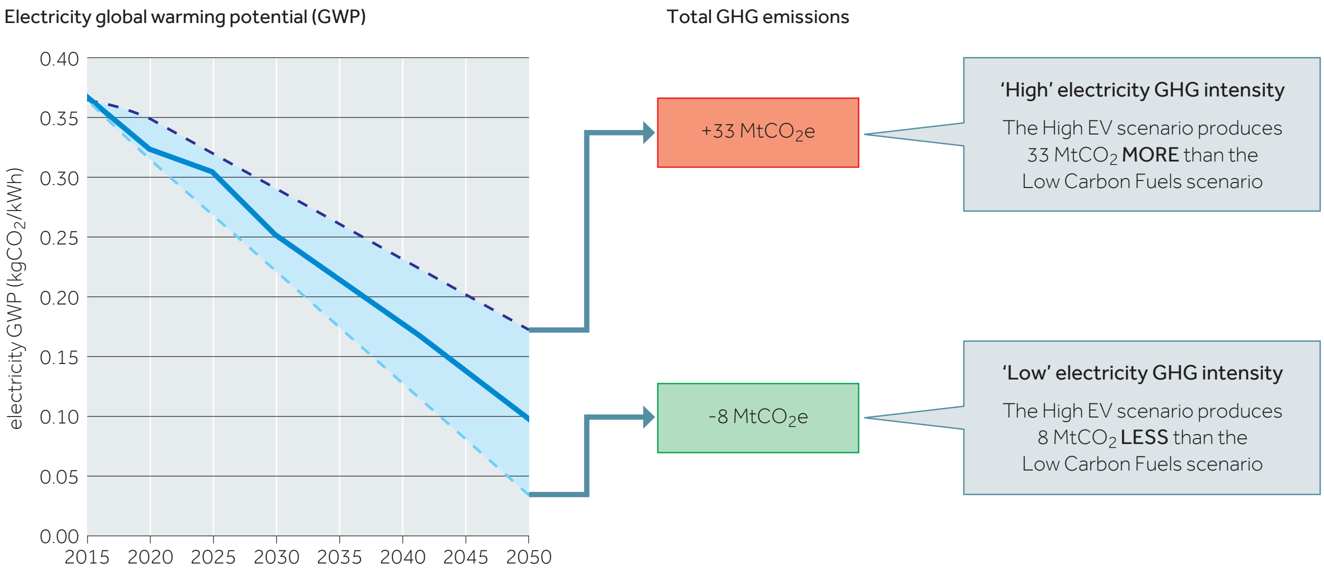


b) Low Carbon Fuels scenario



A sensitivity study shows that the level of GHG emissions under each scenario is heavily dependent on the electricity GHG intensity of the different scenarios (Figure 9), with the High EV scenario giving higher emissions when the electricity GHG intensity is high, and the Low Carbon Fuels scenario giving higher emissions when the electricity GHG intensity is low. Clearly the availability of low-carbon fuels will also influence this outcome.

Figure 9: The effect of electricity GHG intensity on GHG emissions: High EV scenario vs Low Carbon Fuels scenario



Results: comparison of costs

When costs for the two main scenarios are compared (Figures 10 and 11) it can be seen that, while costs for the High EV scenario are higher in the period to 2035, the net costs are ~€70 billion lower per year than for the Low Carbon Fuels scenario up to 2050. Including the Net Fiscal Revenue (NFR) loss (vs BAU) closes the gap to €9 billion per year. Both scenarios reduce GHG emissions and meet reduction objectives at a lower overall cost to the end user, primarily due to lower fuel and energy costs than under the BAU scenario. It should be noted that the BAU scenario does not meet the GHG reduction objectives.

The study shows that the total parc end-user annual costs of vehicles under the High EV scenario or the Low Carbon Fuels scenario are likely to be similar with no competitive advantage for the EV vs the ICE.

Figure 10: Total parc annual costs to end use — High EV scenario

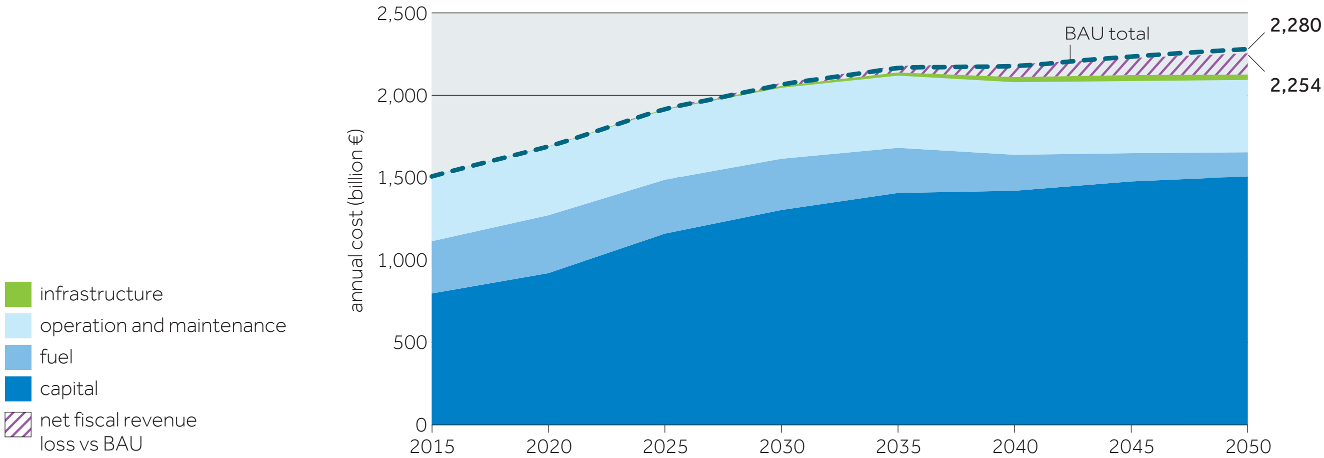
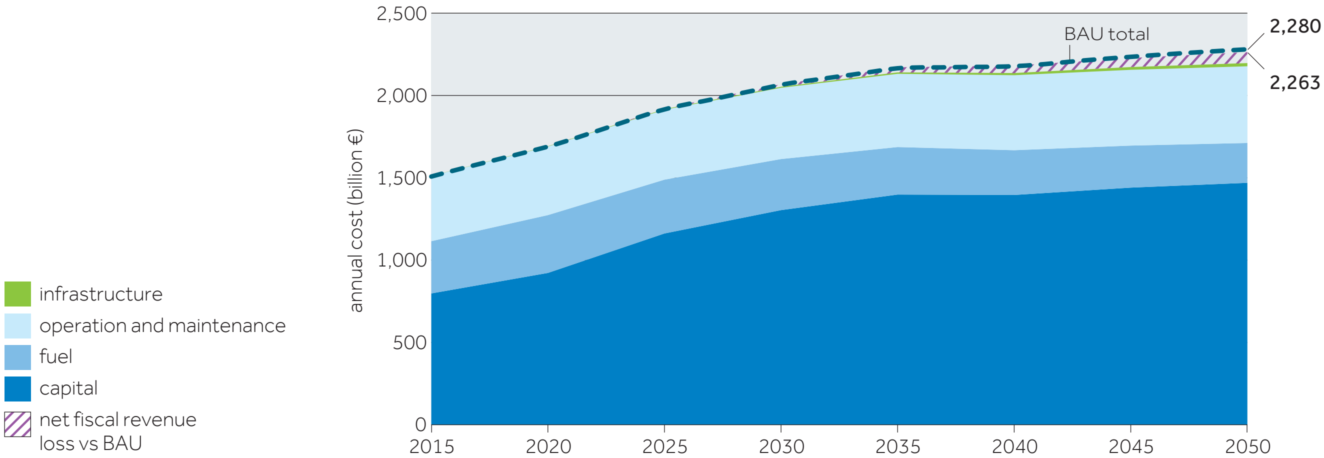
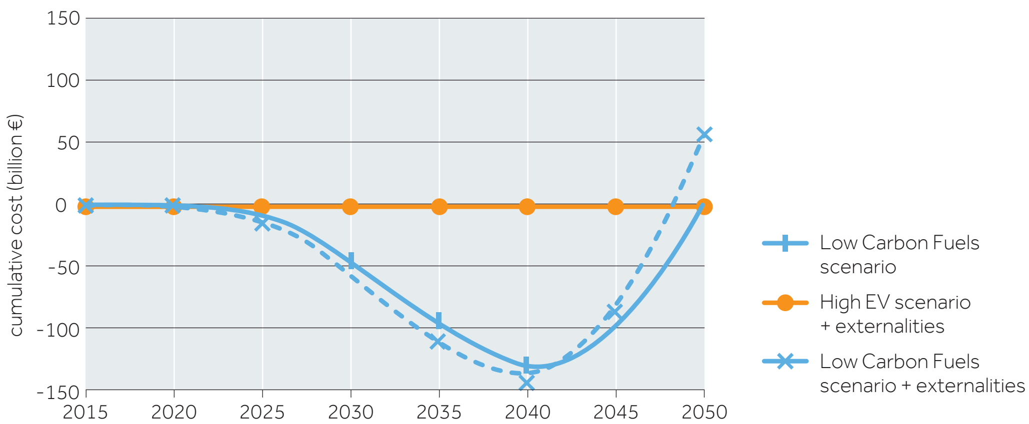


Figure 11: Total parc annual costs to end use — Low Carbon Fuels scenario



Ricardo also assessed the cost of each scenario from the societal perspective after inclusion of 'externalities' for GHG and air pollutant emissions. Externalities are the monetary values attached to the impacts of GHG, air quality pollutant emissions and other impacts such as noise and congestion (not calculated here) due to indirect effects, for example on public health and other elements. Figure 12 on page 29 shows that the net cumulative societal costs (i.e. excluding taxes), including externalities related to the Low Carbon Fuels scenario, are similar to the full electrification scenario.

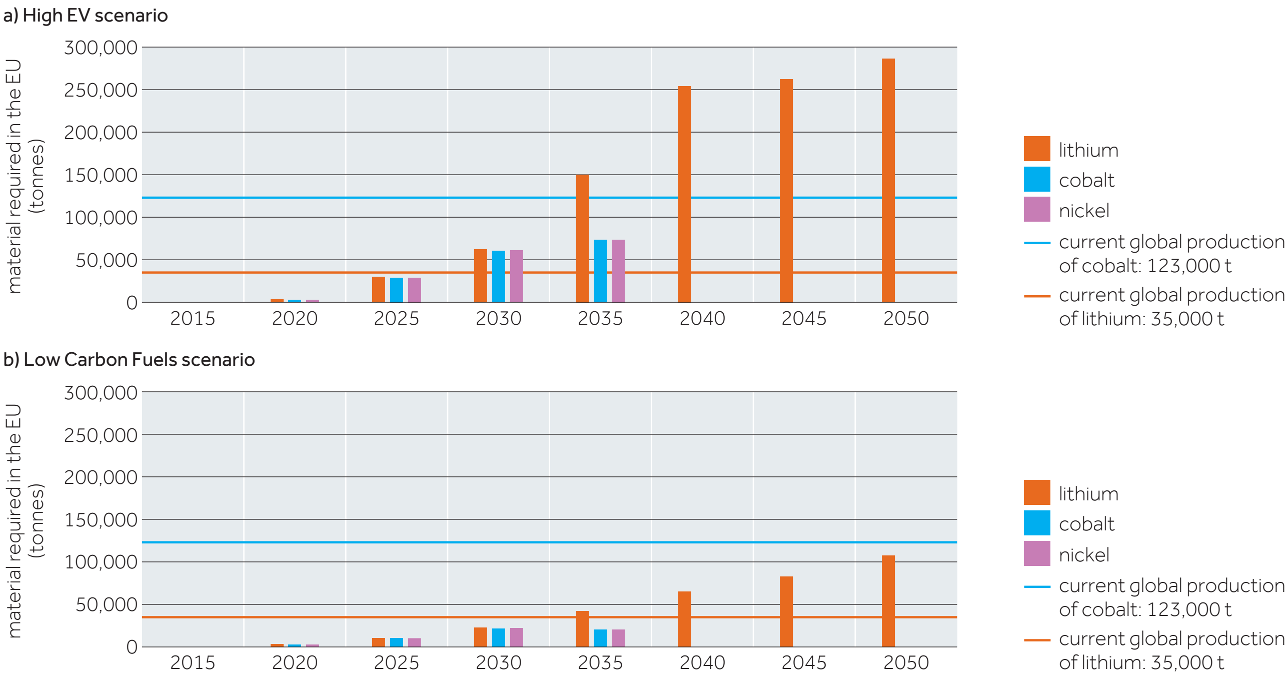
Figure 12: Cumulative net societal costs (excluding taxes) relative to the High EV scenario



Results: comparison of implications for resources and materials

In all the scenarios, the availability of raw materials for battery production was explored in detail. Assuming current chemistry mixes the resource requirements for lithium, cobalt and nickel would increase substantially over the period to 2050, which would pose a potential availability risk (Figure 13).

Figure 13: Materials required for battery production in the EU (lithium, cobalt and nickel)

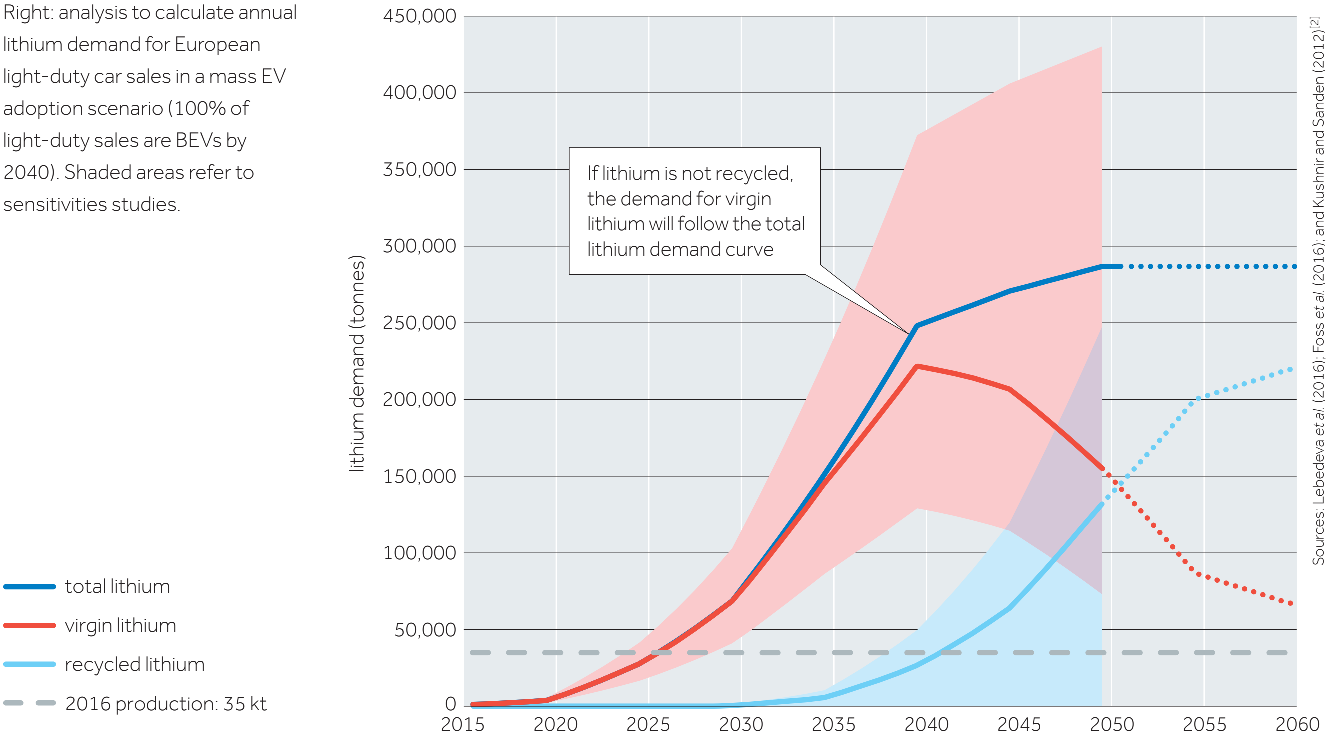


Impact analysis of mass EV adoption and low-carbon intensity fuels scenarios

Mass EV adoption in Europe will consume a larger share of global lithium reserves than the European share of global vehicle sales, potentially causing a shortage of lithium if other regions also undergo mass EV adoption. Therefore, new lithium resources will likely need to be accessed to meet the required demand, although the supply of such resources will vary according to feasibility, production capacity and local impacts; it should also be noted that very few countries have lithium reserves. Battery recycling technologies that enable the recovery of lithium could help to reduce the total virgin demand, but these are expected to have a limited impact by 2050. Research is also under way into non-lithium battery chemistries, but it is unclear to what extent these might contribute in the future.

Figure 14: Analysis of annual lithium demand (High EV scenario)

Right: analysis to calculate annual lithium demand for European light-duty car sales in a mass EV adoption scenario (100% of light-duty sales are BEVs by 2040). Shaded areas refer to sensitivities studies.



Advantages and uncertainties for the two main scenarios

a) High EV scenario

The High EV scenario is expected to achieve a reduction of up to 87% of the 2015 GHG life-cycle emissions levels by 2050, and is an efficient use of renewable electricity. The use of electrification in the passenger car sector would also free up other renewable fuels for other sectors. However, uncertainties exist in a number of areas, for example:

- Network reinforcement will be required beyond 15–20% EV penetration to deliver adequate EV recharge power, requiring an estimation of the associated capital cost at EU level (EV charging infrastructure and charging facilities).
- An estimate of the cumulative investment in EV charging and network infrastructure lies between €630 billion and €830 billion to 2050, and the electricity demand for charging EVs is assumed to be equal to 17.5% of the EU's 2015 overall electricity generation.
- The construction of 15 gigafactories to supply batteries to the European EV market (550 TWh) and a large battery recycling industry would need to be developed using low-carbon electricity as the main energy source.
- The installation of increased peak power of 115 GWh (15% of current installed peak power generation) would be required to meet electricity demand.
- There would be a need to address the annual loss of €66 billion in fiscal revenue from fuel sales.
- Resources requirements for cobalt, nickel and lithium would increase substantially over the period to 2050, posing a potential availability risk and creating a new import dependency for the EU. Given that the majority of lithium and cobalt is located in a small number of countries, there is a further potential risk for resource prices and security of supply. For example, the increase in lithium extraction to support the full electrification of European cars and vans alone is estimated at six times the 2016 worldwide volume of lithium production. Battery recycling to recover lithium could become a large industry by 2050; however, it may not be economically feasible for all battery types (for example, current LFP batteries have little recyclable material of value, and potential future lithium-sulphur chemistries might also be problematic).

b) Low Carbon Fuels scenario

It is expected that the Low Carbon Fuels scenario will also reduce, by 2050, the 2015 life-cycle GHG emissions level by 87%, equivalent to the High EV scenario. However, the Low Carbon Fuels scenario would require significantly lower cumulative investments in infrastructure because only 50% of the recharging capacity of the High EV scenario will be needed (€326 to €390 billion) and only half of the peak power generation will be required compared to the High EV scenario. It would also require only 5 or 6 gigafactories for battery production (compared to 15 for the High EV scenario), and the demand for raw materials would be reduced to less than half of the demand required under the High EV scenario. The availability of low-carbon fuels is intended to reflect a scenario where the whole biomass supply chain is optimised to maximise the use of bioenergy across different sectors.

Uncertainties in the Low Carbon Fuels scenario include the following:

- low-carbon fuels technologies, supply chain and scale-up including costs.
- The scenario estimates that the amount of biofuels required for light-duty transport would be around 35% of today's total (petrol and diesel) fuel volumes. This would result from, and is reliant on, significant efficiency gains for the ICE, resulting in a reduction of the total volumetric demand by 60% compared to today's volumes.
- Estimates for the use/availability of the (larger) imported e-fuel share for this scenario in a competitive marketplace is uncertain (estimated at 19% of the total low-carbon fuel supply in 2050).

One of the main takeaways of the study is that both GHG savings and total cost were calculated to be similar for both scenarios, and the costs for both scenarios are lower than for the business-as-usual case. The study shows that both electrification and low-carbon fuel technologies are complementary and require the adoption of policies based on a neutral approach to technology support, ultimately leading to the best choices and decisions for the future of the EU.

References

1. Concawe (2018). *Impact Analysis of Mass EV Adoption and Low Carbon Intensity Fuels Scenarios*.

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