Climate Change Committee

# The Sixth Carbon Budget
# Surface Transport

*This document contains a summary of content for the surface transport sector from the CCC's Sixth Carbon Budget Advice, Methodology and Policy reports.*

# Introduction

The Committee is advising that the UK set its Sixth Carbon Budget (i.e. the legal limit for UK net emissions of greenhouse gases over the years 2033-37) to require a reduction in UK emissions of 78% by 2035 relative to 1990, a 63% reduction from 2019. This will be a world-leading commitment, placing the UK decisively on the path to Net Zero by 2050 at the latest, with a trajectory that is consistent with the Paris Agreement.

Our advice on the Sixth Carbon Budget, including emissions pathways, details on our analytical approach and policy recommendations for the surface transport sector, is presented across three CCC reports, an accompanying dataset and supporting evidence:

- **An Advice report**: *The Sixth Carbon Budget – The UK's path to Net Zero*, setting out our recommendations on the Sixth Carbon Budget (2033-37) and the UK's Nationally Determined Contribution (NDC) under the Paris Agreement. This report also presents the overall emissions pathways for the UK and the Devolved Administrations and for each sector of emissions, as well as analysis of the costs, benefits and wider impacts of our recommended pathway, and considerations relating to climate science and international progress towards the Paris Agreement. Section 1 of Chapter 3 contains an overview of the emissions pathways for the surface transport sector.
- **A Methodology Report:** *The Sixth Carbon Budget – Methodology Report*, setting out the approach and assumptions used to inform our advice. Chapter 2 of this report contains a detailed overview of how we conducted our analysis for the surface transport sector.
- **A Policy Report:** *Policies for the Sixth Carbon Budget and Net Zero*, setting out the changes to policy that could drive the changes necessary particularly over the 2020s. Chapter 2 of this report contains our policy recommendations for the surface transport sector.
- **A dataset** for the Sixth Carbon Budget scenarios, which sets out more details and data on the pathways than can be included in this report.
- **Supporting evidence** including our public Call for Evidence, 10 new research projects, three expert advisory groups and deep dives into the roles of Local Authorities and businesses.

All outputs are published on our website (www.theccc.org.uk).

For ease, the relevant sections from the three reports for each sector (covering pathways, method and policy advice) are collated into self-standing documents for each sector. A full dataset including key charts is also available alongside this document. This is the self-standing document for the surface transport sector. It is set out in three sections:

1) The approach to the Sixth Carbon Budget analysis for the surface transport sector
2) Emissions pathways for the surface transport sector
3) Policy recommendations for the surface transport sector

Chapter 1

# The approach to the Sixth Carbon Budget analysis for the surface transport sector

*The following sections are taken directly from Chapter 2 of the CCC's Methodology Report for the Sixth Carbon Budget.*[1]

## Introduction and key messages

This chapter sets out the methodology used to generate the surface transport sector pathways for the Committee's advice on the level of the Sixth Carbon Budget. The results of our scenarios, including emissions pathways, technology uptake, costs, investment and co-benefits are presented in the accompanying Advice Report. The policy implications of our analysis are detailed in the accompanying Policy Report. A full dataset including key charts is available alongside this document.

The key messages from our analysis for surface transport are:

- **Background.** Total emissions from surface transport in 2019 were 113 $MtCO_2e$, comprising 22% of total UK GHG emissions. These are primarily tailpipe emissions from fossil-fuelled road vehicles, with cars (68 $MtCO_2e$), vans (20 $MtCO_2e$) and heavy-goods vehicles (HGVs) (19 $MtCO_2e$) the largest contributing types.
- **Demand reduction and modal shift.** There are opportunities to reduce demand for car travel, through both societal and technological changes (such as shared mobility and increased home-working) and by enabling journeys to be shifted onto lower-carbon modes of transport. In addition, there is potential for logistics and operations improvements to reduce demand in road freight.
- **Conventional vehicle efficiency.** Emissions from conventional vehicles can be reduced through efficiency improvements. This includes more aerodynamic and lighter-weight designs, retrofitting drag-reduction improvements and eco-driving training.
- **Zero-emission vehicles.** Achieving decarbonisation of surface transport will require a sector-wide transition to vehicles that produce zero tailpipe emissions. For cars and vans, battery-electric vehicles are now widely available and are likely to become cost-saving by the late-2020s. For HGVs options include battery-electric vehicles, hydrogen fuel-cells and electric road systems. Continued electrification of the rail network, together with hydrogen, battery-electric and hybrid trains, will also play a significant role.
- **Analytical approach.** We have derived our assumptions in each area based on a detailed review of available evidence. This includes consideration of research across the sector that has been produced since our advice on the Fifth Carbon Budget, analysis of recent market developments and trends, analytical modelling conducted within the CCC, new research to assess options for road freight decarbonisation and extensive stakeholder engagement. These assumptions are combined to produce our Balanced Net Zero Pathway and four exploratory scenarios, which explore alternative pathways to deliver emissions reductions across the surface transport sector.

We set out evidence in the following sections:

1) Current and historical emissions from surface transport
2) Options to reduce emissions in the transport sector
3) Approach to analysis for the Sixth Carbon Budget

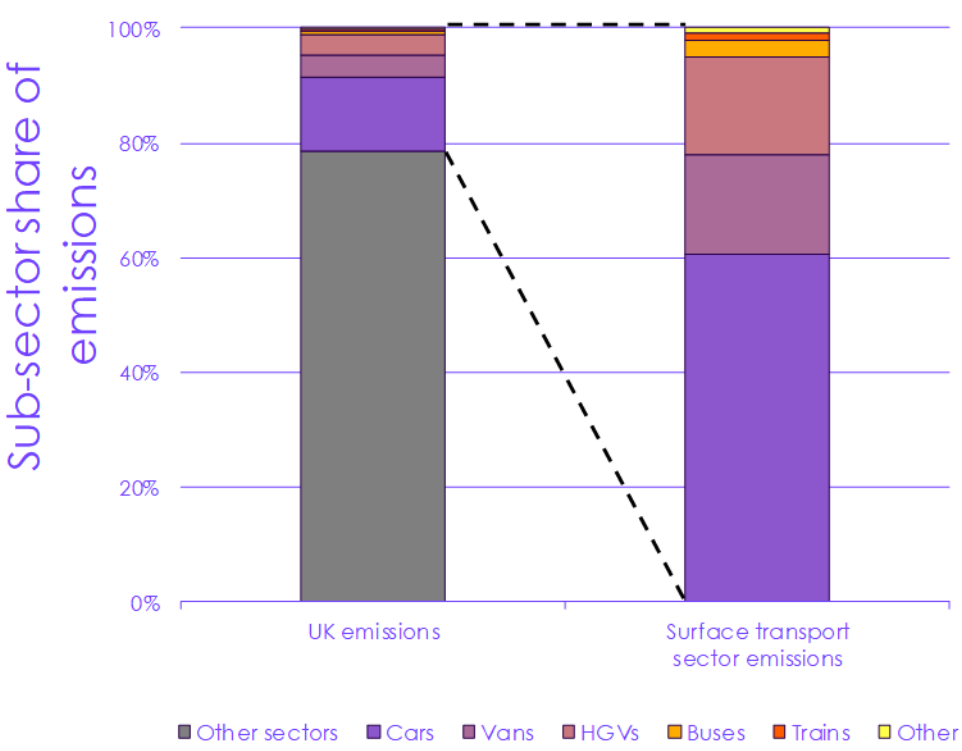
# 1. Current and historical emissions from surface transport

## a) Current surface transport emissions

Surface transport is currently the UK's highest emitting sector.

Emissions from surface transport in 2019 were 113 $MtCO_2e$, which accounted for 22% of total UK GHG emissions (Figure M2.1). This makes surface transport the UK's highest emitting sector.

Figure M2.1 Breakdown of surface transport sector emissions (2019)




Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; CCC analysis.

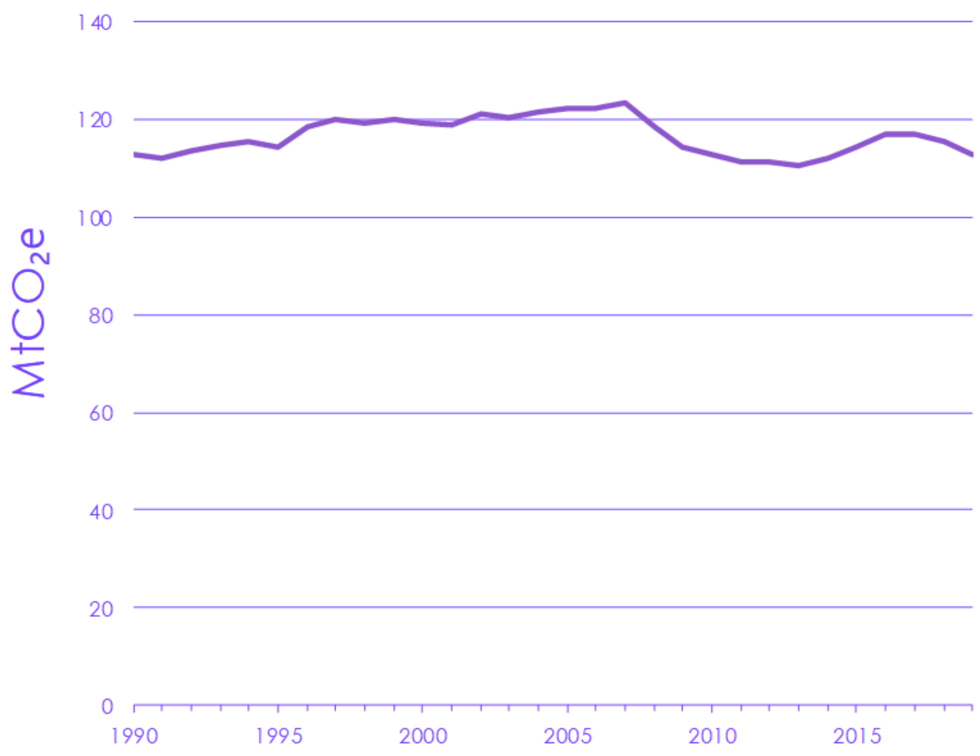
Car travel dominates surface transport emissions, followed by vans and HGVs:

- Cars account for 61% (68 $MtCO_2e$) of surface transport emissions and a larger share (78%) of UK road travel (in terms of vehicle-kilometres).
- HGVs account for 17% (19 $MtCO_2e$) of total surface transport emissions, despite making up just 5% of road vehicles. This is due to their comparatively large average mileage and weight.
- The remaining emissions are shared between vans (17%; 20 $MtCO_2e$), buses (3%; 3 $MtCO_2e$), rail (2%; 2 $MtCO_2e$) and other surface vehicles (1%; 0.9 $MtCO_2e$).
- Emissions are predominantly $CO_2$ (99%), with the remaining emissions being $N_2O$ and $CH_4$ from the combustion of fossil fuels.

## b) Trends and drivers in surface transport emissions

Emissions from surface transport have largely been flat since 1990 (Figure M2.2).

Figure M2.2 Surface transport GHG emissions since 1990




Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; CCC analysis.

The rapid increase in sales of SUVs has driven an increase in average new car emissions over recent years.

Total distance travelled increased by 17% since 1990, roughly in line with population growth.[2] Efficiency of new cars had also been steadily increasing since 1990 but this reversed between 2017-19, driven by the rapid increase in purchases of higher-emitting vehicles, particularly sports utility vehicles (SUVs), whose market share has risen from 7% in 2007 to 25% in 2019. This growth has more than offset the benefit delivered by the increase in sales of electric vehicles (EVs) from 1.9% to 3.1% during 2017-19.[3]

# 2. Options to reduce emissions in the transport sector

Delivering Net Zero emissions across the UK by 2050 will require reducing surface transport emission to near zero. This will require a combination of behavioural change, efficiency improvements to fossil fuel vehicles and the introduction and uptake of zero-carbon technologies. Several key decisions will need to be made both in the lead up to and during the Sixth Carbon Budget period in order to determine the trajectory that the country follows towards achieving Net Zero.

This section sets out these options and presents the latest evidence on their feasibility, risks and costs in the following sections:

a) Demand reduction and modal shift, which considers how behavioural and societal shifts could lead to reduced or changed demand for travel.

b) Conventional vehicle efficiency, which discusses improvements to conventional vehicles that can make them more fuel-efficient.

c) Zero-emission vehicles, which explores the technological options available for delivering transport with zero tailpipe emissions and the expected rates of uptake of these vehicles across different transport sectors.

## a) Demand reduction and modal shift

### i) Reducing demand for car travel

Passenger car journeys currently account for 78% of vehicle-kilometres travelled and 61% of emissions in the UK. Reducing demand for car travel offers significant potential for reducing emissions, with associated benefits for congestion, air quality and health. We looked at four factors that could contribute to a reduction in private car travel:

Home-working, local working and internet shopping all offer the potential to reduce the total number of journeys that each individual undertakes.

- **Societal and technological changes.** This includes factors such as increased home-working, increased use of IT and technology and continuing trends towards greater use of internet shopping. Relative to the baseline*, our scenarios assume that there is potential for a 1-4% reduction in total car mileage by 2030, and between 4% and 12% by 2050[4], from societal behaviour change and technology. These are based on the latest academic evidence and CCC analysis of travel data.

Trends towards increased home-working and videoconferencing have been accelerated during the COVID-19 pandemic.

  – The National Travel Survey[5] shows that 25% of car mileage is for commuting purposes and 11% is for business. Even before the COVID-19 pandemic, there was a gradual increase in the prevalence of home-working and videoconferencing, but the need for social distancing has seen rapid movement in this area. In April 2020, 47% of people did some work at home[6], while a recent study[7] has estimated that 43% of UK jobs can be done entirely from home. Other factors that could impact demand in this area include growth in the gig economy or movement towards living closer to workplaces.

* The baseline scenario represents the growth in emissions that we would expect to see in the absence of any action to reduce emissions across the sector. See Section 3 a) i).

– The average number of shopping trips per person had been declining steeply until recent years.[5] Moreover, average shopping trip length for cars has fallen, which could be related to the shift towards online retail (which could account for up to 50% of sales by 2030[8]). This may be partially offset by increases in leisure journeys and by the extra van traffic required to deliver online purchases.

- **Increase in car occupancy.** Shared mobility (e.g. shared cars and shared trips) can also reduce car travel demand. These are uncertain but our scenarios assume that there is scope for average car occupancy to increase from 1.6 today to up to 1.7 by 2030 and up to 1.9 by 2050.

  – Current utilisation rates of shared mobility are low, at around 3-4% of journeys[9], while two-thirds of trips are undertaken with just the driver in the vehicle and average car occupancy is 1.6.

  – High-occupancy vehicle lanes are one example of local interventions that can encourage car-sharing. Studies have shown these to reduce vehicle trips by between 4% and 30% in certain cases.[10]

  – Social pressure to increase car occupancy could play a role as the public becomes increasingly environmentally aware. More companies may begin to encourage car-sharing schemes for commuters.

  – A variety of shared mobility innovations could play a role in increasing occupancy. These include car clubs, real-time ridesharing apps and ride-pooling.

- **Modal shift to active travel.** Walking trips have increased in recent years, cycling has been relatively flat, while trips taken by bus have declined. We assume that 5-7% of car journeys could be shifted to walking and cycling (including e-bikes) by 2030, rising to 9-14% by 2050. These assumptions translate to lower percentages of distance, given that the shortest trips are the most likely to switch.

Comparison between UK cities and with other countries shows that there is substantial scope for increased cycling.

  – The total number of cycling trips undertaken has remained fairly constant at around 1-2% of all journeys over recent years5, although the average distance of each cycling journey has increased. Based on international comparisons and experience in some UK cities, there is scope to encourage more trips by bike. In the Netherlands, 26% of all journeys are cycled, while in Germany the proportion is 10%.[11] In UK cities with high levels of cycling (for example Oxford and Cambridge), cycling rates can be up to 29%.[12]

  – In 2019, 7% of car journeys were less than 1 mile, while a further 17% were between 1 and 2 miles.[13] A recent study[14] based in Cardiff concluded that walking or cycling could realistically displace around 41% of car journeys of less than 3 miles.

  – DfT's recent cycling and walking plan for England[15] sets out a vision for high-quality infrastructure and other measures (for example cycle parking at stations and loans for bikes) to encourage significant uptake of active travel. This sets out a future in which half of all journeys in towns and cities are cycled or walked, up from 29% today.

E-bikes could allow even some longer journeys (up to 9 miles) to switch from car to cycling.

- E-bikes offer considerably greater range, so if they become widespread then there may be potential to shift a greater number of journeys away from cars.[16] We assume that this could enable e-bikes to displace car journeys of up to 9 miles (in contrast to a maximum of 4 miles assumed for conventional bicycles).

- In considering how many trips and what share of car-kilometres could be switched to these modes, we considered evidence on the types of trip that could be easiest to switch. This is a function of length, purpose, age group and time of trip. An assumption was then applied on the proportion of trips in each category that could switch, based on analysis of National Travel Survey data.

- Active travel schemes have been implemented in several regions across the UK in recent years (Box M2.1).

Public transport offers a lower-carbon alternative for many journeys in urban areas. A reliable, properly funded service needs to be provided to encourage uptake.

- **Modal shift to public transport.** There is scope to switch some car journeys onto appropriate public transport, particularly in urban areas. Our scenarios assume that between 2-4% of car-kilometres by 2030 can be switched, increasing to 5-8% by 2050.

  - Bus and rail account for 5% and 4% of all journeys respectively5. A recent study found that public transport usage within major cities could rise by 6% by 2030.[17]

  - We assess that around 9-12% of trips could be shifted to buses by 2030, increasing to 17-24% by 2050. This is based on applying a series of filters, including whether a journey is in a rural or urban area, to determine the number of trips that could be suitable for switching onto public transport.

  - During the COVID-19 pandemic, many forms of public transport have experienced a sustained drop in demand, which has continued after the lifting of travel restrictions. Car usage has recovered more quickly.[18] There is a risk that reduced public confidence in public transport could reduce the potential to shift journeys away from cars in the medium term (see Section 3(c) for further discussion of this risk).

The combined effect of the above factors is a reduction in demand of 7-16% of total car-kilometres in 2030 and 12-34% by 2050 compared with baseline demand.

- The UK Climate Assembly recommended a reduction in the amount we use cars by 2-5% per decade[19], relative to today's levels. The demand reduction assumed in our Widespread Engagement scenario is consistent with the more ambitious end of this range.

- We also take account of the risk of higher travel demand, which we model in the Widespread Innovation scenario. This is detailed below.

Our analysis also considers potential rebound effects where the reduction in car operating costs resulting from the switchover to electric vehicles leads to an increase in total kilometres travelled:

- Most estimates suggest a rebound effect of 10-30% for road transport, although some researchers indicate that this may be conservative for EVs.[20] This means that 10-30% of energy savings are offset through additional mileage. We assume this range in our scenarios.

Increased use of consolidation centres and innovative vehicles could reduce van demand.

For vans, we assume much smaller levels of demand reduction, reaching 3-4% from 2030 onwards. This is focussed on the parcel-delivery sector, where changes are already happening:

- Van travel is the fastest-growing sector, with total van-kilometres having increased by 71% since 2000.[21] At least a quarter of this is due to the growth in online shopping.[22]
- Several delivery companies have begun to introduce small electrified vehicles, such as e-cargo bikes and micro-vehicles, for last-mile delivery in UK cities. Within dense urban areas there is significant potential for such vehicles, along with improved logistics and consolidation, to reduce emissions and alleviate congestion.
- The Energy Saving Trust found that 33-50% of urban deliveries could be shifted to cargo bikes or e-cargo bikes.[23]
- Collaboration between operators on the same route has been shown to reduce delivery operations by around 14% in urban areas.[24]

Case studies and modelling have demonstrated a strong economic case for switching from cars to walking and cycling.

Evidence suggests that there are cost-savings from switching from cars to walking and cycling, with cost-benefit ratios of 3 to 4, including social benefits on factors such as congestion, health and air quality (Box M2.1). However, the two main sources of evidence on this are unlikely to be directly applicable to our scenarios:

- The Sustrans model, developed by the University of Copenhagen, excludes the cost of cycling infrastructure.
- The Cycling and Walking Investment Strategy (CWIS) model, used by DfT and developed by Transport for the Quality of Life, is unlikely to be suitable to our more ambitious scenarios as there are likely to be threshold effects as infrastructure is built and public attitudes towards cycling change.

We have taken a conservative approach and assumed that there is zero net cost to the economy of switching from cars to walking and cycling. This is reasonable as the cost of provision of improved walking and cycling infrastructure is expected to be substantially outweighed by the benefits through reduced cost of travel, better air quality, lower congestion and improved health and wellbeing.

**Box M2.1**

Demand-side case studies – costs and benefits

We assessed two models to estimate the costs and benefits of active travel:

- **Sustrans Societal Gain Model.** This expresses the economic benefits of cycling as a gain to the individual and society and is based on extensive cycling data in Copenhagen, together with UK costs. It estimates the net value of cycling and driving, considering the benefits and disbenefits of both modes across a number of elements:
  - Costs include travel time, vehicle and infrastructure operating expenditure and congestion.
  - Benefits cover prolonged life, health, local air quality, noise and greenhouse gases.

  This model estimates the total private benefit of cycling versus cars as £0.4 per mile, and the total social benefit as £0.9 per mile, with a benefit-to-cost ratio above 4. A drawback is that the model does not include capital expenditure on vehicles or infrastructure. The latter is important where larger cycling infrastructure is needed to incentivise cycling.
- **CWIS Active Travel Investment Models.** These were developed for DfT by Transport for the Quality of Life.

They can be used to assess the impact on the level of cycling and walking of different types of policy intervention and different levels of capital and revenue investment, over the period 2020-40. Data are drawn from the National Travel Survey, Active Lives Survey and School Census and cover different intervention types and scenarios. Costs and benefits are similar to those in the Sustrans model but also cover infrastructure and vehicle capex. This model estimates a benefit-to-cost ratio of cycling versus driving of around 3.

There have been several active travel initiatives implemented across the UK:

- **Waltham Forest.** £27 million of TfL funding was invested, encouraging walking, cycling and improving public spaces, with the aim of it becoming a 'mini Holland'. Measures included introducing segregated cycle lanes on seven major routes, introducing a zero-emission cargo bike delivery service, delivering cycle training to 15,000 people, 15 new parks and planting of more than 660 trees. Benefits included residents walking and cycling for an extra 41 minutes each week[25], an increase in life expectancy of around 7-9 months for residents and improved air quality due to a reduction in $NO_2$ by between 15-25% and $PM_{2.5}$ by 6-13%.[26]
- **Greater Manchester.** The Bee Network vision[27] is the longest planned walking and cycling network in the UK, with significant funding and new measures to encourage active travel. The programme costs £1.5 billion and is to be delivered over ten years.
  - Estimated benefits are valued at £6.0 billion and include: 45,000 cars taken off the road each year; over £100 million in economic benefits to the area; prevention of serious health issues, saving the NHS an estimated £3.7 million per year; better air quality; and reduced GHG emissions. The estimated benefit-to-cost ratio is 4.
  - Measures include: protecting 435 miles of main road corridors and town centre streets; cycling corridors; new interchanges, increasing access to bikes; and creating filtered neighbourhoods where movement of people is prioritised over cars and driving through is restricted to residents.
- **Cycle-to-work.** It is estimated that the cycle-to-work scheme has encouraged over 1.6 million commuters to cycle to work. In June 2020, there was a 120% increase in the number of people joining the scheme, compared to the previous year. Scheme users save £780 per year on their commute on average, totalling an estimated saving of £390 million per year. 64% of employers felt that the scheme also had a positive impact on staff health.[28]

## ii) Connected and autonomous vehicles

The impact of connected and autonomous vehicles on travel demand is highly uncertain.

Connected and autonomous vehicles (CAVs) are an emerging technology which could have a significant impact on levels of demand for road transportation.[29] However, impacts are highly uncertain and could increase or reduce travel:

- Autonomous vehicles could extend road travel to those previously unable to travel by car, including people who currently do not hold a driver's licence.
- The ability to use in-vehicle time productively (e.g. for work or leisure) or more comfortably could reduce the value that users place on travel time. This could make people willing to make more regular or longer trips.
- More efficient driving and dynamic routing could effectively increase road capacity, freeing up road space for more cars.
- CAVs could drive the development of new business models. For instance, greater uptake of ride-sharing, platooning of freight services or empty-running (where a leg of a truck's journey is completed with no payload) of vehicles to areas of demand could all become more feasible.

The timing of introduction of CAVs and level of technology readiness are highly uncertain. The Transport Systems Catapult's market sizing estimates suggest that CAVs could comprise between 5% and 58% of UK vehicle sales by 2035, with a central assumption of 31%. Similarly, estimates by DfT[29] determine that road traffic growth could be between 30 percentage points below and 36 above their reference scenario, depending on how the market engages with CAV technology.

Given this uncertainty, we consider the potential impact of CAVs in our Widespread Innovation scenario, in which we adopt the assumption that CAVs reduce car occupancy in line with DfT's private travel scenario (a reduction of 13% by 2050). This leads to around a 20% increase in car-kilometres by 2050 (equating to an overall increase in car-kilometres of 5% above baseline levels, after also considering all of the demand-reduction assumptions discussed above). This was to test the robustness of our decarbonisation pathways to higher demand, with the Widespread Engagement scenario being more ambitious on demand reduction.

### iii) More fuel-efficient driving

Initiatives to encourage more fuel-efficient driving are important to help reduce emissions in the short term.

Vehicle emissions depend on the style in which the vehicle is driven, and it is possible to reduce emissions through technology and more efficient driving:

- Since 2014-15, it has been mandatory for all new cars to be fitted with Gear Shift Indicators and Fuel Consumption Meters. Respectively, these reduce fuel consumption by 1.5% and 0.3-1%.[30]
- Reducing speeds can also improve fuel-efficiency. Driving at 70mph rather than 80mph can use up to 25% less fuel, while limiting speeds to 60mph can save a further 15%.[31] We estimate that full enforcement of 70mph speed limits could reduce overall fuel consumption by 2%, while reducing these limits to 60mph could reduce fuel consumption by 7%.
- Training drivers in eco-driving styles has been seen to deliver fuel-efficiency improvements and several other benefits. For example, since introducing vehicle telematics and speed limiters and launching their Young Driver Academy, British Gas have seen a 14% reduction in overall fuel consumption.[32] Across light vehicles, we assume that eco-driving can offer an efficiency saving of 8% for up to 20% of drivers who adopt these styles.

Likewise, scope for improved driving efficiency exists within the HGV sector:

- There are several design options. For example, retrofitting drag reduction devices to existing HGVs can improve aerodynamics by up to 19%[33], while recent changes to weights and dimensions regulations will allow an additional 80-90cm of cab length for safety and efficiency measures, which could allow designs that are 3-5%[34] more aerodynamic.
- Driver training in and use of eco-driving is also possible in the HGV sector.
- Our scenarios assume that 50-100% (central 80%) take-up of a range of comprehensive measures to improve driving efficiency is possible, based on a study by Centre for Sustainable Road Freight.[35] In total, these can offer efficiency savings ranging from 13% for a small rigid HGV up to 22% for an articulated HGV.

### iv) Improvements in freight operations

A range of data- and logistics-driven improvements could be possible in the freight sector, consolidating journeys and improving efficiency.

In 2019, 154 billion tonne-kilometres of goods were moved by road in the UK.[36] UK logistics operators already aim to maximise efficiency and minimise costs, but there are opportunities to go further, estimated within our scenarios at 9-11%:

- Increasing availability of data (e.g. through vehicle telemetry) could increase the efficiency savings that can be made through route optimisation. Standardisation of data formats across the industry may allow further steps to be made towards optimal consolidation and load pooling.
- Urban consolidation centres allow goods to be delivered to one central location on the outskirts of a built-up area. Their use would reduce the need for larger vehicles to travel into congested town centres and would allow consignments to be consolidated into fewer journeys for final delivery. Trials[37] have shown urban consolidation centres to be able to reduce the number of vehicle movements by 50-85% and to be cost-effective.
- Relaxing delivery time restrictions could allow some deliveries to avoid hours of peak congestion, speeding up delivery times and improving efficiency.
- Empty-running has slowly increased over recent years, up to 30% in 2019.[38] This may be partly attributable to accelerating delivery time expectations and the increasing reliance on just-in-time supply chains. Relaxing these could allow better consolidation and increase backhaul opportunities.
- The World Economic Forum[39] forecasts that further growth in e-commerce and faster expected delivery times could lead to a 36% increase in urban last-mile deliveries by 2030. They found that a combination of increased use of lockers, allowing delivery vehicles access to bus lanes and dynamic analytics-based rerouting could reduce emissions by 10% and costs by 30%.
- Analysis conducted for the CCC by the Centre for Sustainable Road Freight estimated that, in total, improved logistics could reduce emissions by between 9% for small rigid HGVs and 11% for articulated HGVs by 2030.

Rail freight could be used more in the short term as a lower-carbon way of moving goods.

There is also potential for emissions reduction through modal shift of freight:

- Moving freight by rail can be up to 76% more environmentally friendly than road haulage.[40] The total tonne-kilometres moved by rail in 2019-20 was 27% lower than in 2013-14[41], demonstrating that there is capacity to shift freight transport onto the railways. DfT's Rail Freight Strategy[42] laid out the potential for rail freight to increase by around 12% (maximum 69%) by 2030.
- In the short term, this could aid decarbonisation of the freight sector. In the longer term, however, zero-emission HGVs are expected to become available across the road haulage sector sooner than it will be possible to completely remove diesel from rail freight.

## b) Conventional vehicle efficiency

### i) Reducing tailpipe emissions in new road vehicles

Our analysis uses slightly higher emissions figures for new conventional cars in 2030 than we assumed for the Fifth Carbon Budget, in recognition of the recent growth in SUV market share.

Efficiency of new conventional cars and vans has improved in the past two decades, but this progress has stalled in recent years, with average emissions of new vehicle increasing since 2017. This trend will need to be reversed to meet existing new car $CO_2$ regulations and to deliver our Balanced Pathway:

- Average new car $CO_2$ emissions fell from 181 $gCO_2$/km to 120 $gCO_2$/km from 2000-16. Since then it has increased, reaching 128 $gCO_2$/km in 2019.[43]

- This has been driven by the increase in purchases of larger vehicles, such as SUVs. While sales of minis/superminis fell between 2016 and 2018, the market share of SUVs increased from 16% to 24%. Although there has been a shift away from diesel cars in recent years, the impact of this on new car emissions intensities has been limited. The gap between petrol and diesel car emissions has fallen over recent years, and in 2019 average new diesel $CO_2$ emissions were higher than for petrol cars.

- EU regulations require average emissions of new cars to meet 95 $gCO_2$/km from 2021, with a 15% reduction from 2021 levels by 2025 and a 37.5% reduction by 2030.[44] DfT has signalled its intention to retain emissions standards that are at least as ambitious[†] as those in the EU.[45]

- Similar regulations apply to vans, requiring a fleet average of 147 $gCO_2$/km in 2021, followed by a 15% reduction by 2025 and 31% by 2030. Average van emissions in 2018 were 167 $gCO_2$/km, 16% lower than in 2011.[46]

WLTP measurements are often not fully representative of real-world driving. The industry will need to ensure that this does not undermine consumer purchasing confidence in reported range figures for electric vehicles.

- The 2017 move from the New European Driving Cycle (NEDC) to the World harmonised Light-duty vehicle testing Procedure (WLTP) provided a more up-to-date test profile which better represents typical modern driving conditions and thus reduces the gap between test-cycle and real-world emissions. This gap is expected to grow due to driving style evolution, new technologies and flexibilities within the testing system – we estimate that it could reach 26% by 2030.[47] We take this into account in our modelling.

- Analysis for the CCC shows that real-world efficiency of new conventional cars and vans could improve by 12% by 2030, through measures such as hybridisation, smaller engines and more lightweight construction (Table M2.1).

- The scope for efficiency improvement beyond 2030 is limited and the associated marginal cost is likely to increase.

Zero-emission technologies for HGVs are further from market than for cars and vans and are expected to take longer to become widespread. Therefore, there is a greater role for conventional efficiency improvements in delivering medium-term emissions reductions within this sector:

- We estimate that there is potential for heavy-duty vehicle (HDV) efficiency improvements from 11% (for buses) up to 21% (for HGVs) by 2030, driven by uptake of measures such as hybridisation, heat recovery and low rolling resistance tyres, as well as the use of lighter materials. There is likely to be limited further scope for improvement beyond this.

- Urea is emitted from the tailpipes of Euro IV, V and VI HGVs, where it is used for $NO_x$ control.[48] While these emissions are equivalent to less than 1% of a typical HGV's emissions, we include their impact in our analysis.

[†] In practice, the formula for applying this target at a manufacturer-level will be based on the average weight of the vehicles sold by that manufacturer as compared to the EU average. Since the UK's average vehicle mass is heavier than the EU's, the average target in the UK will be slightly higher than this 95 $gCO_2$/km level.

| Table M2.1<br>Real-world $CO_2$ intensity of new petrol and diesel vehicles in $gCO_2$/km (% change from 2020) | | | |
|---|---|---|---|
| | **2025** | **2030** | **2035** |
| **Cars** | 118 (-6%) | 110 (-12%) | Not on sale |
| **Vans** | 170 (-6%) | 160 (-12%) | Not on sale |
| **HGVs‡** | 589 (-11%) | 518 (-21%) | 521 (-21%) |
| **Buses** | 908 (-5%) | 857 (-11%) | 857 (-11%) |

Efficiency improvements to new conventional vehicles are cost-effective, low-regret abatement measures.

These measures are cost-effective and will continue to be so in the medium term. Our analysis estimates the current abatement cost of efficiency improvements at -£83/t$CO_2$e for cars and -£7/t$CO_2$e for vans, with costs of £15/t$CO_2$e and £14/t$CO_2$e in 2030, remaining below BEIS carbon values.

The high annual mileage of many larger HGVs means that fuel savings are higher, and the economic case is even clearer, with the average abatement cost of efficiency improvements falling to -£59/t$CO_2$e by 2030. As these measures are cost-saving or low-cost and are needed to meet regulatory obligations, they are low-regret abatement measures that we include in all scenarios.

## ii) Biofuels

Use of sustainable biofuels has the potential to reduce transport emissions in the short and medium term:

- Unleaded petrol available on UK forecourts currently contains up to 5% bioethanol, a blend known as E5. DfT proposes to introduce E10[49] (up to 10% bioethanol) as the default 95-octane 'premium' grade petrol at forecourts from 2021. Our scenarios assume widespread use from 2021, which could reduce car emissions by up to 1% (0.3 Mt$CO_2$e/year) by 2030.
- The proportion of biodiesel in UK forecourt diesel has risen from 3.7% in 2018 to 5.3% in 2019 and 6.7% in the first half of 2020. 76% of this biodiesel was produced from used cooking oil.[50] Growth in commercialisation of advanced biofuels could offer the potential to further increase this share within the HGV sector up to around 10% by 2030 and 15-20% by 2040.

Given that the optimal decarbonisation technology for the HGV sector is not yet certain, biofuels are likely to play a role for a longer period of time in this sector than for cars and vans.

Biomass is a valuable limited resource. Our analysis[51] finds that its best use in driving emissions abatement across the economy is through uses that maximise carbon sequestration (e.g. in industry and with CCS). Our scenarios assume that biofuels will play an important transitional role in reducing emissions from surface transport, but that use is limited post 2040 as they are best used in other sectors.

## iii) Electrification of rail

Around 40% of the UK's rail network is currently electrified, with the remainder of the network using diesel trains. Options exist to improve diesel train efficiency by 2050:

- Analysis[52] suggests that mild hybridisation can reduce diesel engine emissions by 25% from typical current levels of 0.8 kg$CO_2$/kWh, while the use of stop-start technology, selective engine shutdown and advanced driver advisory systems can contribute a further 20% reduction (primarily applicable to passenger services, which stop and start more frequently). Further innovations, including better heating/cooling, cruise control and improved aerodynamics could offer a further 10% in the longer term.[53]

‡ The increase in the $CO_2$ intensity of new diesel HGVs after 2030 is due to an assumed gradual shift in purchasing towards larger vehicles.

- For vehicles that cannot be transitioned away from diesel (which could include heavy plant machinery), the use of biodiesel in place of fossil fuel diesel could provide a lower-carbon alternative.

Continued gradual electrification of the railway will allow electric trains to run on more of the network.

To meet the ambition set out in our scenarios, rail will need to be decarbonised further, with gradual electrification up to 55-60% of the network by 2050:

- Analysis by the Rail Delivery Group[54] shows that already-committed schemes would be expected to increase electrification to 50% of the network by 2039, which could increase the proportion of the passenger fleet using electrical power by 10-20% by 2050.
- Only a small proportion of rail freight is currently hauled by electric locomotives, due to the need to be able to travel widely across the network. However, research[55] has suggested that targeted electrification of 515km of track could allow two-thirds of rail freight to be electrically hauled.

Battery-electric and hydrogen trains may be suitable for routes that cannot be electrified.

Battery-electric and hydrogen technologies could be suitable for some routes:

- In 2019, Vivarail unveiled a battery-electric train with 60-mile range, while in July 2020, Hitachi and Hyperdrive Innovation signed an agreement to form a battery development hub in the North-East of England. Further innovation offers the potential to extend battery ranges over the coming years.
- While such battery-only models are likely to be suitable only for category A[§] operations[56] (around 25-30% of remaining diesel passenger vehicles), bi-mode battery-catenary configurations could expand this suitability.
- Two Alstom hydrogen trains have been operating in Germany since 2018, while 2019 saw the first mainline test of the HydroFLEX prototype in the UK.
- As with battery-electric models, hydrogen is likely to be suitable for category A trains and in future potentially lighter-duty category B trains56, which together comprise around 25-50% of remaining diesel passenger vehicles. Hybridisation approaches may offer the potential to extend this coverage across categories B and C and to freight vehicles, but this is likely to be dependent on technological innovation.
- Both hydrogen and batteries offer low energy densities compared to diesel.[57] The high energy requirements of freight trains mean that these traction methods could require additional wagons simply for storing fuel or batteries. For this reason, we do not assume uptake of these modes in the freight sector within our scenarios.

It is not yet certain what combination of technologies will be optimal, with different studies suggesting different combinations of options. For example, Network Rail analysis[58] suggests electrification of a further 13,000km of track[**], battery operation on around 800km and hydrogen operation on around 1,300km. Whereas the Rail Industry Decarbonisation Taskforce[52] found that Net Zero emissions could be achieved with electrification of around 8,500km of track, while making greater use of battery-electric and hydrogen trains and of biodiesel out to 2050.

§ Category A covers shorter-distance self-powered trains, generally with maximum speeds below 75mph. Categories B and C are middle- and long-distance self-powered trains, with capability up to 90-100mph and 100-125mph.

** Rail electrification is typically measured in terms of single-track kilometres, i.e. one kilometre of twin-track railway being electrified would count here as two kilometres of electrification.

## c) Zero-emission vehicles

Widespread deployment of zero-emission vehicles (ZEVs) will be needed to meet Net Zero. In this section, we set out evidence on the technological characteristics, impacts and costs of zero-emission options for cars, vans and heavy-duty vehicles.

### i) Electric cars and vans

Battery-electric cars offer considerably lower lifecycle emissions than conventional vehicles, and these reductions are likely to increase.

Battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) entered the UK market in the early 2010s and now make up around 5% and 3% of new car sales during 2020 to-date.[59] BEVs already offer considerable lifecycle emissions savings compared with Internal Combustion Engine (ICE) vehicles, and by 2030 we expect embedded production emissions to be around the same as current ICE vehicles. By contrast, recent evidence[60] suggests that real-world emissions of PHEVs could be two to four times type-approval values which, at the upper end of this estimate, could make PHEV driving emissions similar to those of ICE cars (Box M2.2).

**Box M2.2**

Life-cycle emissions from electric vehicles

Although production of batteries means that the manufacture of UK BEVs today is more carbon-intensive than for a comparable ICE, the significant reductions in operational emissions mean that a BEV's total lifecycle emissions are substantially lower (Figure MB2.2).

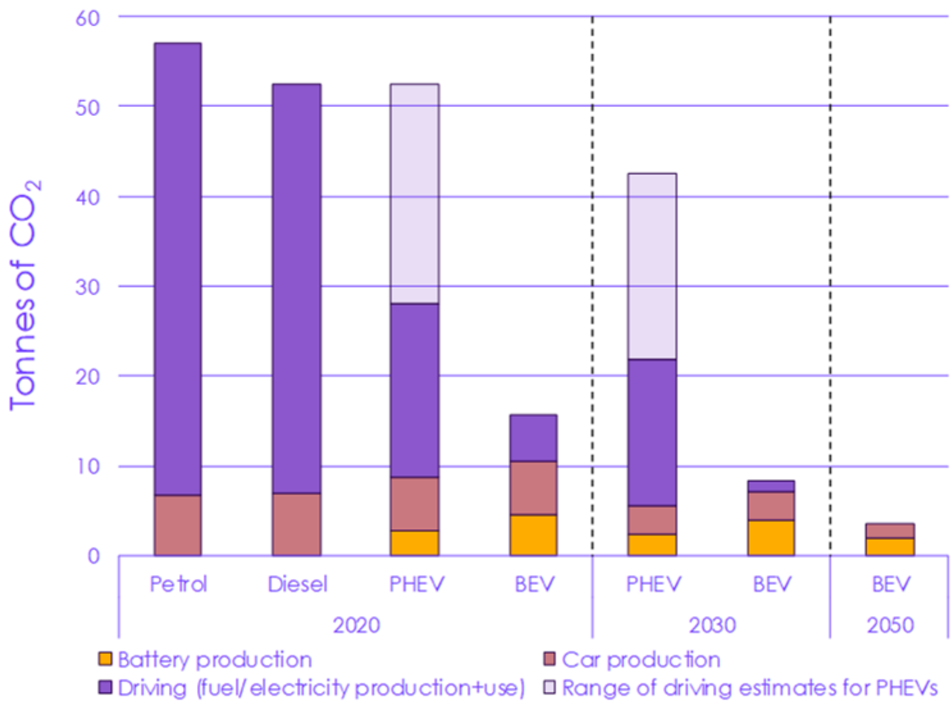
- Operational emissions account for just under 90% of petrol and diesel cars' total lifecycle emissions, compared to under 50% of total emissions of BEVs today.[61]
- While we expect to see some fuel efficiency improvements for fossil fuel vehicles to 2030, driving emissions for BEVs are expected to decrease much more (by around 60%) as the carbon intensity of the UK grid electricity reduces.
- Our analysis shows that BEVs, powered with today's UK average electricity, repay the 'carbon debt' from the production of their battery within slightly more than a year and save more than 35 tonnes of $CO_2$ over their lifecycle versus a conventional equivalent.

PHEVs have the potential to reduce emissions if they drive mainly on electricity. However, a recent study by the International Council on Clean Energy (ICCT) suggests this is not the case, bringing real-world emissions of PHEVs more in line with those of fossil fuel vehicles.

- Based on a study of real-world driving of around 100,000 PHEVs, ICCT found that real-world driving emissions were two to four times higher than type-approval values. This was true for both the NEDC and the WLTP test cycles.
- The largest difference between test-cycle and real-world emissions was found for company cars, where charging is less frequent, but mileage higher.
- The real-world share of electric driving for PHEVs is about half of that assumed in type-approval tests on average. For all private cars in the study, the ratio of kilometres driven on electric power to combustion engine kilometres is 69% under NEDC testing but 37% for real-world driving. For company cars (only sampled in Germany and the Netherlands), the average ratio under NEDC was 63% versus 20% in real-world driving.
- Private users in Germany were found to charge their PHEVs on average three out of four driving days. For company cars, charging takes place every second driving day.

A remaining challenge for all electric vehicles is around end-of-life battery use.[62] Strengthening battery collection, recycling and recovery will help with raw material supply and availability (Box M2.3). The carbon impacts of end-of-life battery use or disposal are not included in Figure MB2.2 due to limited accurate evidence.

## Figure MB2.2 UK lifecycle emissions of fossil fuel and electric cars




Source: CCC analysis based on T&E (2020) *Analysis of electric car lifecycle $CO_2$ emissions*; ICCT (2020) *Real-world usage of plug-in hybrid electric vehicles*; EEA (2018) Electric vehicles from lifecycle and circular economy perspectives.

Notes: Based on medium-sized cars driven in the UK. For PHEVs, a range of estimates have been considered, based on high and low estimates from T&E and ICCT, along with CCC modelling. This range is shown with the light-purple column. The breakdown for BEVs in 2050 has been estimated by CCC based on the breakdowns for other categories.

Battery-electric cars and vans are now widely available in the UK, across most manufacturers and a range of vehicle sizes.

Electric vehicle (EV) technology is developing quickly and we expect uptake of BEVs to grow to between 90-100% of new sales by 2030:

- **Availability:** The supply of different EV models is increasing, widening consumer choice. Evidence suggests that raw materials and supply chains will be able to scale up quickly enough to enable this to continue (Box M2.3).
  - Worldwide, 105 new BEV models and 38 new PHEVs were launched in 2019.[63] A further 293 BEVs and 137 PHEVs are planned by 2022.
  - In the UK, there were 14 BEV car models from 14 manufacturers and 8 BEV van models from 2 manufacturers available in 2015. By 2020, these increased to 37 BEV cars from 20 manufacturers and 18 BEV vans from 14 manufacturers. There are at least 8 upcoming BEV car models, from 5 different manufacturers, in the next year.
  - Delivery times for EVs have fallen rapidly over the past year[64], with waiting times for all models now within 12 weeks, compared with over a year for some models in 2019. This is comparable to waiting times for new conventional vehicles.

Electric cars are considerably more energy-efficient than ICEs. By 2035, we expect BEVs to average 0.5 MJ/km. This compares to current ICE efficiencies of 1.7-2.2 MJ/km.

- **Fuel efficiency:** While EVs are already three-times more energy-efficient than ICE vehicles, technological improvements can deliver further efficiency improvements in the next decade.
  - Measures such as aerodynamics and weight reduction, as well as battery technology development, can improve fuel-efficiency.
  - Our analysis suggests real-world BEV efficiency can improve by around 12% to 0.5 MJ/km by 2035. PHEV efficiency will be lower at 0.9 MJ/km.[65]

Battery ranges are likely to reach 350-400 km by 2030, which will be enough to allay range anxiety.

- **Driving range:** Battery technology is progressing rapidly, and typical BEV ranges could reach around 350-400 km (220-250 miles) by 2030, with larger cars most likely to have longer battery range and van range slightly lower (Table M2.2). As range improves and battery costs reduce, EVs are well placed to become a viable option for all consumers.
  - The average range of a new BEV today is around 300 km.[66] While this is skewed upward by the luxury models, there are a significant number of vehicles across all size with ranges exceeding 200 km.
  - As battery costs reduce (see Figure MB2.5), manufacturers are likely to increase battery capacity, leading to greater range. The IEA forecast[67] average driving range to reach 350-400 km by 2030.
  - Research has shown that a driving range of 370 km is sufficient to eliminate 'range anxiety' among consumers.[††] As range approaches this threshold, manufacturers may choose to make EVs cheaper rather than to improve range further. For some drivers, affordability will be more important than long driving range and it is important that EVs are appropriately sized to meet the needs of different market segments.
  - We expect electric-only range for PHEVs to remain at around 40 km, with drivers driving in electric mode around 50% of the time (Box M2.4).
  - The larger weight, size and payload of vans means that they require larger batteries to offer a comparable range. Therefore, van ranges are likely to remain slightly below those of cars.

**Table M2.2**
Average real-world driving range of a typical new battery electric vehicle in km

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| Car – small | 289 | 361 | 434 | 500 |
| Car – medium | 300 | 375 | 450 | 500 |
| Car – large | 349 | 436 | 500 | 500 |
| Van | 250 | 350 | 375 | 400 |

Significant deployment of public charging infrastructure, including on-street charging for those without private car-parking and inter-urban chargers for charging during long journeys, will be needed in the 2020s and 2030s.

- **Infrastructure availability:** Provision of charging infrastructure is key to enabling the high uptake of EVs across the UK. We expect around 260,000-480,000 public chargers to be required by 2040 across our scenarios (Figure A3.1.b in the Advice Report; Table M2.3 for Balanced Pathway assumptions).

[††] 'Range anxiety' is the concern that an EV will not have sufficient usable range for the consumer's purposes and may suddenly and unexpectedly run out of charge.

The number of public electric vehicle chargepoints has grown more than five-fold since 2015, to 18,000 today. We expect this to increase around ten-fold by 2030.

- A recent survey[68] of UK motorists found that 69% are discouraged from switching to an EV due to a perceived lack of charging infrastructure.
- There are currently over 18,000 public charge points in the UK, of which over 3,000 are rapid chargers.[69]
- Around 70% of car owners have access to off-street parking and so will be able to recharge their vehicle at home. These typically cost up to £1,000 to install today (although a Government grant will contribute up to £350), and we expect this cost to fall to around £850 by 2030 and £680 by 2040. We include these costs in our estimates of the capital expenditure on the vehicle.
- For the remaining 30% of car users, extensive provision of on-street charging will be necessary. We estimate that there will need to be around 140,000-270,000 on-street/local chargers by 2030, increasing to 250,000-460,000 across our scenarios by 2040. This is based on an extensive model developed by Systra for the CCC in 2018[70], updated with latest assumptions on EV costs and range.
- A network of rapid charge points (in particular along the strategic road network) will enable users to recharge reliably during longer journeys. Companies such as Ecotricity already provide a network of individual chargers at motorway service stations, while Gridserve is due to open the UK's first electric forecourt later this year. Our scenarios anticipate the installation of 8,000-15,000 chargers in interurban locations by 2030, rising to 10,000-20,000 by 2040.
- On a similar scale, analysis by Transport and Environment[71] found that the UK would require 370,000-500,000 public chargers by 2030.

**Table M2.3**
Total public charging infrastructure in our Balanced Pathway in thousand units

| | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| **On-street/local** | 17 | 270 | 460 | 520 |
| **Inter-urban** | 0.5 | 8.5 | 10 | 10.5 |
| **Total** | 18 | 280 | 470 | 530 |

Electric vehicle charging will add substantial demand to the electricity grid. Smart charging and possibly vehicle-to-grid schemes can mitigate the impact of this.

- **Network upgrades:** Electricity demand among road vehicles in our scenarios will increase from 1 TWh in 2020 to 92 TWh by 2040, which will require network reinforcement, appropriate planning and timing of which is important for this to be achieved cost-effectively.
  - This increased demand will require reinforcement of the distribution network. It is expected to be more cost-effective to proactively ensure that networks are able to cope with increased demand, rather than to wait until demand outstrips capacity.[72] Thus, our scenarios assume that these upgrades begin in the 2020s and do not constrain EV uptake.
  - Our analysis suggests that the cost of these reinforcements will lead to a 2p/kWh increase in the average price of electricity used for vehicle charging during the 2030s. This is included in our cost estimates.

– The scale of upgrades required can be reduced (but not eliminated altogether) through effective use of smart charging. This can smooth the new peaks in residential demand resulting from home charging and shift charging demand into off-peak periods.[73] Further, the introduction of vehicle-to-grid schemes could offset up to 85% of the remaining peak EV demand[74], depending on uptake.

Battery-electric cars are expected to reach upfront cost parity with conventional vehicles by 2030. They will be cost-saving on a total cost of ownership basis by the late-2020s.

- **Costs:** Our analysis shows that the upfront cost of a BEV will reach parity with an ICE in 2030, while the significantly lower running costs mean that BEVs will be cost-saving before then (Figure A3.1.h in the Advice Report).
  - A typical BEV is currently around 34% more expensive to purchase than a comparable conventional vehicle. For a £20,000 vehicle, this means that a BEV version would be likely to attract a cost premium of around £6,800. The Government's plug-in car grant would currently contribute up to £3,000 towards this difference.
  - Battery costs currently make up at least 30% of the upfront cost of a BEV. Battery costs will continue to reduce during the 2020s (Box M2.5).
  - As a result, we expect BEVs to reach upfront cost parity with comparable ICE vehicles in 2030. By 2040, a typical medium-sized BEV is expected to be around £500 cheaper than an ICE vehicle.
  - Electric drivetrains have fewer moving parts than ICEs, meaning that they will typically have lower servicing and maintenance costs. For a typical medium-sized car, we estimate an annual saving of £170.

The electricity required to power an electric vehicle is significantly cheaper than petrol or diesel.

  - BEVs can offer significant annual fuel cost savings. Over the assumed 14-year lifetime of the vehicle, a typical medium-sized BEV will save almost £1,000 in fuel costs (£750 in discounted terms), excluding fuel duty and the impact of carbon emissions. If taxes are included, then the cash value of the saving to the owner increases to around £6,700 (£2,200 over the first five years of ownership).
  - By contrast, a medium-sized PHEV will be around £300 more expensive to purchase in 2030, will offer zero maintenance savings and gives lifetime fuel savings of only £300 (£2,400 in cash terms including taxes).
  - Similarly, we estimate that BEV vans will also reach upfront cost parity with ICE vans around 2030 and will be around £1,400 cheaper by 2040. Due to their typically higher mileage, a new BEV van in 2030 will realise higher lifetime fuel savings of around £2,800 (£14,600 including taxes).

A new battery-electric car purchased in 2030 will have a negative abatement cost of -£38/t$CO_2$e.

From a societal perspective[‡‡], our analysis suggests that BEV cars are likely to become cost-effective by the late-2020s, while the higher fuel savings for vans mean that BEV vans will become cost effective by the mid-2020s. By 2030, the average abatement cost of a new BEV will be negative at -£38/t$CO_2$e for cars and -£43/t$CO_2$e for vans. Thereafter, they will continue to become even more cost-effective, reaching -£84/t$CO_2$e for cars and -£48/t$CO_2$e for vans by 2050.

[‡‡] Including cost of the vehicle and cost of fuel (excluding taxes), discounted at the social discount rate of 3.5% p.a.

Battery-electric vehicles will make up over 90% of all new car and van sales by 2030.

Based on these cost advantages, we expect BEVs to make up the majority of new sales by 2030 across all scenarios (Figure A3.1.e in the Advice Report):

- The above factors are important determinants of the rate at BEV adoption and are used in our modelling of consumer decision-making (Box M2.6).
- All of our scenarios assume no sales of new petrol or diesel cars, vans or PHEVs from 2035 at the latest (2032 as the central assumption).
- Across our scenarios, we estimate that BEVs could make up 24-56% (central assumption 48%) of new car and just over half of new van sales in 2025 and 90-100% (central assumption 97%) in 2030. PHEV sales fall from 25% in 2025 to 1% by 2030 to meet the phase-out date assumptions in our scenarios.

By 2035, over half of the fleet of cars and vans on the road in the UK will be battery-electric.

- New BEV sales will take time to feed through to the fleet as the average car remains in use for around 14 years. In our analysis, BEVs will comprise 27-37% of the car and van fleet in 2030, rising to 56-67% by 2035 and 81-88% by 2040 (central assumptions 35%, 65% and 87% respectively).
- For comparison, the National Grid's Future Energy Scenarios[75] have slower initial take-up, but this rises quickly in the 2020s with 11-36% BEV penetration across the fleet in 2030, 30-81% by 2035 and 61-99% by 2040.

**Box M2.3**

Supply of raw materials for EV batteries

To meet the Paris Climate Agreement, the level of EV production in the UK and globally will need to increase significantly from current levels. For example, global production could rise to 40-90 million vehicles annually by 2030 compared with around 2 million today. Global supplies of key raw materials for battery production such as cobalt, lithium, aluminium, graphite and manganese will need to scale up significantly, but are expected to remain a low proportion of estimated global reserves (e.g. lithium demand for EVs could be 1-2% of global reserves).

The CCC wanted to explore issues around the challenges and opportunities for future raw materials supply globally and for the UK. In March 2020 we sent a questionnaire to key stakeholders asking for views and evidence. We received a range of responses from academics, industry and research bodies. The key findings were:

- There are plentiful global supplies of raw materials to supply the growing battery market. The issue is around scaling up, particularly around 2025-30. Developing new mining opportunities and new supply chains will be crucial to meeting that demand.
- Changes to battery chemistry will take time and lithium nickel manganese cobalt oxide (NMC) batteries are expected to dominate for the next decade. Appropriate sizing of batteries and standardisation of manufacturers' battery chemistries would improve resource efficiency and enable higher levels of recycling and reuse.
- Security of supply and of raw materials for batteries can be enhanced by: supporting R&D of batteries and recovery technologies; localising more of the supply chain in the UK and linking battery and EV manufacturers; having a clear assessment of how best to reuse batteries; and developing competitive, large-scale UK recycling facilities.
- A certification scheme for ethical sourcing of raw materials would help to address issues around working conditions, low pay and use of child labour in mines.

**Box M2.4**

Real-world PHEV operations

While PHEVs are often advertised as low-emission vehicles, recent studies by Transport and Environment[76] and the International Council on Clean Transportation[77] show that PHEVs emit two- to four-times more during real-world driving than test values. This makes their real-world emissions more comparable with conventional vehicles than with ZEVs.

- Typical real-world emissions from PHEVs are around 117 $gCO_2$/km, compared to 165 $gCO_2$/km for ICE cars.
- Typically, PHEVs are not charged as often as they could be, reducing the share of kilometres driven on electricity.
- Even when PHEVs are supposed to be in zero-emission mode, the car does not drive using only the electric motor and continues to use its engine, emitting $CO_2$.
- The ICE in a PHEV will typically turn on in situations that require high power.[78] For example, in each of the UK's top-ten selling PHEVs, turning climate control on engages the ICE.

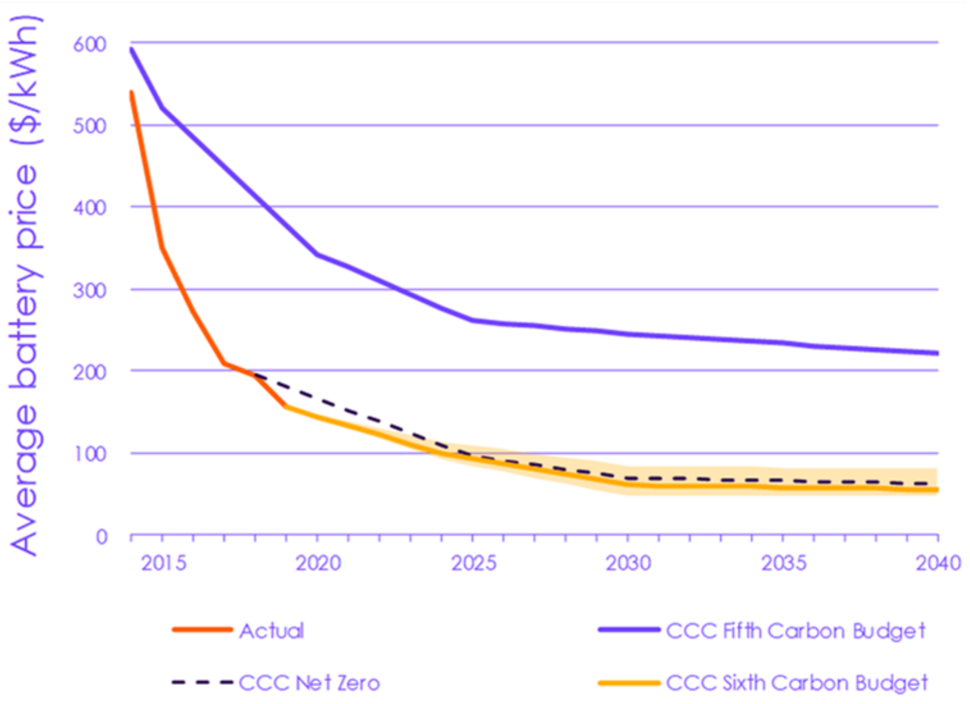
**Box M2.5**

Battery cost assumptions

Battery costs currently make up around one-third of the cost of a typical BEV. Changes in battery cost will thus have a significant impact on the cost of a BEV.

- Advances in battery technology and manufacturing, together with market expansion, have driven more rapid falls in battery prices than previously expected. Further reductions are anticipated.
- Our assumptions are based on Bloomberg New Energy Finance price projections[79], which show the average price per kWh falling below $100 in 2024 and to $61 by 2030.
- Beyond 2030, we assume further gradual reductions down to $53/kWh in 2050. In our Widespread Innovation scenario, this minimum price is reached by 2030.
- The cost of battery packs for HGVs and buses is assumed to be higher, because of the use of different battery chemistries and constructions to achieve greater durability and the reduced economies of scale within this market. A bottom-up analysis conducted by Element Energy80 estimates that costs today are around $470/kWh and are expected to fall to around $155/kWh by 2030 and $83/kWh by 2050.

Figure MB2.5 Average battery cost for electric vehicles, actual and forecast to 2040




Source: Bloomberg New Energy Finance (2019) *Battery Price Survey*; CCC analysis.
Notes: Our central projection (orange line) follows the BNEF forecast. The shaded area around this shows the range between the low battery pack prices assumed in the Widespread Innovation scenario and our upper price sensitivity based on further price reductions being only 75% of central forecasts. These battery costs are for battery-electric cars and vans.

**Box M2.6**
Updated assumptions in charging and uptake modelling

In our decarbonisation pathways analysis, we have updated existing models for EV uptake (developed by Element Energy) and EV infrastructure requirements (developed by Systra). Here we describe the approach and key changes.

**EV uptake modelling.** Our EV uptake paths are based on a decision model that simulates likely consumer behaviour when purchasing a new vehicle. The primary assumptions are:

- **Tax/subsidy gradient between ICEs and EVs.** Our pathways assume that during the 2020s, a differential between ICEs and EVs from subsidies, benefits-in-kind and taxes remains (reducing from 2020). Over time, we would expect this gradient to shift from EV subsidy to ICE taxation.
- **New conventional vehicle sales phase-out**. Our scenarios explore the impact that different phase-out dates could have. Our Balanced Net Zero Pathway assumes a phase-out date of 2032, compared to 2030 in Widespread Engagement/Widespread Innovation/Tailwinds and 2035 in Headwinds. Modelling assumes that these phase-out dates are accompanied with EV percentage sales targets for suppliers as well as a market response reducing the supply of new petrol and diesel models available to UK customers as the phase-out date is approached.

**EV infrastructure modelling.** Our modelling of infrastructure requirements uses two models: a 'parking-based model' which calculates public charging infrastructure required in towns and cities and an 'inter-urban model' which determines public charging points needed to facilitate long-distance travel. For our Sixth Carbon Budget analysis, we consulted with industry experts, manufacturers and broader stakeholders to produce a range of credible input assumptions to these models and mapped these to our scenarios.

Some assumptions are constant across the two models:

- **Cost of building charging infrastructure.** In all scenarios except Widespread Innovation, the cost of deploying charging infrastructure, including the associated network upgrades, is assumed to be the same as present-day values. This is likely a conservative assumption. In the Widespread Innovation scenario, the cost of building charging infrastructure falls by 5% every 5 years.
- **Number of trips.** In all scenarios, we begin with Government projections of future trip demand by region. In each of our scenarios, we explore the potential for varying levels of demand reduction due to increased use of public transport, modal shift etc.
- **EV percentage uptake.** EV uptake is determined by the uptake modelling (see above). We assume that regional differences in current EV uptake remain during the 2020s but dampen over time as percentage roll-out increases.
- **Battery capacities and vehicle ranges.** In most of our scenarios, we assume that the majority of new vehicle sales have battery capacity greater than 350 km by 2030, in line with industry trends. To reflect possible market segmentation, our Widespread Engagement scenario continues to sell EVs with ranges as low as 150 km in 2050.

The parking model deploys three speeds of charger – 7kW, 22kW and 50kW – to serve drivers, and incorporates some additional specific assumptions:

- **Target service level.** The model assumes that when an EV parks around town, it will try to charge irrespective of its level of charge (a 'top-up'). The percentage of time that a charger is available to do this for the duration needed is the target service level. Our Balanced Pathway assumes that the acceptable service level for EV drivers remains the same as at present. The Widespread Engagement scenario explores a future where drivers are more comfortable with forgoing a top-up, and the Widespread Innovation scenario expands the charging network to allow more regular topping-up.
- **Percentage of drivers with home charging.** In all scenarios, it is assumed that the percentage of EV drivers with home charging increases to the percentage of households that have off-street parking.

The inter-urban model deploys three speeds of charger – 50kW, 150kW and 350kW – and includes the following specific assumptions:

- **Range anxiety.** When making a long trip, behaviour suggests that new EV drivers are uncomfortable making trips close to the range capacity of their vehicle, and that a degree of this effect remains. This means that the maximum used range of EVs is lower than their actual range. The percentage buffer that new and experienced drivers allow is known as the range anxiety factor. All our scenarios assume that range anxiety factors fall over times as EVs become the norm, however our Widespread Engagement scenario accelerates this effect.
- **Charging compatibility.** High-speed chargers require a compatible EV. The highest-speed chargers currently have low levels of compatibility. Our scenarios all assume that by 2035, all cars and vans making long-distance trips are compatible with rapid chargers. In our Widespread Innovation scenario, compatibility increases more quickly.

Continued advancement of battery technology is likely to make battery-electric technologies suitable for widespread heavy-duty use in the coming decade.

## ii) Zero-emission HGVs and buses

Decarbonisation of the transport sector will require widespread uptake of zero-emission HDVs by 2040 to enable almost full decarbonisation of the fleet by 2050.

We commissioned Element Energy[80] to consider pathways to decarbonising this sector (Box M2.7). The study showed that each of battery-electric vehicles, electric road systems and hydrogen fuel-cells could play a role within this sector and it is too soon to say with certainty which technology choices will be cost-optimal.

**Battery-electric HDVs.** If battery technology continues to advance quickly, then it is projected to become suitable for many HDV applications within ten years. This is explored in our Widespread Innovation scenario.

- Packaging sufficient battery range into the vehicle is a major challenge with battery-electric HGVs. The volumetric and gravimetric densities of a battery pack are 50-60 times lower than those of diesel.

- This means that, even correcting for an electric drivetrain's higher efficiency, batteries take up considerably more of the vehicle's size and weight allowances than diesel. This is a particular challenge for certain designs of HGV (including articulated trucks) and for buses, where available space is limited.

- While models developed over the coming years may provide enough range for some smaller HGVs[81], some larger HGVs can drive up to 800 km in a single day and are heavier. Covering this range without the need to recharge would greatly increase the vehicle's cost and reduce the space and weight available for the payload.

- Research conducted by Ricardo for the CCC[82] emphasised the need to develop infrastructure that would be suitable for HGV use. This analysis estimated that each depot would require 0.3-0.85 chargers per vehicle, in addition to around 130 strategically located ultra-rapid chargers.

Ultra-rapid chargers suitable for HGVs will be required across the strategic road network to support the use of battery-electric vehicles on longer routes.

- In practice, long-distance vehicles are likely to require at least 400 km of independent range, plus the provision of sufficient density of HGV-suitable ultra-rapid chargers to be able to recharge ahead of mandated breaks (every 4.5 hours). Element Energy found that would require a network of recharging points at least every 50 km on the UK's strategic road network.

- If this were available and battery technology develops sufficiently, then battery-electric HGVs could make up 19% of all new sales in 2030, increasing to 82% by 2035. Large articulated HGVs are likely to be slowest to adopt this technology, due to their greater range requirements and limited spare capacity.

- Battery-electric buses are already being deployed[83], often due to local authority efforts to reduce air pollution.

- This means that costs are falling relatively quickly, and total cost of ownership (TCO) parity is likely to be reached in the early-2020s. As such, uptake is expected to be faster than for HGVs, and could reach up to 68% of sales in 2030 and 100% by 2035.

- Aircraft support vehicles are similar to small rigid HGVs. In line with the analysis for them, it is therefore likely that electric vehicles will be suitable for all new sales of aircraft support vehicles by the mid-to-late-2030s.

Catenary systems avoid the need for lengthy recharging and are a more mature technology. However, such systems require substantial infrastructure and may become uncompetitive.

**Electric road systems.** Electric road systems (ERS), consisting of overhead catenary to which HDVs can connect via a pantograph to draw power directly or recharge, can offer operational benefits to operators. However, once other zero-emission technologies become widely available, the use of an ERS may become expensive relative to other options. Our Widespread Engagement scenario considers the sector if there is large-scale ERS deployment.

- Both Germany and Sweden have an operational ERS (of 10 km and 2 km in length, respectively), while Siemens now offer a commercial ERS product.[84] ERS is similar to the overhead wires used for rail electrification, so it is a proven commercial technology.

- ERS technology could be attractive to fleet operators who are concerned about the impact of the need to recharge their vehicles on operations. Being able to recharge while driving would mitigate these concerns.

- To recoup the significant infrastructure investment from limited users, an ERS operator would need to charge relatively high electricity prices. This may drive fleet operators to prefer depot- or public-charging where possible.
- Recent research[85] laid out a plan by which ERS could be deployed across 7,500 km of the strategic road network, beginning in 2025 and completing by the late-2030s. This would cover 65% of HGV-kilometres (18 billion kilometres) at a cost of around £1-1.5m per kilometre. The Ricardo work, by contrast, assumed a more modest 3,600 km of ERS infrastructure, with a similar unit cost.
- Element Energy's analysis expects that once an ERS network is fully deployed (assumed to be 2045), then ERS becomes the most cost-effective option for around one-fifth of HGVs operating on the longest routes. This could lead to uptake rising from 24% of new articulated trucks in 2040 to 33% in 2045, with a small percentage of large rigid HGVs also using the system. Smaller HGVs are expected to prefer the lower electricity prices of depot-charging, as this should cover their range requirements by this time.
- ERS infrastructure could help meet range requirements of longer-distance buses and coaches, reaching up to 50% of total sales from 2035 onwards.

Hydrogen vehicles offer a similar operational profile to current vehicles and are attractive for operators who require long ranges.

**Hydrogen fuel-cell vehicles.** Hydrogen offers the closest user experience to current diesel operations. Given sufficient hydrogen refuelling infrastructure, fleet operators would be able to fill up vehicles either in-depot or from filling stations en route as currently, or both. Hydrogen is also a particularly attractive solution for vehicles requiring longer independent range. Its widespread deployment is considered as part of our Headwinds exploratory scenario.

- There are currently 11 hydrogen refuelling stations in the UK, with a further 5 planned.[86] These mostly cater for light-duty vehicles, for which hydrogen consumption per vehicle is low. There is potentially a stronger business case for hydrogen in the HDV sector, due to the higher fuel consumption.
- Energy storage poses a challenge, although not to the same extent as for batteries. Pressurised hydrogen tanks are relatively space-inefficient and cannot efficiently be divided to fit into available space within the vehicle.
- The energy storage challenge is likely to be quicker to resolve for hydrogen than for batteries. This could allow hydrogen-fuelled vehicles to meet most operators' range requirements (potentially even delivering independent ranges of up to 800 km for an articulated truck with additional space allowed for fuel storage within the trailer) more quickly than electrification.
- This rapid potential is seen in a partnership between Hyundai and H2 Energy, which aims to deploy 1,600 hydrogen HGVs in Switzerland by 2025.
- By 2050, the Ricardo analysis expects that around 500-600 hydrogen refuelling stations would be required to support the use of hydrogen by larger HGVs only. If smaller vehicles were to use hydrogen in preference to electrification, this could increase to around 1,000.[87]
- With this infrastructure, Element Energy's analysis shows that hydrogen uptake could be relatively quick, reaching 77% of larger HGVs by 2035 and 99% by 2040. Hydrogen could also be suitable for smaller HGVs, but the cheaper running costs of depot-charged BEVs will likely be more attractive.

- London currently has 8 hydrogen buses operating, and UK manufacturer Wrightbus recently announced plans to manufacture 3,000 hydrogen buses. Hydrogen bus sales could ramp up relatively quickly, potentially reaching up to 69% of all sales by 2030 and 95% by 2035.
- Hydrogen cars already exist in the market[88], while hydrogen vans have also been demonstrated.[89] If there were to be significant rollout of hydrogen refuelling infrastructure to support the HDV sector, then it is conceivable that hydrogen-fuelled smaller vehicles may also see further development.
- The decarbonisation potential of hydrogen in transport is intrinsically linked to the wider hydrogen strategy.

If public infrastructure for all three technologies were deployed, battery-electric vehicles are expected to become cost-optimal for all operators by 2050.

**Mixed infrastructure deployment.** In a model in which all three technology options are developed simultaneously, BEVs were found to be cost-optimal by 2050, but hydrogen fuel-cell vehicles had a significant role in meeting the range requirements of many operators in the early-2030s (Table M2.4). This is the basis (in modified form[§§]) for our Balanced Pathway and Tailwinds scenario.

- In the early-2030s, the range provided by a hydrogen vehicle is likely to be greater than a comparably priced BEV. Furthermore, most operators' range requirements can be met through in-depot refuelling, allowing uptake of hydrogen vehicles prior to full public refuelling infrastructure deployment.
- For short-range HGVs and buses, BEV sales are likely to grow quickly from today.
- TCO is relatively competitive between BEVs and hydrogen vehicles from 2025 to 2035. However, once an ultra-rapid charging network is deployed, HDVs with smaller batteries become viable due to the ability to recharge en route. This makes BEVs increasingly more cost-effective than hydrogen vehicles from 2035 onwards.
- Hydrogen HGVs may retain a significant portion of the market, however, due to operators who have invested in hydrogen infrastructure being 'locked in' to that technology and because of its lower operational complexity. Small fleets may also choose hydrogen as it allows 100% public refuelling rather than requiring charge points to be installed in the depot.
- ERS is currently the most mature technology and would be the most suitable to decarbonise the HDV sector today. However, supply of zero-emission HDVs is likely to be limited by original equipment manufacturer (OEM) production until the early-2030s. By this point, we expect hydrogen costs to have reduced and battery technology to have improved – if this occurs, then ERS is likely to be uncompetitive with these technologies for most operators' requirements.
- Under this mixed model, around 330 public ultra-rapid charge points, 100 hydrogen refilling stations and up to 90 km of ERS network are expected to be required by 2035. In addition to this, around 140,000 depot chargers would be needed. These comprise the majority of the expected infrastructure costs at £1.1 billion, with the public infrastructure provision costing an additional £200m. By 2050, the cumulative cost of HGV infrastructure is expected to have risen to around £9.8 billion.

§§ The Balanced Net Zero Pathway follows this mixed technological roll-out but assumes that a substantial ERS network is not developed due to its low uptake. The Tailwinds scenario considers how much this mixed model's uptake could be accelerated with maximum rates of infrastructure deployment and technological development.

| **Table M2.4**<br>Uptake of zero-emission technologies among HDV sales if all solutions progressed (% of all new sales) | | | | |
|---|---|---|---|---|
| | **2020** | **2030** | **2040** | **2050** |
| **Battery-electric** | <1% | 13% | 50% | 71% |
| **Hydrogen** | 0% | 11% | 48% | 26% |
| **ERS** | 0% | <1% | 1% | 2% |

It is too soon to tell which will be the most cost-effective and feasible solution for heavy-duty vehicles. Large-scale demonstrations are needed in the coming years.

Given the state of market development and uncertainty over costs, it is too soon to tell which will be the most cost-effective and feasible solution for HDVs. Large commercial-scale demonstrations, involving hundreds of vehicles and lasting at least 1-2 years, should be planned and implemented over the coming years to further test deployment of each technology and produce real-world data on costs and operational feasibility.

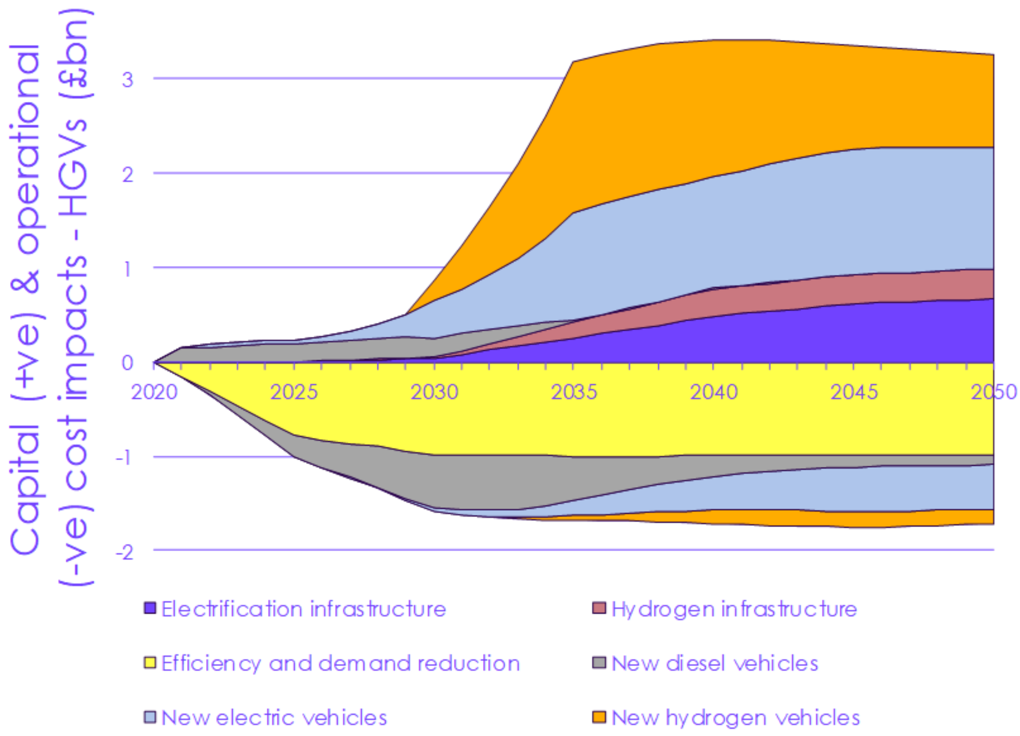
The high upfront cost of zero-emission HDVs means that our analysis does not expect them to become cost-saving from a social perspective before 2050, but they are cost-effective against current expected carbon values:

- The unit abatement cost of a new articulated HGV in 2035 is estimated at £64/t$CO_2$ for a BEV and £178/t$CO_2$ for a hydrogen vehicle. By 2050, these could reduce to £26/t$CO_2$ and £110/t$CO_2$. These are below expected carbon values in these years, meaning that they represent a good value means of abatement.
- Due to the high upfront costs, we expect there to be TCO shortfall of £24,000-33,000 for a private owner of a rigid truck in 2035 relative to a diesel vehicle, with only higher-mileage articulated HGV owners realising a TCO saving. For smaller HGVs, TCO parity may take until 2050 to be reached.

Significant Government support will be needed to incentivise widespread timely uptake of zero-emission options across the HDV sector.

- Government support or significant market development will be needed to bridge this gap, in order to ensure that diesel sales are phased out in time that diesel vehicles do not continue to remain in circulation beyond 2050.
- Our uptake modelling assumes that sufficient support is in place to ensure TCO parity in 2035 across all scenarios.
- Under our Balanced Pathway assumptions, annual investment (both public and private) in infrastructure and new vehicles will need to ramp up to around £3.2 billion per year in 2035. As more ZEVs are taken up, operational savings will offset some of these costs (Figure M2.3).

## Figure M2.3 Additional capital and operation Expenditure associated with HGVs




Source: Element Energy and Ricardo modelling for the CCC.
Notes: Chart displays in-year societal capital and operational cost impacts relative to the baseline. Segments above the horizontal axis represent additional capital expenditure (infrastructure and the purchase of new vehicles), while segments below the horizontal axis represent operational cost savings (reduced consumption, efficiency improvements and fuel/maintenance cost savings).

**Box M2.7**
HDV uptake trajectory modelling

Our analysis of decarbonisation of the HDV sector is based on research that we commissioned from Element Energy, which built upon previous work by Ricardo. The research considered several alternative zero-emission powertrain options:

- BEVs, using either just in-depot or a combination of in-depot and public recharging.
- Hydrogen fuel-cell vehicles, refuelling either in-depot or at public refilling stations.
- ERS, with power drawn to either a battery or a hydrogen fuel-cell.

It then considered how key variables such as fuel costs and technology development would be expected to evolve under five scenarios:

- Hydrogen refilling stations are deployed as the only public refuelling option for HDVs, and BEV technology does not develop in a way that is suitable for HDV use.
- Ultra-rapid chargers are the only public refuelling option for HDVs, and hydrogen is not available for use in HDVs.
- ERS is the only public refuelling option for HDVs, although both BEVs and hydrogen fuel-cell vehicles are available for use, relying solely on in-depot refuelling.
- All three public refuelling options are deployed, alongside in-depot refuelling.

- All three public refuelling options are deployed at an accelerated rate, alongside in-depot refuelling, and manufacturers accelerate zero-emission HDV production.

Infrastructure in each scenario is assumed to be deployed in line with demand (based on the uptake modelling below), according to the Ricardo modelling.

Within each scenario, the model begins by looking at which available powertrains in which range capacities can feasibly be packaged into eight vehicle sizes – four sizes of rigid trucks, two sizes of articulated trucks, buses and coaches – in each year. It then applies a series of filters to determine the optimal technology mix in each year:

- **Range suitability.** Tests the distribution of vehicle daily distance requirements against the range available through each technology option, to determine what proportion of each vehicle type each option is suitable for.
- **TCO suitability.** For the subset of the vehicle distribution that remain, the model then calculates the TCO under each available powertrain option. All options that have TCO cheaper than diesel pass through, while a proportion (decreasing with the size of the TCO excess) of more expensive options are allowed through to reflect possible non-financial reasons for ZEV uptake.
- **TCO ranking.** For each vehicle size and year, the suitable technology options are ranked in TCO order, from cheapest to most expensive.
- **Technology selection.** For the technology ranked first, the number of vehicles of this type to be chosen is simply the number that passed through the suitability filters. For each technology that is not ranked first, the final number is the number who passed through each technology filter but did not pass range suitability for every cheaper technology. This equates to every vehicle choosing the cheapest option that meets its range requirements.
- **OEM supply constraints.** Available supply is expected to scale up in line with the timescales seen in the UK for BEV cars, towards the goal of being able to support 100% zero-emission sales by 2040. If there is insufficient supply to meet the number of vehicles passing through the above filters, then they must select their next highest ranked option instead.

These filters are used to model uptake of each zero-emission vehicle option under each of the five scenarios. These uptake profiles are used in our analysis.

The previous section set out the range of options that could contribute to decarbonisation of the surface transport sector. Achieving near-zero emissions across the sector will require contributions from all of these. In this section, we set out the combination of measures and their impacts that we assume in our scenarios for the Sixth Carbon Budget advice.

## a) Abatement scenarios

Each of our scenarios is based on a combination of measures that will enable the surface transport sector to reach close to zero emissions by 2050, which will be critical in enabling the UK to deliver Net Zero.

### i) Expectations for emissions without abatement action

Our analysis compares emissions under our decarbonisation scenarios against a baseline scenario, which represents the growth in emissions that we would expect to see if no action to reduce emissions were taken.

Our baseline scenario assumes that car demand continues to grow in line with population and GDP.

For road transport, we use DfT's National Transport Model (NTM), which generates forecasts of the total number of vehicle-kilometres and emissions that would be expected in the absence of abatement policy or action. For rail, we base our analysis on the Rail Delivery Group's forecasts of the number of passenger trains operating out to 2047[54] and the National Infrastructure Commission's expectations for freight demand out to 2050.[90] In both cases, we then assume no additional electrification or efficiency improvements. These assumptions lead to an 11% increase in road vehicle-kilometres and a 24% increase in train-kilometres by 2035, and result in a 13% increase in the sector's emissions to 128 $MtCO_2e$ by 2035.

### ii) The Balanced Net Zero Pathway

The Balanced Net Zero Pathway represents our central scenario for how the transport sector will need to evolve towards delivery of Net Zero by 2050:

In the Balanced Pathway, sales of new petrol and diesel cars and vans are phased out by 2032.

- **ZEV uptake.** BEVs make up the majority of new car and van sales by 2030, while HDV sales of a mixture of BEVs and hydrogen vehicles ramp up during the 2030s.
  - We assume that sales of new petrol and diesel cars and vans are phased out by 2032. BEV ranges increase as shown in Table M2.2, while battery cost reduces from around £121/kWh today to £48/kWh by 2030 and £44/kWh by 2040 (see Box M2.5). As a result, BEVs make up 48% of all new sales in 2025, 97% in 2030 and 100% from 2032 onwards.
  - PHEV sales increase in the short term, reaching 25% in 2025, before falling to near zero by 2030.

- Commercial-scale zero-emission HDV trials take place from the early-2020s. Infrastructure development continues for the most cost-effective solutions, assumed to be batteries and hydrogen initially. Government subsidies ensure TCO parity between zero-emission and diesel options in 2035. As a result, BEVs make up 12% of new HGV sales and 25% of new bus sales in 2030, rising to 51% and 44% in 2040. Hydrogen fuel-cell vehicles make up 7% of new HGV sales and 44% of new bus sales in 2030, and 48% and 55% in 2040.***

- **Efficiency and biofuels.** New conventional vehicles become more fuel efficient. Biofuels have a role in reducing emissions from remaining petrol and diesel vehicles during the transition to ZEVs.
  - The carbon intensity of new conventional vehicles improves as in Table M2.1. HGVs realise operator efficiency savings, ranging from 13% for small rigid trucks to 22% for large articulated vehicles. Uptake of these measures reaches 80% of HGVs from 2025.
  - Following the introduction of E10 in 2021, biofuels makeup around 7% (by energy) of the conventional fuel used by cars and vans.
  - Among HDVs, the proportion of biofuels in the diesel consumed rises from 4% in 2030 to 12% by 2040.

Overall, we expect that 6% of baseline car demand can be avoided or switched to other modes by 2030, rising to 17% by 2050.

- **Demand reduction.** Demand for car travel is reduced by a combination of societal and technological changes reducing the need for travel and modal shift. Logistics and operational improvements reduce HGV demand.
  - Average car-kilometres decrease††† by 6% by 2030, and this demand reduction increases gradually to 17% by 2050. Demand reduction for vans is lower, reaching 3% from 2030 onwards. Improved speed limit enforcement gives efficiency savings of 2% from 2025.
  - Factors including improved logistics mean that demand reductions for HGVs increase gradually to 10% for rigid HGVs and 11% for articulated HGVs by 2030, remaining at these levels thereafter.

- **Rail.** Electrification of the network continues steadily, including of key freight corridors. Battery-electric, hydrogen and hybrid trains are also introduced.
  - Total passenger rail traffic and total rail freight hauled grow linearly to 58% and 9% above today's levels by 2050, respectively.
  - The rail network is steadily electrified at a rate of 200 km/year. This takes the electrified proportion of the network to 55% by 2050.
  - All diesel trains are removed from category A passenger routes by 2035 and from all passenger routes by 2040. By 2040, most new passenger trains are electric (68%) or battery-electric (26%), with smaller roles for diesel-electric and hydrogen.

*** These uptake percentages are similar to those shown in Table M2.4, but there is assumed to be no ERS provision, so those sales instead have to choose between battery-electric, hydrogen and diesel.

††† Note that these reductions are relative to a baseline in which car ownership, and hence total car-kilometres, are assumed to be increasing. Overall vehicle-kilometres are expected to grow by 5% by 2030 and by 15% by 2050.

- Some diesel freight trains remain out to 2050, but the proportion drops from 87% today to 12% by 2050. In 2030, 84% of new freight trains are diesel-electric, but by 2050 almost half are pure electric.

- The efficiency of diesel trains improves linearly from 0.8 $kgCO_2/kWh$ today to 0.5 $kgCO_2/kWh$ by 2050.

The Balanced Net Zero Pathway delivers a reduction in surface transport emissions of over 70% by 2035, and 100% by 2050.

Overall, these measures reduce surface transport emissions from 128 $MtCO_2e$ in the baseline to 32 $MtCO_2e$ in 2035 and 0.9 $MtCO_2e$ in 2050 and are cost-effective (Table M2.5; see also Figure A3.1.g in the Advice Report).

- The largest portion of this abatement is due to uptake of ZEVs (69 $MtCO_2e$).
- Other contributions come from demand-side measures in road transport (18 $MtCO_2e$), better efficiency of new conventional vehicles (5 $MtCO_2e$), uptake of PHEVs (2 $MtCO_2e$) and rail decarbonisation (2 $MtCO_2e$).

**Table M2.5**
Abatement costs for key surface transport sectors in 2035 in £/$tCO_2e$

| | Average abatement cost across fleet | Marginal abatement costs for a new measure | |
|---|---|---|---|
| | | Efficiency improvements to a new conventional vehicle | New electric vehicle (BEV in the case of road vehicles) |
| Cars | -10 | Not on sale | -56 |
| Vans | -34 | Not on sale | -48 |
| HGVs | 106 | -40 | 110 |
| Buses | 89 | -78 | -14 |
| Motorcycles | 384 | 51 | 331 |
| Passenger rail | -1,690 | -1,020 | -2,880 |
| Freight rail | 288 | -1,020 | 210 |

## iii) Exploratory scenarios

Our exploratory scenarios explore alternative pathways by which the UK's Net Zero commitment can be achieved.[‡‡‡] This section discusses the main differences between these scenarios and the Balanced Pathway.

In Headwinds, emissions reductions are lower due to slower zero-emission vehicle uptake and higher demand.

**Headwinds.** Remaining emissions in 2035 are higher at 38 $MtCO_2e$, compared with 32 $MtCO_2e$ in the Balanced Pathway. This is primarily due to slower uptake of ZEVs and lower levels of behavioural change.

- Sales of new petrol and diesel cars and vans continue to be allowed until 2035 and barriers to EV acceptance take longer to overcome. Therefore, BEVs make up only 24% of new car sales in 2025 and only begin to rise steeply towards the end of the 2020s.
- Battery technology does not become suitable for HDV use, and instead there is large-scale use of hydrogen in HDVs. Fewer low-carbon options mean diesel retains a higher proportion of HGV sales in 2030 (86%), and the transition occurs at higher cost.
- Slower transition to ZEVs means that total biofuel consumption is 26% higher in 2035 than in the Balanced Pathway.
- HGV uptake of operator efficiency measures is lower at 50%.

[‡‡‡] To this end, each scenario delivers a very low level of emissions from the surface transport sector in 2050, ranging from a minimum of 0.6 $MtCO_2e$ in Tailwinds to a maximum of 1.4 $MtCO_2e$ in Widespread Engagement. Emissions in 2050 under the Balanced Pathway are 0.9 $MtCO_2e$.

- Car demand falls to only 12% below baseline levels by 2050.

Widespread Engagement demonstrates that enhanced behavioural change, through higher demand reduction and quicker electric vehicle uptake, can deliver deeper emissions reductions.

**Widespread Engagement.** Decarbonisation of the transport sector occurs more rapidly due to high levels of consumer engagement, which delivers higher demand reduction and quicker EV uptake. Emissions fall to 29 $MtCO_2e$ by 2035.

- Consumer biases against EVs are 30% lower, leading to faster uptake and sales of new petrol and diesel cars and vans end in 2030. 55% of all new cars sold in 2025 are BEVs.
- There is significant investment in a large-scale ERS network for HDVs, instead of investment in ultra-rapid public charging infrastructure. The maturity of this technology allows diesel sales to begin falling slightly faster than in any other scenario, but most HDVs (particularly small rigid HGVs) continue to choose BEVs, even with only depot-charging available. 14% of sales in 2040 are for ERS vehicles.
- Demand reduction among car users is at the upper end of what is possible, reaching 16% by 2030 and 34% by 2050. Speed limit reductions increase further efficiency gains to 7% from 2025.
- This demand reduction is partly accounted for by increased modal shift to rail, with passenger and freight demand 17% and 11% higher than in the Balanced Pathway. Rates of rail electrification are also higher, resulting in 60% of the railway being electrified by 2050 and allowing more electric passenger trains to be introduced. For freight, the need to travel across a wider portion of the network leads to more diesel-electrics being used.

If battery technology advances more rapidly, then electric vehicles could become cost-saving sooner, leading to quicker uptake. This is explored in Widespread Innovation.

**Widespread Innovation.** Battery technology improves rapidly, leading to more affordable BEVs which are adopted more quickly. CAV usage leads to increased demand, resulting in emissions of 35 $MtCO_2e$ in 2035.

- Sales of new petrol and diesel cars and vans end in 2030, while battery costs fall to £42/kWh, allowing typical BEV prices to be almost £200 lower and ranges to reach 400 km by 2030. This leads to faster EV uptake, with BEVs making up 56% of all new car sales in 2025.
- Battery innovation also enables BEVs to become more suitable for a variety of HDV operations more quickly. Therefore, infrastructure to support BEVs is the only area of investment to support HDV ZEV uptake. BEVs still take time to become suitable for the longest-range operations, so diesel vehicles still comprise 8% of new HDV sales by 2040. By 2045, however, BEVs (either charging only in-depot or using ultra-rapid public chargers) are suitable for all HDV operations.
- The introduction of CAVs largely offsets demand reduction in passenger vehicles until the mid-2030s, before leading to growth in overall demand by up to 5% by 2050.
- Advanced biofuels are developed exclusively for other sectors, so total biofuel use is 29% lower in 2035 than in the Balanced Pathway.
- Diesel train efficiency improves to 0.45 $kgCO_2$/kWh. Improved capability of battery-electric options means that the number of diesel-electric passenger trains operating in 2050 is 33% lower than in the Balanced Pathway. Further, two-thirds of all new freight trains are electric from the mid-2030s.

Tailwinds showcases how quickly transport emissions could be reduced within ambitious technological and societal contexts.

**Tailwinds.** Rapid technological development combined with widespread consumer engagement leads to swift adoption of EVs plus substantial reduction in demand. This results in emissions of 28 $MtCO_2e$ in 2035.

- For cars and vans, battery technology and EV uptake develop as in the Widespread Innovation scenario.
- Deployment of a range of HDV decarbonisation infrastructure occurs at an accelerated pace, supported by significant technological and market development. This leads to a ramp-up in supply and faster uptake of ZEVs. ZEVs comprise 96% of all new HDV sales by 2035, and diesel vehicles are removed from sale by 2040.
- 100% of HGV fleets adopt operator efficiency measures.
- Demand reduction is as in the Widespread Engagement scenario.
- Rail developments are as in the Widespread Innovation scenario.

## b) Devolved administrations

The above scenarios cover surface transport emissions across the whole of the UK, but differences across Scotland, Wales or Northern Ireland could materially affect how the pathway is delivered. In some areas of our modelling, we have been able to give explicit consideration to each administration. The resulting decarbonisation pathways for surface transport in each devolved administration are similar:

- Our modelling of road transportation is calibrated against DfT's National Transport Model. This includes separate forecasts of travel demand and traffic growth for Scotland and Wales, but our analysis does not explicitly take account of differences in geography or journey types. For Northern Ireland, we assume that these totals grow in line with 4% of the Great Britain totals, based on historic vehicle-kilometres data.
- Our analysis assumes that infrastructure deployment and ZEV uptake in each nation are proportional to distance travelled and does not factor in any differences between nations in these factors. We will continue to monitor policy, deployment and uptake to understand if there are any geography-specific factors which should be accounted for.
- For rail, our analysis is conducted at a UK-wide level and then scaled by the proportion of track-kilometres in each nation. Again, we will continue to monitor for any geography-specific factors that should be considered.

## c) Risks and uncertainties

The scenarios we set out illustrate the different choices and possible future contexts and the impacts that these could have on the decarbonisation pathway. We have also considered key uncertainties on car ownership, battery prices and fossil fuel prices, as well as the impact of COVID-19 on transport demand and consumer preferences (Box M2.8).

If car ownership growth can be avoided, then fewer electric vehicles will be needed and the transition will be achieved at lower cost.

**Car ownership.** Our baseline travel demand assumptions in the absence of climate policy are based on DfT's National Transport Model, which is largely driven by GDP and population growth. In the baseline, car ownership and demand grow by 19% to 2050. If car ownership (and demand) do not continue to increase, then overall emissions and the capital costs of the transition will be lower.

- All of our scenarios assume that car ownership continues to grow in line with population and GDP to 38 million by 2035 and that demand reduction is realised through a fall in kilometres driven by each car.
- If, instead, demand reduction were met through a reduction in the rate of car ownership (for instance through greater reliance on car-sharing and public transport), then the total number of cars by 2035 would be almost 4 million lower than this, and there would be correspondingly fewer EVs (Table M2.6).
- In this case, the capital cost of the transition would fall by £17 billion over the period to 2050, as fewer EVs need to be purchased.

**Table M2.6**
Number of battery-electric cars under three car ownership growth scenarios, in millions

| Car ownership | 2030 | 2035 | 2040 |
|---|---|---|---|
| Increasing with population/GDP to 38m in 2035 (Balanced Pathway) | 13 | 25 | 35 |
| Central demand reduction through lower car ownership – growth to 35m in 2035 | 12 | 22 | 31 |
| Higher demand reduction through lower car ownership – decline to 31m in 2035 | 11 | 20 | 26 |

- If it were possible to reduce both car ownership and kilometres per car, then total emissions over the five years of the Sixth Carbon Budget period would be 8 $MtCO_2e$ lower than in our Balanced Pathway. There are opportunities to deliver further emissions reduction, or to balance any barriers to EV uptake, through schemes to reduce car ownership.

Higher battery prices could inhibit electric vehicle uptake through higher prices. Nonetheless, they will still deliver cost savings by 2030.

**Battery prices.** If battery prices do not continue to decrease at the rate shown in Figure B2.5, then EV prices will remain higher for a longer period of time. EV uptake will be slower and emissions higher.

- If further reductions in battery prices from today are 25% below what is expected (see Box M2.5), then the upfront cost of a typical BEV in 2030 will be 6% higher than in our Balanced Pathway.
- A typical BEV would then begin to offer the purchaser cost savings – on a TCO basis – from 2027, which is 2 years later than in our Balanced Pathway.
- The ramp-up of BEV sales would be correspondingly slower, resulting in 570,000 fewer BEV cars and vans being sold by 2030. The resulting emissions would be almost 3 $MtCO_2e$ higher than in our Balanced Pathway over the Sixth Carbon Budget period.
- If there were no phase-out of conventional vehicles, then petrol and diesel cars would continue to make up a substantial portion of sales out to 2038.
- Battery development for HDVs is less certain. In the event that prices remain higher than expected, HDVs would likely see greater uptake of hydrogen, while larger subsidies may be required to incentivise BEV uptake.

Lower fossil fuel prices would also delay electric vehicle uptake. In addition, they could increase the mileage driven by conventional vehicles.

**Fuel prices.** If fossil fuel prices are lower than expected, then the operational cost benefits of BEVs will be reduced and so the financial incentive to adopt them will fall. This will lead to slower uptake and higher emissions.

- The lower cost of running a BEV than an ICE is a key factor in achieving TCO savings by the mid-2020s, and thereby in driving the wide uptake of BEVs.

- Similar to higher battery prices, this would lead to slower EV uptake. If the long-run variable costs of petrol and diesel follow their low forecasts, then retail fuel costs by 2030 would be around 10% lower than in our Balanced Pathway. This would reduce the lifetime cash fuel saving offered by a BEV purchased in 2030 by £1,000, potentially leading to 150,000 fewer BEV car and van purchases by 2030. In addition, cheaper fuel could lead to increased mileage among remaining conventional vehicles.
- Together, these impacts could lead to 3 $MtCO_2e$ higher emissions during the Sixth Carbon Budget period.
- For HGV fleets, lower diesel prices would further delay the point at which TCO parity is reached across all zero-emission options, increasing the level of subsidy that will be required during the 2030s to ensure timely switchover.

Through our exploratory scenarios and the above sensitivity tests, we have shown that our analysis is robust to a variety of alternative societal and technological contexts. However, while our scenarios attempt to capture the potential influence of a broad range of potential societal and technological developments, it remains possible that there could be unforeseen occurrences that cause demand and/or travel behaviour to change beyond the ranges considered within our scenarios.

This could include, for example, the advent of a new disruptive technology within the transport sector, whose impact goes beyond what we have considered in our Widespread Innovation scenario. In that case, Government would need to consider how best to make use of this new technology so as to deliver effective emissions reductions in parallel with enabling society to realise its wider benefits.

**Box M2.8**

Impact of COVID-19 on surface transport

The impact of COVID-19 has been felt across the transport sector, with an initial drop in both car and HGV usage followed by a slow recovery as lockdown restrictions eased. However, public transport continues to be affected with usage today at around a third of its pre-pandemic levels:

- In the immediate weeks following national lockdown, car usage was between 30-40% of pre-pandemic levels.[91] During that same period, HGV usage was between 60-75% of pre-pandemic levels, perhaps because of the increase in online food deliveries.[92]
- From May onwards, car usage began to gradually increase and in October reached 80-94% of pre-pandemic levels. By September, HGV usage surpassed pre-pandemic levels by between 2-25%. Total vehicle usage in September remained slightly lower than pre-pandemic levels, at around 85-97% on weekdays but 87-107% at weekends.
- National Rail use dropped to around 4-7% of pre-pandemic levels from March to May, with a gradual increase, from June, to around 40% in September. This demonstrates that public transport has not seen the same recovery that private transport has.
- Pre-pandemic demand for London buses and the London Underground were 6 million and 4 million journeys per day, respectively.[93] During lockdown, these figures fell to approximately 1.3 million bus journeys and 400,000 underground journeys per day. Following the easing of restrictions, the demand for public transport increased, but not to pre-pandemic levels. During September, at peak travel demand, there were approximately 3.8 million bus journeys and 1.5 million underground journeys per day.
- Cycling also increased significantly following the imposition of lockdown restrictions, with summer weekends seeing over three-times as many cyclists as pre-pandemic levels. Since the easing of lockdown restrictions, cycling levels have remained high. However, from late September onwards, although still mostly above pre-pandemic levels, the number of cyclists started to decrease.

The impacts of COVID-19 appear to be longer-lasting for public transport than for private transport. Our analysis assumes that this balance reverts to pre-pandemic levels, although we have considered the impact of alternative demand profiles through our exploratory scenarios. Government support and effective communications are likely to be required to support this recovery.

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Chapter 2

# Emissions pathways for the surface transport sector

*The following sections are taken directly from Section 3.1 of the CCC's Advice Report for the Sixth Carbon Budget.*[94]

## Introduction and key messages

Surface transport GHG emissions were 113 $MtCO_2e$ in 2019, comprising 22% of total UK GHG emissions. This could fall to 32 $MtCO_2e$ by 2035 in our Balanced Net Zero Pathway. Delivering this transition will require take-up of low-carbon technologies, low-carbon fuels and efficiency improvements for petrol and diesel vehicles and behaviour change to reduce travel demand and shift journeys onto lower-carbon modes of transport.

Achieving this reduction will require significant investment in technology and infrastructure but these will be more than offset by savings in operational expenditure, delivering an estimated net benefit to consumers of £8 billion per year in 2035.

Our assessment is based on detailed modelling, literature review and stakeholder engagement. We commissioned Element Energy to assess trajectories for uptake of zero-carbon options for HGVs.

The rest of this section is set out in three parts:

a) The Balanced Net Zero Pathway for surface transport

b) Alternative routes to delivering abatement in the mid-2030s

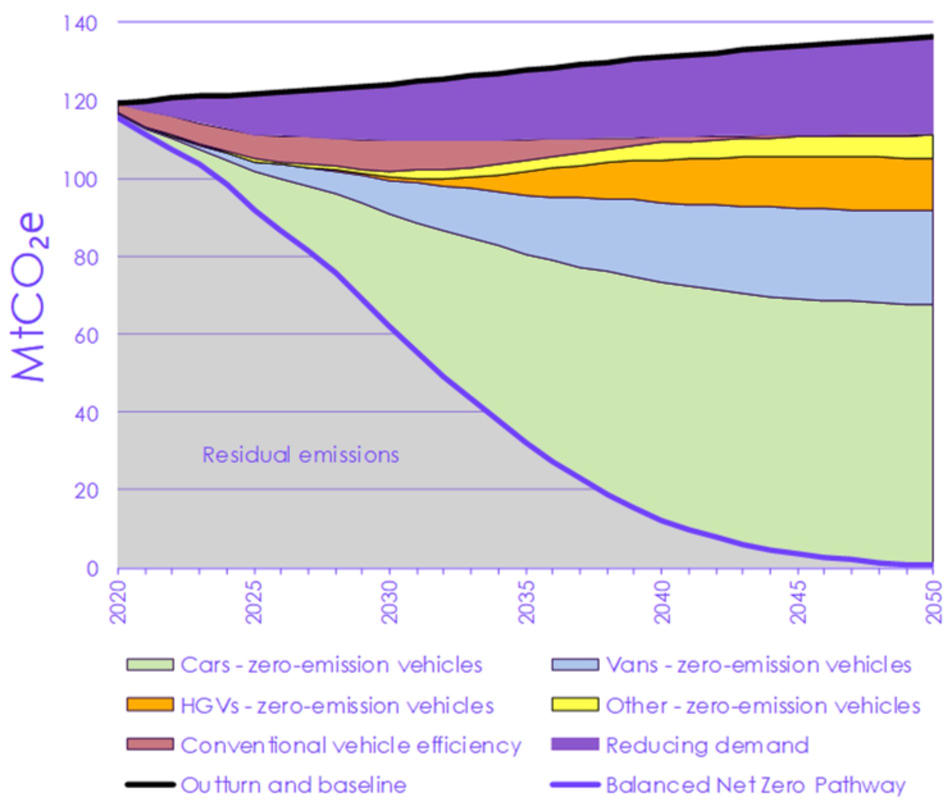
c) Impacts of the scenarios: costs, benefits and co-impacts on society

## a) The Balanced Net Zero Pathway for surface transport

Surface transport is currently the UK's highest emitting sector.

In our Balanced Pathway, options to reduce emissions, including take-up of zero-emission technologies and reduction in travel demand, combine to reduce surface transport emissions by around 70% to 32 $MtCO_2e$ by 2035 and to approximately 1 $MtCO_2e$ by 2050 (Figure A3.1.a).

Figure A3.1.a Sources of abatement in the Balanced Net Zero Pathway for the surface Transport sector




Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; CCC analysis.

The Balanced Pathway covers low-cost, low-regret options as well as more challenging and/or more expensive measures needed to meet Net Zero (Table A3.1.a). The key elements of this are:

Factors such as increased home-working and greater use of active modes of transport could reduce UK demand for car travel.

- **Reduction in car travel.** Our demand scenarios are based on modelling by the UK Centre for Research into Energy Demand Solutions (CREDS), along with other literature and evidence across UK cities and in other countries. Compared to baseline growth, we assume that approximately 9% of car miles can be reduced (e.g. through increased home-working) or shifted to lower-carbon modes (such as walking, cycling and public transport) by 2035, increasing to 17% by 2050. The opportunities presented to lock-in positive behaviours seen during the COVID-19 pandemic and societal and technological changes to reduce demand (e.g. shared mobility and focus on broadband rather than road-building) are key enablers.

Sales of new petrol and diesel cars and vans, including plug-in hybrids, should end by 2032 at the latest.

- **Cars and vans.** A high take-up of electric vehicles (EVs), resulting in the end of sales of new conventional cars, vans and plug-in hybrids (PHEVs) by 2032 at the latest. From 2030, regulatory approval to drive fossil fuel cars, vans and motorbikes should be limited to 2050 so that remaining fossil fuel vehicles are removed from the fleet at that point. High take-up of EVs will require significant roll-out of charge points:

By 2035, there could be 25 million fully electric cars on UK roads.

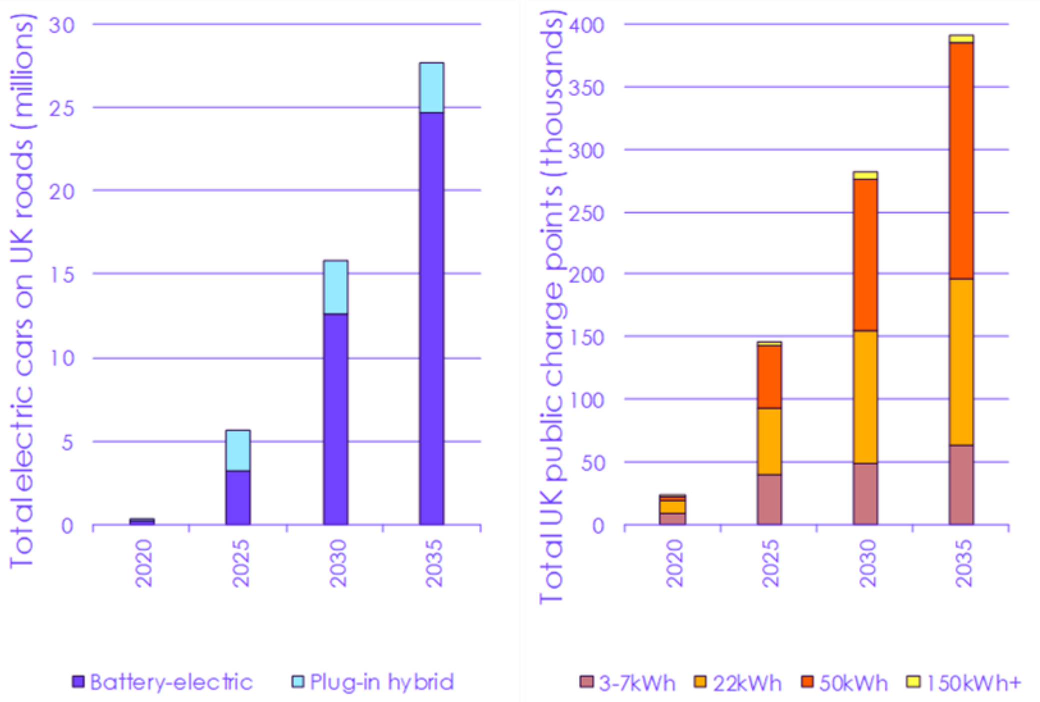
– The number of battery-electric vehicles (BEVs) will need to scale up rapidly in the 2020s from 5% of new sales today, reaching 100% by 2032 at the latest. By 2035, we estimate that there could be around 28 million EVs on the road*, comprising 25 million BEVs and 3 million PHEVs.

– Analysis shows that BEVs have considerably lower lifecycle emissions than petrol and diesel cars, but that PHEVs are only marginally better (see the Methodology Report).

Significant public charging infrastructure needs to be rolled out during the 2020s and 2030s, including on-street charging for those without private car-parking and inter-urban infrastructure for charging during long journeys.

– Charge points for electric vehicles will also need to be scaled up rapidly in the 2020s to support the phase-out of new petrol and diesel cars and vans by the early 2030s. These will comprise a mix of private chargers at homes and workplaces and public on-street charge points for those without off-street parking, around towns and cities for top-up charging and on the strategic road network for longer-distance inter-urban charging. The most cost-effective mix is expected to focus primarily on 22kW, 50kW, 150kW and 350kW chargers (Figure A3.1.b).

Figure A3.1.b Total electric cars on the road and supporting charging infrastructure in the Balanced Net Zero Pathway




Source: CCC analysis. 2020 figures based on DfT, OLEV, SMMT and Zap-Map statistics.
Notes: Includes all small, medium and large cars and all publicly accessible charge points in the Balanced Net Zero Pathway.

* This is based on car ownership forecasts from the Department of Transport's National Transport Model, which anticipate growth in line with population and GDP. If rates of car ownership fall, then the total number of electric cars could be lower.

Decarbonisation options for heavy-goods vehicles include battery-electric trucks, hydrogen fuel-cell trucks, and overhead catenary systems.

- **Heavy goods vehicles.** There is currently considerable uncertainty over the most cost-effective and feasible decarbonisation option for heavy goods vehicles (HGVs), and Government will need to fund large-scale trials of different technologies to gain a better understanding of options and for the market to develop. We commissioned Element Energy to assess trajectories and costs for the roll-out of zero-emission HGVs to 2050.[95] Based on this evidence, our Balanced Pathway assumes that the roll-out of zero-emission HGVs accelerates to reach nearly 100% of sales by 2040. Decisions on the UK approach to HGVs must also integrate with the decarbonisation strategies in mainland Europe. The scenario will require:
  - Zero-emission vehicles (ZEVs) to make up 96% of new sales of HGVs, buses and coaches by 2035 and almost 100% by 2040.
  - There to be around 170,000 zero-emission HGVs and coaches (approximately 33% of the fleet) in operation by 2035, rising to 67% of the fleet by 2040.
  - Public infrastructure to support this, which is likely to require over 300 ultra-rapid public charge points and 100 hydrogen refuelling stations by 2035, increasing to around 650 and 250 respectively by 2040. These are in addition to depot charge points and refuelling facilities.

Emissions reductions in the Balanced Pathway are also delivered through improved efficiency of conventional vehicles, logistics improvements and decarbonisation of the rail network:

- **Efficiency improvements.** New petrol and diesel cars, vans and HGVs continue to be fitted with cost-effective technologies and design improvements to improve fuel efficiency, leading to reductions in $CO_2$ intensity of 12% (cars and vans) and 21% (HGVs) for new models by 2030. Biofuels are used in surface transport, with E10 petrol introduced from 2021. Biofuels are phased out from cars and vans by 2040 and in HGVs by 2050 as they are best used in other sectors.

Greater use of consolidation, changes to supply chains and innovations such as e-cargo bikes could lower the adverse impacts of road freight.

- **Shifts in van usage.** Van travel is the fastest growing sector, with total van miles increasing by 70% since 2000.[96] Around a quarter of this can be explained by the growth in internet sales and the associated parcel delivery sector. We assume that 3% of van miles can be reduced by 2035 through measures such as last-mile deliveries by portering/e-cargo bikes, micro-consolidation centres in urban areas, reduction in delivery failures, use of experienced driver and routing technologies and encouragement of ‘green’ delivery choices.
- **HGV logistics.** There is potential for HGV logistics measures to reduce miles driven by lorries, through measures such as expanded use of consolidation centres, extended delivery windows, higher loading and reduced empty-running. Our Balanced Pathway, drawn from a study by the Centre for Sustainable Road Freight[97], assumes a reduction in total HGV miles of around 10% by 2035 through these measures.
- **Buses.** Take-up of low-carbon buses and infrastructure is already occurring across the UK. The Confederation of Passenger Transport (the trade body for bus and coach operators) has set a target for all new buses to be ultra-low or zero-emission by 2025. Our Balanced Pathway assumes that all sales of new buses are zero-carbon (largely hydrogen or BEV) by 2035.

- **Rail.** Government has set an ambition to phase out diesel trains by 2040, while the Rail Industry Decarbonisation Taskforce (supported by the Rail Safety and Standards Board) published pathways to decarbonise rail in 2019. Our Balanced Pathway assumes the Government ambition is achieved for passenger rail, with almost half of the network electrified where this is cost-effective and a mix of hydrogen, battery-electric and electric hybrid trains replacing existing diesel trains where it is not. Several key freight corridors are also electrified. These measures combine to reduce emissions from rail by around 55% by 2035.

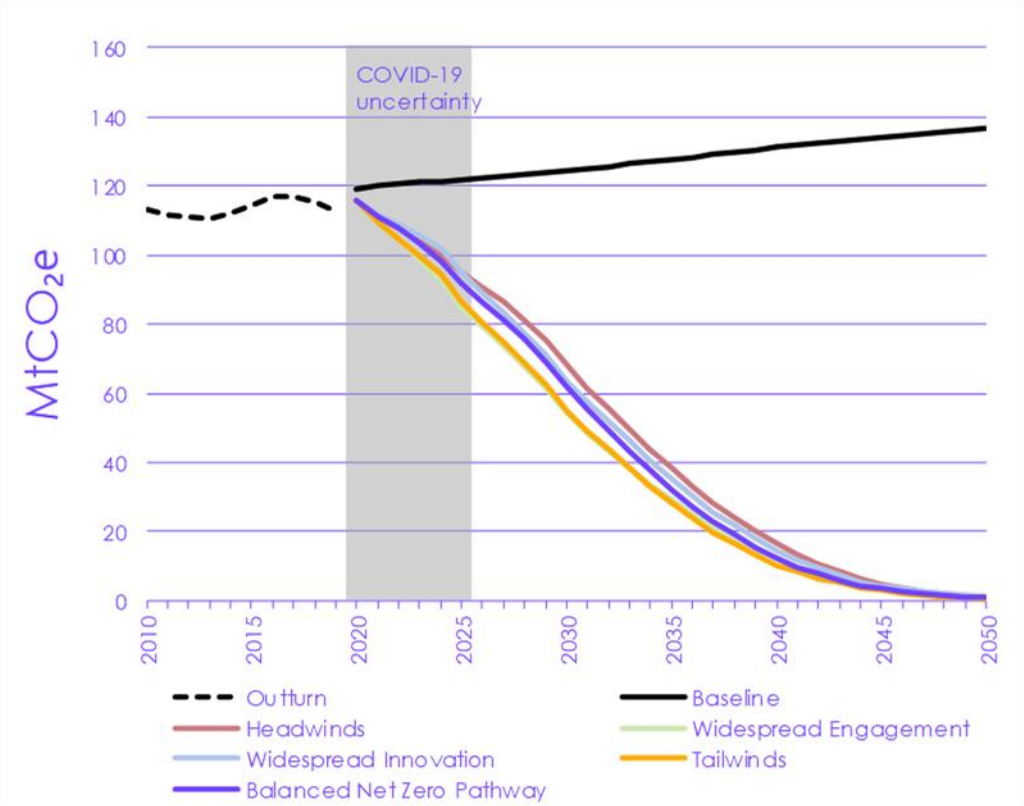
**Table A3.1.a**
Summary of key assumptions used for the Balanced Net Zero Pathway in 2035

| | **Balanced Net Zero Pathway – assumptions in 2035** |
|---|---|
| **Behaviour change and demand reduction** | • Total car miles fall by 9% by 2035 relative to the baseline. This is driven by modal shift from cars to walking, cycling (including e-bikes) or public transport, an increase in average car occupancy and a reduction in travel from factors such as increased working from home.<br>• For vans, demand is reduced by 3% through measures such as increased use of urban consolidation centres and e-cargo bikes.<br>• Factors such as improved logistics lead to 10% lower total HGV miles, relative to baseline forecasts. |
| **Efficiency** | • The average real-world $CO_2$ intensity of new conventional cars and vans needs to improve by around 12% relative to today's levels, before these are phased out in the early 2030s.<br>• Efficiency of new HGVs increases by up to 21% through measures such as improved aerodynamics and lighter-weight construction. Most existing HGVs realise efficiency savings of 13-22% due to measures including retrofitting aerodynamic improvements and eco-driving training.<br>• 47% of the UK's railways are electrified by 2035, and diesel engines are 18% more efficient than today. |
| **Low-carbon technology** | • Sales of new petrol and diesel cars and vans (including PHEVs) are phased out by 2032 at the latest. BEVs make up 64% of all cars and 68% of all vans on the road.<br>• Zero-emission HGVs comprise 96% of all sales and 99% of bus and coach sales are zero-emission. Diesel vehicles still comprise 67% of the HGV fleet.<br>• All diesel trains have been removed from operations on category A passenger routes. These are mostly replaced by electric trains, with increasing numbers of battery-electric trains. Electric and diesel-electric trains make up 44% of the freight fleet. |

## b) Alternative routes to delivering abatement in the mid-2030s

There are alternative technical or behavioural approaches that could deliver emissions reductions. These are represented in our exploratory scenarios, which consider how emissions can be reduced across a variety of consumer and technology contexts (Figure A3.1.c and Table A3.1.b).

Figure A3.1.c Emissions pathways for the surface transport sector




Source: BEIS (2020) *Provisional UK greenhouse gas emissions national statistics 2019*; CCC analysis.
Notes: Baseline emissions begin slightly higher than the latest outturn data – this is because our scenario modelling is calibrated against DfT's National Transport Model, which uses a base year of 2017.

These scenarios demonstrate that options remain to go further in some areas as technology choices and the extent of possible behaviour change become clearer.

Higher levels of demand reduction could be achieved through significant investment in active travel, enabling widespread behavioural change.

- Greater reductions in travel demand through a higher shift to lower-carbon travel modes, ride-sharing solutions or societal shifts would mean that fewer electric cars and vans would be needed, with corresponding savings on EV capital costs and in charging investment and running costs.
    - Our most ambitious scenario for car demand results in a reduction in miles driven of 34% by 2050 relative to baseline demand. This is achieved through greater ambition on modal shift to active travel and public transport, a higher level of car-sharing and higher behavioural change through measures such as working from home and a reduction in business trips through greater use of technology.
    - Across our scenarios, the assumed demand reductions are partially offset by rebound effects due to the fuel cost savings from EVs, which are much cheaper to run than fossil fuel vehicles.

- There are also risks that travel demand could be higher than in our Balanced Pathway. We have modelled this in the Widespread Innovation scenario, where the introduction of connected and autonomous vehicles (CAVs) is assumed to lead to higher travel demand through improved mobility options and better utilisation of road space. In this scenario, overall car demand is 5% higher than in the baseline by 2050.
- An earlier switchover date for ending petrol and diesel cars sales could be possible and deliver cost reduction and emissions benefits.

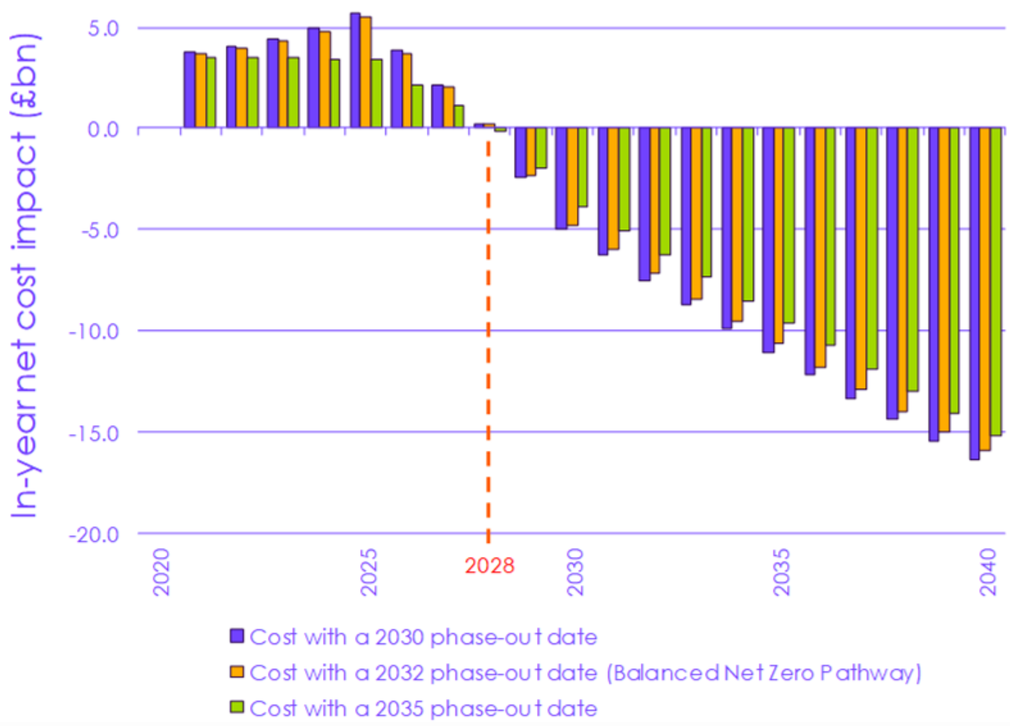
Electric cars and vans are likely to be cost-saving for society by the end of the decade.

  – Our analysis suggests that new electric cars and vans are likely to be cost-saving from a social perspective during the 2020s, with upfront cost-parity reached by 2030. On this basis, the cumulative costs of passenger cars and vans are likely to be lower if the end of sales is brought forward to 2030 compared with a later date (Figure A3.1.d).

Phasing out the sale of new conventional cars and vans earlier in the 2030s is expected to reduce emissions and deliver increased cost savings.

  – A 2032 phase-out is expected to deliver almost 90 $MtCO_2e$ lower cumulative emissions and £6 billion additional cost-savings across the period from 2020-2050, compared to continuing to allow conventional vehicles to be sold until 2035. Moving the phase-out date forward to 2030 could deliver even larger cost savings and a small amount of further abatement.

Figure A3.1.d Impacts of alternative phase-out dates for new petrol and diesel cars and vans

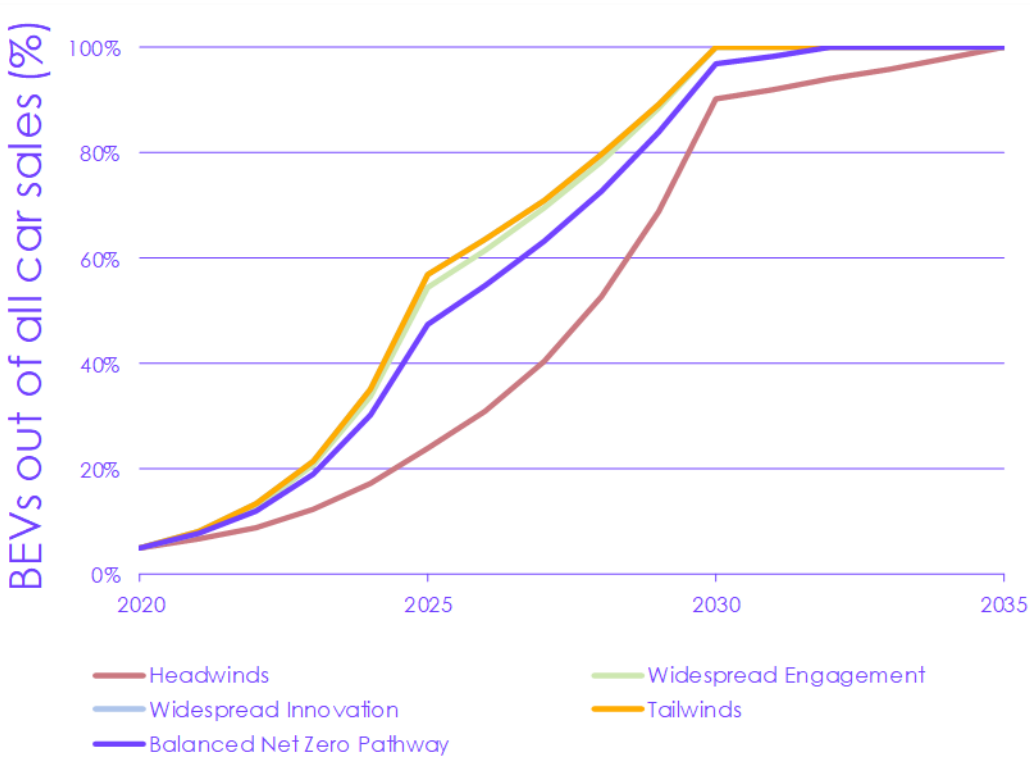



Source: CCC analysis.
Notes: Comparison between the annual cost to society (cost of vehicles, infrastructure, fuel and maintenance) of the EV transition under three phase-out dates for new petrol and diesel car and van sales (including PHEVs): i) 2030; ii) 2032 (as in our Balanced Net Zero Pathway); and iii) 2035.

- Our scenarios consider the impact of various phase-out dates for new petrol and diesel vehicles: 2032 in the Balanced Pathway; 2035 in Headwinds; and 2030 in all other scenarios (Figure A3.1.e). Analysis and evidence suggest that raw materials and supply chains can scale up to support a phase-out of all new petrol and diesel cars and vans by 2032 (see Methodology Report), and there is a clear economic and climate case to deliver it by then at the latest.
- Our scenarios all assume that PHEVs are phased out at the same time as conventional fossil fuel vehicles. If this does not occur and PHEVs are instead allowed to be sold for longer, there is a risk that this could lead to greater uptake of PHEVs and undermine the switchover to fully zero-emission options. Real-world emissions from PHEVs are often only marginally lower than emissions from conventional vehicles.

Battery-electric cars are expected to make up over 90% of all new sales by 2030.

Figure A3.1.e Proportion of all new car sales that are battery-electric vehicles




Source: CCC analysis.
Notes: Includes all new sales of small, medium and large cars – note that EV uptake in the Tailwinds scenario is aligned to the Widespread Innovation scenario.

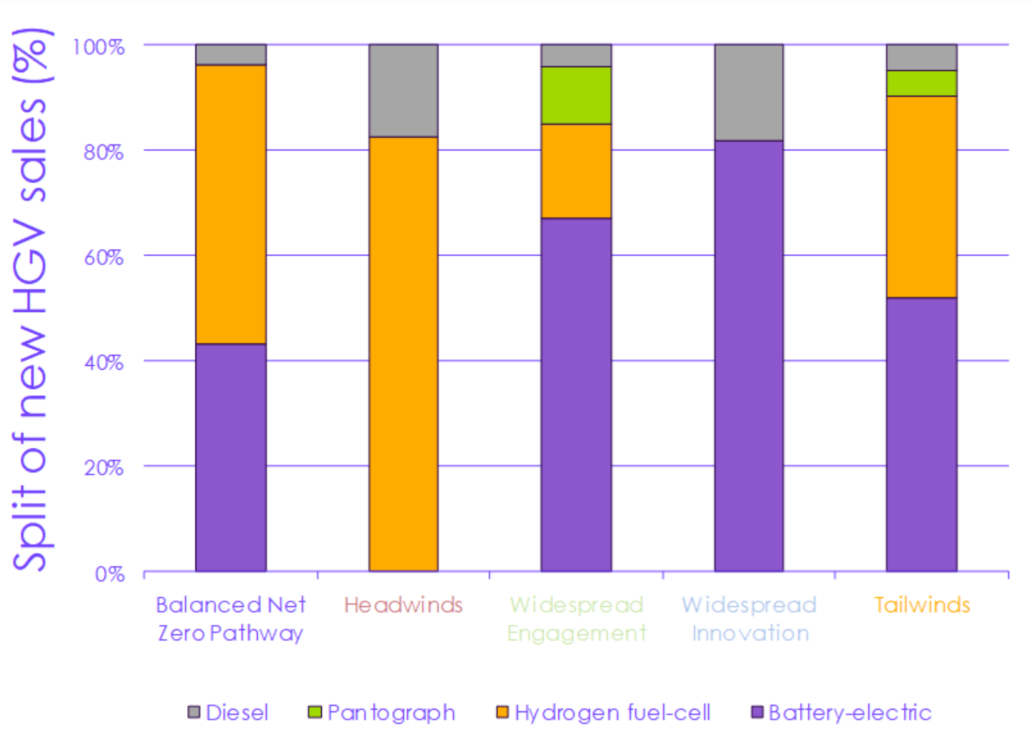
- Our Balanced Pathway for HGVs assumes the most cost-effective technologies are taken up, resulting in a mix of hydrogen and battery-electric vehicles using ultra-rapid chargers. Our exploratory scenarios consider HGV costs and take-up under alternative technological development assumptions (Figure A3.1.f).

Battery-electric HGVs are likely to be cost-optimal eventually, but battery technology will need to continue to develop for this to be achieved.

- In each exploratory scenario there is focus on one main zero-carbon technology: in Headwinds, hydrogen refuelling stations are the only publicly available refuelling option; Widespread Engagement focuses on battery-electric with ultra-rapid public chargers; and Widespread Innovation assumes an electric road system (ERS) with both BEV and hydrogen vehicles recharging at depots.
- Each of battery-electric, hydrogen and ERS could play a role in decarbonising the HGV sector. Small rigid trucks are likely to predominantly adopt BEVs, while hydrogen or ERS could be valuable for heavier vehicles with longer range requirements. By 2050, BEVs with ultra-rapid public chargers are likely to become the cost-optimal choice.
- Whichever technologies emerge, there needs to be significant HGV infrastructure investment in the 2020s and 2030s. This will give confidence to fleet operators that they will be able to refuel as part of their daily operations. The total investment requirement (including the cost of infrastructure and new vehicles, and comprising both public and private investment) is estimated to be £35-65 billion across the period 2020-2050, which is expected to be partly offset by operational savings of £30-55 billion.

At least one zero-emission option for HGVs is likely to be suitable for 90%+ of fleet operators by 2035.

Figure A3.1.f Proportion of all new HGV sales in 2035 by powertrain type




Source: Element Energy analysis for the CCC (2020).
Notes: Assumes that sufficient financial support is available to make zero-emission options cost-competitive versus diesel vehicles from 2035.

| **Table A3.1.b**<br>Summary of key differences between our scenarios for the surface transport sector | | | | | |
|---|---|---|---|---|---|
| | **Balanced Net Zero Pathway** | **Headwinds** | **Widespread Engagement** | **Widespread Innovation** | **Tailwinds** |
| **Behaviour change and demand reduction†** | **Moderate behavioural change, with gradual reduction up to 17% of total car miles by 2050** | Limited levels of behavioural change, with car demand falling to 12% below baseline by 2050 | High demand reduction, modal shift and ride-sharing, leading to 34% lower car demand and 11% higher rail demand by 2050 | Introduction of connected and autonomous vehicles leads to a net 5% increase in total car demand by 2050 | High levels of societal change leading to a 34% reduction in car demand by 2050 |
| **Efficiency**<br><br>**(in addition to efficiency improvements for new ICEs, which are assumed in all scenarios)** | **80% of HGVs adopt efficiency measures; up to 200km/year of rail electrification and diesel efficiency improving by 2050 to 0.5kg$CO_2$/kWh (from current levels of 0.8kg$CO_2$/kWh)** | Slower BEV uptake so higher biofuel use; 50% of HGVs adopt efficiency measures; up to 200km/year of rail electrification and diesel efficiency improving by 2050 to 0.5kg$CO_2$/kWh | 80% of HGVs adopt efficiency measures; up to 250km/year of rail electrification and diesel efficiency improving by 2050 to 0.5kg$CO_2$/kWh | 80% of HGVs adopt efficiency measures; up to 200km/year of rail electrification and higher diesel efficiency improvements to 0.45kg$CO_2$/kWh by 2050 | All HGVs adopt efficiency measures; up to 250km/year of rail electrification and higher diesel efficiency improvements to 0.45kg$CO_2$/kWh by 2050 |
| **Low-carbon technology** | **2032 phase-out date for fossil fuel cars and vans; no clear technology choice for HGVs, so most cost-effective technology mix is deployed** | 2035 phase-out of fossil fuel cars and vans; large-scale use of hydrogen in HGVs | 2030 phase-out of fossil fuel cars and vans, with rapid EV uptake driven by engagement; deployment of a substantial ERS network for HGVs | 2030 phase-out of fossil fuel cars and vans, with rapid EV uptake driven by cost reductions; battery density and cost improve leading to high use of BEV HGVs with ultra-rapid charging | 2030 phase-out of fossil fuel cars and vans, with rapid EV uptake driven by cost reductions; max roll-out rates for technology and infrastructure allow deployment of mix of low-carbon HGV options at pace |

## c) Impacts of the scenarios: costs, benefits and co-impacts on society

The transition to zero-emission vehicles will lead to an overall annual saving of £8 billion in 2035.

Delivering the Balanced Pathway results in a cost saving to the economy of £8 billion in 2035 compared with a theoretical counterfactual without any action on emissions, as investment costs are offset by lower operational expenditure (Figure A3.1.g). Most measures in the Balanced Pathway are cost-effective.

- Average lifetime abatement costs for the key surface transport sectors are cost-effective at BEIS carbon values (Table A3.1.c).

| **Table A3.1.c**<br>Abatement costs for key surface transport sectors in 2035 (£/t$CO_2$e) | | | |
|---|---|---|---|
| | **Average abatement cost across fleet** | **Marginal abatement costs for a new measure** | |
| | | **Conventional vehicle efficiency** | **New battery-electric vehicle** |
| **Cars** | 2 | -8 | -13 |
| **Vans** | -19 | -14 | -22 |
| **HGVs** | 52 | -38 | 212 |

† These figures are before rebound effects, which will increase demand as EV uptake grows, due to lower fuel costs.

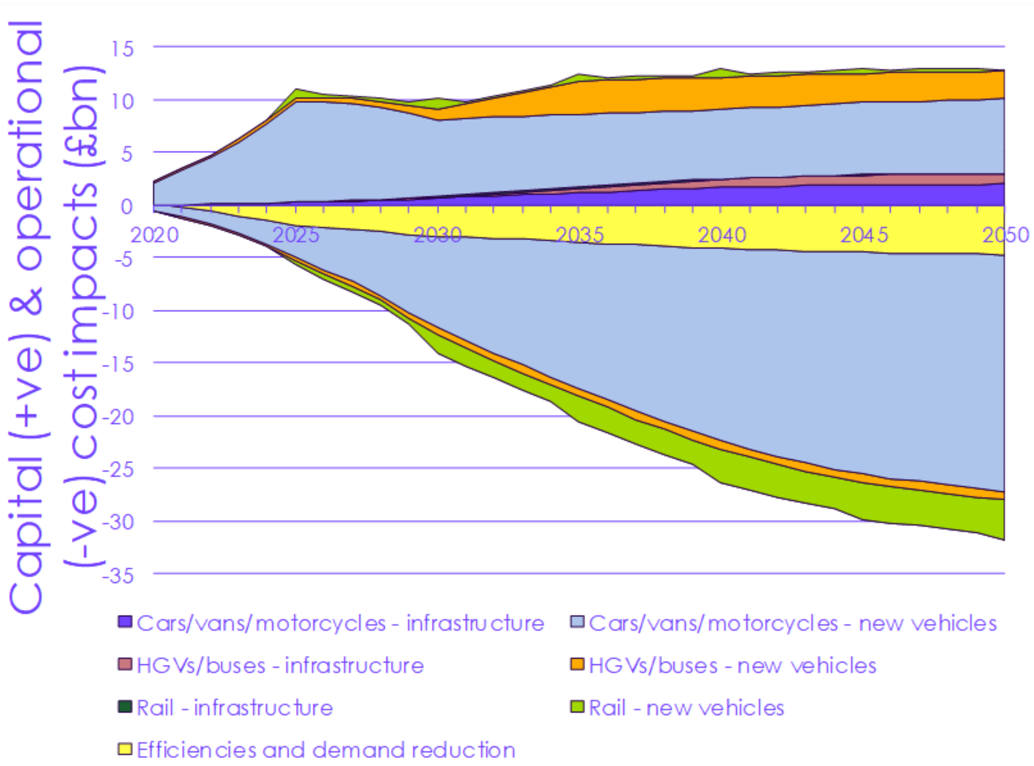
The annual capital cost of decarbonising transport will be £12 billion in 2035. This includes public investment in charging infrastructure and private spending on new vehicles.

- Significant investment in vehicles and charging infrastructure starting from now and rising to £12 billion per year in 2035 will be required. Investment costs continue to rise to 2050 as zero-emission technology and infrastructure is rolled out. This includes both public investment (including on deployment of public charging infrastructure) and private expenditure (such as for purchase of vehicles).

Drivers will benefit from operational savings totalling £20 billion per year in 2035.

- As EVs are much more efficient than conventional vehicles, these will be offset by lower operational expenditure from around 2030, with annual operating cost savings of around £20 billion in 2035.

**Figure A3.1.g** Additional capital expenditure and operational cost savings in the Balanced Net Zero Pathway




Source: CCC analysis.
Notes: Chart displays in-year societal capital and operational cost impacts relative to the baseline. Segments above the horizontal axis represent additional capital expenditure (infrastructure and the purchase of new vehicles), while segments below the horizontal axis represent operational cost savings (reduced consumption, efficiency improvements and fuel / maintenance cost savings).

By 2025 we estimate that a new battery-electric car will be cost-saving compared with a petrol or diesel car over the lifetime of the vehicle, even when including costs of developing charging infrastructure and upgrading power networks to deal with increased demand for electricity and taking account of the need to replace exchequer revenue from fuel duty (Figure A3.1.h).

Battery costs are falling rapidly. By 2030, a battery-electric car is expected to be no more expensive to purchase than a conventional vehicle.

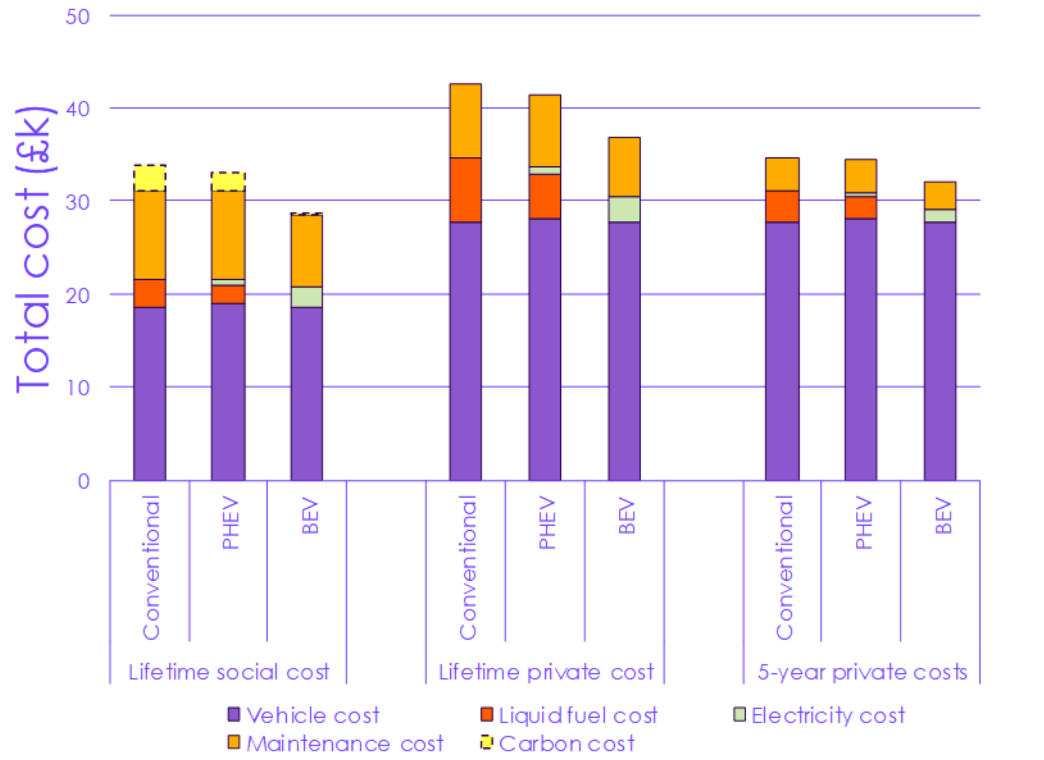
- A typical BEV car today is around 35% more expensive to purchase than a comparable conventional car. By 2030, we expect these upfront costs to reach parity, and by 2035 a typical BEV would offer a small upfront cost saving.

The electricity required to power an electric vehicle is significantly cheaper than petrol or diesel.

- Over the lifetime of the vehicle, the total societal cost of fuel for a typical conventional car is around £2,900. By comparison, the cost of electricity is lower at around £2,200. If fuel duty is included, the cost saving to a private owner is around £6,700 (around £500 per annum) in cash terms.
- BEVs have fewer moving parts, so also typically have lower maintenance costs than conventional vehicles. This can save the owner up to £170 per year.
- The cost of installing a home charger is expected to fall by around 25% by 2035.

In 2030, the total cost of owning an electric car will be substantially lower than that for a petrol or diesel vehicle.

Figure A3.1.h Cost comparison for new BEV, PHEV and conventional vehicles in 2030




Source: CCC analysis.
Notes: Societal costs are discounted at the social discount rate of 3.5% and represent net costs to society over the lifetime of the vehicle (i.e. excluding taxes and duties). Private costs are discounted at a private discount rate of 7.5% and include all taxes and duties.

Demand reduction, shifts to lower-carbon modes of transport and widespread EV uptake will bring significant co-benefits alongside emissions reduction.

In addition to significant emissions reductions and operating cost savings, many of the measures we outline have wider benefits to society:

- Reduced demand for car travel and improved delivery logistics will lead to lower levels of congestion and better air quality, particularly in urban areas.
- Switching to active forms of travel, such as walking and cycling, should offer health and wellbeing benefits.
- Widespread uptake of zero-emission vehicles will deliver improvements in air quality (particularly in $NO_2$ and $CO_2$) and noise reduction.

# Endnotes

[94] CCC (2020), *The Sixth Carbon Budget – Methodology Report.* Available at: www.theccc.org.uk

[95] Element Energy for the CCC (2020), *Analysis to provide costs, efficiencies and roll-out trajectories for zero-emission HGVs, buses and coaches*.

[96] Department for Transport (2019) *Road traffic estimates: Great Britain 2019*.

[97] Centre for Sustainable Road Freight for the CCC (2015) *An assessment of the potential for demand-side fuel savings in the Heavy Goods Vehicle (HGV) sector.*

Chapter 3

# Policy recommendations for the surface transport sector

*The following sections are taken directly from Chapter 2 of the CCC's Policy Report for the Sixth Carbon Budget.*[98]

**Table P2.1**
Summary of policy recommendations in surface transport

| | |
|---|---|
| **Active travel and public transport** | • **Strengthen schemes to support walking, cycling and public transport to reduce demand for higher-carbon travel.** This should include maintaining positive behaviour shifts and addressing risks resulting from the COVID-19 pandemic, provision of cycling infrastructure and investment in public transport.<br>• The public sector should lead the shift to other positive behaviours that reduce travel demand, for example encouraging home-working, facilitated through prioritising broadband investments over road network expansion. |
| **Cars and vans** | **Develop a comprehensive policy package to deliver on the Government's commitment to phase out new petrol and diesel cars and vans by 2030.** This will require:<br>• Strong consumer incentives to purchase zero-emission vehicles in the form of purchase subsidies, preferential company car tax, fuel duty exemption and lower vehicle excise duty should continue. These can be scaled back as costs of EVs fall.<br>• Introducing a zero-emission vehicle mandate requiring car manufacturers to sell a rising proportion of zero-emission vehicles (excluding hybrids), reaching nearly 100% by 2030, with only a very small proportion of hybrids allowed alongside until 2035.<br>• Continue to support EV charging infrastructure to ensure it can support high uptake levels. Project Rapid has the right ambition for the strategic road network and should be developed into a full strategy for the 2020s and beyond. Further investment is needed to support on-street and other urban charging solutions for those without off-street parking and destination charging.<br>• Implement the recommendations of the EV Energy Taskforce to ensure that delivering additional power capacity and electricity demand required for EVs is efficient, cost-effective and fair for the consumer. Ensure that as many EV users as possible can access smart charging, so that EVs can provide a flexible demand resource to the wider power system and consumers can realise cost-savings.<br>• Deliver plans to ensure investment in networks can accommodate future demand levels in coordination with Ofgem.<br>• Set out ambitious UK regulations on new car and van $CO_2$ emissions to 2030, consistent with our Sixth Carbon Budget trajectory, with more regular intervals than the EU's five years, backed by rigorous real-world testing.<br>• Government should deliver on its commitment to 100% of the central government car fleet being zero-emission by 2030 and extend this to include all Government vehicles.<br>• Produce a clear assessment of how best to re-use and recycle EV batteries and fund development of competitive, large-scale battery recycling facilities in the UK. |
| **Heavy-goods vehicles and the delivery sector** | • Implement large-scale trials of zero-emission HGVs in the early-2020s to demonstrate the commercial feasibility of these technologies and establish the most suitable and cost-effective technology mix.<br>• End new diesel HGV sales by 2040 at the latest to ensure the UK has a near zero-carbon freight industry by 2050. A comprehensive plan should be published in the early-2020s setting out how this will be delivered to give freight and vehicle operators time to plan for this transition. This should cover stronger purchase and other incentives, infrastructure plans and clean-air zones.<br>• Evaluate schemes to reduce HGV and van use, particularly in urban areas (e.g. e-cargo bikes and use of urban consolidation centres), to reduce traffic and improve the safety of active travel.<br>• Support freight operators to take advantage of opportunities to meet demand more efficiently, through logistics measures such as improved routing, better loading and reduced empty-running. Identify and address financial and non-financial barriers to improvements in this area. |
| **Rail and buses** | • Government should set out a clear vision to deliver Net Zero in rail and support Network Rail in delivering the target to remove all diesel trains by 2040. This is expected to cover a mix of zero-emission technologies (e.g. battery-electric, hydrogen and track electrification). The strategy should be published by 2021 as recommended by the National Infrastructure Commission.<br>• End new diesel bus and coach sales by 2040 at the latest, with most operators encouraged to switch over much sooner. Empower Local Authorities to continue driving zero-emission bus take-up and to improve bus services. |

Decarbonisation of surface transport has been slow over the past decade and surface transport remains the largest GHG-emitting sector. Policies have been implemented in some areas (e.g. new car and van $CO_2$ regulations and support for electric vehicles), but policies are off-track to contribute to the Net Zero target and need strengthening. Earlier this year, Government published a paper entitled 'Decarbonising Transport: Setting the Challenge', which set out the key decarbonisation challenges, and is currently developing a 'Transport Decarbonisation Plan' which aims to set out a comprehensive policy framework for surface transport.

Our recommendations are based on an assessment of existing policies, stakeholder engagement and a review of evidence. We also consider the Climate Assembly views, which recommend a future which minimises restrictions on travel and lifestyles, placing the emphasis on shifting to electric vehicles and improving public transport, and ensuring that solutions are accessible to all people. This chapter covers:

1) Challenges in decarbonising surface transport
2) Current Government policy commitments
3) Key changes needed

## a) Cars and vans

### i) Electric vehicles

Enabling the rapid take-up of electric vehicles (EVs) across society will be vital to delivering emissions reductions in the surface transport sector. There are several challenges that will need to be resolved in order to deliver this crucial transition:

Electric cars are currently more expensive to buy than comparable petrol and diesel vehicles. We expect upfront cost parity for a typical car to be reached by 2030, with savings over the vehicle lifetime realised before then.

- **EVs are currently more expensive** than equivalent petrol and diesel vehicles. For example, a VW e-Golf fully electric car is almost £7,000 more expensive than the standard petrol VW Golf (after the plug-in car grant) and electric vans can have a cost premium of around £10,000 over diesel vans. While running costs are much lower for EVs, consumers do not always factor in the benefit of fuel savings over the vehicle lifetime when making purchase decisions.
- **The supply of zero-emission vehicles** will need to scale up rapidly across all consumer segments in the next few years to ensure it does not constrain demand. Manufacturers are already responding to this challenge, driven by EU $CO_2$ regulations for new cars, but further progress in developing supply chains will be needed.

Electric car availability has rapidly expanded, and waiting times have reduced, over the past few years.

  - There are 130 fully or part electric vehicle models available in the UK in 2020, compared with just 38 in mid-2018. Long waiting times for EVs and launch delays, experienced in the last few years, have been reduced. However, only 73,000 EVs were sold in the UK in 2019, compared with 2.2 million petrol and diesel vehicles, and there still needs to be a significant switch in investment from petrol and diesel vehicles to high-volume EV production.
  - While EVs are less complex to produce and assemble, new supply chains, skills and production methods will need to be developed and original equipment manufacturers (OEMs) will need time to adjust. Re-training and re-skilling across the sector could be needed.
  - Global battery capacity will need to accelerate to meet demand. There are sufficient global supplies of raw materials for current-generation batteries (e.g. lithium, graphite, cobalt, nickel and manganese), but supplies will need to scale up significantly, especially from the mid-2020s. New mining facilities, appropriate battery-sizing and re-use and recycling will be fundamental to meeting demand cost-effectively. While new battery chemistries are being developed, these will take time and it is uncertain when or if they will come to market.

Battery capacities are expected to get larger, enabling electric vehicles to offer sufficient driving range to allay range anxiety among consumers.

- **Battery range**. Range anxiety needs to be addressed to enable mass-market EV roll-out. The average real-world driving range[*] of a new battery-electric vehicle (BEV) today is around 180 miles, and this is expected to reach 220-250 miles by 2030. Research suggests that a driving range of 230 miles is sufficient to eliminate range anxiety among consumers, although the vast majority of trips are less than 25 miles.[99]

[*] The range of an electric vehicle is the distance it can travel on a full battery without needing to be recharged.

However, larger vehicles require larger batteries to offer comparable range figures, therefore, van ranges are likely to remain below those of cars. Real-world battery range is also an issue, particularly in cold weather where there are other demands for power.

Substantial roll-out of charging infrastructure across the UK will be a key enabler for electric vehicle take-up. This will need to include on-street chargers for households without off-street parking.

## ii) Charging infrastructure

Widespread deployment of charge points is needed to enable reliable and accessible charging both during longer journeys and for those without access to off-street parking:

- **EV infrastructure**. A high take-up of BEVs will require significant charging infrastructure at homes, offices and on-street. We estimate there will be 14 million BEV cars and vans on the road by 2030, requiring 280,000 public chargers by 2030. Key challenges are:
  - A disproportionate share of public charging devices currently being rolled out are focused in London.[100] Charging infrastructure needs to be spread more evenly across the UK.
  - The need to provide on-street charge points for households without off-street parking is essential to enable the roll-out of EVs across society. This will give confidence that people will be able to charge when they need to. Technology is developing and options include lamp-post charging which could offer a convenient, low-cost solution.
  - There are currently 16 major public charging networks across the UK. Roaming agreements will be important to enable easy interoperability between these networks, so that EVs can be plugged in anywhere and paid for in a simple, transparent way for the consumer. Consumers will also need to be able to rely on each network's charge points to deliver high levels of reliability and availability.

Electric vehicle charging will significantly increase demand on the power system. Investment will be needed to ensure that the grid can support this additional load.

- **Networks.** Our scenarios have significant impacts on the power system, increasing electricity demand from today's very low levels to 104 TWh by 2050. Meeting this increased demand will require investment in system capacity and upgrades in the distribution network. The way consumers charge their EVs will be important in determining the cost of meeting this.
  - 'Smart charging', where EV charging is intelligently controlled (e.g. overnight when there is spare capacity), can help to ensure that charging of EVs is used as a flexible resource, responsive to the needs of the wider power system.
  - Building trust between EV owners and energy providers that any data provided are safe and will be used only as intended will be vital to enable this.
  - It is important that the benefits of smart charging should be available to as many consumers as possible. This includes exploring how its benefits can be extended to those without home chargers.

### iii) Conventional vehicles

Conventional cars and vans that are purchased during the 2020s are likely to remain on the road well into the 2030s. Therefore, it is important that newly purchased vehicles continue to become more fuel-efficient and reverse recent trends towards increasing carbon emissions:

- **Fuel-efficiency**. Our analysis shows that there is scope for significant improvements in the fuel-efficiency of conventional cars and vans, with the real-world intensity of new vehicles expected to improve by 12% by 2030.
    - While EU new car $CO_2$ regulations have been successful in driving reductions in new car emissions, progress has reversed since 2017. This has been mainly due to the trend towards larger, heavier vehicles, particularly SUVs. This must be halted if our decarbonisation pathways are to be met. The Climate Assembly[101] highlighted this issue and advocated stopping selling the most polluting cars.

## b) Heavy-goods vehicles

Despite comprising only 5% of UK road vehicles, heavy-goods vehicles (HGVs) produce 17% of GHG emissions from the surface transport sector. Therefore, it is important to enable this sector to transition to zero-carbon alternatives in a timely manner:

- **Zero-carbon HGV** technologies are currently at an early stage and it is too soon to say which will emerge as market-leaders. Manufacturers are developing battery-electric and hydrogen trucks and trucks suitable for use on electric road systems, as well as demonstrating infrastructure.
    - Many major HGV manufacturers now offer electric options for smaller, short-range models. DAF Trucks is aiming to offer electric versions of all its models by 2023 and Mercedes intends to offer a battery-electric truck with 300 miles of range by 2024.
    - Hydrogen fuel-cell trucks are expected to take slightly longer to reach the market but could offer longer range. Mercedes and Iveco are developing models that could offer up to 500-600 miles of range.
    - Scania currently offer the only commercial HGV suitable for use on an electric road system.
    - Electric road system demonstrations using overhead catenary are underway in Germany and Sweden, while a trial commercial hydrogen partnership has recently commenced in Switzerland.

## c) Road demand, active travel and public transport

Reducing demand for car travel will require improvements to provision and reliability of public transport, along with investment in schemes to support active travel.

Reducing road travel and incentivising shifts to public transport or active modes of travel can bring both significant emissions reductions and a variety of important co-benefits to society:

- **Surface transport demand** is forecast to increase by 10-20% from today's level by 2050.[102] Reducing demand and switching to lower-carbon modes of travel is cost-effective and delivers significant co-benefits, but requires a range of barriers to be addressed:

- Investment in walking and cycling infrastructure schemes, bicycle storage facilities and schemes to improve safety, security and accessibility.
- Perceived comfort, cost and convenience of alternatives to car travel need to be improved, so that these options are viewed as similarly attractive as driving. Disincentives against driving designed to reduce congestion or improve urban environments (e.g. restricted or expensive parking and low-emissions zones) could also contribute.
- Improvements in IT and network connectivity for people with options to work from home and to conduct business meetings online as a substitute for travel.
- Barriers to ride-sharing include longer journey times, autonomy, control and comfort (e.g. social interactions may be perceived as difficult or unhygienic for some). This is a particular challenge following the COVID-19 pandemic.

• **Public transport**. Public transport must be well funded, frequent, reliable and safe to encourage more people to use it.

  - The number of journeys by local bus has reduced by 12% over the past decade[103], while rail travel has increased by 29%.[104]
  - Public transport needs to compete on cost, but improvements are also needed to link journey stages, address reliability and accessibility issues and make it easier to use travel time productively (e.g. providing free high-speed wi-fi to enable working).
  - Increased provision of bus lanes and high-occupancy vehicle lanes can incentivise switching to public transport and shared mobility by making these easier and quicker than individual transport.
  - Use of public transport has rebounded more slowly following the easing of COVID-19 lockdown restrictions than has car travel. Rebuilding public confidence in the safety of public transport will be crucial for increasing its use.

# 2. Current Government policy commitments

The Government's recent ten-point plan includes a number of welcome measures towards decarbonising the transport system. However, gaps remain

There have been important advances in policy in many parts of this sector, including regulations on existing vehicles, support for EVs and infrastructure and a strategy for active travel. Some new measures were announced in Government's 'Ten-Point Plan for a Green Industrial Revolution'[105]:

- EU regulations on average $CO_2$ intensity have been in place for new cars since 2009 and new vans since 2011. Government has committed to be at least as ambitious as new EU regulations for 2025 and 2030 and plans to publish a Green Paper on the post-EU framework next year.
- Government's ten-point plan recently announced bringing forward the phase-out date for new fossil fuel cars and vans to 2030, setting a clear pathway to the transition to EVs.
- Plug-in car and van grants, providing up-front purchase subsidies for EVs, have been in place since 2011 and will continue until 2022-23. Additional support is provided through zero and lower rates of VED and company car tax for the lowest-emitting vehicles.
- Financial support for EV infrastructure is provided through home and workplace charge point installation grants and through financial support to Local Authorities to fund public charge points. Project Rapid commits £500 million to fund high-powered charge points on motorways and major roads.
- The Faraday Challenge provides funding for research and innovation in battery technology. Government has also committed £1 billion to develop Gigafactories in the UK to produce batteries needed for EVs at scale.
- The Road Transport Fuel Obligation (RTFO), the main policy to support biofuels in transport, has been in place since 2008. It has been extended to 2032.
- The Cycling and Walking Investment Strategy (CWIS) was introduced in April 2017. It has committed £2.4 billion to be invested to 2023 and sets out targets to increase active travel.
- Government intends to implement EU-wide $CO_2$ emission standards for heavy-duty vehicles, which set targets for reducing emissions from new lorries by 2025 and 2030.
- Government has also committed to investing £20 million in 2021 to fund zero-emission HGV freight trials and consulting on a phase-out date for new diesel HGVs.
- Government has set out an ambition to end diesel trains on UK railways by 2040.

However, gaps remain, and plans will be needed to tackle them.

## a) Cars and vans

Our Balanced Pathway assumes that all sales of new petrol and diesel vehicles (including hybrids) end by 2032 at the latest. Policies should ensure that hybrids play a minimal role beyond 2030.

Our Balanced Net Zero Pathway has been determined on the basis of ending sales of all new petrol and diesel vehicles (including PHEVs and full hybrids) by 2032 at the latest. We also explore earlier and later dates in our exploratory scenarios:

- Government has recently announced that new sales of conventional petrol and diesel cars and vans will not be permitted beyond 2030, laying the foundation for a full transition to EVs. However, Government is proposing to continue to allow sales of hybrids with a minimum emissions-free range between 2030-35. Hybrids burn fossil fuels and are not zero-emission vehicles. In developing the precise details of its proposal, Government should ensure that the resulting emissions and miles driven are consistent with our Balanced Pathway (Table P2.2).
- Policies must ensure that hybrids play a declining role relative to pure electric vehicles, and minimal beyond 2030. This will benefit air quality and consumers, as we expect pure battery-electric models to be cheaper to buy and cheaper to run than hybrid models by 2030. Policy should be designed to ensure clear consumer benefit to buying full electric over hybrid models (including through provision of effective charging solutions) and to encourage manufacturers to supply them (e.g. by setting stringent $CO_2$ emissions targets for new vehicles or requiring a high minimum electric mileage for hybrid models).

**Table P2.2**

Proportion of car and van mileage driven by each powertrain among all new vehicles sold in each year, in our Balanced Net Zero Pathway

| | 2020 | 2022 | 2024 | 2026 | 2028 | 2030 | 2032 (and beyond) |
|---|---|---|---|---|---|---|---|
| **Fossil fuel vehicles (including mild and full hybrids)** | 92% | 77% | 52% | 27% | 18% | 2% | 0% |
| **Plug-in hybrid electric vehicles** | 3% | 10% | 17% | 17% | 8% | <1% | 0% |
| **Battery-electric vehicles** | 5% | 12% | 31% | 56% | 74% | 97% | 100% |

Delivering this transition in an effective and equitable manner will require sufficient funding, monitoring of market developments and timely investment in charging infrastructure:

Financial incentives for electric vehicle purchases will need to continue but will be able to be scaled back as costs reduce.

- **Financial incentives for EV purchases** need to continue as long as purchase costs of EVs remain higher than for fossil fuel cars and vans. These can take the form of upfront grants, lower vehicle excise duty (VED), preferential company car tax and fuel duty exemptions. These can be scaled back as economies of scale and technological innovation reduce costs.
- **Disincentives to purchase the most polluting vehicles** should be increased. Stronger VED gradients between more and less polluting vehicles (including between BEVs and other electric vehicles such as PHEVs and full hybrids) can send a clear signal that high-carbon vehicles should be avoided, which could help reverse the recent trend towards larger, more polluting, cars.

- **A zero-emission vehicle mandate** should be introduced, requiring car and van manufacturers to sell a rising proportion of zero-emission vehicles, reaching nearly 100% by 2030, with only a very small proportion of hybrids allowed alongside until 2035. This should strengthen incentives to sell EVs in the UK market.
- **Government should deliver on its commitment** to 100% of the central Government car fleet being zero-emission by 2030 and extend this to include all Government vehicles.

Current investment in charging infrastructure is at an appropriate level. This will need to continue through the 2020s and beyond.

- **Support for EV infrastructure** should ensure it can support high uptake levels.
  - Project Rapid has the right ambition for the strategic road network and should be developed into a full strategy for the 2020s and beyond.
  - Government has committed to investing £1.3 billion to accelerate the roll-out of charging infrastructure, including on major roads and on-street near homes and workplaces. This is around the right level of investment at present, and investment, including through facilitation of private-sector investment, will need to continue throughout the 2020s and beyond to support widespread EV roll-out.
  - OLEV has allocated £20m of funding for Local Authorities to install on-street charging bays during 2020-21.[106] This should continue and be extended to provide on-street charging for all those without off-street parking as well as around towns and cities for top-up charging.
- **Networks and the wider energy system** will require investment to support increased demand from EV charging.
  - Government should deliver plans to ensure investment in networks can accommodate future demand levels in coordination with Ofgem (further details in Chapter 5 on policy for the electricity sector).

Common data and interoperability standards should be agreed to enable the electric vehicle and electricity sectors to work together effectively.

  - Implement the recommendations of the EV Energy Taskforce to ensure that delivering additional power capacity and electricity demand required for EVs is efficient, cost-effective and fair for the consumer:
    - Agree common standards to enable interoperability between the EV and electricity sectors and sharing of data. This should be an immediate priority.
    - Foster innovation in charging infrastructure in developing interoperability standards.
    - Developing national and local approaches to coordination of network and charge point infrastructure and future-proofing assets.
    - Enable as many EV owners as possible to realise the benefits of smart charging (e.g. charging their EV when electricity prices are low), to ensure EVs provide a flexible resource to the power sector.
    - Further, innovations such as vehicle-to-grid schemes should be supported.

- **Set ambitious UK regulations on new car and van $CO_2$ emissions** to 2030, to provide a strong incentive to manufacturers to continue to improve fuel-efficiency of petrol and diesel cars and vans consistent with the Sixth Carbon Budget trajectory.
  - There should be a coherent framework that incentivises greater fuel-efficiency of petrol and diesel vehicles and encourages a rapid transition to EVs. This should give OEMs the flexibility in meeting emissions targets in a way that works best for them.
  - They should be backed by a rigorous testing regime, with more regular intervals than the EU's five years.

Security of supply for raw materials should be enhanced by a clear assessment of how best to re-use and recycle batteries and developing UK-based recycling facilities.

- **Security of raw materials for batteries**. We welcome Government plans to develop Gigafactories in the UK to produce batteries needed for EVs at scale. Security of raw materials supply should be enhanced further by a clear assessment of how best to re-use and recycle batteries and through funding development of competitive, large-scale battery recycling facilities in the UK.

## b) Heavy goods vehicles and deliveries

Large-scale trials of zero-carbon HGV options are needed in the early 2020s, to demonstrate technological feasibility and establish the most suitable technology mix.

While it is too early to decide what combination of zero-carbon technologies for HGVs will be optimal for the UK, action is needed now to support market development and put plans in place to enable the sector to deliver the transition to zero-emission vehicles:

- **Implement large-scale trials for zero-carbon HGVs**. We welcome Government's announcement of £20 million in 2021 to fund zero-emission trials for HGVs. Funding needs to continue in future so that commercial-scale trials can commence in the early-2020s and continue for up to five years, to demonstrate the feasibility of these technologies and establish which is the most suitable and cost-effective technology mix for the UK (Box P2.1).

Sales of new diesel HGVs should end by 2040 at the latest.

- **End sales of new diesel HGVs by 2040** at the latest, to be on track to nearly fully decarbonise this sector by 2050. This date should be moved earlier if information from the trials shows this to be feasible.
  - The Government is planning to consult on a date for phasing out the sale of new diesel HGVs, and a comprehensive plan should be published in the early-2020s setting out how this will be delivered to give freight and vehicle operators time to plan for this transition.
  - This plan should cover stronger purchase and other incentives, infrastructure plans and support (e.g. ultra-rapid chargers for battery-electric HGVs and hydrogen refuelling stations for hydrogen HGVs) and clean-air zones.
- **Set ambitious $CO_2$ emission standards for HGVs** that are at least as ambitious as those set by the EU requiring a 15% reduction in carbon-intensity by 2025 and 30% by 2030. This is achievable with options that are market-ready including hybridisation, improving aerodynamics and lighter-weight construction.

Schemes to reduce HGV and van use can deliver improved efficiency, reduced emissions and lower levels of congestion.

- **Support schemes to reduce HGV and van use**, particularly in urban areas.
  - Encourage, support and enable options for green last-mile deliveries (e.g. through e-cargo bikes and use of urban consolidation centres), to reduce traffic and improve the safety of active travel.
  - Support freight operators to take advantage of opportunities to reduce travel demand and increase efficiency through logistics measures such as improved routing, better loading and reduced empty-running.

**Box P2.1**

What is needed from low-carbon HGV trials

Government has recently committed £20m for trials of hydrogen and other zero-emission HGVs, to help position the sector to be able to phase out diesel trucks. This funding, alongside the stated intention to consult on a phase-out date, are welcome and timely.

Our research and stakeholder engagement have clearly shown that commercial-scale demonstrations of zero-emission HGVs are needed in the early-2020s, in order to test the deployment of the available technology options, demonstrate their commercial feasibility and stimulate further market development. Separate demonstrations should be conducted for hydrogen fuel-cell and pantograph-electric HGVs. These should involve:

- **Infrastructure deployment.** Supporting infrastructure, covering hydrogen refuelling stations and overhead line equipment (catenary), will need to be deployed. Concern as to the availability of infrastructure is frequently cited as a major barrier to adoption of zero-emission vehicles, so this will need effective planning and communication.
  - For hydrogen vehicles, refuelling stations will need to be distributed across the country to enable the demonstrator vehicles to refuel conveniently for travel across large portions of the road network.
  - For pantograph-electric vehicles, an electric road system of several tens of kilometres in length should be set-up along a corridor that is frequently travelled by a variety of freight operators.
- **Collaboration with business.** Planning of the demonstrations should be conducted in partnership with the freight industry, to ensure that the demonstrations will produce evidence that is of use to businesses. Collating vehicle orders and providing demand guarantees to OEMs and infrastructure providers, as in the H2 Energy/Hyundai partnership in Switzerland, could help to overcome initial barriers to involvement.
- **Commercial-scale participation.** Each demonstration should involve at least 50-150 zero-emission HGVs covering a range of sizes. This scale of participation will ensure reasonable minimum levels of demand for infrastructure and maintenance provision, helping to develop viable business-cases for these crucial supporting industries. Any smaller trials would not be in keeping with the scale of the Net Zero challenge.
- **Broad scope.** The demonstrations should also include a wide range of vehicles across multiple operators. This is important because the HGV industry is very diverse, with different operators using their vehicles in different ways. Ensuring a broad scope will allow the evidence and experience gathered through the demonstrations to be applicable across a larger proportion of the UK's HGV fleet.
- **Real-world operations.** The demonstrations should be located on major freight corridors, to enable the technologies to be implemented across a wide range of real-world haulage operations. This will ensure that the evidence gathered is widely applicable and showcases benefits and challenges associated with zero-emission technologies in practical use.
- **Sufficient duration.** All vehicles should be in operation for a minimum of 1-2- years. This will enable fleet operators to establish business models and demonstrate the effectiveness of the technology across all conditions. It will also enable issues regarding adaptability of operations, vehicle maintenance and infrastructure longevity to be better understood.

- **Strong communication.** The findings from the demonstrations should be disseminated widely across the UK HGV sector to help operators better understand the zero-emission options available to them. Data collected from the demonstrations could be used to provide this understanding through tailored advice or comparison tools.

For battery-electric HGVs, technological readiness may preclude a comprehensive trial at this stage, while read-across from the experience of battery development in the low-duty vehicle sector together with research and development by manufactures may be sufficient to stimulate this market and give operators purchasing confidence. However, this is uncertain, and development of the technology and levels of adoption should be closely monitored to inform whether a battery-electric HGV trial would also be beneficial.

The trials should collect data on costs, system performance and reliability and suitability to different HGV operations. They should aim to begin by 2023 with all vehicles fully operational by 2025, in order to provide evidence to support zero-emission uptake across the sector from the second half of the 2020s. This requires planning to begin immediately – the Connected Places Catapult's TranZET project has already produced Strategic Outline Business Cases for each potential trial[107], so these timelines are achievable.

For any technologies that are taken forward, there will need to be significant and timely roll-out of infrastructure to provide confidence to fleet operators that they will be able to refuel. Given the long lead-times associated with infrastructure deployment, a comprehensive plan for how this will be delivered will be needed in the early-2020s. The UK's approach will also need to integrate with that in mainland Europe, to ensure that fleets can operate across both territories without barriers. Emissions standards that apply to UK-registered vehicles should also apply to overseas vehicles operating on UK roads, in order to avoid placing UK fleets at a commercial disadvantage.

Source: Element Energy research for the CCC (2020).

## c) Road demand, active travel and public transport

Recent initiatives, at both national and local levels, to support and encourage increased walking, cycling and public transport use are welcome. This should continue with increasing levels of ambition in order to realise the substantial opportunities for place-based and system-wide approaches to reduce road travel:

Schemes to reduce car usage should build on positive behaviour shifts and address risks in response to COVID-19.

- **Strengthen schemes to support a shift to active and public travel.** Measures should look to maintain and encourage positive behaviour shifts (e.g. increased home-working and shifts to cycling and walking) as well as address risks (e.g. reduced public transport use) in response to the COVID-19 pandemic. Provision of active travel infrastructure and other support schemes, including high-quality cycle lanes, secure bicycle parking facilities in city centres, places of work and train stations and park-and-ride schemes, as well as measures to make it less attractive to drive, are needed. Working across delivery bodies is critical:
  - Local Authorities play a key role in setting local transport policy and developing locally-based solutions that work for their communities (Box P2.2).
  - The public sector should lead the shift to other positive behaviours that reduce travel demand (e.g. encouraging homeworking), facilitated through prioritising broadband investments over road network expansion.

Zero-emission buses are already being deployed on many routes across the UK. Local Authorities should be empowered to continue driving this and to deliver improvements to services.

- **Incentivise the continued roll-out of zero-emission buses and coaches** to ensure that new sales of diesel vehicles end by 2040 at the latest. For the majority of routes, switchover to zero-emission options can and should occur considerably earlier than this. For instance, the Confederation of Passenger Transport has set a target for all new buses to be ultra-low or zero-emission by 2025. Local Authorities should be empowered to continue driving zero-emission bus take-up and to deliver improvements to bus services.

- **Set out a clear vision to deliver Net Zero in rail** and support Network Rail and other bodies in delivering the target to remove all diesel trains by 2040. This should cover a mix of zero-emission technologies (e.g. track electrification, battery-electric, hydrogen and hybrid trains). The strategy should be published by 2021 as recommended by the National Infrastructure Commission.

**Box P2.2**
The role of Local Authorities in local transport policies

Local Authorities (LAs) have a key role in reducing emissions and facilitating strategies to deliver decarbonisation, with leverage in several areas:

- They often have direct or strong control over local transport, housing and land-use policies, although the extent of this varies for each LA.
- They are part of the wider system of national Government, regional, private, public and third-sector organisations with a range of regulatory and financing powers.
- They have a critical role in coordinating partnerships across the country that link key climate change delivery organisations.

LAs have the potential to influence the transition to low-carbon transport across areas such as planning, investment in active travel networks, developing climate action and delivery plans and supporting local economic partnerships, as well as using parking powers to incentivise moves to sustainable transport:

- **Planning policy** can steer spatial and local planning that favours housing and commercial developments in the right places to reduce traffic and support efficient logistics.
- **Investment in walking and cycling networks** and development of Local Plans and Transport Plans to deliver modal shift from cars to active and public transport. These can also identify locations for consolidation centres near road links and urban micro-consolidation centres.
- Introduction of **low-emissions zones** that set minimum standards for carbon and other emissions.
- Planning and support for installation of **EV charging networks** across their jurisdictions.
- Supporting **Local Economic Partnerships** to invest in transport infrastructure including road junction improvements, link roads, park-and-ride schemes, cycling infrastructure and digital connectivity. For example, Sheffield City Region's £34 million 'Getting Building' funding includes support for active travel, digital infrastructure, construction skills training and a 12% increase in EV charge points in South Yorkshire.
- They can use **parking powers** under Traffic Regulation Orders to repurpose parking spaces for car clubs, cycle parking and EV charge points and use parking charges to discourage private car use and promote public transport. Nottingham City Council is a renowned example, where its Workplace Parking Levy – levied on private car-parking spaces – promoted modal shift to sustainable modes and raised funds for link buses and tram extensions in the city.
- LAs can **work jointly with bus operators** to provide a bus network that is rapid, reliable and affordable (e.g. through a bus strategy and bus quality partnership). However, improving bus services is more challenging because most LAs do not control routes, frequencies and fares.

## d) Delivering the transition fairly

It is important to ensure that the transition to a zero-emission transport sector is fair and affordable across all sections of society, and that the benefits are available to everyone.

The Treasury's Net Zero Review[108] is considering how the transition to Net Zero it should be funded and where costs might fall. The Climate Assembly highlighted the importance of accessibility to avoid negative impacts on rural communities, those at risk of isolation and for those on low incomes. Delivering the transition in a way that is fair and affordable across all sections of society is challenging and will need careful policy design and implementation, including ensuring widespread EV charge points across the country, ensuring a strong second-hand market for EVs and improvements in the accessibility and reliability of public transport.

# Endnotes

[98] CCC (2020) *Policies for the Sixth Carbon Budget and Net Zero*. Available at: www.theccc.org.uk
[99] Department for Transport (2019), *National travel survey*, Table 0308.
[100] Department for Transport (2020), *Electric vehicle charging device statistics*.
[101] Climate Assembly UK (2020), *The path to Net Zero: final report*.
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[104] Office for Rail and Road (2020), *Passenger rail usage*, Table 1220.
[105] HM Government (2020), *The ten-point plan for a green industrial revolution*.
[106] Office for Low-Emission Vehicles (2018), *On-street residential charge point scheme*.
[107] Connected Places Catapult (2020), *Transitioning heavy-duty vehicles to zero-emission technology (TranZET)*.
[108] HM Treasury (2019), *HM Treasury's review into funding the transition to a Net Zero greenhouse gas economy: terms of reference*.

Climate
Change
Committee

Climate Change Committee
151 Buckingham Palace Road
London SW1W 9SZ

w theccc.org.uk