ENVIRONMENT

Is it necessary to reduce car mileage to meet our carbon emission goals?

Doreen Lam and Dr Ivo Wengraf

February 2023

RAC Foundation

Table of Contents

Acknowledgements

The authors would like to thank Neville Jackson and RAC Foundation colleagues, Sujith Kollamthodi (Ricardo), Stephen Glaister (Imperial College London), Mark Brown (Aczel), Glenn Lyons (UWE), Jillian Anable (University of Leeds), Andy Eastlake (Zemo Partnership), David Wong (SMMT), Matt Croucher (SMMT), Eoin Devane (CCC), Jaya Jassi (CCC), Stephen Elderkin (National Highways), Simon Price, James Peet (WSP), Roger Himlin (National Highways), Michael Boother (National Highways), Adam Simmons (National Highways), Mark Clements (National Highways), Ciara Cook (New Automotive), Andrea Di Antonio (New Automotive), Ben Nelmes (New Automotive)

Executive Summary

The UK is committed to decarbonisation, with the ultimate aim of achieving 'net zero'. For this to become a reality, action is required across all sectors, including transport, to keep them within the carbon budget limits set by the Committee on Climate Change. Within transport, the spotlight often falls on road traffic as posing a particular challenge, with road traffic levels having for many years travelled in step with the growth of GDP – the enduring measure of economic success viewed from the Treasury.

The government has been busily pursuing policies to wean road transport off its century-long affection for the internal combustion engine and promote zero-tailpipe alternatives, for example by ending the sale of new non-plug-in cars from 2030, developing its zero-emission vehicle mandate (requiring a percentage of manufacturers' new car and van sales to be zero emission each year from 2024), and promoting the take-up of plug-in battery electric models.

If it were possible to swap out the entire fossil-fuelled fleet of motor vehicles for battery electric or hydrogen-powered options then, setting to one side the issues of how that power is to be generated and how the vehicles themselves are to be manufactured, at least the carbon emissions from running combustion engines would be dealt with. But that is a mammoth task – the government's licensing statistics suggest there are well over 30 million cars on the UK's roads, the vast majority of which are petrol- or diesel-fuelled, while the global supply of zero-tailpipe models is just starting to ramp up in earnest, to the point where the plug-in battery electric proportion of new UK car registrations hit 17% for 2022 (data from the SMMT).

All of this begs the question of the extent to which the hoped-for acceleration in adoption of zero-tailpipe cars will still need to be accompanied by complementary policies, specifically ones which influence the extent to which fossil-fuelled models stay in the parc[1] and in reasonably frequent use. In short, are those who argue that a net reduction in car-driven miles is a necessary requirement for achieving our climate goals correct? That is the question which the analysis presented in this report set out to answer – the answer revealed by the modelling, as explained below, being "No – but the task is a whole lot harder if individual car mileage stays put or rises".

The analysis is not easy, not least because the scale of the contribution needed from cars depends on that achieved by other road vehicles, by other parts of the transport sector, and by other sectors of the economy. For this reason a number of assumptions were needed, starting with estimating a ceiling value for car-based carbon emissions implicit in the government pathway to meeting climate change targets. Thereafter the heart of this report is the product of running a model with ten different parameters, four of which were held constant because they referred to characteristics with some certainty. The other six parameters referred to characteristics where we felt there was a range of possible, plausible futures.

The six which varied were (only tailpipe analysis):

1. The departure[2] rate of vehicles from the national car parc
2. New car registrations
3. The change in average new car fuel economy
4. The average mileage of ultra-low and zero-emission cars relative to petrol and diesel cars
5. The fuel economy of plug-in hybrid cars
6. Annual changes in miles driven for all cars, regardless of fuel type

Note: There were 14 parameters in the well the wheel analysis. These additional parameters accounted for ICE inflation and carbon intensity of electric used in BEV and PHEVs. Seven of those were held constant and the other seven varied.

The modelling does not allow for any transformational or one-off future shift in the affordability of motoring or in behaviour – regarding car ownership and use – such as could result from a policy lever that might be exercised, but to which there is no tangible commitment (e.g. significant motoring taxation changes or the launch of large-scale scrappage schemes), neither does it account for any substantial shift in public attitudes towards travel and transport. Rather, a wide range of plausible values has been set for each of the six variable parameters derived from established – and referenced – projections, policy commitments and recent historic trends.

It is tempting, but would be misleading, to put any weight on the proportion of the 9,900[3] permutations run through the model that delivered a particular outcome. It is impossible to say whether any one model outcome would be any more likely than any other. The right way to view what the modelling outputs reveal is to look at those where both the desired carbon outcome is achieved and at the same time there is no reduction in driven car miles, and then consider what is happening to make that outcome possible.

The modelling reveals which of the input assumptions appear to offer the greatest impact in achieving the desired carbon reductions, and, in turn, which permutations of those elements work best.

The five variables that delivered the greatest impact were found to be:

- individual car annual mileage;
- the rate of improvement of new ICE cars;
- the registration rate of new battery electric cars;

- the extent to which battery electric use replaces internal combustion use; and
- the rate at which petrol and diesel cars depart the parc.

Of these, it was decreasing individual car annual mileage had the most impact – and by some margin.

Although the rate of improvement of ICE cars had an affect on outcomes, recent history has not shown a consistent trend towards improvement.

Then turning to the other three output permutations where mileage doesn't fall, the finding we draw from the modelling is that if any one of those three elements in some sense falls behind, then greater weight is necessarily placed on the other two to do the heavy lifting required.

So the answer to the exam question we set out to address – is a net reduction in car-driven miles a *necessary* requirement for achieving our climate goals? – is "No, not necessarily". But *without* that reduction, the pace of migrating the parc away from internal combustion needs to be dramatic in terms of **both** the registration of new battery electric cars coming into the parc **and** the departure of internal combustion engine models.

The process of developing the model inputs has also been illuminating, because it has revealed some important trends that pre-date the substantial upheaval in the automotive market which resulted from the coronavirus pandemic and other global events of the last two years. Most notably we observe that the average age of cars in the UK car parc has been increasing (from 6.2 years in 1994 to 8.3 years in 2021) – this isn't about low-mileage historic and 'classic' cars being maintained by enthusiasts but 3- to 13-year-old 'daily driver' cars continuing to undertake relatively inexpensive but fossil-fuelled travel. In other words, from a tailpipe carbon perspective this trend appears to be heading the wrong way.

Our conclusion is that the progress being made in carbon reductions from adding more battery electric (or other zero-tailpipe emitting) cars to the parc is at risk if the trends in retention and use of petrol and diesel cars continues to head in the wrong direction, and thus it creates an incomplete and potentially misleading picture to focus on new car sales alone as a measure of progress. Hence our intention is to establish a single index, looking beyond registration rates, that combines battery electric car take-up and usage with internal combustion engine car departure as the best way of revealing whether we are on track to achieve the scale of carbon reductions from car traffic that we are likely to need if we are to achieve our overarching net zero carbon goal.

1 Introduction

The UK government has legally bound itself to reduce carbon emissions in line with its carbon budgets.[4] As a consequence of these budgets, there has been much discussion exploring ways of reducing the amount of greenhouse gases emitted in the UK so that it stays within that cap. A large proportion of total emissions in the UK originate from surface transport – and mainly from cars (CCC, 2022b).

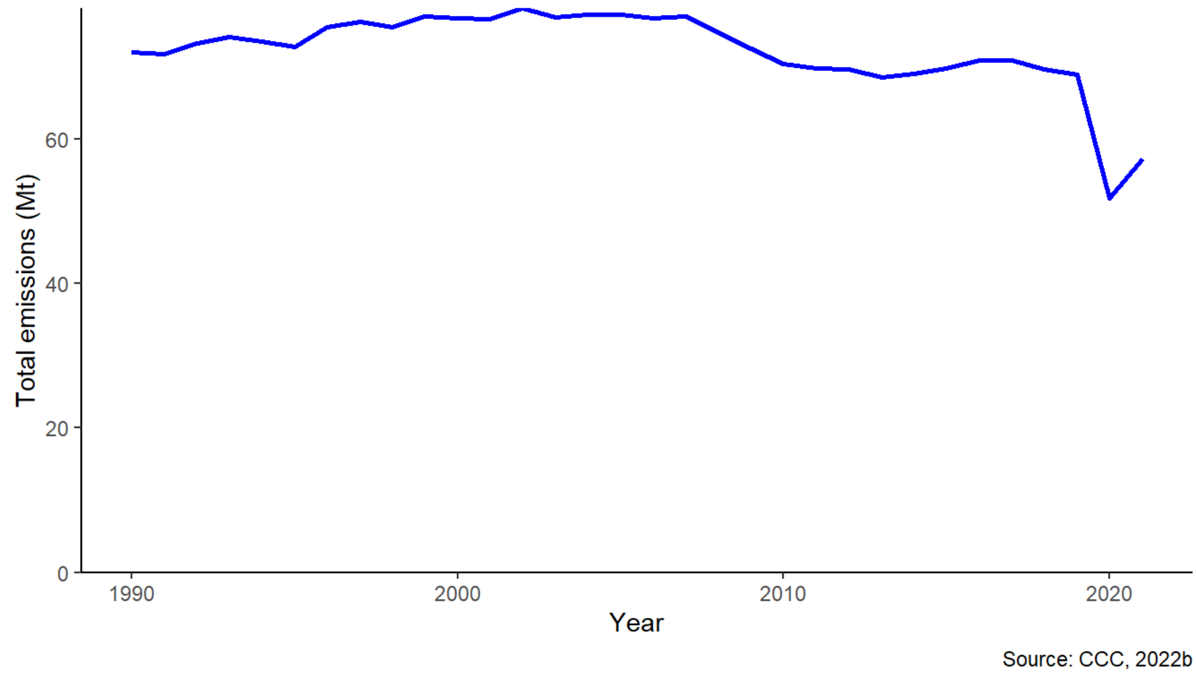


Figure 1.1: Historical car emissions

It naturally follows that reducing emissions from cars will constitute an important part of the solution, but the question arises: what needs to be done to accomplish these reductions? There are currently many ideas being mooted as contributions to the goal, such as increasing the uptake of battery electric vehicles (BEVs) and encouraging the shift to public transport, and of course in 2020 the government announced that it was bringing forward its ban on new petrol and diesel sales from 2040 to 2030; several organisations (notable amongst them being Green Alliance (Bennet & Brandmayr, 2021), and Transport for Quality of Life and Friends of the Earth (Hopkinson & Sloman, 2018)) are also advocating for a reduction in traffic mileage.

A reduction in car mileage would mean shifting people’s habits regarding how they travel day to day. Government policies such as lockdown periods during the COVID-19 pandemic significantly reduced the use of cars, as shown in Figure 1.2, but since the ease of this policy, car usage in aggregate has returned to 'normal' levels (DfT, 2022a).

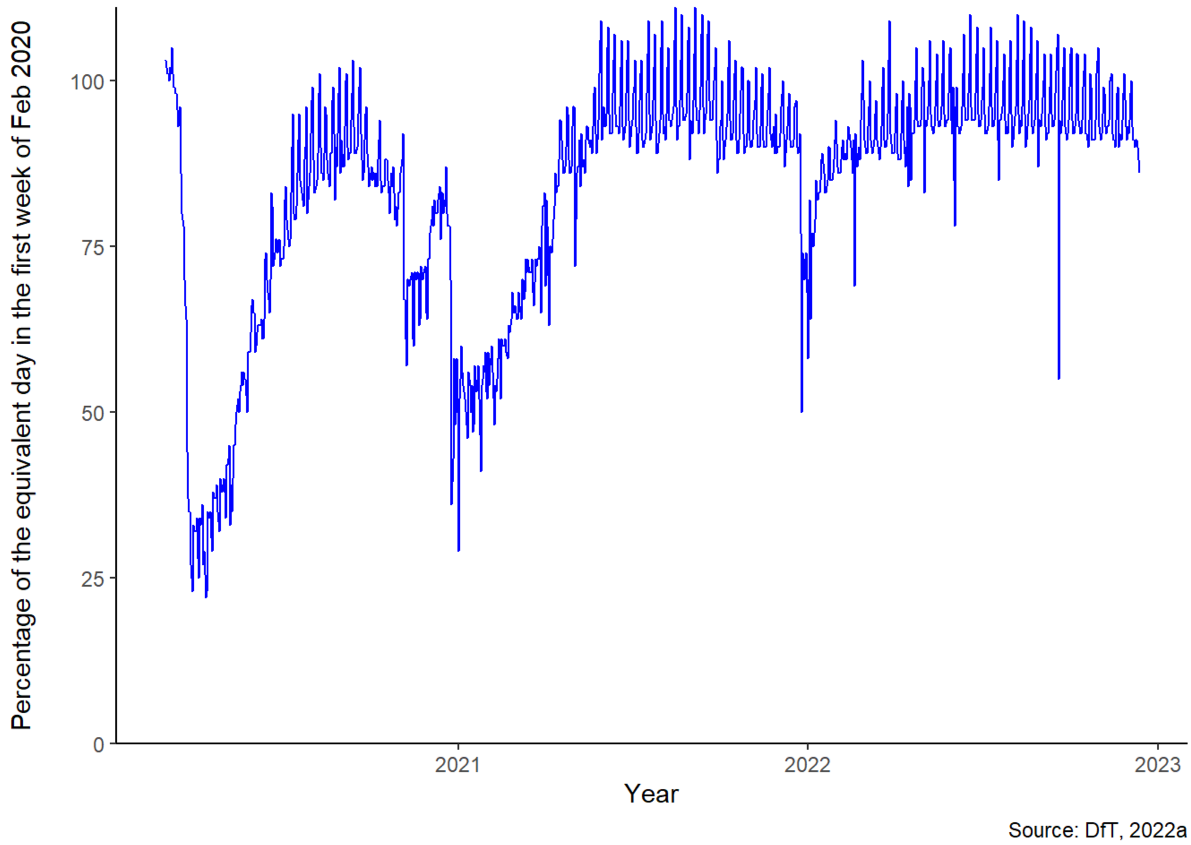


Figure 1.2: Car usage as a percentage of the first week of February 2020 in Great Britain

Figure 1.3 shows that over recent decades a decline in average individual car mileage (of around 2% year-on-year) can be seen in both the NTS (National Travel Survey) and MOT data (deriving from the MOT test that motor vehicles in GB of more than a specified age must undergo annually to test for safety and exhaust emissions). But how long this decline can realistically continue, and at what rate, is a matter of vital importance.

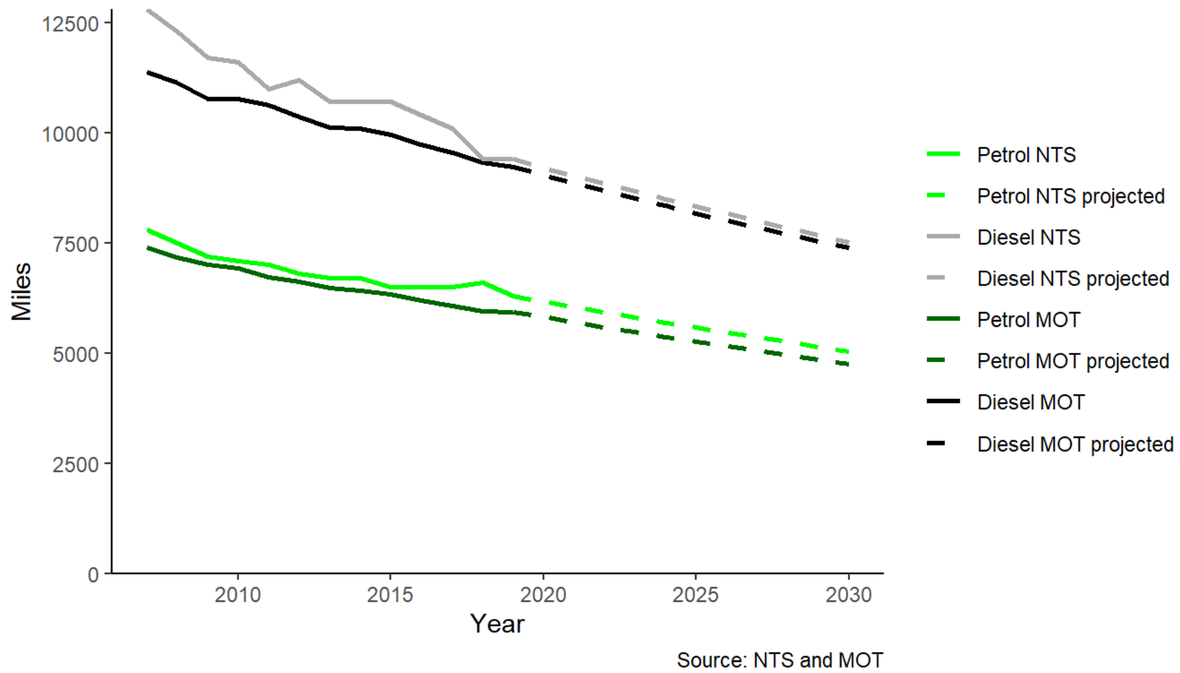


Figure 1.3: Annual mileage of a petrol and diesel car from 2007 to 2030 (projected from 2020)

The aim of this study was to establish whether it will be necessary to reduce overall car mileage in order for car emissions to fall in line with the currently set overall carbon budgets. As there are many factors that can influence emissions from cars – such as decreases in mileage, BEV uptake rates and the improvement of the sales-weighted fuel economy of internal combustion engine (ICE) cars – it is important to keep in mind that there is no single solution that is likely to achieve these aims. This report therefore considers the collective interaction of these factors to ascertain what combinations of them, and in what degrees, might cause emissions to comply with implicit carbon targets for cars.

The method used in this analysis is based on some of the methodologies from work on predicted declines in fuel duty that was published by the RAC Foundation in 2021, using similar assumptions and parameters (Lam, 2021). Additional parameters were added in order to account for other factors, such as the electricity CO_2 intensity used by BEVs and plug-in hybrid electric vehicles (PHEVs). The model forecasts the possible composition of the future parc (the population consisting of all the cars on the road) up until 2030. Finally, from that output, emissions and mileage data is applied to every possible permutation of the parameters to calculate estimates of the total mileages and carbon emissions.

The report is divided into six main sections. Chapter 2 explains the methods used, going into the specifics of the input data, the assumptions made and the methodology employed. Chapter 3 explains all the parameters used in the model. Chapter 4 reviews the emissions aims and targets for 2030. Chapter 5 shows the results in the context of two exemplar carbon targets (the UK Government pathway and the Committee on Climate Change pathway). Chapter 6 introduces a controlled analysis of each parameter to determine which have the greatest influence over carbon emissions within the model. Lastly, Chapter 7 brings together the conclusions of the report.

Important note: in this report, as far as the innovative modelling is concerned, **only cars are modelled** (according to DVLA's definition: see section 2.2) – and **this specifically excludes most vans**, as they have a very widely varying mileage which renders them unsuitable for including in such a model. In particular, the terms PHEV and BEV should normally be understood to refer to cars only, not vans or any other type of vehicle.

2 Methods

This section describes the data sources, assumptions and methodology used.

2.1 Input data

The following data sources were used in the creation of the model:

- Bespoke Department for Transport (DfT) tables of Driver and Vehicle Licensing Agency (DVLA) data:
    - cars by fuel type and year of registration as of 31 December 2019 in the UK. DVLA defines cars as a 'vehicles constructed for passenger carrying with up to eight seats (excluding the driver)' (including private hire vehicles that are car-based but not Hackney Carriages)
    - average gCO_2/km emissions values from licensed cars at the end of the year by year of first registration and fuel type for the United Kingdom in 2019
- Published DfT tables :
    - VEH0124: Licensed cars at the end of the year by make and model and year of first registration for the United Kingdom in 2016 (DfT, 2016)
    - VEH0124: Licensed cars at the end of the year by make and model and year of first registration for the United Kingdom in 2017 (DfT, 2017)
    - VEH0124: Licensed cars at the end of the year by make and model and year of first registration for the United Kingdom in 2018 (DfT, 2018a)
    - VEH0124: Licensed cars at the end of the year by make and model and year of first registration for the United Kingdom in 2019 (DfT, 2019)
    - VEH0124: Licensed cars at the end of the year by make and model and year of first registration for the United Kingdom in 2020 (DfT, 2020)
    - VEH0124: All licensed vehicles in the United Kingdom, for 2021 Quarter 4 (end December) only (Table VEH0124; DfT, 2021b)
- Divergence between Spritmonitor.de[5] and type-approval gCO_2/km emissions values by year of registration and fuel type (Tietge et al., 2019)
- Annual mileage per car, by fuel type and year of age, for all MOT-tested cars in Great Britain via Driver and Vehicle Standards Agency (DVSA) anonymised data (DfT, 2018b)
- New car registrations outlook scenarios sourced from the Society of Motor Manufacturers and Traders (SMMT) (SMMT, 2021)

- additional new registration sources, added to the new-registration parameter alongside the SMMT scenarios: first, the **CCC** scenario (CCC referring to the Committee on Climate Change, sometimes known as Climate Change Committee) in which both the number of total new registrations is greater than SMMT scenarios and the BEV uptake is very high; and second, the **zero-emission vehicle (ZEV) mandate** new registration outlook (DfT, 2022d) (see subsection 2.3.4)
- Forecasted carbon intensity in the UK in gCO_2/kWh (National Grid ESO, 2021)
- Uplift factors for petrol and diesel to reflect accurately the well-to-wheel (WTW) carbon of ICEs in the WTW analysis (BEIS, 2022)
- A real-world 'utility factor' (the proportion of the driven distance that is travelled in electric mode) for PHEVs (cars) to estimate WTW CO_2 of those PHEVs in the WTW analysis (Plötz et al, 2020)

2.2 Assumptions

Before explaining how the model works, it is important to first explain the assumptions made for the purpose of achieving a plausible working model. Some aspects of forecasting CO_2 emissions would have been extremely complex to input into the model, so these components have been simplified. The main assumptions used here are as follows.

- The government continues to tax cars and their use by means of the same principles and methods currently in place, so that there is no sudden and large change in affordability or behaviour.

- The model forecasts the CO_2 emissions from cars only, based on the DVLA definition of a car which was used for vehicle counts. By contrast, mileage estimates used the DVSA definition of a car, that is the makes and models that have undergone at least one Class 4 MOT test. The DVLA and DVSA definitions of a car are different. Every effort was made to clean the DVSA MOT data to best match the DVLA definition of a car.

- As little MOT data is available for cars less than three years old, all cars that are less than three years old are attributed a mileage that is the weighted average of all three-year-old cars and any cars that are newer but have had an MOT test within their first three years (for whatever reason).

- All manufacturers/registered fuel economy and gCO_2/km figures are adjusted by Spritmonitor.de data to make them more representative of everyday use. (Spritmonitor.de is a German Internet-based service that collects and delivers information about the fuel consumption of vehicles under real-world conditions.)

- The model contains no scrappage schemes, or sudden and large-scale shifts in public attitudes that might create a similar effect to such a scheme. (Despite the fact that implementing such policies could influence how people purchase and dispose of their cars, it is impossible to predict when, how, or whether this might happen.)

- Cars are assumed to leave the parc following one of a number of historic patterns of the very recent past. This pattern is called the 'departure rate' throughout this report, and the corresponding parameter is the likelihood that a car of a given age in a given year will still be on the road the next year. The model uses a set of historic departure rates to choose between, based on past behaviour from specific pairs of years.

- *All makes and models of cars are attributed the same average gCO_2/km fuel economy*[6] *figures*, with these varying only by age and fuel type. This is an extreme simplification as, in reality this differs not only from model to model but also by the way that car is driven and its state of maintenance. However, trying to arrive at a more sophisticated measure would have added too much complexity to the modelling task, not least because all new vehicle sales projections used here lack this level of detail.

- Plug-in hybrid electric vehicle (PHEV) fuel economy values (for cars) were estimated using two different approaches owing to a lack of sufficient data on their real-world usage patterns (changes in charging behaviour of PHEV drivers lead to far greater variations in possible real-world fuel economy values than is the case with the extent to which the behaviour of drivers of cars of other fuel types affects their fuel economy). In the tank-to-wheel (TTW) analysis, PHEVs are deemed to either (a) emit CO_2 at a rate which is a fixed proportion of that for petrol cars in the same year of manufacture (1.1) or (b) create emissions at a rate derived from Spritmonitor.de estimates. In the WTW analysis, the Spritmonitor.de approach is adjusted so that a PHEV's emissions are a combination of a period of use as an ICE car (with fuel economy adjusted by the utility factor (see section 2.1 above) to account for the zero-rated electric CO_2 of TTW economy values) and a period as a BEV (using the efficiency of the Mitsubishi Outlander – the UK's most popular PHEV – and the same carbon intensity of electricity as BEVs in the same year of use). The mix of these two modes is determined by the utility factor. Sufficiently detailed data on real-world PHEV usage is very rare, so the approaches used here are data-driven best-effort estimates. However, model outputs from this work forecast that the proportion of PHEVs (cars) in the total parc is, and will remain, relatively small and consequently it is unsurprising that sensitivity testing of the model suggests that the impact in any plausible variation in PHEV fuel economy is negligible.

- All data used within the model (except Spritmonitor.de adjustments, the PHEV utility factor, SMMT's new car registrations plus the Committee on Climate Change's outlook scenarios data and carbon intensity rates) is taken from government sources, which are assumed to be the most reliable open source data available.

- There was no attempt to model any fundamental post-COVID-19 changes, such as, for example, any modification of commuting patterns resulting from increased homeworking.

- Cars registered in Northern Ireland are assumed to be driven similarly to their Great Britain-based equivalents (as DVSA data pertains only to England, Scotland and Wales).

- The model considers only what will happen to the car parc, and does not take into account any (human) population changes.

- Battery electric car efficiency is held constant in the model. Although there will clearly be improvements in the future, the carbon intensity from BEVs is inconsequential to the end result, as the carbon emissions from grid electricity used for charging them is currently excluded from government surface transport budgets (BEV/PHEV efficiency in the well to wheel results have also shown to be inconsequential).

- The carbon intensity of PHEVs changes to some degree with the greening of grid electricity, but the utility factor and the electric efficiency of PHEVs remains fixed across the period of study.

As part of the fuel duty decline work (Lam, 2021), a researcher from Imperial College London previously carried out a detailed peer review to check that these assumptions were all correctly represented in the code within this model. The additional assumptions and parameters were explained to, and discussed with, experts from various organisations with backgrounds in the car industry, carbon emissions, government, roads operation and academia.

2.3 Methodology

2.3.1 Overview

The model starts off with the current state of the parc in an initial base year (in this case 2019), split by age and fuel type. The departure rate is then applied to the parc, and new car registrations are also added, to predict the composition of the following year's parc. This parc is then used as the new base year and the process repeated iteratively until the model reaches 2030 (in actual fact the model does produce output beyond this year, which is available to interested parties on request). Once the parc for each modelled year is created, annual car mileages and gCO_2/km figures are then applied to each modelled year, according to age and fuel type. These are then summed and three headline outputs are created from the raw results: the total composition of the car parc, total car parc mileage, and CO_2 emissions.

Each component of the method is explained in greater detail below.

2.3.2 Detailed methodology

The first bespoke DVLA dataset 'Cars by fuel type and year of registration of 2019' is imported. This is the initial car parc that starts off the model.

2.3.3 Calculating departure rates

Departure rates are then calculated using the published DfT VEH0124 tables (see section 2.1). To do this, the model takes data for every two pairs of consecutive years from 2016 to 2021 (these pairs overlap, so there are five). From this, for every age of car (as year integers), the proportion of those cars that are still registered (i.e. UK road legal and not SORNed, scrapped or exported) in the parc in the following year is calculated. This creates five different empirical departure rates that can be used in the model. The chosen departure rate is used across all fuel types in the model to calculate the next year's parc (before new sales are incorporated as described in subsection 2.3.1). Rates of departure differ significantly in each pair of years looked at. The more recent the departure rate, the more cars remained in the parc (implying that cars are staying in the parc for longer: the 2016–17 departure rate shows the most cars leaving the parc and the 2020–21 departure rate shows the fewest.

Figure 2.1 shows the departure rates for each pair (abbreviated to '16–17' for 2016–17 and so on) looked at and makes these differences clear. The more recent the departure rate, the more cars that were left in the parc from the previous year, indicated by these lines being closer to a probability value of 1, meaning that cars of any given age are more likely to stay in the car parc than in previous years. The older departure rates show that cars in earlier years were more likely to leave the parc than is the case more recently. The reason that the probability of cars staying in the parc increases with the age for 20-year-old cars upwards is that these cars have greater historical value, and the ever smaller overall number of them left are less and less likely to come off the road as time goes on. The points where the probability value is greater than 1 are points where the SORNed historic vehicles are restored and/or foreign classics are imported, with the result that the overall number of that car in the following year actually increases.

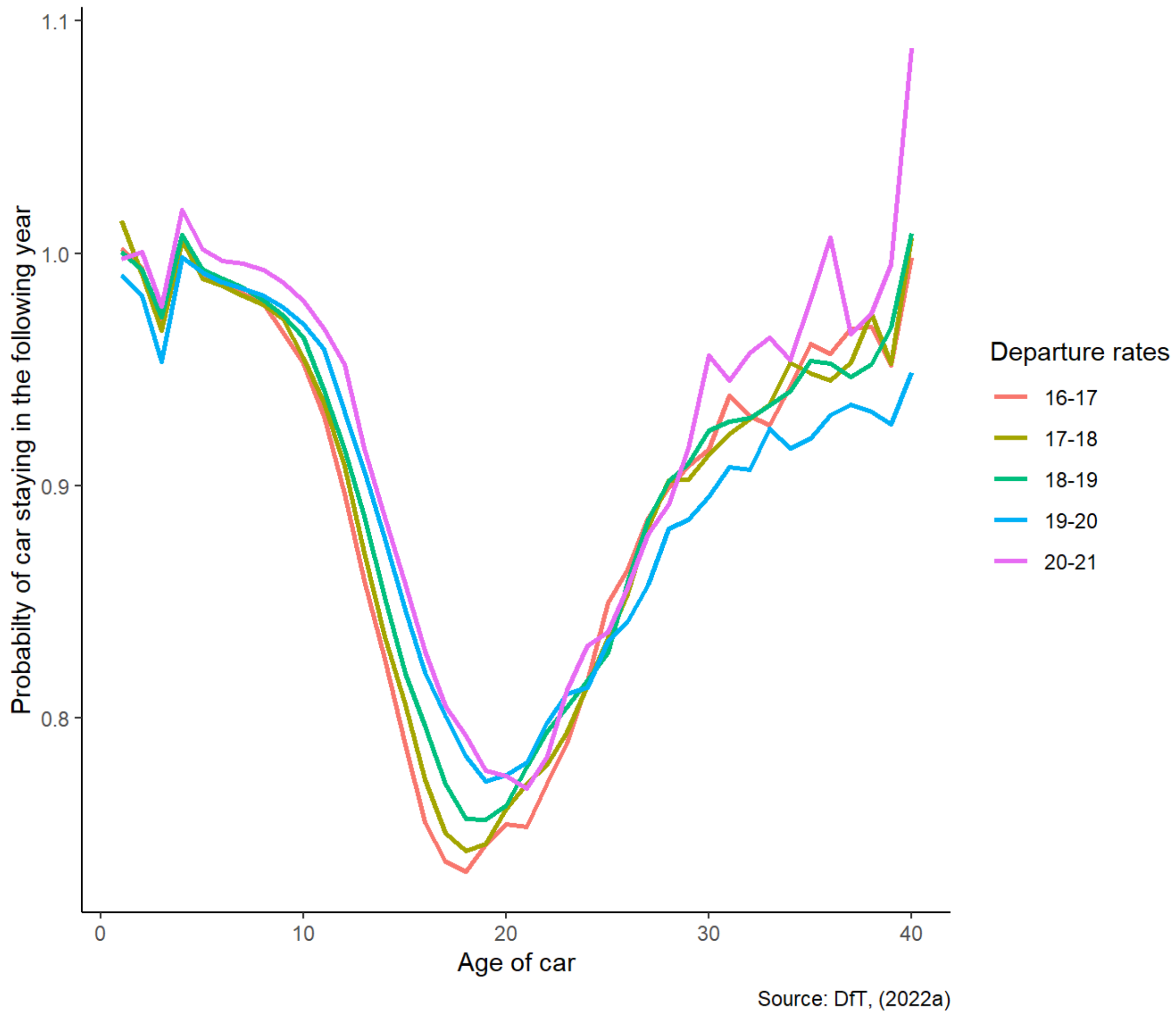


Figure 2.1: The historic probability of cars staying in the car parc in the following year

2.3.4 New car sales

The sale of new cars entering the parc are then introduced into the model. The SMMT, CCC and the ZEV mandate data is used, providing six different scenarios for new car sales from 2020 to 2035. These are described below (the first four being based on the SMMT data):

- a **low scenario** in which the uptake of BEVs (again referring to cars only, as is always the case in this model) is slowest, where the charging infrastructure is not supported by government intervention and there are no fiscal incentives for purchase or ownership for BEVs;
- a **central scenario** showing a slow uptake of BEVs, where the charging infrastructure is supported and there are some fiscal incentives, but only for the coming few years;

- a **high scenario** with a fast uptake of BEVs, where the charging infrastructure is supported and there are sustained and improved fiscal incentives – this assumes that 75% of all BEV registrations (private and fleet/business) qualify for the incentive;
- a **high private scenario** that also shows a fast uptake of BEVs but assumes that VAT incentives are for private BEV purchases only, and further assumes that 50% of BEV registrations which qualify for the incentive are private ; unlike the high scenario, which benefits both private and fleet buyers, the **high private scenario** benefits private cars only (it should be noted that the model does not distinguish between private and fleet owners in parc estimates);
- the **CCC scenario**, which is based on the number of total registrations increasing into the future along with a high rate of uptake of BEVs; this scenario forecasts all new registrations to be of BEVs by 2032; and
- the **ZEV mandate scenario**, which is similar to the SMMT central.

From the SMMT projections, the ICE car counts are divided into separate diesel and petrol columns using the DfT new registration car data for the split (Table VEH0253; DfT, 2021c). In 2020, the split between new petrol and diesel registrations was 77:23 (petrol:diesel). This ratio was applied to the **SMMT** projections for 2020, gradually progressing to a 9:1 ratio (petrol:diesel) by 2029 on the basis of advice from the SMMT. The very small numbers of mild hybrid (non-plug-in) cars are then summed together with petrol cars, also as advised by the SMMT. PHEVs and BEVs are treated individually. The CCC's new registration predictions are handled similarly (using initial DfT data as the base and SMMT advice on future sales) to split these into diesel and petrol sales.

The **ZEV mandate** data is in the form of *percentages of new car sales* from 2024 onwards. These percentages were therefore used along with the total registration numbers of the SMMT **high private scenario** from 2024 to 2035. The years 2020 to 2023 in the **ZEV mandate scenario** use the SMMT **central scenario** figures. Again, the ICE cars are split accordingly, as in the SMMT and CCC scenarios, and the diesel proportion reduced gradually. This handling of the ZEV mandate data (to convert published percentages into absolute values needed for the model) was agreed with DfT.

New car registrations are then added to the parc (after the departure rate was applied to reduce the numbers of existing cars appropriately) to create the new total car parc in the next year.

2.3.5 Iterating the model

Once the car parc for the following year has been created, this new parc is used as the base to create the following year's parc up until the ultimate forecast year, in this case 2035 (the modelled end of PHEV sales). As new sales projections do not distinguish between characteristics like weight, market category and make, this model is unable to make those distinctions – it is only able to create outputs distinguished by year of manufacture and fuel type.Once the car parc for the following year has been created, this new parc is used as the base year to create the following year's parc up until the ultimate forecast year, in this case up to 2035 (the end of PHEV sales). As new sales projections do not distinguish between characteristics like weight, market category and make, this model is unable to make those distinctions i.e. it is only able to create outputs distinguished by year of manufacture and fuel type.

2.3.6 Incorporating fuel economy and emission figures

The next step was finding the average fuel economy of the cars (gCO_2/km). To do this, the second bespoke DfT table, the 'average gCO_2/km emissions values from licensed cars at the end of the year by year of first registration and fuel type for the United Kingdom in 2019' (see beginning of section 2.1), was imported into the model.

It is important to note that the fuel economy estimates were amongst the least reliable input data used in modelling the fuel duty decline output (Lam, 2021). Therefore measures have been taken to improve this parameter: fuel economy values before 2015 were removed for PHEVs, since these were outliers owing to registration errors and the small number of PHEVs on the market at the time.

The Worldwide harmonized Light vehicles Test Procedure (WLTP) was introduced in 2018 and is based on the use of more realistic driving cycles to establish more accurate data on fuel consumption and CO_2 emissions. This method has replaced the New European Driving Cycle (NEDC), which was based solely on laboratory testing. Although the WLTP figures are slightly more accurate than the NEDC figures, both sets of figures (being laboratory-derived data published by DfT/DVLA for tax purposes) fail to accurately reflect real-world performance, since they are still conducted under controlled laboratory conditions.

To address this, the WLTP and NEDC figures were both adjusted using data from the Spritmonitor.de website to arrive at figures that are closer to emissions from real-world driving. This data is collected by real-world users of vehicles, mostly in Germany. It was decided to use the Spritmonitor.de data because it consists mostly of private cars and provides values for petrol, diesel and PHEV cars separately, whereas the published figures of other organisations did not (Tietge et al., 2019). The method used applies to cars a percentage increase in fuel consumption and CO_2 emissions, separately for each fuel type.

A further adjustment was applied to the adjusted economy values since it was recognised that cars in the UK are used somewhat differently to the way they are in Germany where Spritmonitor.de's data comes from, in that UK cars undergo a different and rather less efficient mix of town and motorway driving from their German counterparts and are also typically driven for shorter journeys, with a longer proportion of the time on the road spent with an engine not yet warmed up to efficient running temperatures. Both diesel and petrol cars had a 'deflation' factor of 1.01 applied to their fuel economy values, meaning that the emissions value increased to represent a lesser fuel economy. This value was determined by comparing Spritmonitor.de results to the known 2019 UK fuel economy figures.

Future fuel economy/CO_2 figures for ICE cars were predicted by varying how much the ICE car parc sales-weighted average worsens or improves year-on-year. This improvement applies only to the emissions of ICE cars, with BEVs not contributing to this change.

2.3.7 Average sales-weighted emission changes

Historically, average sales-weighted emissions of ICE cars have fluctuated from year to year. Figure 2.2 shows that, since the turn of the millennium, the petrol average sales-weighted emissions have decreased at most by 5% and increased at most by 3% from one year to the next, whereas diesel average sales-weighted emissions have decreased by at most 3% and increased by at most 6% in a single year.

Figure 2.2: Historic average sales-weighted emissions percentage change year on year

In view of this data, the respective parameter within the model was set to one of five values from −6% to +6% in increments of 3%, reflecting either increases or decreases in sales-weighted emissions from both petrol and diesels.

Using a 0% change in average sales-weighted emissions represents a future in which cars reduce in fuel consumption but, as a result, consumers buy less-efficient cars (reflecting the Jevons paradox); a −4% change represents a future where consumers instead moved down a vehicle size class, as they have done with C-segment or 'compact' cars, such as the Ford Focus, taking market share away from larger D-segment ('saloon') models, such as the now-discontinued Ford Mondeo. A change of 4% would represent a situation where consumers moved up a class to larger, less efficient cars. (The Jevons paradox, or the rebound effect, describes the situation in which advancements in technology, or government policy, improve the efficiency with which a particular resource is used, but this then leads to an increase in its consumption rather than a decrease, owing to increasing demand for it – which has been brought about by that improved efficiency.)

2.3.8 Model outputs

There are two main model outputs: one based only on the tailpipe emissions from (ICE) cars (petrol and diesel cars, and PHEVs when running in ICE mode), and the second based on WTW emissions from petrol, diesel, plug-in hybrid and battery electric cars. In carbon budget accounting, electricity used for BEVs (and PHEVs when driven in electric mode) does not count towards the transport part of the budget. By looking at both numbers, emissions can be seen both in terms of the two targets used (government and CCC: see Chapter 4 on emissions targets), and also with respect to the overall picture of transport's effect on the UK carbon footprint.

The results that look only at tailpipe emissions do not, therefore, take account of the carbon intensity of BEVs and PHEVs (running in electric mode). This is explained more fully below. The results chapter considers only the tailpipe results; however, for completeness, the WTW results have been included in the appendix.

2.3.9 Plug-In Hybrid Vehicles

Because of a lack of reliable data on the usage patterns of PHEVs, these were treated differently to BEVs (remembering, of course, that we are talking of cars only in every case) and ICE cars. Therefore PHEVs were split into two driving styles in different model runs.

The first option was that all PHEVs achieve an estimated real-world fuel economy, which is obtained by adjusting the laboratory test result (either WLTP or NEDC, whichever was available) using Spritmonitor.de deflators.

The second option was a worst-case scenario where PHEVs performed worse than petrol cars of the same age by a chosen percentage. In this scenario, PHEVs are not regularly charged and are less economical, because they carry heavy and under-utilised electric motors and batteries. For the model runs reported here, their economy value has been set to 90% of the petrol fuel economy of cars in that same year of first registration.

For the WTW analysis, this approach was modified slightly. The first approach discussed above was adjusted so that a PHEV's emissions are derived from an assumed combination of two driving modes: considering the PHEV as if it had an ICE powertrain, and alternatively as if it were a BEV. These two numbers are combined as a weighted average by using the utility factor, which is the proportion of travel a PHEV moves in electric mode.

As TTW fuel economy values reflect an assumption that the electricity used is free in the calculations, the fuel economy in ICE-only mode was first determined by adjusting the initial fuel economy using the utility factor. Well-to-wheel ICE-only CO_2 was then calculated from fuel economy figures using the same method as for petrol cars. Real-world electric-mode efficiency was taken from the UK's most common PHEV (the Mitsubishi Outlander), and BEV-mode CO_2 was calculated assuming the PHEV would be charged using the same electricity as for a BEV run in the same year. These two CO_2 values were then averaged using a weighting that reflects the utility factor. It is worth noting that this approach has the electricity used by PHEVs greening over time, but it does not assume any change in BEV-mode efficiency (i.e. it assumes that PHEVs will not become any more efficient in BEV mode over time) and neither does it postulate a change in the utility factor (whereby PHEV motorists would improve the proportion of their driving in BEV mode, through some combination of greater range and more frequent charging).

2.3.10 Carbon emissions for electric vehicles

In the WTW version of the results presented in the appendix, the carbon emissions from the electricity used to charge the cars were included in the calculations. To do this, the carbon intensity forecast was derived from National Grid data under three different scenarios:

- the 'steady progression' is a worst-case scenario where carbon intensity is the highest;
- the 'system transformation' scenario has mid-range carbon intensity; and
- lastly 'leading the way' is the best-case scenario with the lowest carbon intensity (National Grid ESO, 2021).

This was combined with the efficiency of electric cars, again using a low, middle and high range of efficiency. These components were combined as seen in Table 2.1, to produce a single parameter in the model representing three different possible intensity levels of the average carbon emissions per mile for BEVs.

Table 2.1: Carbon intensity levels for BEVs

Carbon intensity	Combination of carbon intensity forecast and assumed BEV efficiency	Resulting CO2 emission intensity of BEVs
Highest	'Steady progression' + least efficient BEV	3.4 miles/kWh
Middle	'System transformation' + efficient BEV	3.75 miles/kWh
Lowest	'Leading the way' + the most efficient BEV	4.1 miles/kWh

2.3.11 Pre-2001 cars

Cars registered before 2001 did not have their fuel consumption recorded by DVLA, so a parameter was included that could set their fuel economy. For simplicity, after sensitivity testing revealed that even large variations in this parameter made little difference to the results, the value chosen for both petrol and diesel cars was the gCO_2/km equivalent of a fairly pessimistic 20 miles per gallon.

2.3.12 Estimating vehicle mileages

Once gCO_2/km emissions figures have been calculated, the most up-to-date estimates of average car mileages are needed in order to calculate overall parc emissions, and the basis of this was a comparison between 2018 and 2019 mileages (with associated dates) taken from MOT records (the entire body of all the country's test results), with much careful filtering and adjusting required, to derive a daily mean mileage figure as the basis for the annual mileage.

First, the 2019 anonymised MOT data from DVSA was filtered to include only Class 4 tested vehicles (this category is the closest that DVSA comes to a definition of what a car is – and it also includes light vans, taxis, minicabs and campervans). This dataset was further filtered to include only DVSA fuel types that fall within the categories that were needed here: petrol, diesel, PHEV and BEV. This model does not consider hydrogen as a future fuel for cars, as this is a very small market currently. (At the end of June 2022 there were 191 hydrogen cars in the UK, while there were 292 cars in the 'steam' and 'other new technology' categories combined (DfT, 2022, Table VEH1103)). The latest test record in the year was selected for each car (discounting those with no test passes). This provided a single record for each car with a test certificate within the calendar year.

The MOT test records for 2018 were then linked to these by choosing the earliest successful test pass in 2018 for every car in the filtered 2019 set. Unless a car's 2019 test was likely to be its first test at three years old, those without a 2018 test were considered to have been off the road and were therefore discounted and removed from the data. Tests that showed a first use date before 1 January 1880 (sic) or after 31 December 2019 were also removed.

The age of each car was then calculated based on the 'first use date' in the 2019 test record. The data was then placed into one of ten categories based on whether the test date in 2018 was missing, and the age of the car.

Those which did have a 2018 test date and which:

- are >= 4 years old were classed as 'normal pair';
- are <= 1 were classed as 'within first year, pair';
- are between ages 1 and 2 were classed as 'within second year, pair';
- are between ages 2 and 3 were classed as 'within third year, pair'; are between ages 3 and 4 were classed as 'normal pair'.

Those with a *missing* 2018 test date and which:

- are >= 4 years old were classed as '+4, no match';

- are <= 1 were classed as 'within first year, no match'; are between ages 1 and 2 were classed as 'within second year, no match';
- are between ages 2 and 3 were classed as 'within third year, no match';
- are between ages 3 and 4 were classed as 'within fourth year, no match'.

All normal pairs were retained. All records in the category '+4, no match' were discarded, as these cars would have spent an unknown time off-road and would thus produce inaccurate mileage rates. The missing 2018 test date results were then set to the first use date of the car. Cars remaining that had no 2018 test were assigned a mileage of zero (in other words, mileages for these cars were derived from their entire life).

Average daily mileages were then calculated by taking the difference between the mileages in the 2019 and 2018 MOT results, and dividing this by the number of days between the two tests. This was then multiplied by 365.25 to obtain an estimated annual mileage. Once an annual mileage had been calculated for each of the cars still in the dataset, these were then averaged by fuel type and vehicle age (in one-year bands).

As new cars are (almost always) not required to have an MOT test until they are three years old, mileages for cars newer than this were estimated. Cars aged between two and three years were given the same annual mileage as a three-year-old one from the normal pair. For each of the age groups from 0–2 years, the mileages were included with those from the three-year-old cars to form a weighted average to better reflect cars of those ages. Missing data values were linearly interpolated up to 40 years old, at which point a car becomes 'classic' and doesn't require an annual test: the mileages for all cars over this age were simply set to 1,000 miles a year. This number for classic car mileages was in line with trends immediately prior to 40 years old, and subjected to sensitivity testing. They were then attributed to each of the matching vehicles in the DVLA licensing data to calculate an overall mileage for the UK car parc.

2.3.13 Total car parc mileages

The model's total car parc mileage estimates do not match exactly with the DfT road traffic statistics (the TRA series[7]). This is because the model uses vehicle registration statistics and estimates mileages for cars using the MOT data to allow overall mileage to be broken down by age and fuel type – details which road traffic statistics do not provide. The DfT-supported MOT project[8] did not get vehicle and MOT data to match road traffic statistics exactly either, as they are two separate estimates of slightly separate things, which is why the TRA series is not used in this work.

2.3.14 Adjustments for BEVs and PHEVs

Initial estimates of the 2018–19 MOT mileages for BEVs/PHEVs showed that cars that were three years old and newer were doing fewer miles than older cars. This statistical anomaly reflects a number of issues with the accuracy or representativeness of mileages attributed to early BEVs:

1. in the early BEV cohort, there was a high proportion of Teslas that were benefitting from free rapid recharging, and therefore doing very high mileages, but this does not look set to continue in the future;

2. a large number of Toyota and Lexus hybrid petrol vehicles appear to have been mislabelled in the MOT data as “Electric” rather than “Hybrid” and these significantly distort estimates (particularly as many of these hybrids were very high mileage taxis/private hire cars), and

3. the BEV market is still a fairly immature market, with low numbers of vehicles in some years, and covering a very wide set of vehicle ranges and charging technologies, which leads to a very ‘noisy’ dataset.

As the BEV market matures, these issues in the MOT data will fade away, but until then, BEV mileage estimates from the MOT data were not used. Instead, three alternative mileage profiles were used:

1. BEVs/PHEVs the same as petrol cars of the same age;

2. BEVs/PHEVs the same as diesel cars of the same age; and

3. BEVs/PHEVs covering 110% of the mileage of a diesel equivalent, based on the assumption that these will drive further than ‘normal’ since doing so would be cheaper.

2.3.15 Other possible adjustments

The average mileages of cars over 40 years old could also be adjusted if data was available. However, as with the calculation of gCO_2/km values of older cars, their low numbers mean that such an adjustment would make no material difference to the overall output.

Lastly, and more usefully, there was a provision for annual individual mileages for subsequent years to be changed by a percentage year-on-year – from no change (a change of 0%), which assumes that average mileages will continue to be as they were in 2018–19, through to a –5% change, where they decline by 5% compared to the previous year, for every year from 2020 onwards. This was to give the model the possibility of considering scope for behavioural change in driving patterns.

Once the future car parc was found for each year up to 2035, fuel economy values (and carbon intensities if looking at the WTW results) and annual mileages were attached to the car parc based on the parameters used, from which then the total

CO_2 emissions could be calculated. The model outputs make one of two possible assumptions about how we drive cars of a given age. Either we drive cars of a given age as per the MOT data in the years 2018 to 2019, or we drive them on this basis but adjusted with a year-on-year percentage value.

Uncertainty will always exist in any forecasting of the future. This model makes a number of assumptions and uses a range of different parameters, as explained earlier in this chapter. A plausible range of values was established for each parameter, using either industry and government projections or by referring to recent historical evidence of past behaviour. Every permutation of these parameter values (as detailed in the next chapter) was run in the model, leading to the final 9,900 outcomes.

3 Parameters

The following list summarises the parameters that can be changed in the model, and also states which were kept constant in all model outputs (shown in italics).

- Departure rates (see definition in section 2.2; these are based on past behaviour from specific pairs of years as listed here, and the departure rate chosen is then applied to all future years):

    - 2016 to 17 - fastest departure rate (abbreviated to 'DfT 16–17' from here on)
    - 2017 to 18 - fast departure rate (abbreviated to 'DfT 17–18')
    - 2018 to 19: slightly slower departure rate (abbreviated to 'DfT 18–19')
    - 2019 to 20: slower departure rate (abbreviated to 'DfT 19–20')
    - 2020 to 21: slowest departure rate (abbreviated to 'DfT 20–21')

- new car registration (i.e. new cars sold; these correspond to the scenarios introduced in subsection 2.3.4 and are shown in bold in the text):

    - SMMT low: slow BEV uptake
    - SMMT central: medium-level BEV uptake
    - SMMT high: accelerated BEV uptake
    - SMMT high private: accelerated BEV uptake (with incentives applying to private cars only) private cars);
    - CCC: increased number of total number of cars sold and a fast uptake of BEV
    - ZEV mandate: similar to SMMT central scenario

- *Fuel economy 'deflation' factor for petrol and diesel cars (to account for differences between Germany and the UK in typical fuel efficiencies achieved): kept at 1.01 in the model*

- Percentage change year-on-year to fuel economy of sales-weighted new car gCO_2/km figures for petrol/diesel/PHEV cars only, (see subsection 2.3.6):

    - between −6% and +6% in increments of 3%

- *PHEV gCO_2/km emissions factor: kept at 1.1, setting the PHEV fuel economy as 110% of petrol CO_2 meaning the emissions are up, economy down*

- The average mileage of BEVs/PHEVs (the mileage style parameter):
    - like petrol cars: a more realistic average mileage
    - like diesel cars: assuming that these will drive at the higher end of normal because they are cheaper and more efficient
    - 10% more than diesel cars
- *Average mileages of cars older than 40 years old: kept at 1,000 miles in the model*
- *gCO_2/km adjustment for cars registered before 2001: kept at the equivalent of 20 miles per gallon*
- annual individual mileage adjustment year-on-year: −0% to −5% in increments of 0.5%
- PHEV gCO_2/km emissions factor:
    - Best: PHEV fuel economy is the real-world fuel economy estimate which is where the laboratory test result (either WLTP or NEDC, whichever was available) was adjusted using Spritmonitor.de deflators
    - Worst: set to 110% of petrol emissions for cars in that same year of first registration

And if looking at the WTW results, the following additional parameters are available for BEV/PHEV carbon per mile (their carbon intensity), for electric mode (these correspond to the carbon-intensity possibilities introduced in subsection 2.3.9).

- Highest carbon per mile: combines high carbon intensity rates with the least efficient electric car: 3.4 miles/kWh
- Middle carbon per mile: combines the middle carbon intensity rate with the average efficiency of an electric car: 3.75 miles/kWh
- Lowest carbon per mile: combines the low carbon intensity rates with the most efficient electric car: 4.1 miles/kWh
- *Real-world PHEV utility factor (the proportion of the driven distance that is travelled in electric mode by PHEV cars): kept at 37%*
- *Petrol inflator for WTW (to reflect the full carbon cost emitted from petrol) was 1.28*
- *Diesel inflator for WTW (to reflect the full carbon cost emitted from diesel) was 1.24*

4 Emission Targets

This section will explain CO_2 emissions targets set by the two relevant bodies: the government (GOV) and the Committee on Climate Change (CCC). These are used to test all permutations of the model to see what parameters are needed to reduce emissions to at or below the target in question. It should be noted that in both cases the bulk of the target values in the carbon budget refer to CO_2e (carbon dioxide equivalent). Since this model deals exclusively in terms of actual CO_2, a small adjustment is required to express CO_2e targets in terms of pure CO_2. CO_2 makes up 99% of the CO_2e figure which is used throughout the report when the conversion is needed (DfT, 2022e).

4.1 Government

The Government pathway (GOV) from the CCC's analysis (CCC, 2022b) indicates that emissions from surface transport need to be no more than around 64.7 $MtCO_2e$ in 2030. In 2021, cars made up 57% of surface transport emissions (CCC, 2022b), and this proportion is thus applied to total transport emissions targets to determine the car-based targets which are needed for the model. It is understood that this proportion may change in future to constrain car emissions targets, because the burden on cars to become efficient may increase even beyond existing intentions, to allow for the fact that other transport modes, such as heavy goods vehicles, may take longer to transition to more emission-friendly fuel types.

So, to continue with the target year, car emissions by 2030 will need to fall to 36.9 $MtCO_2e$ (57% of the overall surface transport target). As the analysis looks only at CO_2 emissions, this figure is then converted to a model input target of **36.5 MtCO2**, since (as mentioned above) CO_2 makes up 99% of the carbon dioxide equivalent value.

Although this target was taken from the CCC's Government pathway, this figure was also within the boundaries of the Decarbonising Transport projections for car emissions in 2030 (DfT, 2021a), which is why it was used in the modelling. It equates to approximately 64% of 2021 emissions levels.

4.2 Committee on Climate Change

For this project the CCC provided the forecasted car emissions values from their 'Balanced Pathway' scenario. In the year 2030 they predict car emissions need to fall to around 34.6 $MtCO_2e$. Although this is not an officially set target from the CCC, for simplicity this figure is used as a target in the modelling. This figure is then converted to just CO_2, arriving at **34.3 MtCO2**. This is 94% of the UK Government pathway target, and equates to approximately 60% of 2021 emissions levels.

5 Results

This chapter goes through the results of each of the two targets detailed in Chapter 4. It considers only the carbon tailpipe emissions of cars, to match the approaches of the two organisations setting the targets (the well-to-wheel graphs and tables can be viewed in the appendix). Each section below starts off by stating the total CO_2 emissions for selected permutations in the model (grouping the thousands of individual model runs into percentiles for graphing, to make the results visually digestible), highlighting which scenarios were successful (i.e. with emissions under the target). As emissions depend on many factors, and as the main focus of this report is to look at total car parc mileage, another graph will then show the same outputs, but displaying the total mileage rather than emissions.

Three successful outputs will then be further analysed from this mileage graph: the 'Low' scenario is the one with the minimum total car parc mileage in 2030[9], the 'Mid' scenario will be the scenario with the median total car parc mileage in 2030, and the 'High' scenario is one with the maximum total car parc mileage in 2030. (Note that to distinguish these scenarios from the car registrations outlook ones introduced in Chapter 2 above, they are not in bold text but do start with a capital letter.)

5.1 Government (GOV)

Low GOV Scenario

The Low scenario represents the model runs using the minimum total car parc mileage in 2030. The Low scenario comprises these parameters:

- Departure rate year: DfT 16-17, which means cars leaving the parc at the fastest rate.
- New registration: SMMT low
- Sales-weighted CO_2 percentage change year on year: -6%
- BEV and PHEV mileage: petrol-like mileage
- PHEV economy handling: best, which means PHEVs are driven in the most efficient way.
- Annual individual car mileage adjustment year on year percentage: -5%

Mid GOV Scenario

The Mid scenario represents the situation with the median total car parc mileage in 2030. The Mid scenario comprises these parameters:

- Departure rate year: DfT 16-17 which means cars leaving the parc at the fastest rate.
- New registration: SMMT high private
- Sales-weighted CO_2 percentage change year on year: -6%
- BEV and PHEV mileage: diesel-like mileage
- PHEV economy handling: best which means PHEVs are driven in the most efficient way.
- Annual individual car mileage adjustment year on year percentage: -4%

High GOV Scenario

The High scenario represents the situation with the maximum total car parc mileage in 2030. The High scenario in the Government pathway (GOV) scenario comprises these parameters:

- Departure rate year: DfT 17-18 which means cars leaving the parc at a fast rate.
- New registration: CCC
- Sales-weighted CO_2 percentage change year on year: -6%
- BEV and PHEV mileage: diesel-like mileage
- PHEV economy handling: best which means PHEVs are driven in the most efficient way.
- Annual individual car mileage adjustment year on year percentage: 0%

This section goes through the modelling using the Government pathway target of **36.5 MtCO2 by 2030** and considering only tailpipe emissions.

There are 99 lines shown in Figure 5.1 Each line shows the modelled emissions trajectory for an integer percentile from the 1st percentile to the 99th percentile result from the overall 9,900 model runs. The lines with a greater CO_2 emissions total in 2030 are those at the higher end of the percentiles (closer to the 99th percentile) and, conversely, the lines with a lower CO_2 emissions total in 2030 are those at the lower end of the percentiles (closer to the 1st percentile). The green lines indicate the outcomes defined as successful, in other words those that result in total CO_2 emissions from cars coming under the respective target, whereas the grey lines indicate unsuccessful outcomes. It can be seen that the point where the target emissions level intersects the year 2030 line is used as the definition of the division between the two.

Of all the runs of the model, 4,992 outcomes are successful in terms of the Government pathway target, which equates to 50% of all outputs. It is important to note that in the following graphs, each line (or scenario) does not have an equal likelihood of being true, as this is not a probabilistic model (a model that produces odds on a particular outcome becoming true). A graph with the majority of lines being successful or unsuccessful does not mean that the odds are necessarily in favour of that outcome. All graphs show the range of the plausible outcomes, and no attempt to infer the likelihood of any specific outcome from these graphs should be attempted.

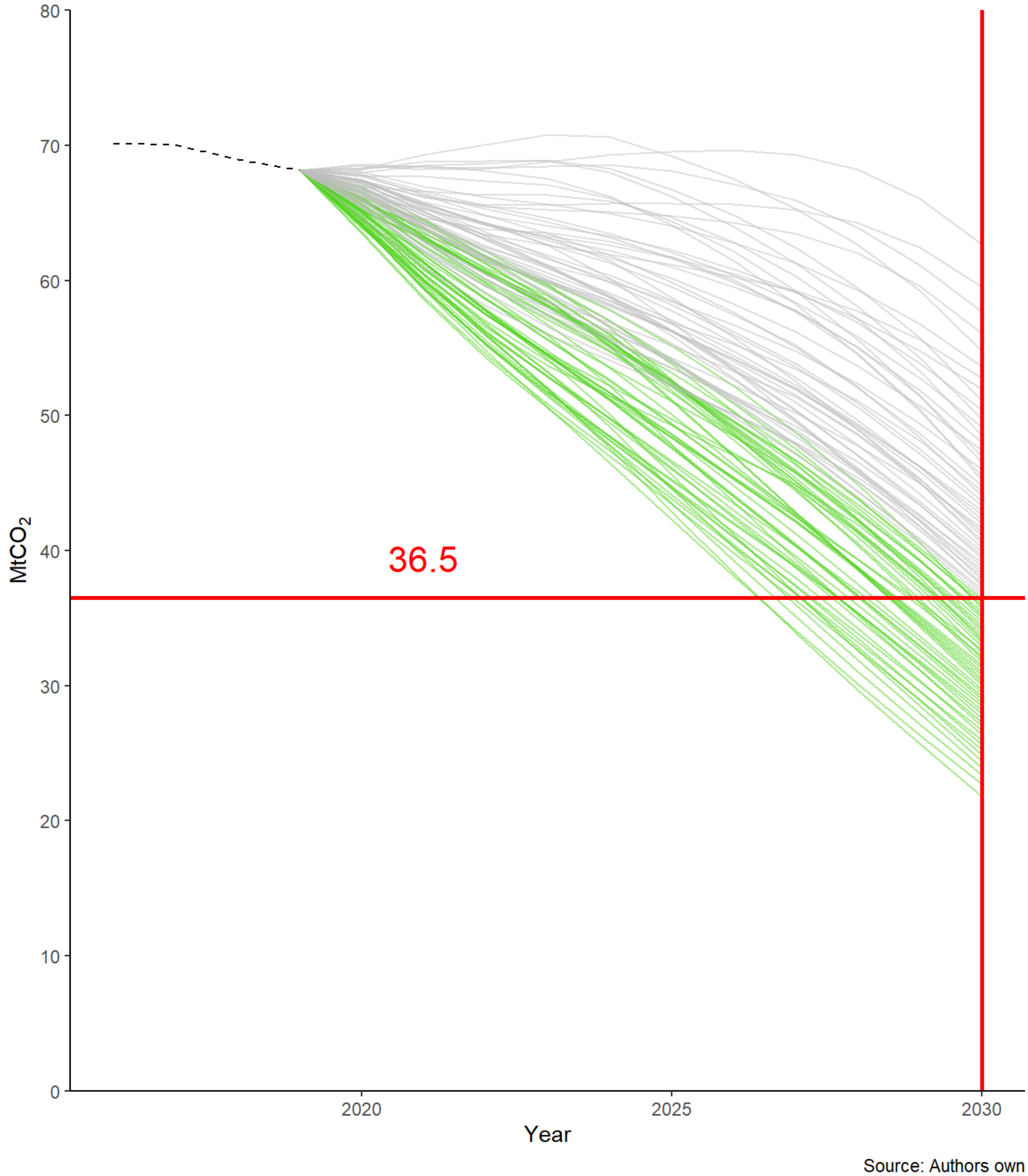


Figure 5.1: Total car tailpipe CO_2 emissions from all scenarios

Note: each line (or scenario) does not have an equal likelihood of becoming true 4,992 number of 9,900, scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

Figure 5.2 then shows the total car parc mileage for all the scenarios. Again, the lines in grey are outputs that are unsuccessful in reaching the target of 36.5 $MtCO_2$ by 2030 and the lines that are green are the successful outputs. In this graph, notice that the unsuccessful (red) lines, which are defined by where they appear at 2030 in the previous graph, are by no means all clustered together, indicating that highest clustered together, indicating that highest emissions are not necessarily associated with the highest total car mileage driven, and conversely that some of the acceptable emission scenarios actually involve relatively high total mileage figures.

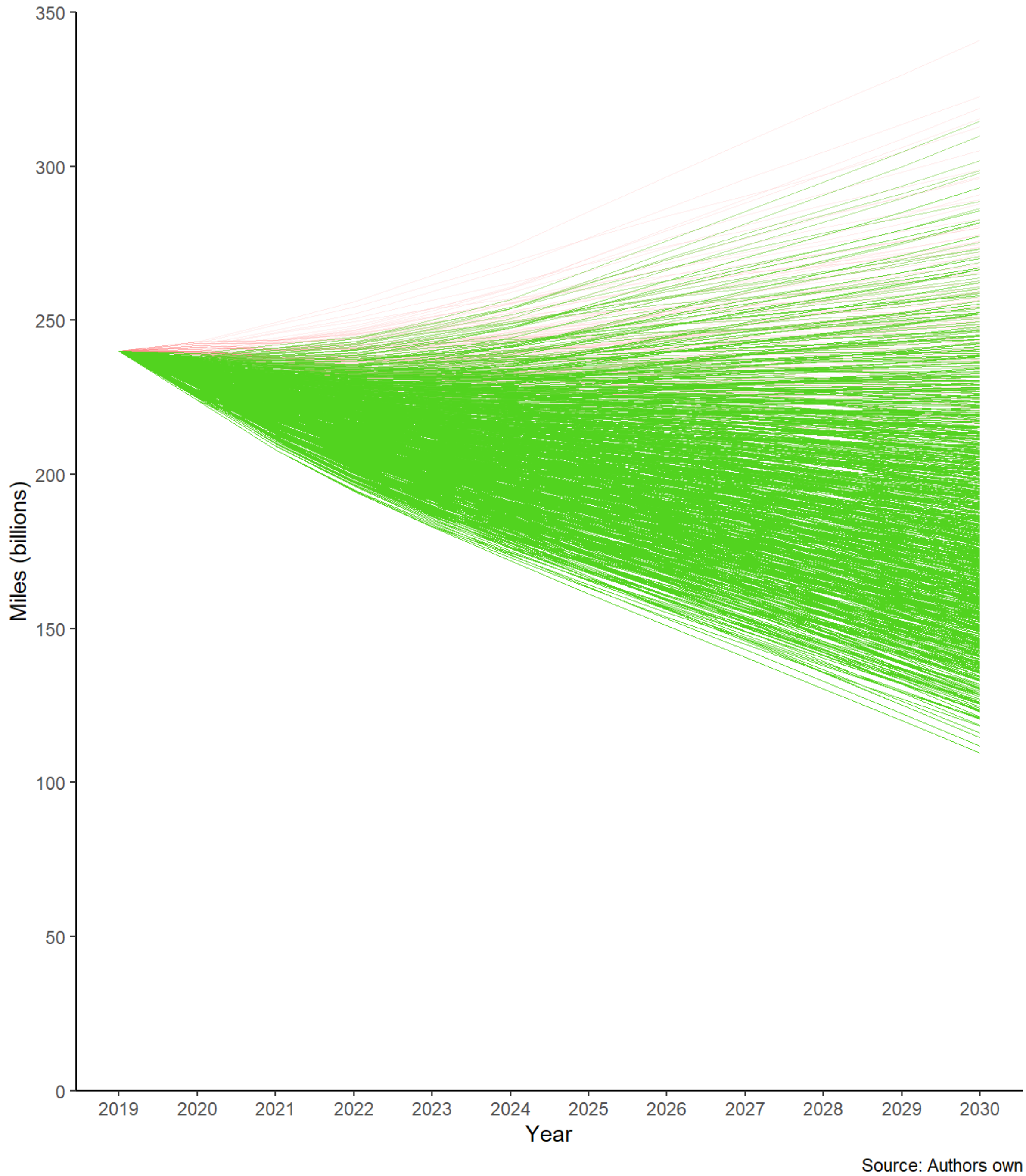


Figure 5.2: Total parc mileage from all scenarios in the model from cars only

Note: each line (or scenario) does not have an equal likelihood of becoming true 4,992 number of 9,900, scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

Figure 5.3 shows, for each of the three GOV scenarios, total tailpipe CO_2 emissions for each fuel type (as stacked bars) for the 16 years from 2020 to 2030.

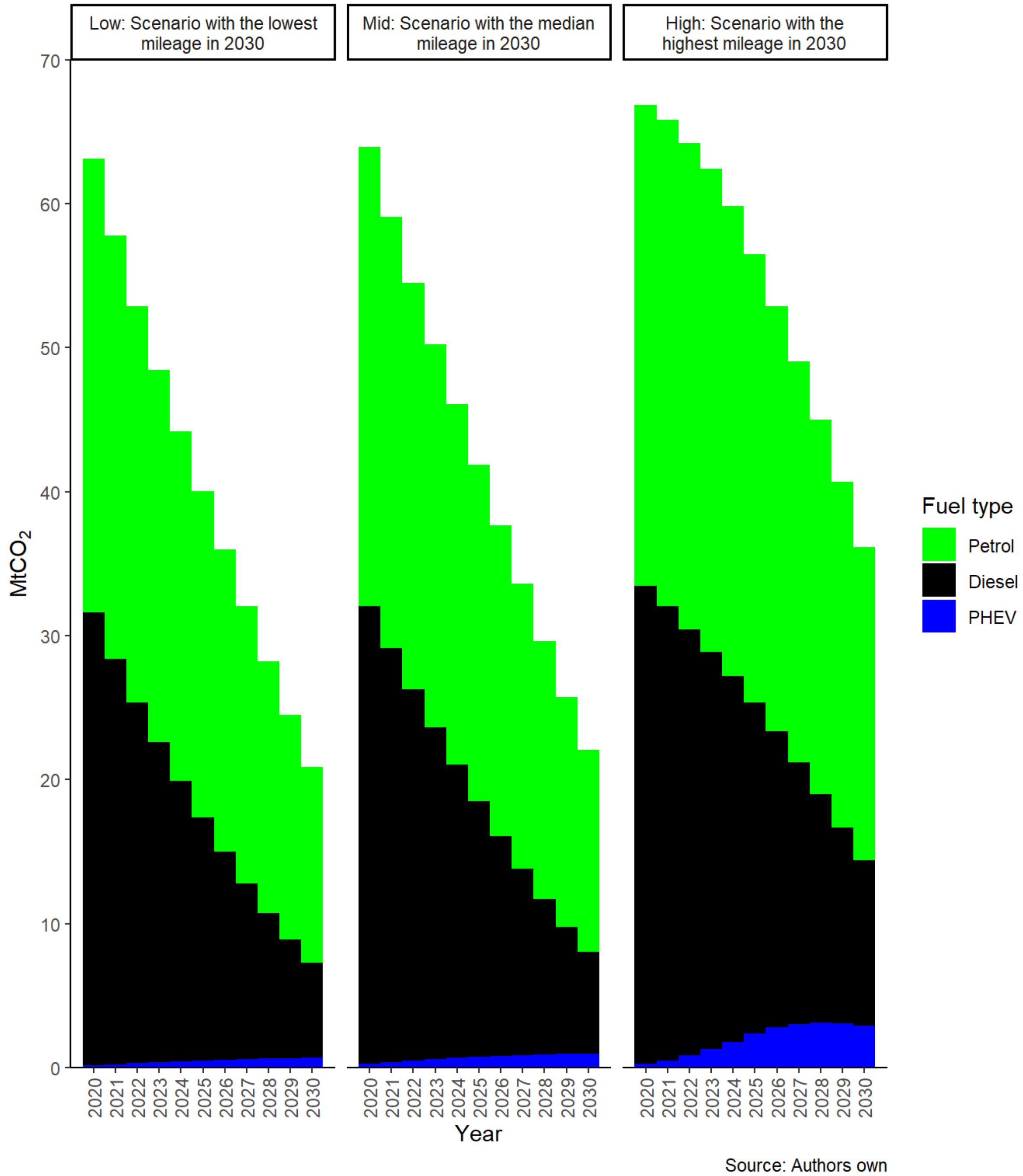


Figure 5.3: Total tailpipe CO_2 emissions split by scenario and fueltype

In the Low scenario, the total tailpipe CO_2 emissions from cars in 2020 stood at around 63 Mt. Of this total figure, petrol made up 49.98 %, diesel made up 49.77% and lastly PHEVs made up a barely discernible 0.25% (note that owing to rounding, some percentages throughout this chapter will appear not to sum to precisely 100%). By 2030, total tailpipe CO_2 emissions from cars in the Low scenario are forecast to fall by 66.95% to around 21 Mt, with petrol making up 65.24% of the total, diesel 31.53% and PHEVs 3.23%.

In the Mid scenario, the total tailpipe CO_2 emissions from cars in 2020 were around 64 Mt. Petrol made up 49.91% of the total, diesel made up 49.69% and lastly PHEVs made up 0.4%. By 2030, total tailpipe CO2 emissions from cars in the Mid scenario are forecast to fall by 65.5% to around 22 Mt, with petrol making up 63.51% of the total, diesel 32.12% and PHEVs 4.37%.

In the High scenario, the total tailpipe CO_2 emissions from cars in 2020 were around 67 Mt. Petrol made up 49.95% of the total, diesel was 49.64% and lastly PHEVs made up 0.4%. By 2030, total tailpipe CO2 emissions from cars in the High scenario are forecast to fall by 45.93% to around 36 Mt (still just managing to meet the Government pathway target), with petrol making up 60.21% of the total, diesel standing at 31.7% and PHEVs contributing 8.09%.

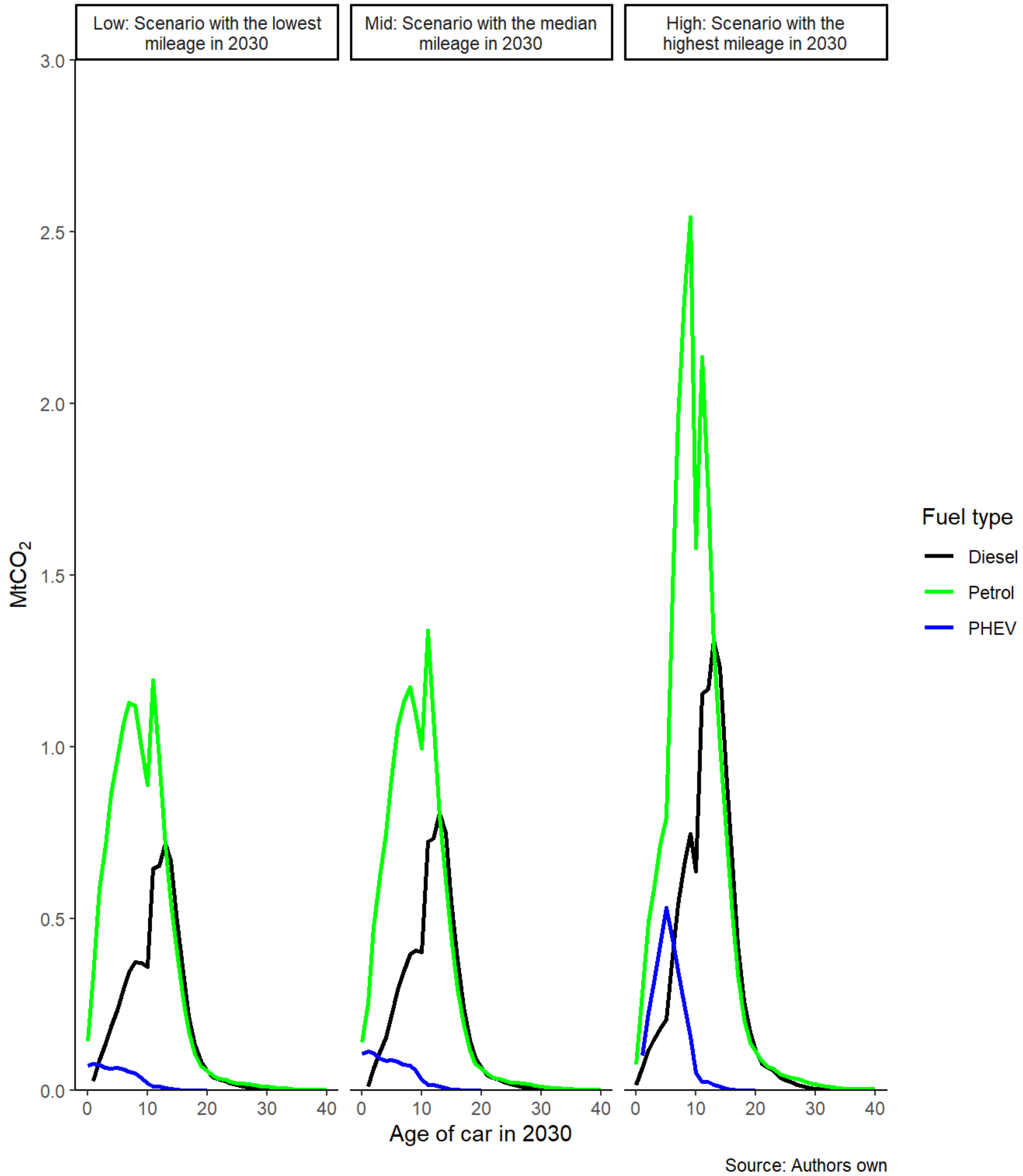


Figure 5.4: Total tailpipe CO_2 emissions split by scenario and age of car (up to 40 years old) in 2030

Carbon dioxide emissions can be split further by age, to indicate where (in terms of age of car) most of these emissions are coming from in 2030. Figure 5.4 shows tailpipe CO_2 emissions split by age and fuel type in the year 2030. Note that since this figure is graphing total emissions of every age of car for a given type rather than per-vehicle emissions, a lower value does not imply greater efficiency – the lower values for the older cars are due to the fact that there are, naturally, fewer of these in existence and/or the older ones are being driven less per year.

For the Low scenario, the model runs reveal that most tailpipe CO_2 emissions in 2030 will be from petrol cars aged 3-13 years old. They make up 50.83% of all tailpipe emissions. CO2 emissions peak for petrol cars aged 11 years old, as can be seen in the figure.

In the Mid scenario, most tailpipe CO_2 emissions are from petrol cars aged 4-13 years old in 2030. They make up 46.86% of all tailpipe emissions. CO2 emissions peak for petrol cars aged 11 years old.

And lastly *in the High scenario*, most tailpipe CO_2 emissions are from petrol cars aged 6-13 years old in 2030. They make up 41.48% of all tailpipe emissions. CO2 emissions peak for petrol cars aged 9 years old.

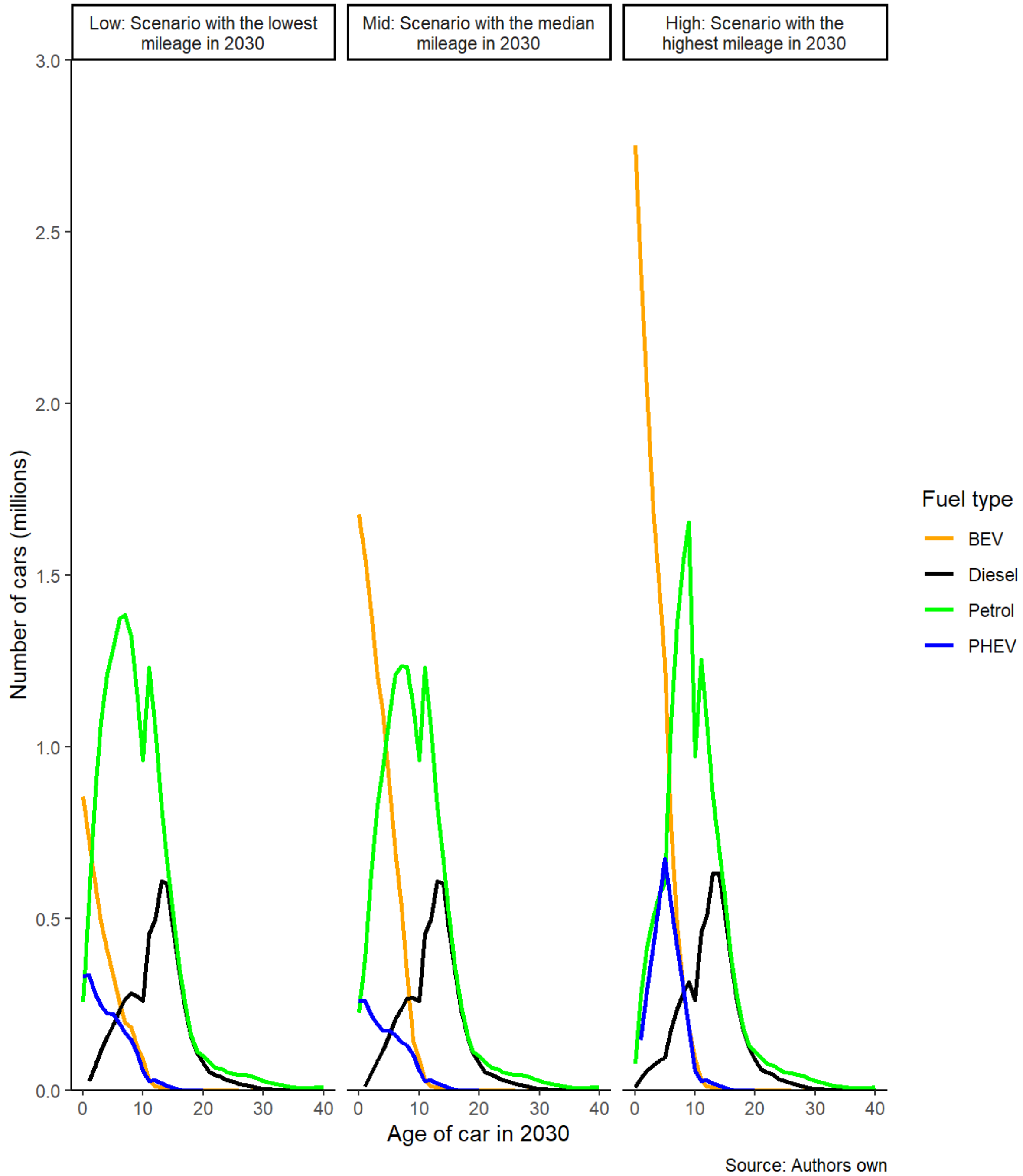


Figure 5.5: The number of cars in the parc by fuel type and age of car (up to 40 years old) in 2030

Figure 5.5 shows the numbers of each type of car (the three tailpipe-emitting fuel types shown in Figure 5.4, this time with the BEVs also) that are being driven in the year 2030, split by age of car, for all three scenarios. It has already been seen from Figure 5.4 that there are problematic amounts of CO_2 being emitted from petrol cars, typically about 3-13 years old by then (give or take a few years) in all scenarios, and Figure 5.5 reveals that the level of petrol emissions can remain high (see the High mileage scenario in particular) even when the number of petrol cars (and diesels and PHEVs) is far exceeded by the number of non-emitting electric vehicles. Moreover, the model reveals substantial mileages being covered annually by the aforementioned 3-13 year-old petrol cars *in the Low scenario* (the 2017 and 2027 cohort), which are numerous, still far from old, and in relatively good condition: around between 3,200-3,800 miles (the mileage interquartile range for this subpopulation of fairly new petrol cars).

In the Mid scenario, it is the 4-13 year old cars (the 2017 and 2026 cohort) driving between around 3,550-4,300 miles annually.

And lastly, *in the High scenario*, the 6-13 year old cars (the 2017 and 2024 cohort) driving around 5,600–6,500 miles a year – and this ‘rump’ of ICE cars is producing significant amounts of CO_2 a good while after production of their kind has ceased.

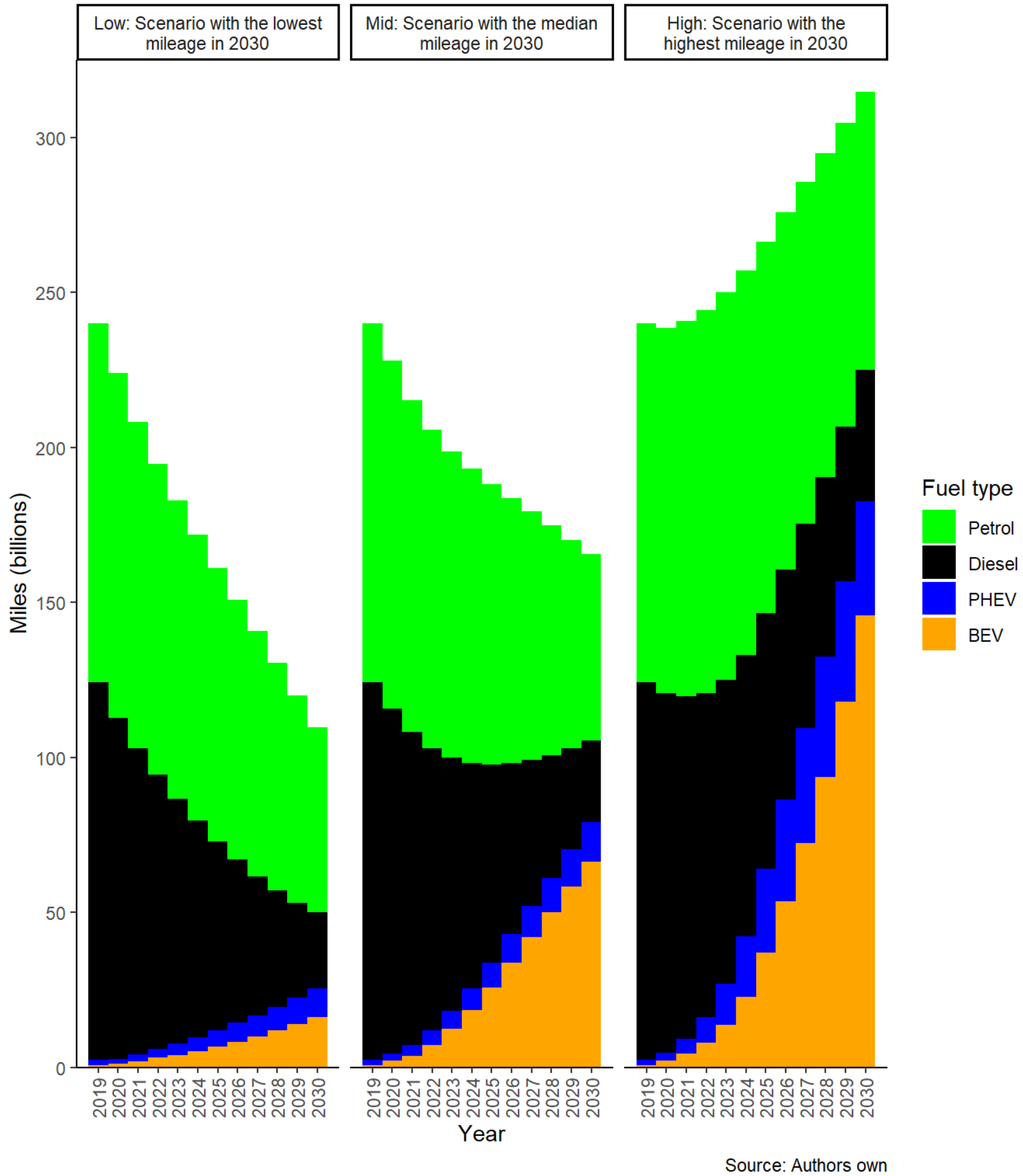


Figure 5.6: Total car parc mileage split by scenarios and fuel type

In 2019, the total car parc mileage of all cars was around 240 billion. Figure 5.6 shows how this mileage, broken down by car type, will develop between 2020 and 2030, for each scenario. We focus below on petrol cars as the chief emitters and on BEVs to chart their gradual takeover of the total national mileage, but it is interesting to note in passing that in contrast to the steadily decreasing total mileage driven by petrol and diesel cars, PHEV mileage is still holding up quite well in the year 2030, at values not markedly different to the distances they have been driving for several years by then.

By 2030 in the Low scenario, total car parc mileage will decrease to around 110 billion miles, with petrol cars making up 54.3% of the total mileage and BEV cars making up 14.92%.

In the Mid scenario, total car parc mileage driven by cars will decrease to around 166 billion miles by 2030. Of this total, petrol makes up 36.23% of the total mileage and BEV cars 40.07%.

Lastly, in the High scenario, by 2030, total car parc mileage will increase to around 315 billion miles, and we see a switch in the dominance of petrol vs electric by comparison with the other scenarios, with petrol making up 28.5% of the total mileage and BEV cars making up 46.34%.

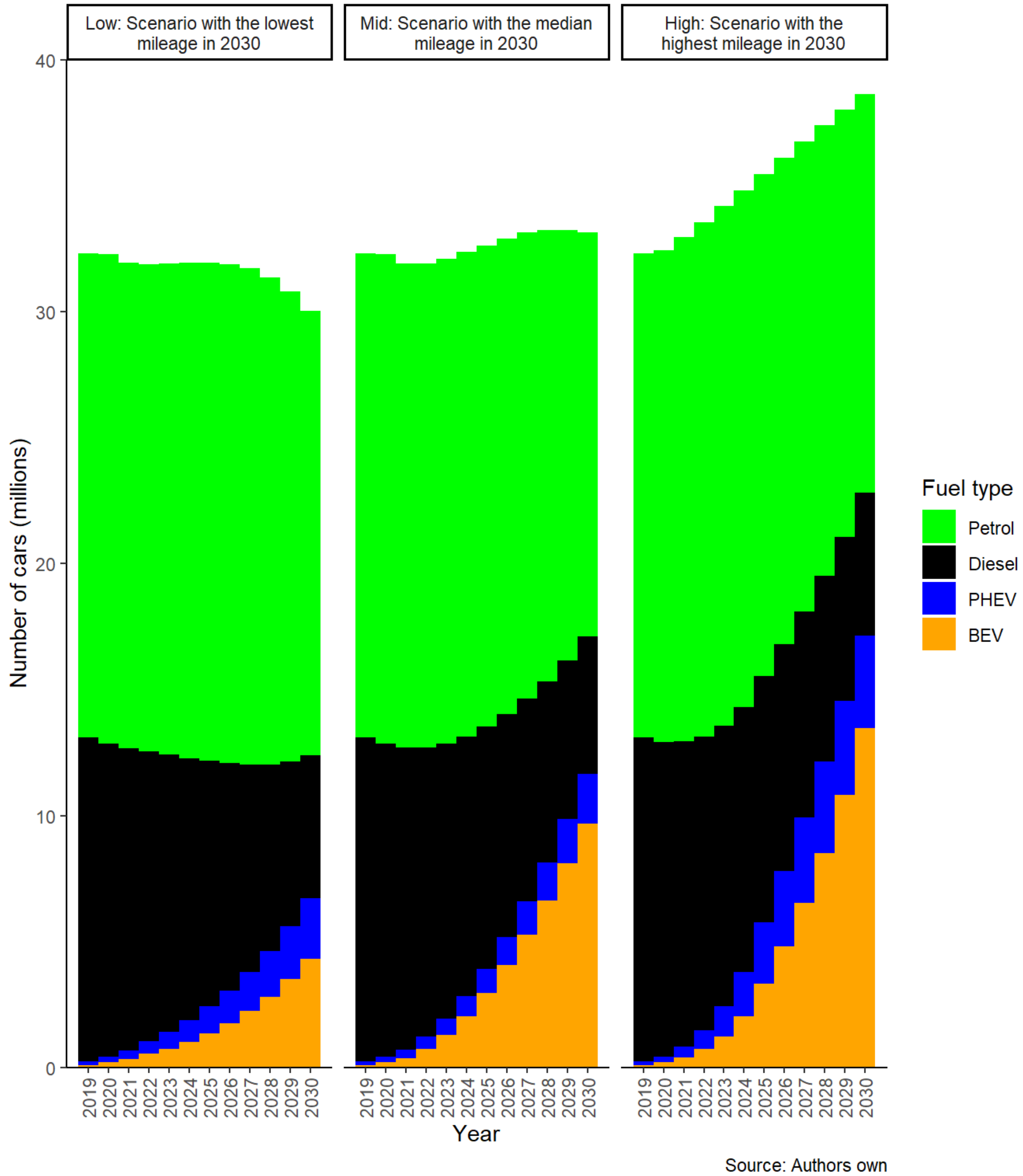


Figure 5.7: Total number of cars in the parc split by scenario and fuel type

In 2019 the total car parc stood at around 32 million. The final graphical analysis, shown in Figure 5.7, charts the progress of the mileage driven by each type of car between 2020 and 2030. By 2030, the total car parc in the Low scenario will decrease by 7.1% to around 30 million. In the Mid scenario, by 2030, the total car parc will increase by 2.56% to around 33 million. Lastly, in the High scenario, there will be an increase of 19.51% to around 39 million by 2030.

5.2 Committee on Climate Change (CCC)

Low CCC Scenario

The Low scenario represents the model runs using the minimum total car parc mileage in 2030. The Low scenario comprises these parameters:

- Departure rate year: DfT 16-17, which means cars leaving the parc at the fastest rate.
- New registration: SMMT low
- Sales-weighted CO_2 percentage change year on year: -6%
- BEV and PHEV mileage: petrol-like mileage
- PHEV economy handling: best, which means PHEVs are driven in the most efficient way.
- Annual individual car mileage adjustment year on year percentage: -5%

Mid CCC Scenario

The Mid scenario represents the situation with the median total car parc mileage in 2030. The Mid scenario comprises these parameters:

- Departure rate year: DfT 19-20 which means cars leaving the parc at a slow rate.
- New registration: SMMT high
- Sales-weighted CO_2 percentage change year on year: -3%
- BEV and PHEV mileage: petrol-like mileage
- PHEV economy handling: worst which means PHEVs are driven in the least efficient way.
- Annual individual car mileage adjustment year on year percentage: -3%

High CCC Scenario

The High scenario represents the situation with the maximum total car parc mileage in 2030. The High scenario in the CCC pathway (CCC) scenario comprises these parameters:

- Departure rate year: DfT 17-18 which means cars leaving the parc at a fast rate.
- New registration: CCC
- Sales-weighted CO_2 percentage change year on year: -6%
- BEV and PHEV mileage: diesel-like mileage
- PHEV economy handling: best which means PHEVs are driven in the most efficient way.

- Annual individual car mileage adjustment year on year percentage: -0.5%

This section goes through the modelling using the CCC pathway target of **34.3 MtCO2 by 2030** and considering only tailpipe emissions.

There are 99 lines shown in Figure 5.8. Each line shows the modelled emissions trajectory for an integer percentile from the 1st percentile to the 99th percentile result from the overall 9,900 model runs. The lines with a greater CO_2 emissions total in 2030 are those at the higher end of the percentiles (closer to the 99th percentile) and, conversely, the lines with a lower CO_2 emissions total in 2030 are those at the lower end of the percentiles (closer to the 1st percentile). The green lines indicate the successful outcomes, in other words those that result in total CO_2 emissions from cars coming under the respective target, whereas the grey lines indicate unsuccessful outcomes. (Aside from the positioning of the target line, and consequently the colouring of the lines to indicate success or failure to reach the target, this figure is the same as the equivalent GOV graph.)

Of all the runs of the model, 4,062 outcomes are successful in terms of the CCC pathway target, which equates to 41% of all outputs. As with the previously analysed runs of the model, it is important to note once again that in the following graphs, each line (or scenario) does not have an equal likelihood of being true, as this is not a *probabilistic* model (a model that produces odds on a particular outcome becoming true). A graph with the majority of lines being successful or unsuccessful does not mean that the odds are necessarily in favour of that outcome. All graphs show the range of the plausible outcomes, and no attempt to infer the likelihood of any specific outcome from these graphs should be attempted.

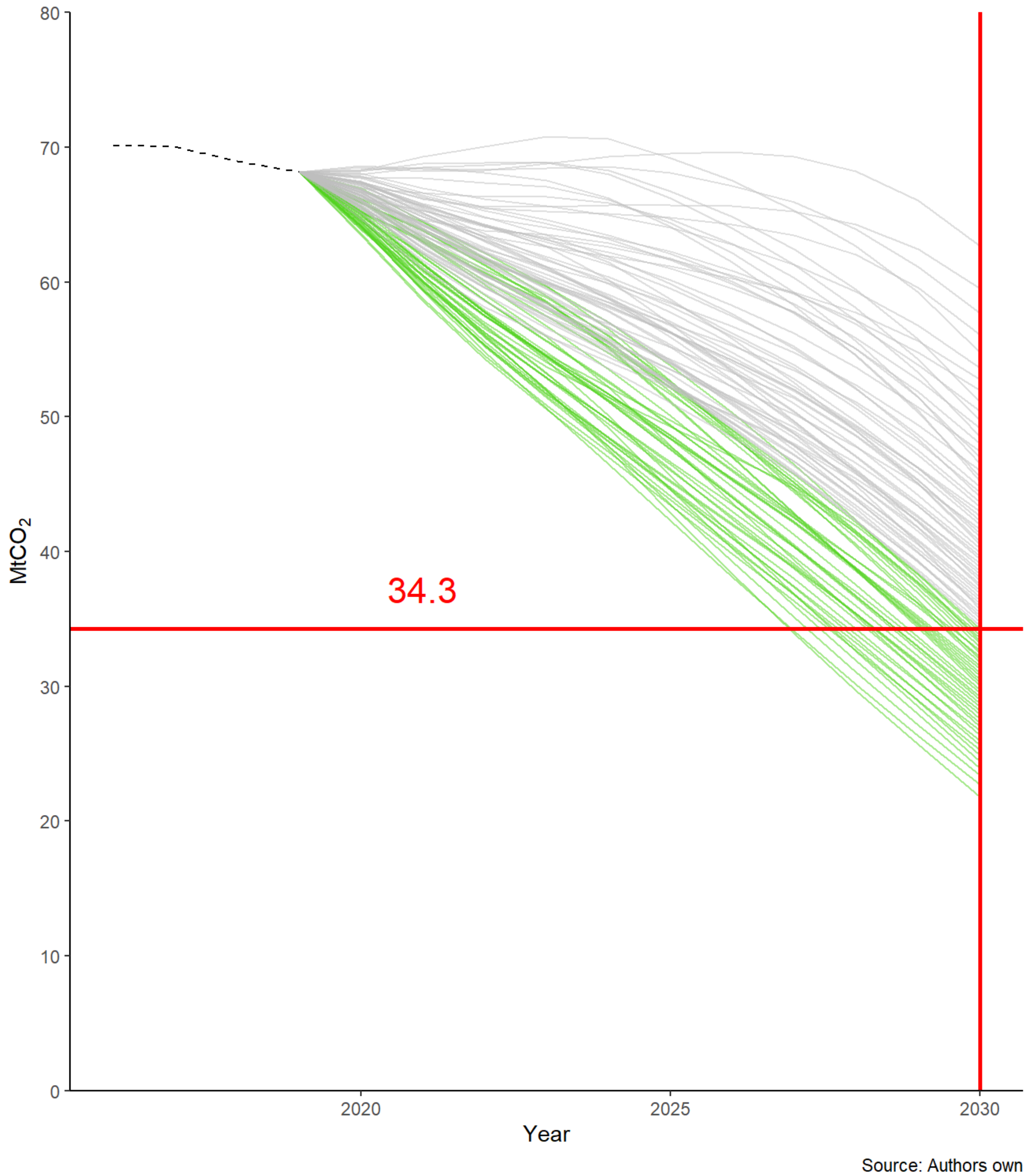


Figure 5.8: Total car tailpipe CO_2 emissions from all scenarios

Note: each line (or scenario) does not have an equal likelihood of becoming true 4,062 number of 9,900, scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

Figure 5.9 then shows the total car parc mileage for all the scenarios. Again, the lines in grey are outputs that are unsuccessful in reaching the target of 34.3 $MtCO_2$ by 2030 and the lines that are green are the successful outputs. In this graph, notice that the unsuccessful (red) lines, which are defined by where they appear at 2030 in the previous graph, are by no means all clustered together, indicating that highest clustered together, indicating that highest emissions are not necessarily associated with the highest total car mileage driven, and conversely that some of the acceptable emission scenarios actually involve relatively high total mileage figures.

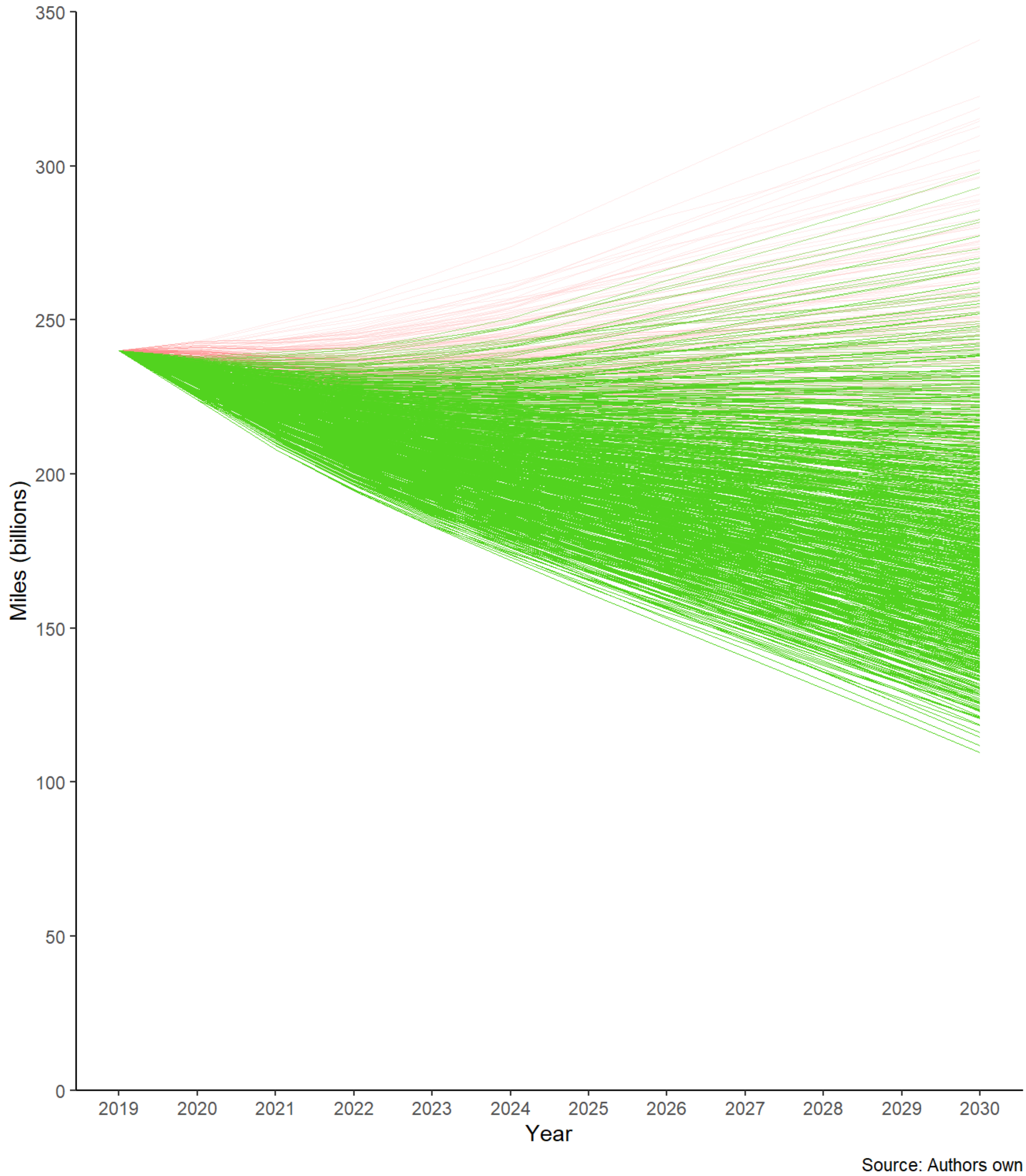


Figure 5.9: Total parc mileage from all scenarios in the model from cars only

Note: each line (or scenario) does not have an equal likelihood of becoming true 4,062 number of 9,900, scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

Figure 5.10 shows, for each of the three CCC scenarios, total tailpipe CO_2 emissions for each fuel type (as stacked bars) for the 16 years from 2020 to 2030.

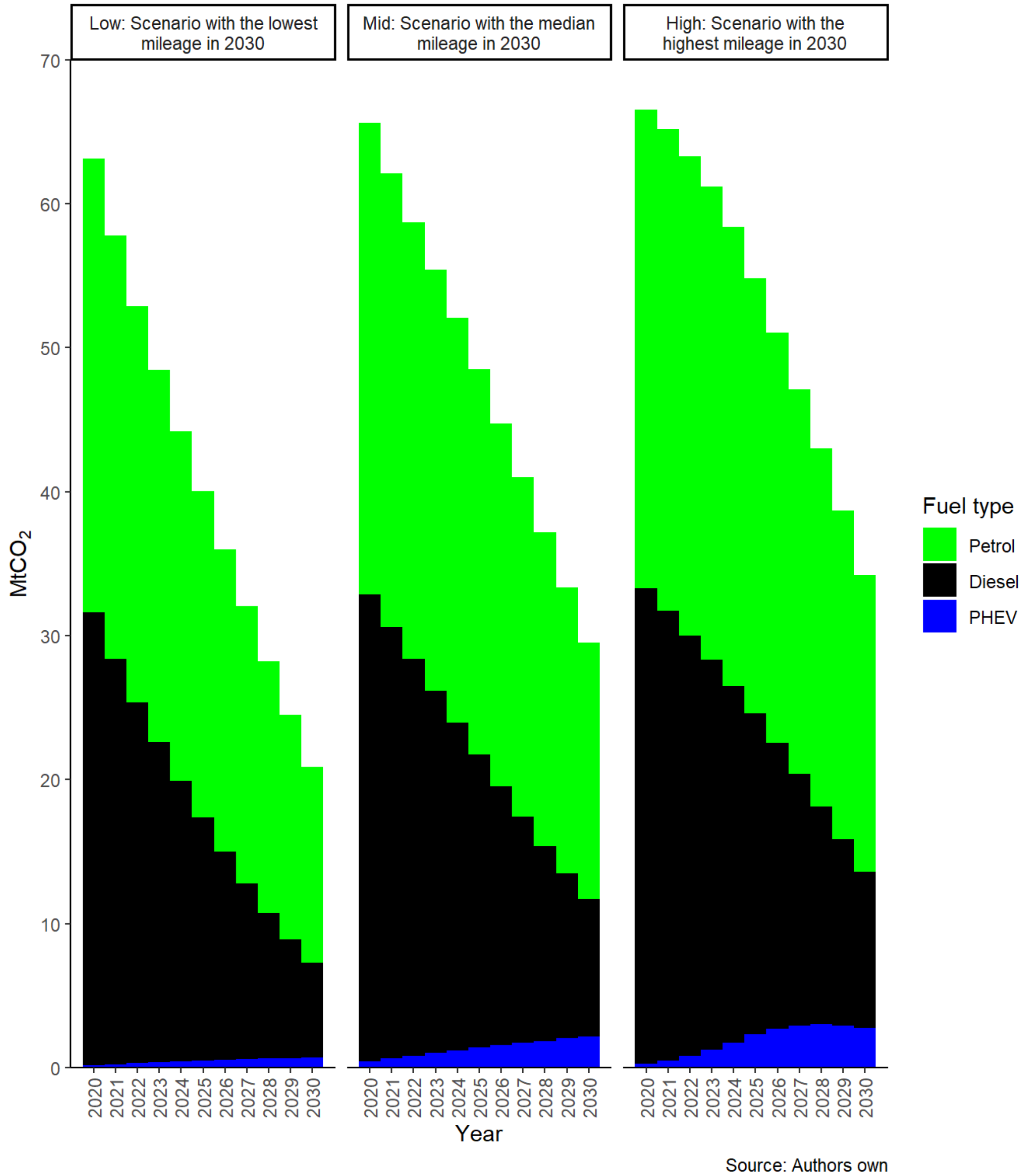


Figure 5.10: Total tailpipe CO_2 emissions split by scenario and fuel type

In the Low scenario, the total tailpipe CO_2 emissions from cars in 2020 stood at around 63 Mt. Of this total figure, petrol made up 49.98%, diesel made up 49.77% and lastly PHEVs made up a barely discernible 0.25% (note that owing to rounding, some percentages throughout this chapter will appear not to sum to precisely 100%). By 2030, total tailpipe CO_2 emissions from cars in the Low scenario are forecast to fall by 66.95% to around 21 Mt, with petrol making up 65.24% of the total, diesel 31.53% and PHEVs 3.23%.

In the Mid scenario, the total tailpipe CO_2 emissions from cars in 2020 were around 66 Mt. Petrol made up 49.92% of the total, diesel made up 49.41% and lastly PHEVs made up 0.67%. By 2030, total tailpipe CO_2 emissions from cars in the Mid scenario are forecast to fall by 55.01% to around 30 Mt, with petrol making up 60.33% of the total, diesel 32.34% and PHEVs 7.33%.

In the High scenario, the total tailpipe CO_2 emissions from cars in 2020 were around 67 Mt. Petrol made up 49.95% of the total, diesel was 49.64% and lastly PHEVs made up 0.4%. By 2030, total tailpipe CO2 emissions from cars in the High scenario are forecast to fall by 48.57% to around 34 Mt (still just managing to meet the CCC pathway target), with petrol making up 60.21% of the total, diesel standing at 31.7% and PHEVs contributing 8.09%.

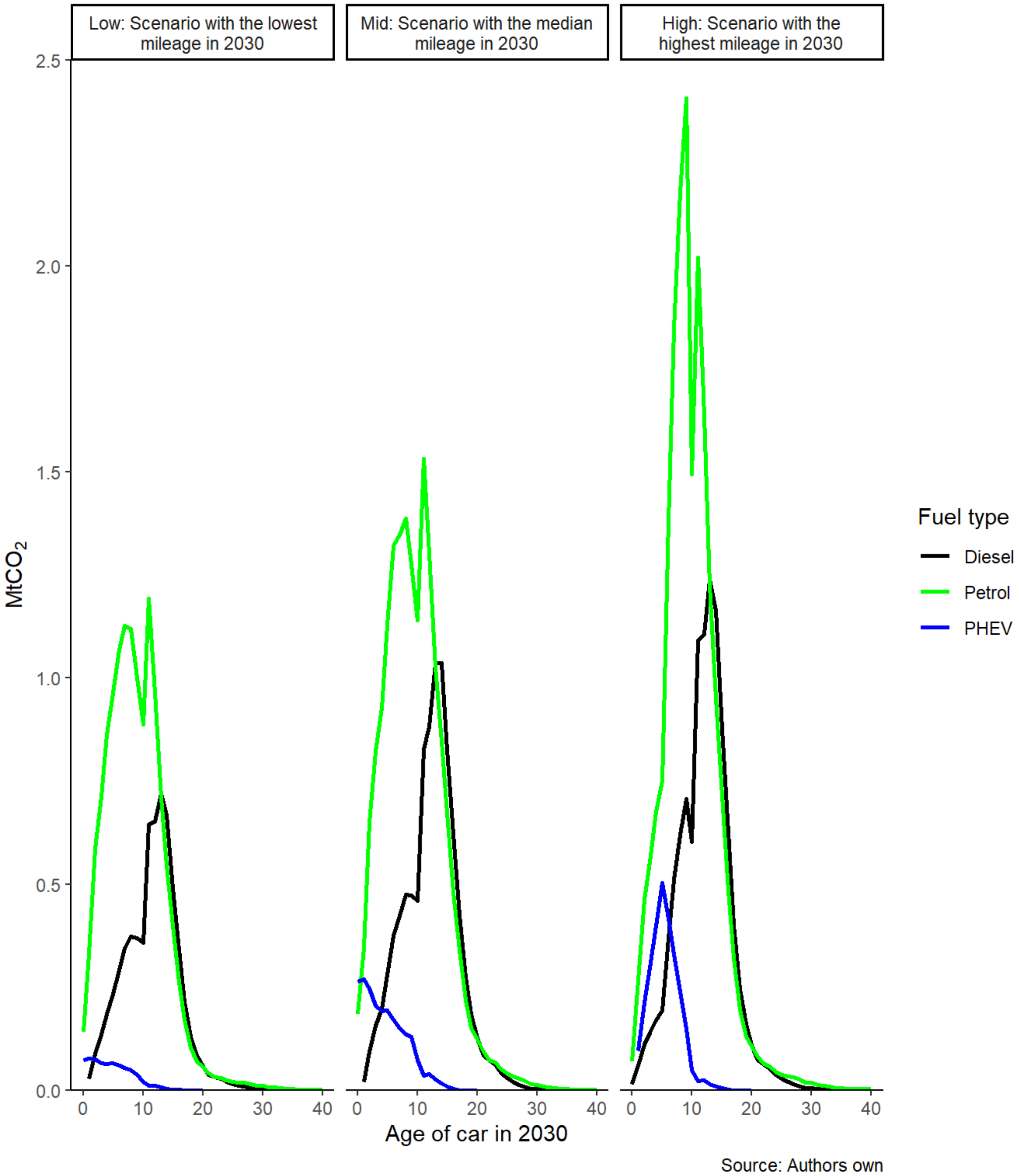


Figure 5.11: Total tailpipe CO_2 emissions split by scenario and age of car (up to 40 years old) in 2030

Carbon dioxide emissions can be split further by age, to indicate where (in terms of age of car) most of these emissions are coming from in 2030. Figure 5.11 shows tailpipe CO_2 emissions split by age and fuel type in the year 2030. Note that since this figure is graphing total emissions of every age of car for a given type rather than per-vehicle emissions, a lower value does not imply greater efficiency – the lower values for the older cars are due to the fact that there are, naturally, fewer of these in existence and/or the older ones are being driven less per year.

For the Low scenario, the model runs reveal that most tailpipe CO_2 emissions in 2030 will be from petrol cars aged 3-13 years old. They make up 50.83% of all tailpipe emissions. CO2 emissions peak for petrol cars aged 11 years old, as can be seen in the figure.

In the Mid scenario, most tailpipe CO2 emissions are from petrol cars aged 3-14 years old in 2030. They make up 47.62% of all tailpipe emissions. CO_2 emissions peak for petrol cars aged 11 years old.

And lastly *in the High scenario*, most tailpipe CO_2 emissions are from petrol cars aged 6-13 years old in 2030. They make up 41.48% of all tailpipe emissions. CO2 emissions peak for petrol cars aged 9 years old.

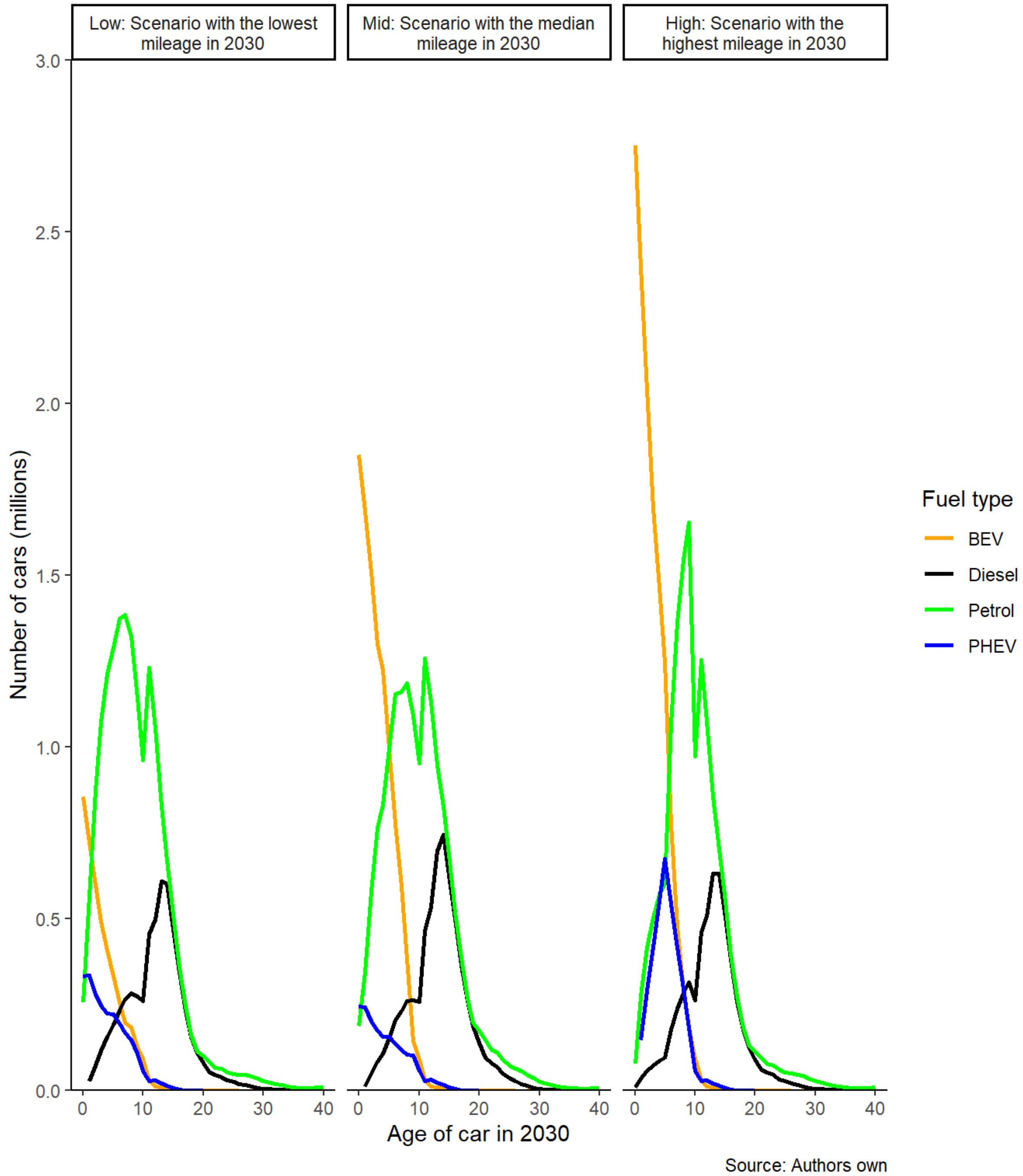


Figure 5.12: The number of cars in the parc by fuel type and age of car (up to 40 years old) in 2030

Figure 5.12 shows the numbers of each type of car (the three tailpipe-emitting fuel types shown in Figure 5.11, this time with the BEVs also) that are being driven in the year 2030, split by age of car, for all three scenarios. It has already been seen from Figure 5.11 that there are problematic amounts of CO_2 being emitted from petrol cars, typically about 3-14 years old by then (give or take a few years) in all scenarios, and Figure 5.12 reveals that the level of petrol emissions can remain high (see the High mileage scenario in particular) even when the number of petrol cars (and diesels and PHEVs) is far exceeded by the number of non-emitting electric vehicles. Moreover, the model reveals substantial mileages being covered annually by the aforementioned 3-13 year-old petrol cars *in the Low scenario* (the 2017 and 2027 cohort), which are numerous, still far from old, and in relatively good condition: 3,200-3,800 miles (the mileage interquartile range for this subpopulation of fairly new petrol cars).

In the Mid scenario, it is the 3-14 year old cars (the 2016 and 2027 cohort) driving between around 3,800-4,800 miles annually.

And lastly, *in the High scenario*, the 6-13 year old cars (the 2017 and 2024 cohort) driving around 5,300–6,150 miles a year – and this 'rump' of ICE cars is producing significant amounts of CO_2 a good while after production of their kind has ceased.

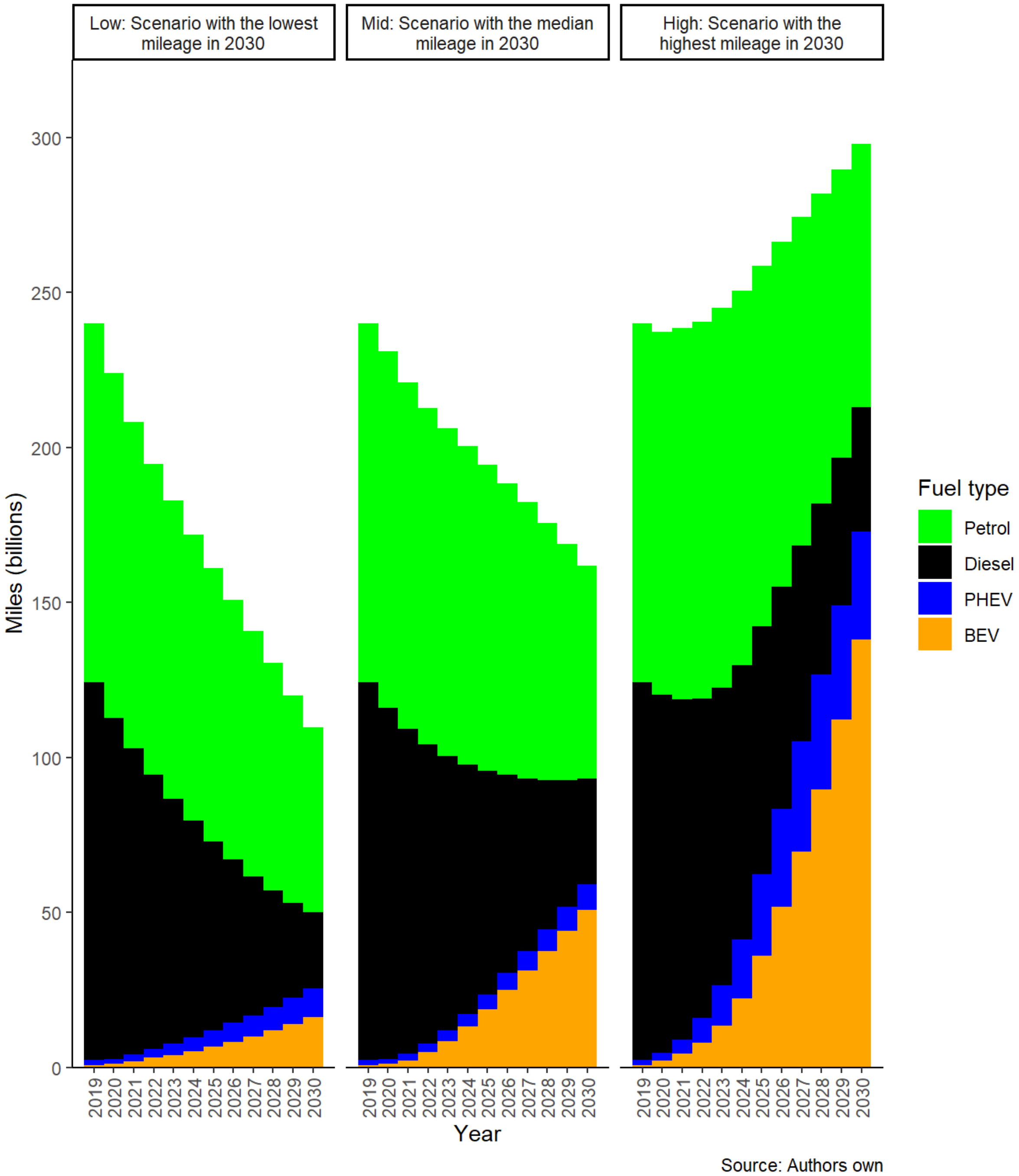


Figure 5.13: Total car parc mileage split by scenarios and fuel type

In 2019, the total car parc mileage of all cars was around 240 billion. Figure 5.13 shows how this mileage, broken down by car type, will develop between 2020 and 2030, for each scenario. We focus below on petrol cars as the chief emitters and on BEVs to chart their gradual takeover of the total national mileage, but it is interesting to note in passing that in contrast to the steadily decreasing total mileage driven by petrol and diesel cars, PHEV mileage is still holding up quite well in the year 2030, at values not markedly different to the distances they have been driving for several years by then.

By 2030 in the Low scenario, total car parc mileage will decrease to around 110 billion miles, with petrol cars making up 54.3% of the total mileage and BEV cars making up 14.92%.

In the Mid scenario, total car parc mileage driven by cars will decrease to around 162 billion miles by 2030. Of this total, petrol makes up 42.48% of the total mileage and BEV cars 31.36%.

Lastly, in the High scenario, by 2030, total car parc mileage will increase to around 298 billion miles, and we see a switch in the dominance of petrol vs electric by comparison with the other scenarios, with petrol making up 28.5% of the total mileage and BEV cars making up 46.34%.

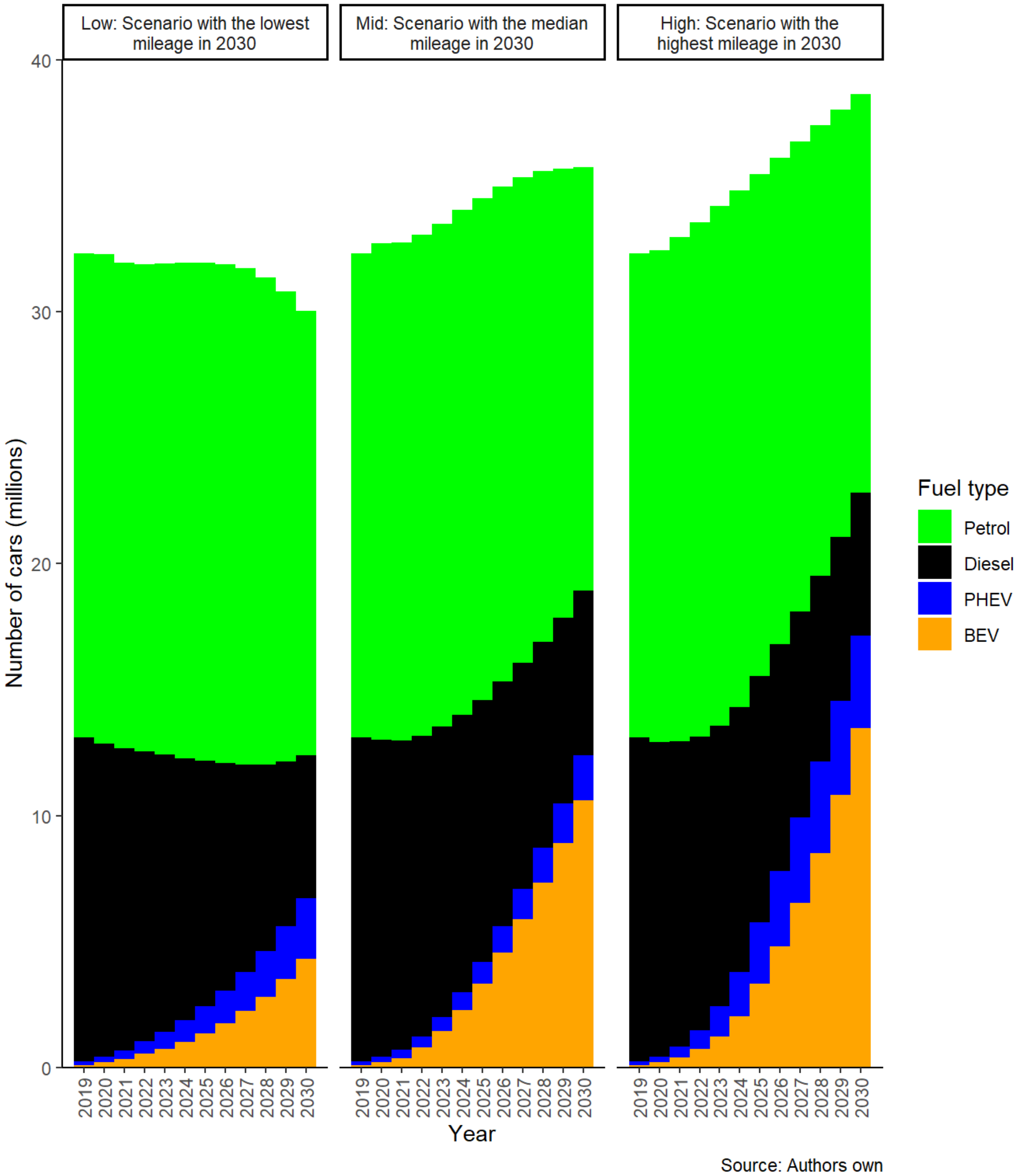


Figure 5.14: Total number of cars in the parc split by scenario and fuel type

In 2019 the total car parc stood at around 32 million. The final graphical analysis, shown in Figure 5.14, charts the progress of the mileage driven by each type of car between 2020 and 2030. By 2030, the total car parc in the Low scenario will decrease by 7.1% to around 30 million. In the Mid scenario, by 2030, the total car parc will increase by 2.56% to around 33 million. Lastly, in the High scenario, there will be an increase of 19.51% to around 39 million by 2030.

6 Parameter analysis

This section provides an insight into the specific parameters used in the model. The model output presents many possible futures. By analysing each parameter separately whilst controlling for other parameters, it can be identified in which areas and in what ways policy levers might be applied to help in reducing carbon emissions, as well as the way in which those different means of applying pressure have particular effects, whether singly or in combination with others.

A total of 14 parameters were used in the model. Seven of them were kept constant (i.e. only ever having one value), whilst the other seven varied across a range of values (note that the tailpipe-only analysis had a total of 10 parameters, 6 were varied and 4 were constant as it did not include the carbon intensity from electric usage and the additional uplift to ICE emissions).

Parameters kept constant throughout the model:

- Fuel economy ‘deflation’ factor for petrol and diesel cars (to account for differences between Germany and the UK in typical fuel efficiencies achieved): kept at 1.01 in the model (meaning an increase in emissions, a decrease in economy)
- PHEV gCO_2/km emissions factor for the *worst* case: kept at 1.1, setting the PHEV fuel economy (as always, for cars) as 110% of petrol fuel economy
- Real-world PHEV utility factor: kept at 37%
- Petrol inflator: kept at 1.28
- Diesel inflator: kept at 1.24
- gCO_2/km adjustment for cars registered before 2001: kept at the equivalent of 20 miles per gallon
- Average mileages of cars older than 40 years old: kept at 1,000 miles in the model

Parameters with a range of values to choose from in the model

- Departure rates:
    - 2016 to 17 - fastest departure rate
    - 2017 to 18 - fast departure rate
    - 2018 to 19 - slow departure rate
    - 2019 to 20 - slower departure rate
    - 2020 to 21 - slowest departure rate.

- car registration (i.e. new cars sold; these correspond to the scenarios introduced in subsection 2.3.4 and shown in bold in the text):
  - SMMT low: slow BEV uptake
  - SMMT central: medium-level BEV uptake – SMMT high: accelerated BEV uptake – SMMT high private: accelerated BEV uptake (with incentives applying to private cars only)
  - CCC: increased number of total number of cars sold and a fast uptake of BEV
  - ZEV mandate: similar to SMMT central scenario
- Percentage change year-on-year to fuel economy of sales-weighted new car gCO_2/km figures for petrol/diesel/PHEV cars only:
  - between −6% and +6% in increments of 3%.
- The average mileage of BEVs/PHEVs (the mileage style parameter):
  - like petrol cars: a more realistic average mileage – like diesel cars: assuming that these will drive at the higher end of normal because they are cheaper and more efficient
  - 10% more than diesel cars
- individual annual mileage adjustment year-on-year: −0% to −5% in increments of 0.5%
- BEV/PHEV carbon per mile (their carbon intensity) for electric mode (these correspond to the carbon-intensity possibilities introduced in subsection 2.3.9):
  - Highest carbon per mile: combines high carbon intensity rates with the least efficient electric car: 3.4 miles/kWh
  - Middle carbon per mile: combines the middle carbon intensity rate with the average efficiency of an electric car: 3.75 miles/kWh
  - Lowest carbon per mile: combines the low carbon intensity rates with the most efficient electric car: 4.1 miles/kWh
- PHEV gCO_2/km emissions factor:
  - Best: PHEV fuel economy is the real-world fuel economy estimate which is where the laboratory test result (either WLTP or NEDC, whichever was available) was adjusted using Spritmonitor.de deflators
  - Worst: set to 110% of petrol emission for cars in that same year of first registration

The year 2030 was focused on in this analysis as this is the chosen target year from the previous chapter.

For each parameter that is examined, scenarios (runs of the model for particular values of that parameter) are grouped based on all *other* parameter values being held constant. Each group is then plotted for various values of that chosen parameter to form charts known in statistical data presentation as 'violin plots', which require some explanation.

The y-axis shows the total amount of CO_2 emissions resulting from each scenario in 2030. The x-axis shows the different values of the chosen parameter, whether they be numeric or categorical variables.

The x-axis shows how the CO_2 output in 2030 alters as the parameter value under examination is varied. The y-axis marks the total CO_2 output in 2030 for each group of outputs. The green area mark successful outcomes (i.e. ones in which emissions come in under the target); the grey area represent unsuccessful ones. Of course the boundary between the two colours will always be fixed at the target level of CO_2 emissions, for all values of the parameter in all charts, showing as a horizontal line.

Each chart, is thus a colour-enhanced version of a violin plot and has a number of features:

1. Results are plotted in groups along the x-axis – each discrete group corresponding to one possible value of the parameter that is being altered (all other parameter values being kept constant).

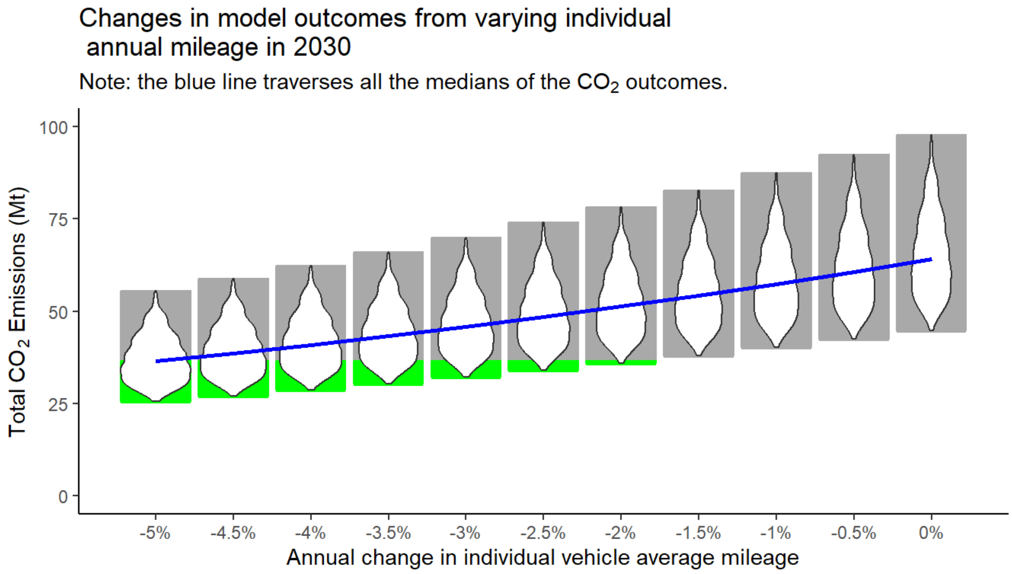
2. The vertical extent (the top and bottom edge values on the y-axis) of the green and grey parts of the plot indicate the range of model outcomes that are either successful or unsuccessful respectively in meeting the chosen target value (in this case the 2030 Government pathway target of 36.5 $MtCO_2$), with the top and bottom of the bars indicating maximum and minimum CO_2 values of the success/failure model outcomes. Where the entire range of the bar (green and grey taken together) becomes smaller (less tall) for certain values of the chosen parameter (i.e. scenarios), this indicates that these scenarios lead to more consistent CO_2 outcomes; where the range is greater, on the other hand, the CO_2 outcomes are seen to be more diverse. Naturally, the same conclusions about how diverse the CO_2 outcomes are can be drawn about either the successful (green) outcomes and the unsuccessful (grey) outcomes considered separately, based on their vertical extent.

3. The shape of the white 'violins' within the bars show the distribution of all model outcomes in terms of CO_2 emissions: the wider the violin is, the more the outcomes there are corresponding to that level of CO_2: the widest part, then, shows the most frequent CO_2 value (bearing in mind always that these outcome do not have equal chances of becoming true, as explained in Chapter 5). Moreover, because the shape of each violin reveals the distribution pattern within the large results set,

the proportion of the total area of the violin that is in the 'green zone' and in the 'grey zone' tells us the proportion of outcomes that are successful or unsuccessful respectively.

4. The blue line superimposed across all the violin plots in any one chart connects the median CO_2 values of each modelled group. In the figures that show variation of numerical parameters (e.g. percentage changes in sales-weighted emissions), the line represents an obvious continuum. In plots showing categorical parameters (e.g. departure rate scenarios), the groups have been ordered along the x-axis to help make this line most intelligible. In either case, the gradient of the line gives an indication of the extent to which the parameter in question has an effect on modelled CO_2 outcomes (the steeper the line, the more influential the parameter on emissions).

Here are two examples of how to interpret the graphs, lifted from the actual results that form the remainder of this chapter:

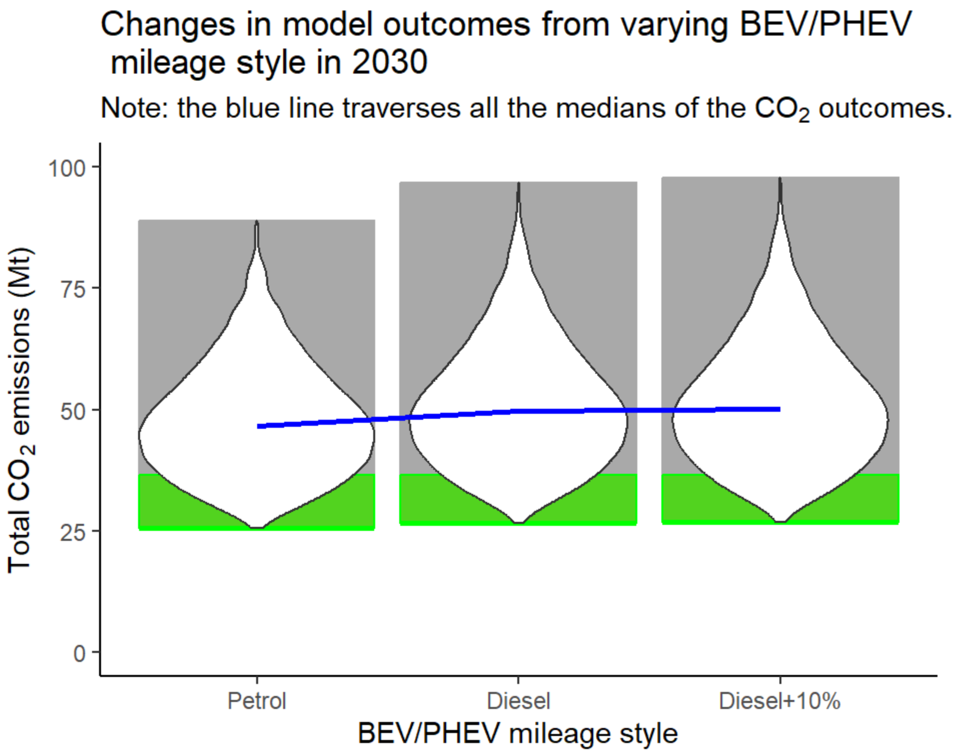


1. Gradient: the gradient of the line in this graph is both consistent and reasonably steep. This indicates that the changing the parameter has a clear impact on the modelled CO_2 outcomes.

2. Vertical compactness: the range of the bars is much tighter to the lower end of the x-axis. This indicates that the larger the reduction in individual annual vehicle mileage, the more consistent the model outcomes become.

3. Distribution of outcomes: as more of the white violin falls within the green 'successful' range on the left-hand side of the plot, this indicates that a greater number of the model outcomes down at the larger-annual-mileage-reduction end successfully meet the CO_2 target in question. Note: it is important to note here that this is not a probabilistic model where each model has a similar,

or comparable chance of being 'correct' in terms of future emissions. These violins merely show, by their varying width, the *proportion* of all possible outcomes which result in particular levels of CO_2 emissions, not their *likelihood*.



1. Gradient: the flatness of the gradient of the blue line in this chart indicates that making changes to the BEV/PHEV mileage style parameter has little overall impact on model outcomes of total CO_2. Similarly, there is little change in the minimum as indicated by the levels of bottoms of the green bars. However, differences in the level of the maximum CO_2 outcomes, indicated by the top of the grey bar, indicate that changing from an assumption that BEVs will be driven like petrol cars, to assuming they will be driven like a diesel car, leads to the possibility of noticeably higher CO_2 emissions.

2. Vertical compactness: the range, shown by the vertical compactness of each bar, is not particularly tight (in comparison to some groups in other charts), neither does it vary much between different BEV/PHEV mileage style scenarios. The conclusion is that this parameter does not have much of a uniform impact on overall CO_2 emissions outcomes.

3. Distribution of outcomes: the proportion of outcomes that are successful, as shown by the vertical proportion of the white violin lying in the green bar, is similar across all three scenarios (values of the chosen parameter). This indicates that none of the scenarios have a closer association with successful outcomes than the others.

This chapter will use only the government's analysis, as this is the one with the greater number of successful outputs out of the two targets (GOV and CCC) used, set by those two relevant bodies. But results will be similar for both, because both rely on the same underlying results from the same model.

6.1 The impact of various parameters on CO_2 output

This section looks at the Government target and only the well-to-wheel analysis for a complete picture.

6.1.1 Annual individual car mileage adjustment year-on-year

The mileage adjustment parameter provided a means of changing the year-on-year annual mileage of cars in the model. There are eleven values used in the model, ranging from no change in mileage (0%) to a 5% decrease.

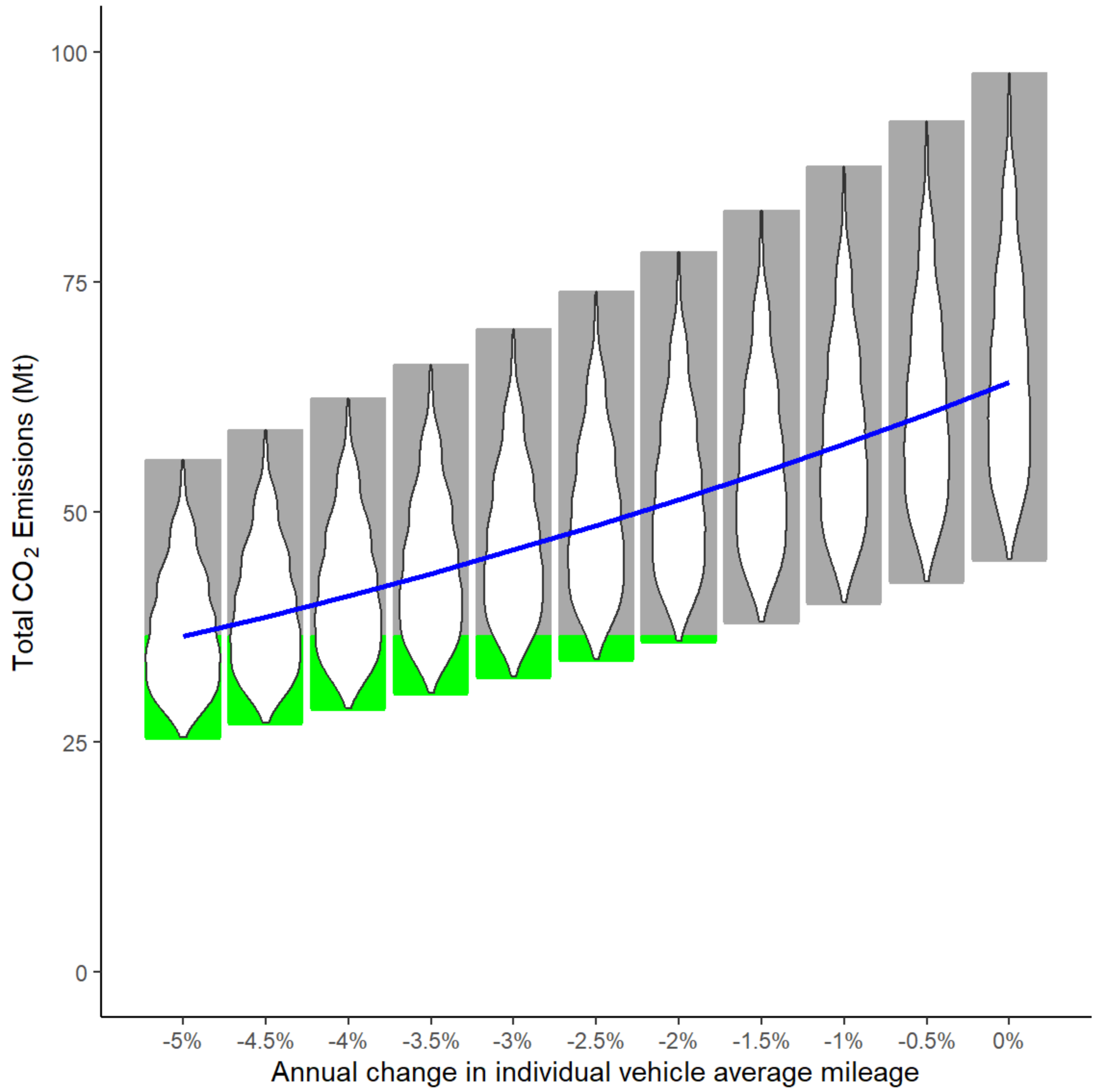


Figure 6.1: Impact of changing the average mileage parameter on total CO_2 emissions

The gradient in Figure 6.1 is consistent and fairly steep, particularly compared to the charts that follow. Lines with a steeper gradient indicate that for any given change in the parameter under examination there is a larger effect on outcomes than is the case with shallower gradients, meaning here that year-on-year mileage adjustment has a clear impact on the modelled CO_2 outcomes. Additionally, as the mileage adjustment is set at values ever smaller values and approaches −5%, the range of outcomes becomes more compact, indicating that reducing mileage leads to more consistent potential outcomes. The violins show that to the left of the chart, most of the outcomes lie in the green portion of the bar, indicating a considerable majority of successful outcomes, whilst to the right-hand side, the greater part (and in the final three cases, the entirety) of the distribution lies in the grey, unsuccessful, portion of the bar.

Mileage reductions are thus associated with more successful outcomes. In other words, adjusting mileage downwards has a relatively large impact on CO_2

emission levels for any given adjustment of it, is more likely to lead to a more consistent outcome as mileage adjustment goes further downwards, and is more likely to be associated with success in meeting CO_2 reduction targets.

6.1.2 Sales-weighted CO_2 percentage change year-on-year

It is important to note that the sales-weighted CO_2 emission parameter used in this model relates only to the ICE car fleet: neither the sales volume nor the efficiency of BEVs, nor of PHEVs, affects it. It is a sales-weighted figure, representing the change to average emissions of all new ICE cars added to the fleet compared to those added in the previous year.

Historically, average sales-weighted emissions of ICE cars have fluctuated from year to year, with differences ranging from 5% decreases to 6% increases. The model has been set up to allow five scenarios for this parameter (from −6% to +6% in increments of 3%, with negative values indicating a reduction in emissions and positive values an increase).

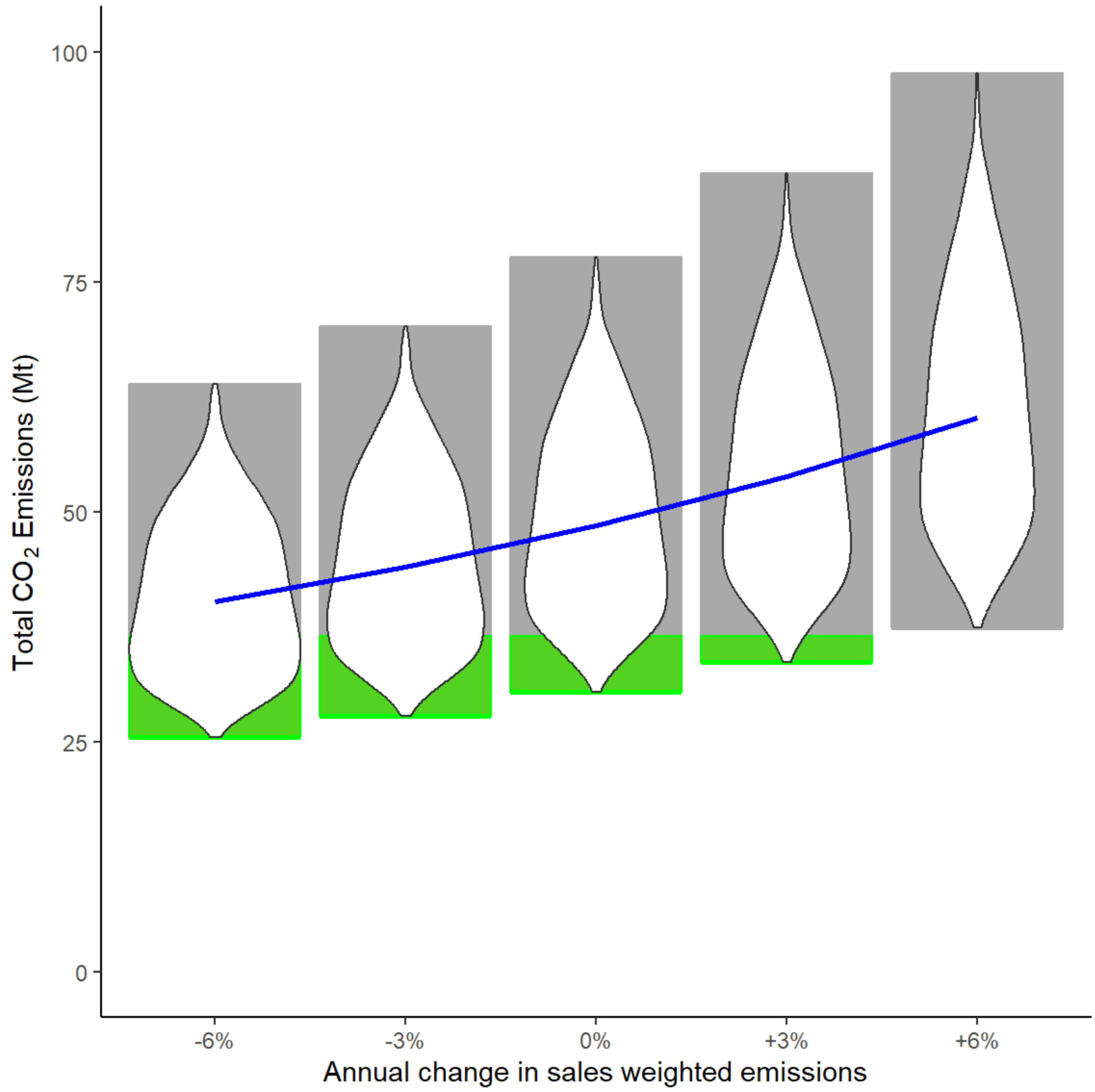


Figure 6.2: Impact of changing the sales-weighted emissions parameter on total CO_2 emissions

The gradient of the line in Figure 6.2 shows a steep increase in total emissions as the sales-weighted emissions increase. This suggests that any adjustments in sales-weighted CO_2 averages of new ICE cars has a large impact on CO_2 outcomes. As sales-weighted emissions are varied from increasing year-on-year, through undergoing no change, to actually reducing year-on-year, the chart shows the range of total emissions outcomes becoming more compact, indicating that as sales-weighted emissions increase less and actually reduce, this leads to a increasingly consistent set of outcomes. The number of successful outcomes (shown by the proportion of the violin that falls within the green bar) also increases.

6.1.3 PHEV economy handling

The lack of data on PHEV charging/usage behaviour has led to the development of two different options for forecasting how these are driven, and their consequent fuel consumption, in relation to use of electric versus ICE drivetrains. In the first 'Best' scenario, PHEVs have the lowest fuel consumption based on laboratory-test fuel economy figures. In the 'Worst' scenario PHEVs are assumed to perform worse than petrol cars owing to minimal use of the electric drivetrain and their greater mass owing to the battery and electric motor.

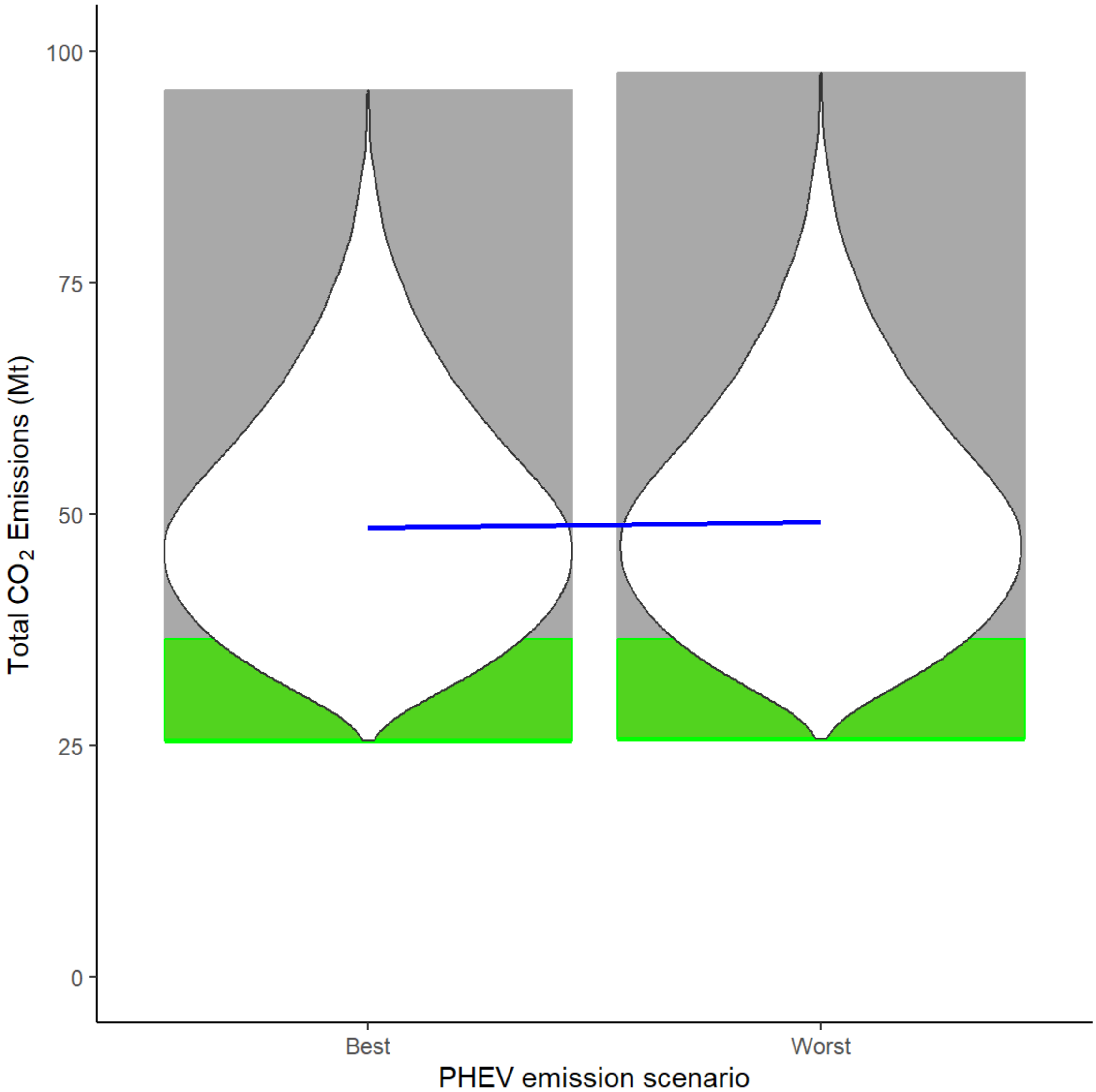


Figure 6.3: Impact of changing the PHEV economy handling parameter on total CO_2 emissions

The gradient in Figure 6.3 is not particularly steep, indicating that changes in the fuel consumption of PHEVs (between the two estimates of real-world PHEV economy) has a relatively small impact on CO2 outcomes. The range of outcomes under the 'Worst' scenario is slightly less compact than under the 'Best' scenario (the overall bar height is slightly greater), indicating that better PHEV usage in this sense will reduce overall CO2 emissions. Under both scenarios, the violins indicate the majority of model outcomes (with no respect to how likely each one is, it must continually be stressed) are successful, however, slightly more will be successful under the 'Best' scenario. It should be noted that this does not indicate that PHEVs cannot offer benefits, but rather that the two plausible scenarios of PHEV use show little difference. For example, if the utility factor was quite significantly greater, it might show PHEVs having an impact – but this was not modelled here.

6.1.4 Average mileage of BEVs/PHEVs (mileage style)

There are three scenarios for setting the parameter for driving distances for BEVs and PHEVs. As the future driving patterns of electric and PHEV cars are unknown, this parameter allows different future driving patterns for BEVs and PHEVs. The three scenarios are based on situations where BEVs and PHEVs are (a) driven similar distances to petrol cars, (b) driven similar distances to diesel cars and (c) driven 10% further than diesel cars.

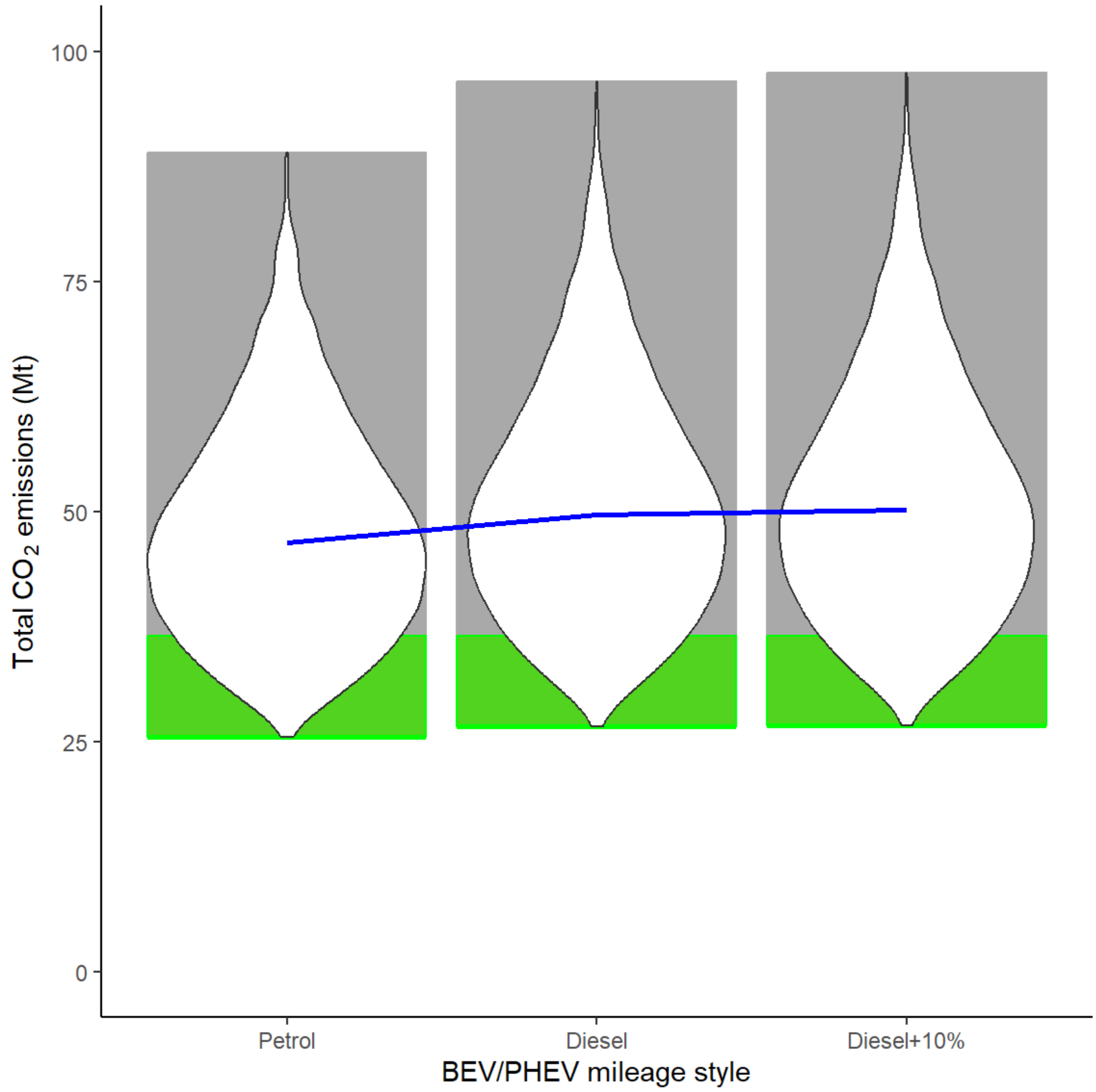


Figure 6.4: Impact on changing EV mileage handling parameter on total CO2 emissions

The blue line in Figure 6.4 is not very steep. This indicates that any changes in the mileage of electric cars has a relatively small impact on CO_2 outcomes. It is worth noting that this is separate to the parameter regarding changes in mileages to all cars. In outcomes where the all-vehicle mileage amount goes down, then the BEV/PHEV mileage under all these scenarios goes down in tandem with the other cars. The parameter referred to here considers how BEVs/PHEVs might be driven relative to cars with other fuel types.

The bars in the petrol-like mileage scenario are noticeably more compact than in the other two scenarios, suggesting that outcomes using this parameter setting will lie within a slightly smaller range of CO_2 emissions than those with either of the diesel-based mileage-style scenarios.

The gradient, compactness and distribution of outcomes all suggest that increasing the mileage of BEV and PHEV cars over and above those of a diesel car has no significant association with successful outcomes.

This makes sense because BEV miles, however many they may be, are so much less CO_2 intensive than ICE mileages that, whether BEVs are driven less or more, the resultant difference in CO_2 is very small in comparison to the impact of ICE cars still on the road at the same time.

6.1.5 Carbon intensity of BEVs/PHEVs

Carbon intensity of electric cars were included only in the WTW analysis. There were three options to choose from.

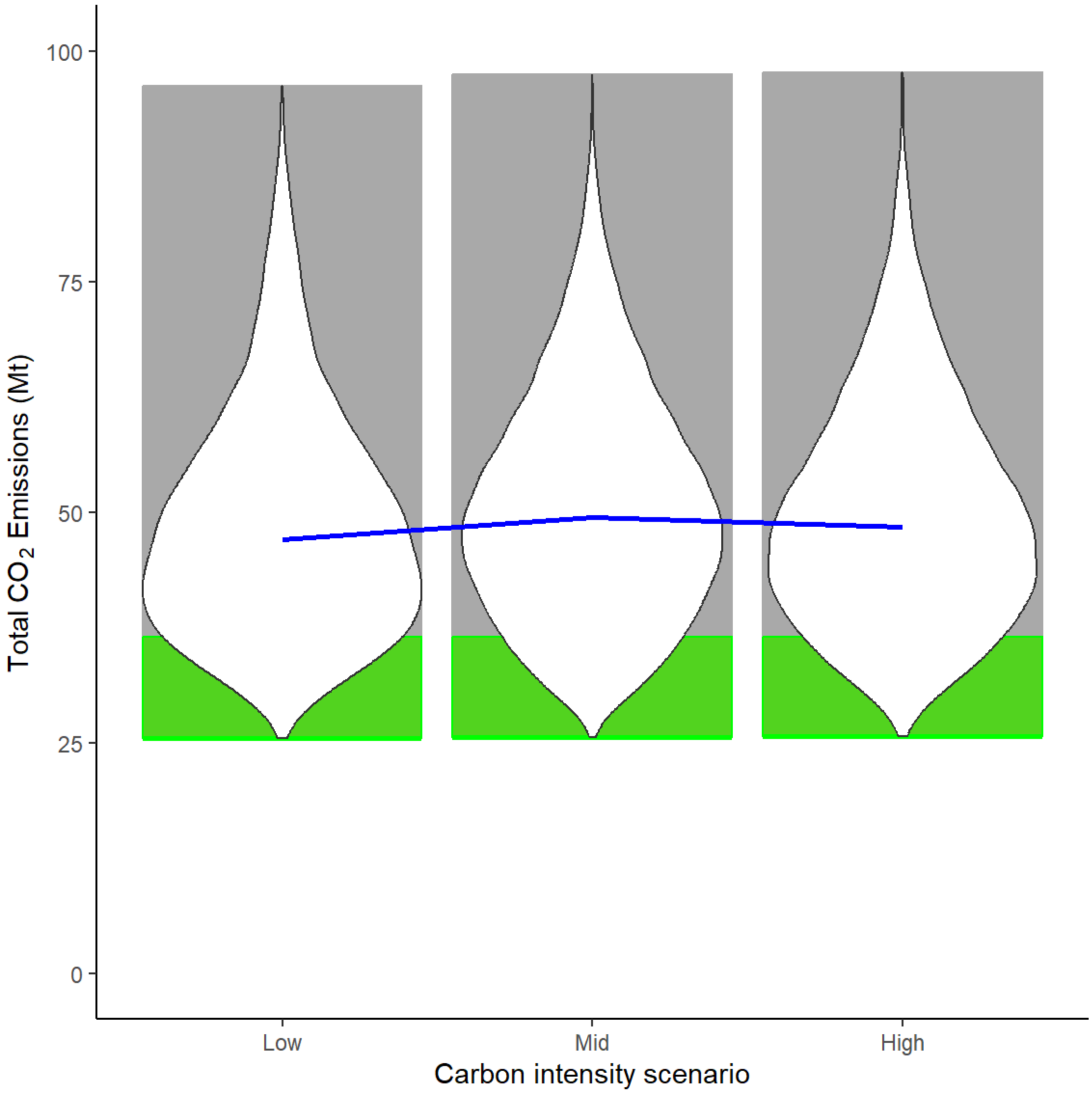


Figure 6.5: Total CO_2 for each scenario split by BEV carbon intensities

The gradient of the line in Figure 6.5 is not very steep. It shows that any adjustments in the carbon intensity of electric cars has little impact on CO_2 outcomes. The range of outcomes is not very compact either, indicating that none of the scenarios is likely to particularly constrain the consequent CO_2 emissions. The distribution of the outcomes, shown by the violins, differs slightly between scenarios; however, there is a similar proportion of outcomes in each scenario within the green, successful, portion of the bar. As is the case with the electric car mileage parameter, this makes sense. BEV mileages are so much less CO_2 intensive than ICE mileages that whether BEVs have a greater or lesser CO_2 impact per mile driven, that difference in CO_2 is very small in comparison to the impact of ICE cars still on the road at the same time.

6.1.6 Departure rate

There are five departure rate scenarios based on historical trends (see Figure 2.1). These showed a trend for cars to leave the parc (the population consisting of all the cars on the road) a bit more slowly every year from 2016–17 to 2019–20. However, in 2020–21 there was a larger drop in this rate than was the case year-on-year until then.

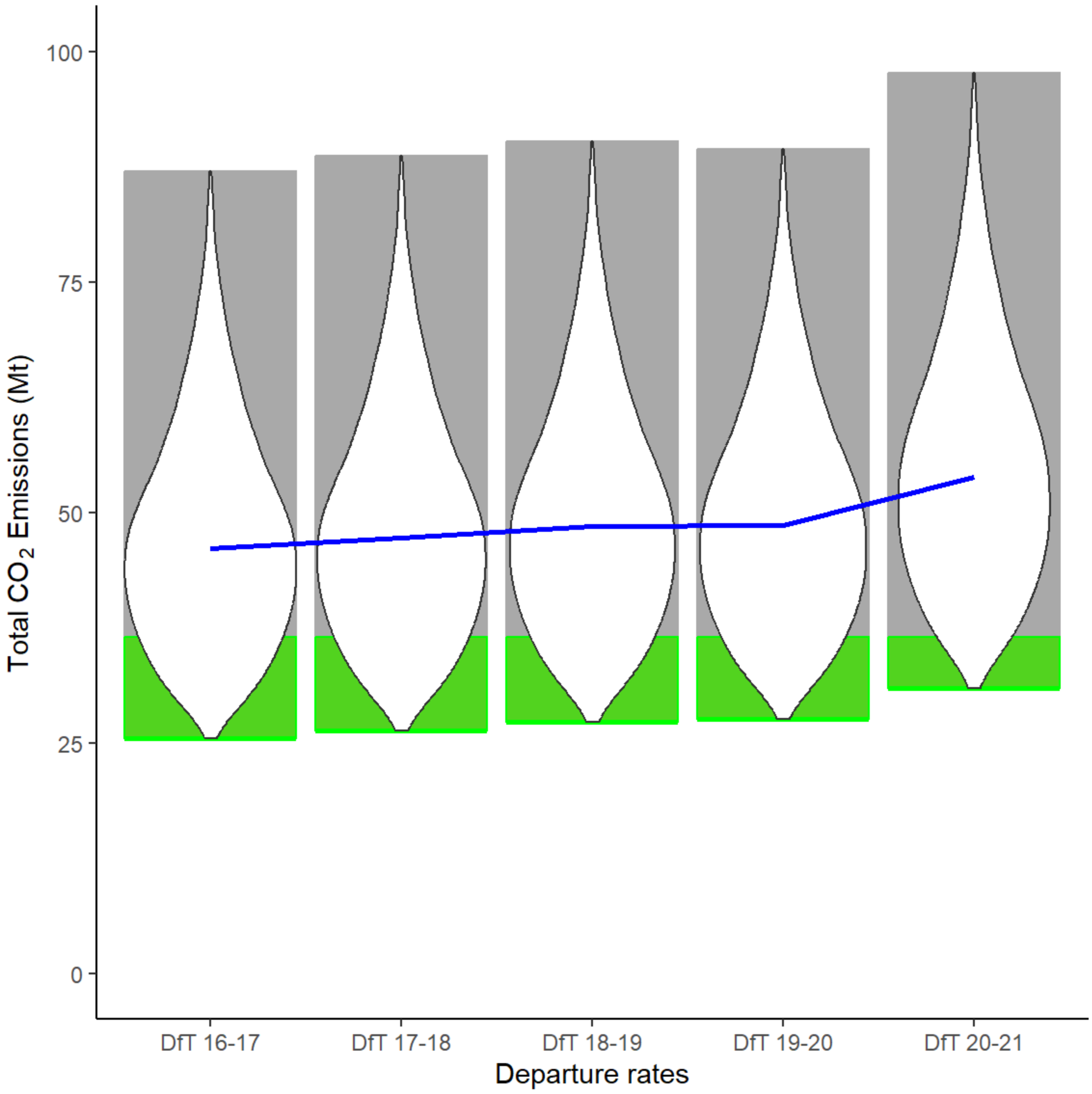


Figure 6.6: Impact of changing the departure rate parameter on total CO_2 emissions

The blue line in Figure 6.6 shows a slight incline from the DfT 16–17 to DfT 19–20 scenarios, indicating only a slight variation between these pairs of years. However, there is a much steeper gradient to the line between DfT 19–20 and DfT 20–21. This indicates that departure rates can have a clear impact on total CO_2 emissions. The range of outcomes shown by the green and grey boxes is not as compact for DfT 2020–21 as for the other scenarios. This suggests that outcomes will be across a greater range of CO_2 than for the other scenarios which have faster departure rates.

The differences in the shape of the violins in the chart also indicate that there are a greater number of predicted successful outcomes for those scenarios with the greater departure rates (i.e. those to the left of the chart).

6.1.7 New vehicle registrations

There are six different scenarios for the new registration parameter (as detailed in subsection 2.3.4). Four are from the SMMT and range from a low and slow uptake of BEVs to a high and fast uptake of BEVs. The CCC's new registration projections show both an increasing number of new registrations and a high and fast uptake of BEVs, such that all new registrations in 2032 will be BEVs. The **ZEV mandate scenario** is very similar to the SMMT **central scenario**.

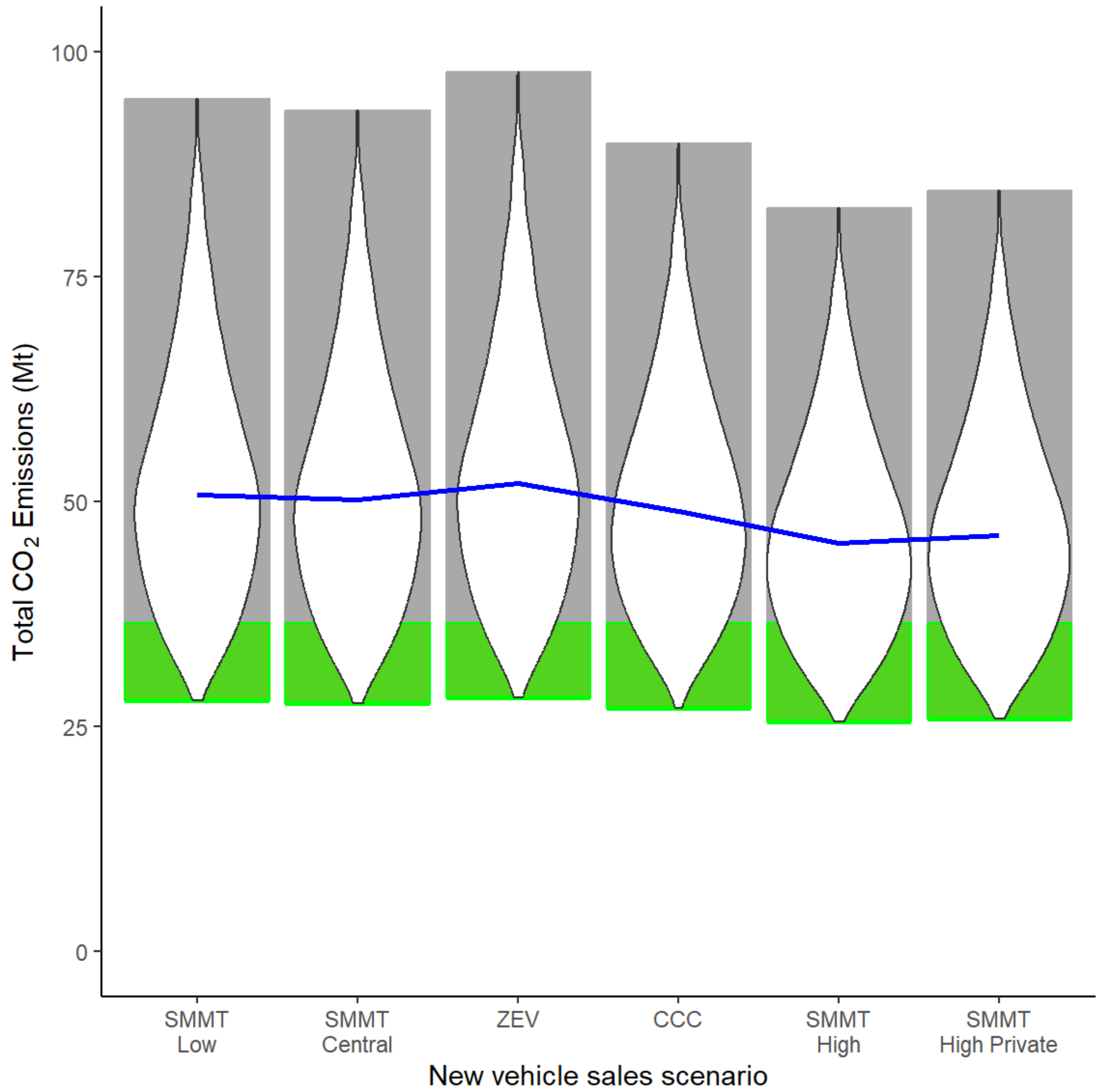


Figure 6.7: The total CO_2 for each scenario split by the new vehicle registrations parameter

Figure 6.7 shows that when all other factors are controlled for, the impact of new-vehicle BEV sales projections are mixed. This graph indicates that simply selling more new BEVs alone does not necessarily equate to successful outputs in the medium term, as the positive effects of this can be easily negated by slow departure rates (as mentioned in Chapter 5), with the petrol cars aged 3-13 years old clearly being a necessary focus of attention.

The bars and violins in Figure 6.7 are quite similar for each of the six new registration scenarios, particularly with regard to the lower part of the charts, which show the range of successful outcomes (as the green portion of the bar) and the relative distribution of successful and unsuccessful outcomes (the shape and proportions of the violins). Two key points to note though, are that the different scenarios do seem to have a greater effect on (1) the upper range of possible CO_2 outcomes, and (2) the median outcomes. As might be expected, the scenarios with higher BEV uptake to the right of the chart both constrain highest levels of CO_2 emissions and slightly reduce the median of the outcomes.

6.2 New-vehicle reg versus departure rate

The make-up of the parc in terms of age and fuel type (before the model takes into account miles driven and CO_2 impact per mile) is a product of both departure rate and the new-vehicle sales projections. It is clear that these two parameters can either work together to make a cleaner, newer parc, or work against each other so that new BEV (car) sales are negated by older cars staying on the road longer. It therefore makes sense to compare the effects of varying these parameters together.

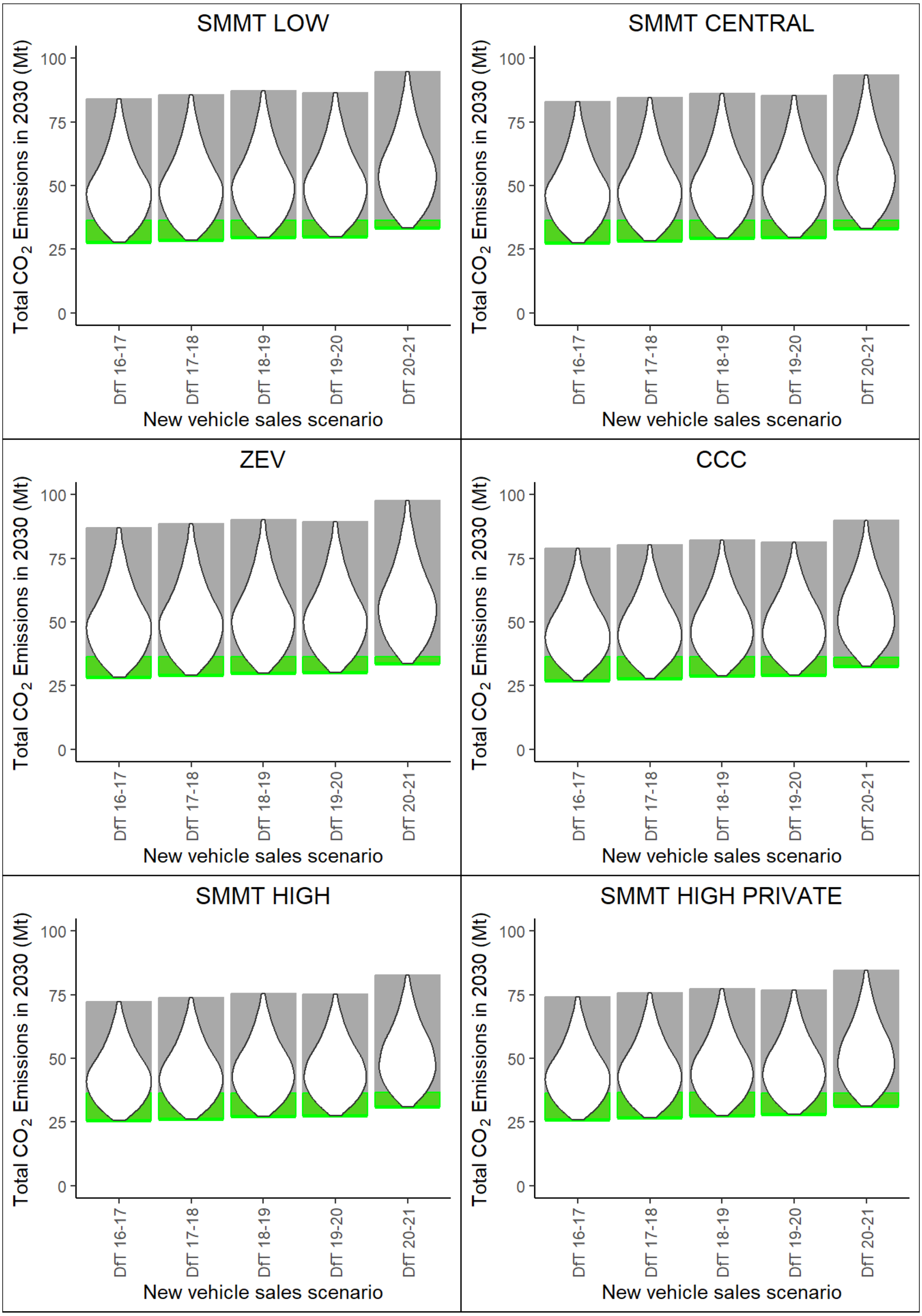


Figure 6.8: Mileage-weighted age of parc against total CO_2

Figure 6.8 shows the same information as Figure 6.6 on varying the five departure rate parameter; however, this time it has been further split on the basis of the six new-vehicle registrations scenarios. The similarity of the six related graphs shows that the effect of the departure rate is very similar across all outputs, regardless of which new registration variable is used. The most noticeable differences in the charts, as with Figure 6.7, is the upper bounds of the grey boxes (seen, for example, by comparing the DfT 16–17 scenarios between the 'ZEV' and 'SMMT high private' charts).

The departure rates from 2016–17 to 2019–2020 look very similar across all new-vehicle registrations scenarios, which means that the distribution of the model run results is not compact, showing that for any given value, the outcome in terms of CO_2 could come anywhere in what is a rather extensive range of results. But there is a slight variation between the four in that the percentage of successful scenarios (the number of green lines) decreases from DfT 16–17 to DfT 20–21. For example, looking at SMMT High Private, 27% of all the scenarios with a departure rate of DfT 16–17 were successful; 23% of all the scenarios with a departure rate of DfT 17–18 were successful; 20% of all the scenarios with a departure rate of DfT 18–19 were successful; 18% of all the scenarios with a departure rate of DfT 19–20 were successful; and lastly, in the scenarios with the slowest departure rate, DfT 20–21, only 8% were successful. So if the departure rates were much faster, especially for the cars ages between 3to 13, this could contribute towards total emissions coming under the target.

The scenarios with the departure rate of DfT 20–21 are less compact. It follows that if the departure rates were much faster, this would make the lines more compact and increase the number of lines deemed green (successful). This suggests that departure rate is an important parameter in helping to reduce CO_2 emissions.

6.3 Age of car parc versus CO_2 emissions

Figure 6.9 shows the mileage-weighted age of the car parc (for all cars up to 40 years old) in 2030 plotted against the total CO_2 emissions for each of the thousands of outcomes. Note: the mileage-weighted age is calculated by dividing every car's mileage into the sum of the total mileage driven by the whole parc to provide per-car weights which are then applied to the age of that car.

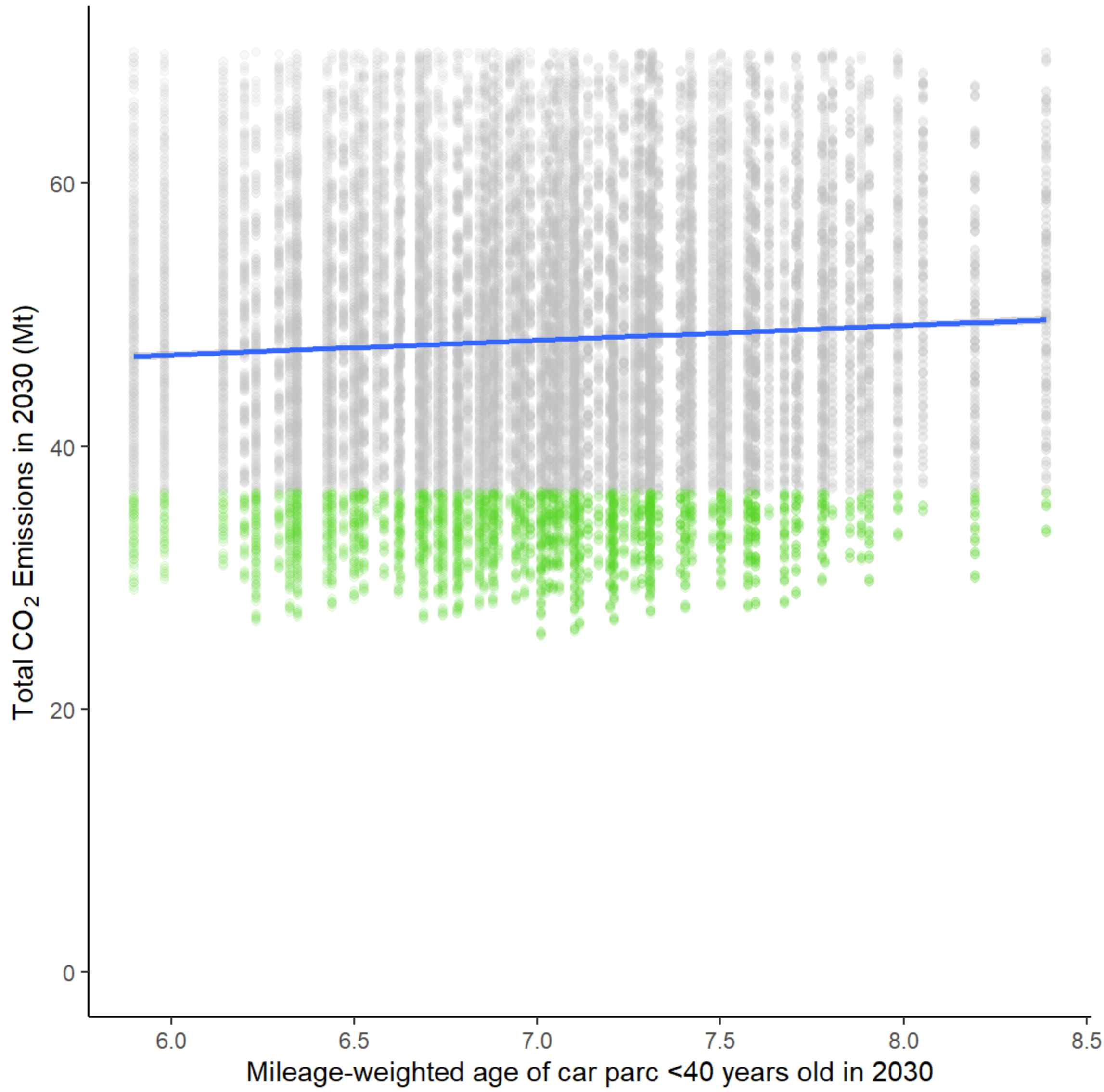


Figure 6.9: Mileage-weighted age of parc against total CO_2

Note: Blue Line = Linear Regression of Age vs CO_2

The plot shows that the spread of emissions for every age of car is considerable. The age of the parc is affected by both new-vehicle registrations and the departure rate. The gradient of the blue regression line indicates that mileage-weighted parc age is somewhat correlated with total CO_2 emissions. However, it is worth noting that all departure rates used in this model are associated with ageing parcs (i.e. the recent historic trend has been for cars to be kept on the road for longer, and consequently the overall age of the parc to increase). The departure rates from 2016 and onwards showed that cars were leaving the car parc ever more slowly. Even though the DfT 16–17 departure rate was considered to be the fastest departure rate, that was only the case in relative terms. Longer-term trends in parc age suggest that all departure rates used were in actual fact relatively slow. This means that a very common pattern of the model scenarios is slow departure rates (which are trending towards getting ever slower), negating many of the potential gains to be made through new BEV sales. However, there is little in the way of current policy or economic climate that suggests that this trend will change direction in the foreseeable future.

The mileage-weighted mean was applied to the 2025 and the 2030 car parc. In 2025, the mileage-weighted mean would be 7.05 years old, in 2030 it would be 7.08 years old. This shows that the mean age of the parc is trending in the wrong direction – that cars are getting older year-on-year. So unless older cars happen to leave the parc sooner, coming under the emissions target may be difficult to achieve.

7 Conclusions

The starting point for the analysis in this report was an aim of establishing whether the needed reduction in tailpipe carbon emissions from cars which is implicit in the sectoral share-out of the Committee on Climate Change's sixth carbon budget could be achieved without there necessarily being a reduction in total driven miles. The answer – mathematically speaking – is that such a reduction is not an absolute prerequisite. However, in looking at the impact of the parameters tested in the modelling it becomes clear that car mileage is in reality a significant factor, and that model outputs which do not involve any reduction in individual car mileages show that other elements must undertake a greater share of the heavy lifting involved. Other than mileage and the sales weighted improvement of ICEs, the variables with the greatest impact on total emissions are the rate of new battery electric vehicle (BEV) registrations (referring in this model, of course, to cars only), the proportion of driven miles accounted for by BEVs, and the departure rate of ICE cars from the parc. To stay within the sixth carbon budget limits without there being a reduction in driven miles, all three of those elements have to be moving in the right direction and working in combination with each other. For that to happen, recent trends in departure rate will have to be reversed.

BEV take-up, of itself, is important, but appears to be insufficient in isolation to outweigh tailpipe emissions from the residual ICE cars in the parc if, as seems at least possible on current trends, those ICE cars are kept in regular use well after the point at which no new pure (non-hybrid) ICE vehicles can be sold, unless the early introduction of a sales-weighted CO_2 emissions average limit is applied, ratcheting more tightly year-on-year (as contemplated alongside the zero-emission vehicle mandate), and thus biting down on the CO_2 performance of those largely petrol cars newly registered over the remainder of the decade. It was of particular interest that the change in average sales-weighted average emissions figures for the car parc pre-COVID-19 fluctuated between positive and negative year-on-year. Whilst, in general, individual models of car became more fuel-efficient, consumer choices in some years appear to have been to bank, as it were, those improvements by trading up into larger and/or higher-performance model options.

The modelling has taken account of the long-term trend that has seen annual average per-vehicle mileage falling year-on-year, but also of the pre-COVID-19 trend for a general growth in the size of the parc (in a nutshell, individual vehicles racking up fewer miles but there being more vehicles in total).

It is also noteworthy that the average age of cars in the parc has slowly been increasing – a trend set prior to COVID-19. There is no clear, generally accepted explanation for this trend – possibly it reflects the increased durability of modern vehicles, being less prone as they are to corrosion and severe mechanical failure; it may reflect economic pressures on households; or perhaps it reflects the decrease in recent years of the incremental improvement in user experience of ICE cars – and to some extent it may be a result of purchasers (particularly non-fleet purchasers free from the influences of the company car-tax regime) being cautious about switching to BEVs and instead deciding to keep their existing cars for longer. In the absence of any firmer evidence, there is no reason to model a reversal of this trend, and consequentially the modelling suggests that a substantial proportion of tailpipe emissions in 2030 will be accounted for by 3- to 13-year-old cars that, barring uneconomic repairs resulting from crash damage or the failure of electrical components, would still be a valid option for those seeking affordable and reasonably reliable vehicles for everyday use.

Air quality concerns, allied to changes in the company car tax regime (and most recently very high per-litre diesel fuel prices), have materially dented the sales of diesel cars. New car registration numbers suggest that while some car purchasers have swapped out of diesel into BEVs, others have opted instead for petrol models, with the availability of mild (non-plug-in) hybrids which offer better than pure-petrol fuel economy proving insufficient to counter the resulting greater CO_2 emissions of (non- and mild-hybrid) petrol drivetrains relative to (zero-rated) BEVs.

The fact that plug-in hybrid cars do not make a more material contribution in the modelling is a product of the way in which many are currently used – in practice this is as ICE cars, with the battery electric option not used enough of the time to make a significant overall contribution to emissions reductions. For plug-in hybrid electric vehicle (PHEV) technology to make a greater impact, there would need to be some large changes. For example, if new PHEVs came with software that strongly compelled electric use, had a shorter ICE range or a greater electric range, or, for fleets, were provided with incentives to drivers to maximise electric operation, progress in this direction might be made. The utility factor of PHEVs (the proportion of the driven distance that is travelled in electric mode) would have to climb significantly higher than where it currently sits. However, there is insufficient evidence of this occurring in practice to justify including scenarios with higher utility factors in the modelling.

Similarly, no attempt has been made to account in our modelling for the possibility of a scientific breakthrough in the affordable production of synthetic e-fuels, biofuels or hydrogen, all of which are nevertheless the subject of substantial ongoing research programmes.

This model, as with any model, has its limitations, both of design and of the assumptions behind the model inputs, and these include the following points.

- There is a need to generate a plausible estimate for future BEV mileage (where the model used three variants – the same as petrol cars, the same as diesel cars and 110% of diesel car mileage), because long-term battery electric car usage patterns are still unclear (in large part because the sample size of BEVs on the road today is so small).
- The model starts with 2019 data, as this was the last ‘normal’ year before the COVID-19 pandemic and the associated restrictions on travel. It remains unclear whether travel patterns

will ever revert to the pre-COVID-19 norm – at the time of writing, full data for entirely post-lockdown years was not available.

- The analysis on which this report is based focuses on tailpipe emissions – that is, those which are allocated to the transport sector when it comes to UK government climate change calculations. This model goes beyond this limitation and represents an attempt to show the broader impact, taking account of emissions associated with electricity generation ultimately used for electric motoring (see Appendix A for these so-called 'well-to-wheel' numbers), but there has not as yet been any attempt to create a complete life-cycle analysis of cars that would reveal the full global impact of their manufacture, use, recycling and disposal.

- This work excludes the possibility of dramatic shifts in travel behaviour such as might result from an extended squeeze on household budgets driven by external factors – for example the economic impacts of the war in Ukraine, restrictions of global oil and gas production, wholesale reforms to motoring taxation, or domestic restrictions on fossil fuel availability (arising, say, if more service station capacity is converted for BEV recharging facilities) – all of which are certainly possible but too difficult to gauge in likelihood and impact to justify venturing assumptions as to what that impact will turn out to be.

The intention of this report was never to do more than shed some light on which variables looked likely to deliver the greatest impacts in respect of carbon tailpipe emissions from cars. The extent to which policymakers wish to craft measures that drive those variables in the desired direction is for debate in the light of this report, and of the broader challenge that the government faces in its quest to achieve net zero across the whole economy, not merely from transport or from car use specifically. It is nevertheless clear from the modelling described here that in order to track whether the trajectory of tailpipe emissions from car use is moving in the right direction, a new index is needed that combines BEV take-up, the proportion of BEV-driven miles, and the rate of departure of ICE cars from the parc. Creating and publishing that index will be the RAC Foundation's next task.

8 References

BEIS (2022). *Greenhouse gas reporting conversion factors*. Accessed 1 December 2022 from www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

Bennet & Brandmayr (2021). *Not Going the Extra Mile: Driving less to tackle climate change*. Green Alliance. Accessed 1 July 2022 from https://green-alliance.org.uk/wp-content/uploads/2021/12/Not_going_the_extra_mile.pdf

CCC (Committee on Climate Change) (2022a). *Progress in Reducing Emissions: 2022 progress report to Parliament*. Accessed Accessed 1 July 2022 from www.theccc.org.uk/publication/2022-progress-report-to-parliament

CCC (2022b). *Progress in reducing emissions: 2022 Progress report to Parliament (Supporting information, charts and data)*. Accessed 1 July 2022 from www.theccc.org.uk/wp-content/uploads/2022/06/Progress-in-reducing-emissions-2022-Report-to-Parliament-Charts-and-data.xlsx

DfT (Department for Transport) (2016). *Vehicle Licensing Statistics: 2016 tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2016

DfT (2017). *Vehicle Licensing Statistics: 2017 tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2017

DfT (2018a). *Vehicle Licensing Statistics: 2018 data tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2018

DfT (2018b). *Anonymised MOT Tests and Results. (MOT data testing results (2018)* and *MOT data testing results (2019)*). Accessed 28 October 2021 from www.data.gov.uk/dataset/e3939ef8-30c7-4ca8-9c7c-ad9475cc9b2f/anonymised-mot-tests-and-results

DfT (2019). *Vehicle Licensing Statistics: 2019 tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2019

DfT (2020). *Vehicle Licensing Statistics: 2020 tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2020

DfT (2021a). *Vehicle Licensing Statistics: 2021 data tables*. Accessed 28 October 2021 from www.gov.uk/government/statistics/vehicle-licensing-statistics-2021

DfT (2021b). *Decarbonising Transport: A better, greener Britain*. Accessed 1 July 2022 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009448/decarbonising-transport-a-better-greener-britain.pdf

DfT (2022a). *Domestic Transport Use by Mode: Great Britain, since 1 March 2020*. Accessed 7 September 2022 from www.gov.uk/government/statistics/transport-use-during-the-coronavirus-covid-19-pandemic

DfT (2022b). *Technical Consultation on Zero Emission Vehicle Mandate Policy Design*. Accessed 1 September 2022 from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067041/technical-consultation-on-zero-emission-vehicle-mandate-policy-design.pdf

DfT (2022c). *Vehicle Licensing Statistics Data Tables*. Accessed 28 October 2021 from https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables

DfT (2022d). Table NTS0901: *Annual mileage of cars by ownership and trip purpose: England, 2022 onwards.* Accessed 7 September 2022 from https://www.gov.uk/government/statistical-data-sets/nts09-vehicle-mileage-and-occupancy#table-nts0901

Hopkinson & Sloman (2018). *Briefing: More Than Electric Cars: Why we need to reduce traffic to reach carbon targets*. Transport for Quality of Life & Friends of the Earth. Accessed 1 June 2022 from <www.transportforqualityoflife.com/u/files/1%20More%20than%20electric%20cars%20briefing.pdf>

Lam (2021). *Fuel Duty Decline*. RAC Foundation. Accessed 1 September 2022 from www.racfoundation.org/wp-content/uploads/Fuel_duty_decline_Lam_January_2022.pdf

National Grid ESO (2021). *Future Energy Scenarios*. Accessed 1 August 2022 from www.nationalgrideso.com/electricity-transmission/document/202851/download

Plötz, P., Moll, C., Biecker, G., Mock, P., & Li, Y. (2020). *Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving, and CO_2 emissions*. Accessed 1 December 2022 from https://theicct.org/wp-content/uploads/2021/06/PHEV-white-paper-sept2020-0.pdf

SMMT (Society of Motor Manufacturers and Traders) (2021). *SMMT New Car Market and Parc Outlook to 2035 by Powertrain Type at 11 June 2021*. Accessed 28 October 2021 from https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-new-car-market-and-parc-outlook-to-2035-by-powertrain-type-11-06-21.pdf

Tietge, U., Díaz, S., Mock, P., Bandivadekar, A., Dornoff, J. & Ligterink, N. (2019). *From Laboratory to Road: A 2018 update of official and 'real-world' fuel consumption and CO2 values for passenger cars in Europe*. International Council on Clean Transportation. Accessed 28 October 2021 from https://theicct.org/sites/default/files/publications/Lab_to_Road_2018_fv_20190110.pdf

9 Annex

9.1 Data tables (tailpipe only)

Table 9.1: GOV total tailpipe emissions split by fuel type

Scenario	Year	Petrol	Diesel	PHEV	Total
Low	2020	31.57	31.43	0.16	63.16
Low	2021	29.39	28.18	0.22	57.79
Low	2022	27.51	25.08	0.30	52.89
Low	2023	25.89	22.21	0.37	48.47
Low	2024	24.29	19.48	0.43	44.21
Low	2025	22.65	16.89	0.49	40.03
Low	2026	20.99	14.46	0.54	35.99
Low	2027	19.29	12.20	0.58	32.07
Low	2028	17.48	10.12	0.62	28.22
Low	2029	15.58	8.24	0.65	24.47
Low	2030	13.62	6.58	0.67	20.88
Mid	2020	31.90	31.77	0.26	63.93
Mid	2021	29.97	28.76	0.36	59.10
Mid	2022	28.22	25.82	0.48	54.51
Mid	2023	26.63	23.04	0.58	50.24
Mid	2024	25.04	20.35	0.67	46.06
Mid	2025	23.36	17.74	0.74	41.85
Mid	2026	21.60	15.26	0.80	37.67
Mid	2027	19.82	12.94	0.85	33.61
Mid	2028	17.93	10.78	0.89	29.61
Mid	2029	15.97	8.82	0.94	25.72
Mid	2030	14.01	7.08	0.96	22.05
High	2020	33.40	33.19	0.27	66.86
High	2021	33.80	31.54	0.49	65.82
High	2022	33.79	29.62	0.83	64.24
High	2023	33.58	27.61	1.27	62.46
High	2024	32.68	25.39	1.79	59.86
High	2025	31.14	22.97	2.37	56.49
High	2026	29.54	20.57	2.78	52.89
High	2027	27.81	18.18	3.04	49.03
High	2028	25.99	15.86	3.12	44.98
High	2029	23.99	13.61	3.08	40.68
High	2030	21.77	11.46	2.93	36.15

Table 9.2: GOV total mileage split by fuel type

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Low	2020	111,283,548,454	109,984,468,708	1,427,970,161	1,264,225,086	223,960,212,409
Low	2021	105,023,859,686	98,922,795,641	2,068,959,223	2,049,153,188	208,064,767,739

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2022	100,095,107,315	88,514,238,380	2,890,778,203	3,108,268,864	194,608,392,762
Low	2023	96,180,390,455	78,911,967,571	3,710,306,766	4,079,958,834	182,882,623,625
Low	2024	92,339,162,253	69,748,215,912	4,554,053,227	5,260,023,336	171,901,454,727
Low	2025	88,203,106,968	60,948,367,498	5,408,173,504	6,639,656,165	161,199,304,136
Low	2026	83,868,709,514	52,628,489,765	6,147,743,533	8,215,683,965	150,860,626,776
Low	2027	79,074,656,675	44,802,452,806	6,879,446,669	9,983,265,459	140,739,821,609
Low	2028	73,487,345,195	37,491,463,793	7,590,321,366	11,889,673,605	130,458,803,960
Low	2029	66,917,966,674	30,728,836,275	8,387,353,379	14,015,237,371	120,049,393,699
Low	2030	59,521,260,037	24,712,689,826	9,039,418,842	16,350,927,801	109,624,296,505
Mid	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Mid	2020	112,454,954,227	111,142,199,957	2,358,903,599	2,106,567,962	228,062,625,745
Mid	2021	107,086,476,947	100,954,134,019	3,418,740,838	3,714,397,935	215,173,749,739
Mid	2022	102,569,093,466	91,107,945,588	4,651,481,632	7,280,272,779	205,608,793,466
Mid	2023	98,691,263,384	81,781,475,114	5,815,063,147	12,367,967,853	198,655,769,498
Mid	2024	94,816,316,357	72,748,553,359	7,000,329,700	18,555,089,351	193,120,288,767
Mid	2025	90,399,008,587	63,886,871,178	8,101,227,983	25,781,598,264	188,168,706,011
Mid	2026	85,456,768,073	55,330,572,948	9,053,256,489	33,878,203,358	183,718,800,867
Mid	2027	80,198,397,510	47,242,499,010	10,005,427,554	41,955,217,425	179,401,541,498
Mid	2028	74,110,626,161	39,611,996,766	10,948,833,540	50,172,305,282	174,843,761,749
Mid	2029	67,223,544,658	32,539,022,568	12,037,607,711	58,359,540,411	170,159,715,347
Mid	2030	59,968,577,403	26,271,594,640	12,941,136,918	66,320,490,027	165,501,798,988
High	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
High	2020	117,668,718,301	116,101,226,487	2,459,327,903	2,198,471,211	238,427,743,902
High	2021	121,027,319,015	110,673,683,093	4,666,712,396	4,463,237,695	240,830,952,199
High	2022	123,345,010,128	104,512,855,100	8,248,825,036	8,086,068,826	244,192,759,090
High	2023	124,979,934,831	98,029,879,496	13,252,835,167	13,794,327,679	250,056,977,173
High	2024	123,900,687,661	90,716,294,776	19,536,414,714	22,799,740,654	256,953,137,806
High	2025	119,731,664,047	82,475,302,265	27,087,364,693	37,073,659,723	266,367,990,728
High	2026	115,242,390,558	74,215,959,832	32,919,659,051	53,551,972,329	275,929,981,770
High	2027	110,155,158,363	65,972,143,341	36,900,057,329	72,479,142,486	285,506,501,518
High	2028	104,563,536,020	57,901,430,799	38,752,373,406	93,739,519,869	294,956,860,093
High	2029	97,833,695,995	49,981,076,754	38,736,418,948	118,035,240,530	304,586,432,227
High	2030	89,689,426,132	42,325,055,165	36,863,187,180	145,856,867,471	314,734,535,948

Table 9.3: GOV total number of cars split by fuel type from 2019 - 2030

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Low	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Low	2021	19,262,598	11,997,213	341,192	337,500	31,938,504
Low	2022	19,328,295	11,518,654	501,084	535,304	31,883,336
Low	2023	19,500,287	10,992,934	675,838	740,552	31,909,611
Low	2024	19,674,241	10,399,548	873,891	1,004,214	31,951,895
Low	2025	19,773,598	9,734,572	1,095,330	1,339,650	31,943,150
Low	2026	19,801,460	9,009,282	1,313,671	1,747,542	31,871,956
Low	2027	19,694,426	8,228,181	1,552,116	2,239,657	31,714,380
Low	2028	19,339,837	7,397,102	1,810,810	2,814,792	31,362,541
Low	2029	18,653,808	6,531,884	2,114,015	3,500,946	30,800,652
Low	2030	17,640,168	5,676,312	2,408,124	4,309,963	30,034,566
Mid	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Mid	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Mid	2021	19,236,634	11,991,178	338,192	362,500	31,928,505
Mid	2022	19,206,572	11,495,309	479,078	735,355	31,916,314
Mid	2023	19,220,025	10,940,099	623,812	1,302,806	32,086,741
Mid	2024	19,225,510	10,318,538	787,020	2,031,301	32,362,370
Mid	2025	19,112,495	9,620,123	958,166	2,947,957	32,638,741
Mid	2026	18,861,213	8,854,258	1,126,482	4,060,475	32,902,428
Mid	2027	18,510,835	8,042,911	1,310,273	5,275,975	33,139,994
Mid	2028	17,923,841	7,187,083	1,509,139	6,626,460	33,246,524
Mid	2029	17,070,014	6,308,353	1,741,933	8,108,329	33,228,629
Mid	2030	16,042,059	5,455,327	1,966,612	9,693,598	33,157,596
High	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
High	2020	19,523,143	12,486,741	222,191	198,718	32,430,794
High	2021	20,025,938	12,122,440	423,724	401,174	32,973,277
High	2022	20,414,026	11,676,328	746,443	722,527	33,559,323
High	2023	20,617,970	11,148,631	1,190,490	1,231,492	34,188,583
High	2024	20,498,087	10,519,464	1,755,062	2,039,545	34,812,158
High	2025	19,921,489	9,778,359	2,442,874	3,323,350	35,466,072
High	2026	19,317,920	9,002,082	2,990,248	4,811,072	36,121,322
High	2027	18,657,376	8,194,369	3,388,300	6,528,366	36,768,411
High	2028	17,893,990	7,362,493	3,633,617	8,510,240	37,400,341
High	2029	16,964,607	6,516,087	3,729,301	10,808,603	38,018,598
High	2030	15,827,132	5,673,785	3,667,223	13,467,885	38,636,024

Table 9.4: CCC total tailpipe emissions split by fuel type

	Scenario	Year	Petrol	Diesel	PHEV	Total
17	Low	2020	31.57	31.43	0.16	63.16
18	Low	2021	29.39	28.18	0.22	57.79
19	Low	2022	27.51	25.08	0.30	52.89
20	Low	2023	25.89	22.21	0.37	48.47
21	Low	2024	24.29	19.48	0.43	44.21
22	Low	2025	22.65	16.89	0.49	40.03
23	Low	2026	20.99	14.46	0.54	35.99
24	Low	2027	19.29	12.20	0.58	32.07
25	Low	2028	17.48	10.12	0.62	28.22
26	Low	2029	15.58	8.24	0.65	24.47
27	Low	2030	13.62	6.58	0.67	20.88
33	Mid	2020	32.75	32.41	0.44	65.60
34	Mid	2021	31.51	29.98	0.64	62.13
35	Mid	2022	30.36	27.54	0.82	58.72
36	Mid	2023	29.24	25.16	1.00	55.41
37	Mid	2024	28.10	22.79	1.18	52.08
38	Mid	2025	26.72	20.39	1.37	48.49
39	Mid	2026	25.18	18.02	1.53	44.73
40	Mid	2027	23.58	15.74	1.69	41.02
41	Mid	2028	21.80	13.54	1.85	37.19
42	Mid	2029	19.84	11.46	2.02	33.32
43	Mid	2030	17.81	9.55	2.16	29.51
1	High	2020	33.23	33.02	0.27	66.52
2	High	2021	33.46	31.22	0.49	65.17
3	High	2022	33.29	29.18	0.81	63.28
4	High	2023	32.91	27.06	1.24	61.22
5	High	2024	31.87	24.76	1.74	58.38
6	High	2025	30.22	22.29	2.30	54.81
7	High	2026	28.52	19.86	2.69	51.06
8	High	2027	26.72	17.46	2.92	47.10
9	High	2028	24.85	15.16	2.99	42.99
10	High	2029	22.82	12.94	2.93	38.69
11	High	2030	20.60	10.84	2.77	34.21

Table 9.5: CCC total mileage split by fuel type

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Low	2020	111,283,548,454	109,984,468,708	1,427,970,161	1,264,225,086	223,960,212,409
Low	2021	105,023,859,686	98,922,795,641	2,068,959,223	2,049,153,188	208,064,767,739
Low	2022	100,095,107,315	88,514,238,380	2,890,778,203	3,108,268,864	194,608,392,762
Low	2023	96,180,390,455	78,911,967,571	3,710,306,766	4,079,958,834	182,882,623,625
Low	2024	92,339,162,253	69,748,215,912	4,554,053,227	5,260,023,336	171,901,454,727
Low	2025	88,203,106,968	60,948,367,498	5,408,173,504	6,639,656,165	161,199,304,136
Low	2026	83,868,709,514	52,628,489,765	6,147,743,533	8,215,683,965	150,860,626,776
Low	2027	79,074,656,675	44,802,452,806	6,879,446,669	9,983,265,459	140,739,821,609
Low	2028	73,487,345,195	37,491,463,793	7,590,321,366	11,889,673,605	130,458,803,960
Low	2029	66,917,966,674	30,728,836,275	8,387,353,379	14,015,237,371	120,049,393,699
Low	2030	59,521,260,037	24,712,689,826	9,039,418,842	16,350,927,801	109,624,296,505
Mid	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Mid	2020	115,043,787,113	113,226,649,245	1,448,072,379	1,285,549,106	231,004,057,844
Mid	2021	111,651,098,859	104,831,457,337	2,116,325,573	2,276,367,282	220,875,249,050
Mid	2022	108,626,234,962	96,517,769,609	2,758,166,556	4,862,767,990	212,764,939,117
Mid	2023	105,748,354,831	88,388,835,831	3,415,734,001	8,593,156,122	206,146,080,785
Mid	2024	102,748,195,600	80,310,874,577	4,098,615,792	13,224,050,119	200,381,736,087
Mid	2025	98,784,486,538	72,052,671,192	4,836,513,745	18,705,041,694	194,378,713,168
Mid	2026	94,029,049,074	63,817,932,657	5,504,084,454	25,012,430,577	188,363,496,761
Mid	2027	89,009,714,435	55,863,424,286	6,197,776,150	31,223,972,206	182,294,887,077
Mid	2028	83,050,441,184	48,130,465,762	6,898,904,347	37,637,560,834	175,717,372,127
Mid	2029	76,170,903,670	40,729,132,107	7,711,598,892	44,135,977,552	168,747,612,221
Mid	2030	68,764,368,210	33,922,750,560	8,425,222,967	50,767,652,413	161,879,994,150
High	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
High	2020	117,080,374,709	115,520,720,355	2,447,031,264	2,187,478,855	237,235,605,183
High	2021	119,820,071,508	109,569,713,104	4,620,161,940	4,418,716,899	238,428,663,451
High	2022	121,504,070,434	102,952,987,674	8,125,710,291	7,965,383,238	240,548,151,636
High	2023	122,499,020,713	96,083,937,434	12,989,759,771	13,520,503,386	245,093,221,304
High	2024	120,833,991,153	88,470,953,368	19,052,864,091	22,235,418,645	250,593,227,256
High	2025	116,184,315,291	80,031,766,019	26,284,834,049	35,975,260,216	258,476,175,575
High	2026	111,268,907,471	71,657,041,541	31,784,610,499	51,705,534,961	266,416,094,473
High	2027	105,825,294,353	63,378,979,177	35,449,628,383	69,630,207,990	274,284,109,904
High	2028	99,951,194,358	55,347,374,272	37,042,989,875	89,604,630,123	281,946,188,628
High	2029	93,050,619,362	47,537,508,432	36,842,600,479	112,264,513,020	289,695,241,294
High	2030	84,877,999,181	40,054,509,796	34,885,646,014	138,032,314,529	297,850,469,520

Table 9.6: CCC total number of cars split by fuel type from 2019 - 2030

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Low	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Low	2021	19,262,598	11,997,213	341,192	337,500	31,938,504
Low	2022	19,328,295	11,518,654	501,084	535,304	31,883,336
Low	2023	19,500,287	10,992,934	675,838	740,552	31,909,611
Low	2024	19,674,241	10,399,548	873,891	1,004,214	31,951,895
Low	2025	19,773,598	9,734,572	1,095,330	1,339,650	31,943,150
Low	2026	19,801,460	9,009,282	1,313,671	1,747,542	31,871,956
Low	2027	19,694,426	8,228,181	1,552,116	2,239,657	31,714,380
Low	2028	19,339,837	7,397,102	1,810,810	2,814,792	31,362,541
Low	2029	18,653,808	6,531,884	2,114,015	3,500,946	30,800,652
Low	2030	17,640,168	5,676,312	2,408,124	4,309,963	30,034,566
Mid	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Mid	2020	19,711,135	12,593,431	220,503	197,549	32,722,618
Mid	2021	19,764,560	12,290,063	334,795	359,828	32,749,245
Mid	2022	19,891,228	11,935,001	448,943	790,085	33,065,257
Mid	2023	19,983,691	11,505,690	572,067	1,441,310	33,502,759
Mid	2024	20,048,789	11,002,665	710,990	2,273,370	34,035,814
Mid	2025	19,931,505	10,404,244	867,284	3,313,926	34,516,958
Mid	2026	19,635,454	9,723,733	1,020,567	4,574,066	34,953,821
Mid	2027	19,268,449	8,991,486	1,188,972	5,893,140	35,342,047
Mid	2028	18,674,056	8,199,373	1,370,894	7,338,469	35,582,792
Mid	2029	17,824,905	7,363,220	1,585,948	8,908,135	35,682,208
Mid	2030	16,809,230	6,525,361	1,794,093	10,603,508	35,732,191
High	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
High	2020	19,523,143	12,486,741	222,191	198,718	32,430,794
High	2021	20,025,938	12,122,440	423,724	401,174	32,973,277
High	2022	20,414,026	11,676,328	746,443	722,527	33,559,323
High	2023	20,617,970	11,148,631	1,190,490	1,231,492	34,188,583
High	2024	20,498,087	10,519,464	1,755,062	2,039,545	34,812,158
High	2025	19,921,489	9,778,359	2,442,874	3,323,350	35,466,072
High	2026	19,317,920	9,002,082	2,990,248	4,811,072	36,121,322
High	2027	18,657,376	8,194,369	3,388,300	6,528,366	36,768,411
High	2028	17,893,990	7,362,493	3,633,617	8,510,240	37,400,341
High	2029	16,964,607	6,516,087	3,729,301	10,808,603	38,018,598
High	2030	15,827,132	5,673,785	3,667,223	13,467,885	38,636,024

9.2 Well to wheel (WTW) results

9.2.1 Government

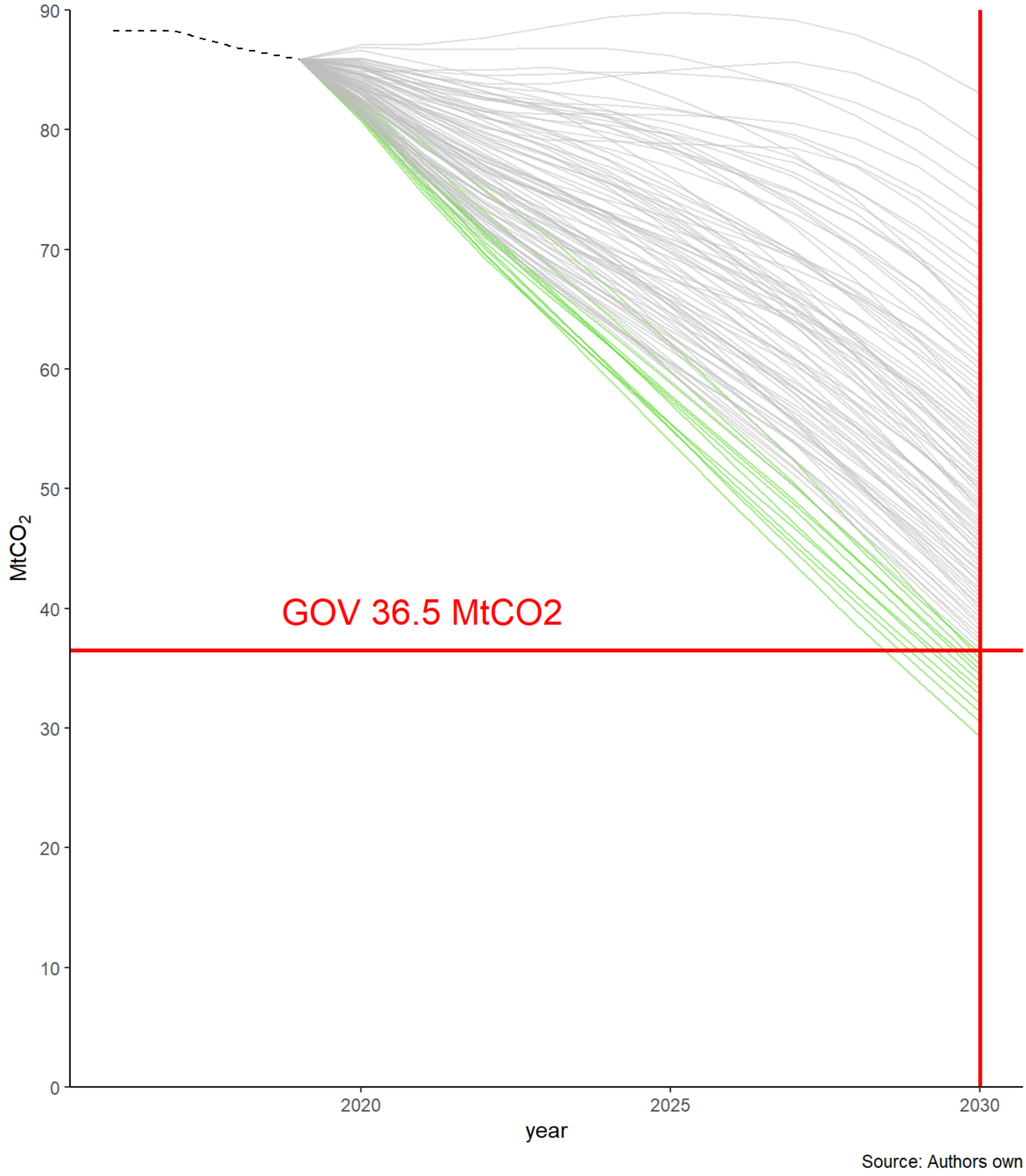


Figure 9.1: Total car well to wheel CO2 emissions from all scenarios

Note: each line (or scenario) does not have an equal likelihood of becoming true, 3,763 number of, 29,700 scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

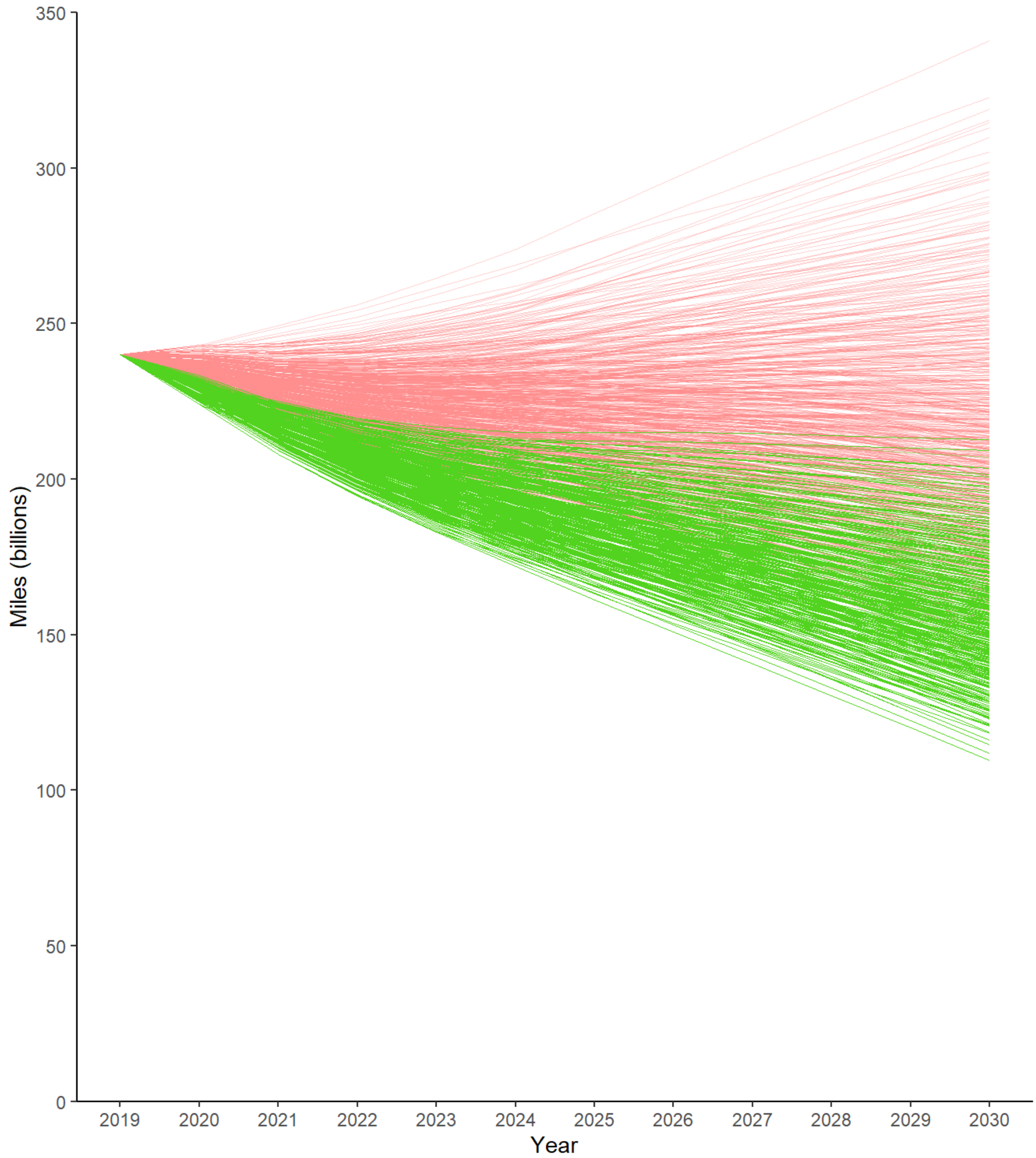


Figure 9.2: Total parc mileage from all scenarios in the model from cars only (WTW)

Table 9.7: GOV total well to wheel emissions split by fuel type

Scenario	Year	Petrol	Diesel	PHEV	Total
Low	2020	40.41	38.98	0.50	79.95
Low	2021	37.62	34.95	0.71	73.34
Low	2022	35.21	31.10	0.95	67.35
Low	2023	33.14	27.54	1.18	61.97
Low	2024	31.09	24.16	1.39	56.78
Low	2025	28.99	20.94	1.59	51.69
Low	2026	26.87	17.93	1.75	46.76

Scenario	Year	Petrol	Diesel	PHEV	Total
Low	2027	24.69	15.12	1.88	41.98
Low	2028	22.38	12.55	1.99	37.17
Low	2029	19.95	10.21	2.11	32.48
Low	2030	17.43	8.16	2.18	27.97
Mid	2020	40.62	39.18	0.91	80.81
Mid	2021	37.96	35.30	1.27	74.65
Mid	2022	35.66	31.55	1.71	69.08
Mid	2023	33.68	28.07	2.12	64.10
Mid	2024	31.71	24.73	2.51	59.26
Mid	2025	29.68	21.53	2.85	54.48
Mid	2026	27.62	18.52	3.12	49.81
Mid	2027	25.47	15.69	3.35	45.27
Mid	2028	23.18	13.08	3.54	40.45
Mid	2029	20.75	10.69	3.74	35.76
Mid	2030	18.21	8.58	3.86	31.21
High	2020	41.25	39.72	0.92	81.96
High	2021	40.28	36.42	1.62	78.42
High	2022	38.87	33.01	2.64	74.65
High	2023	37.27	29.69	3.91	71.07
High	2024	35.01	26.35	5.32	66.92
High	2025	32.19	23.00	6.81	62.37
High	2026	29.46	19.87	7.72	57.45
High	2027	26.77	16.95	8.13	52.31
High	2028	24.14	14.27	8.07	46.98
High	2029	21.50	11.81	7.68	41.52
High	2030	18.83	9.60	7.04	36.14

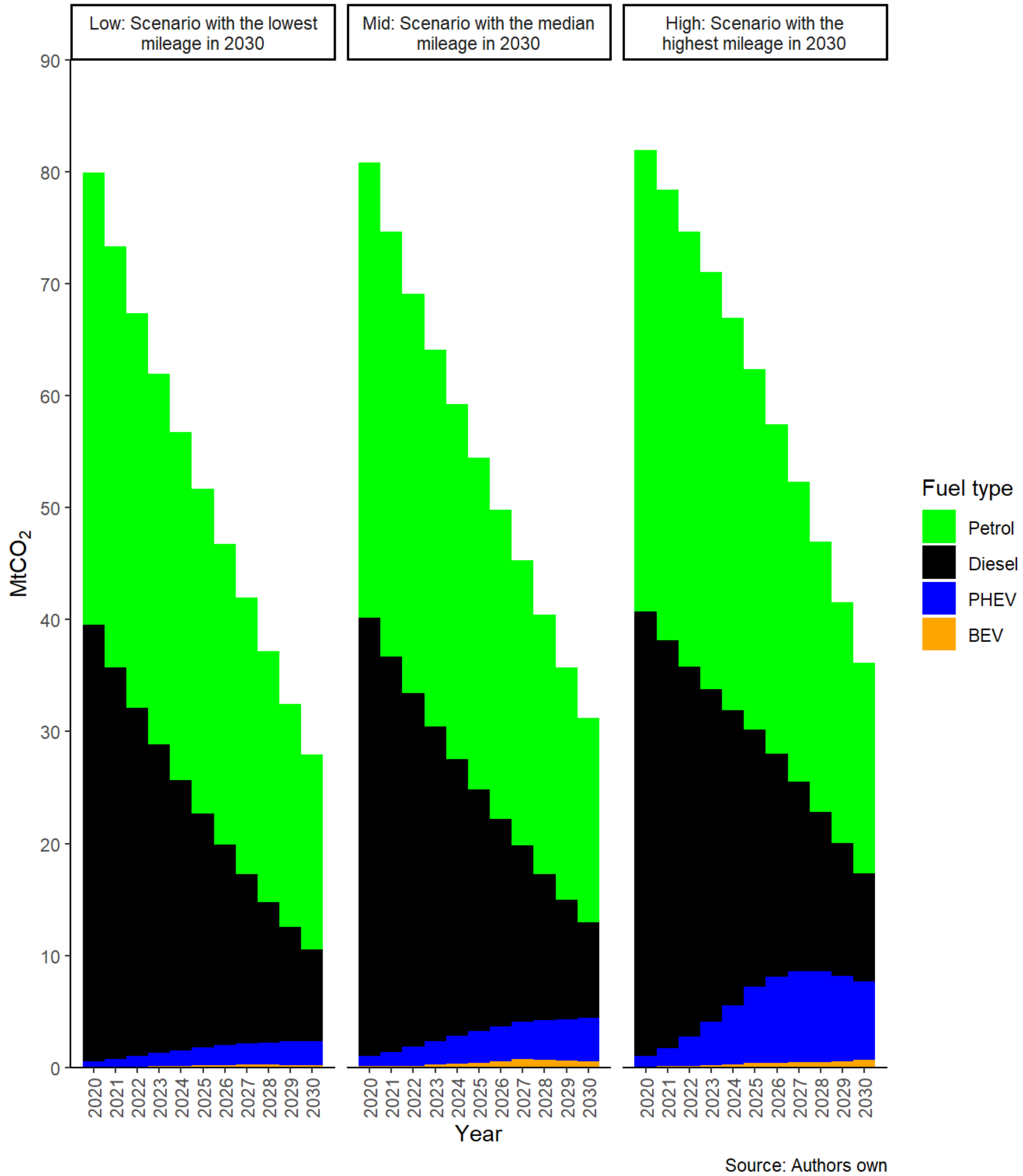


Figure 9.3: GOV total well to wheel CO2 emissions split by scenario and fuel type

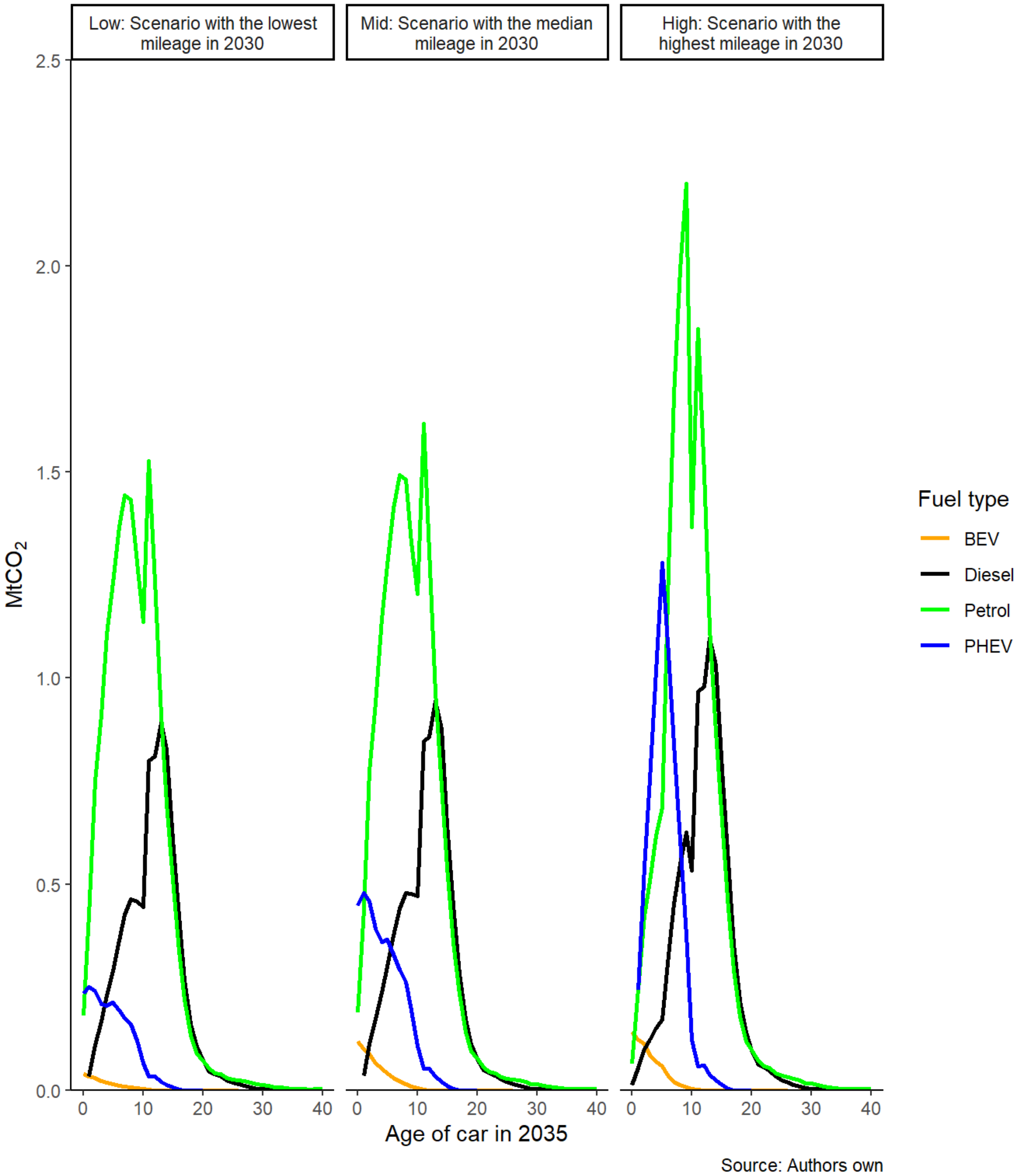
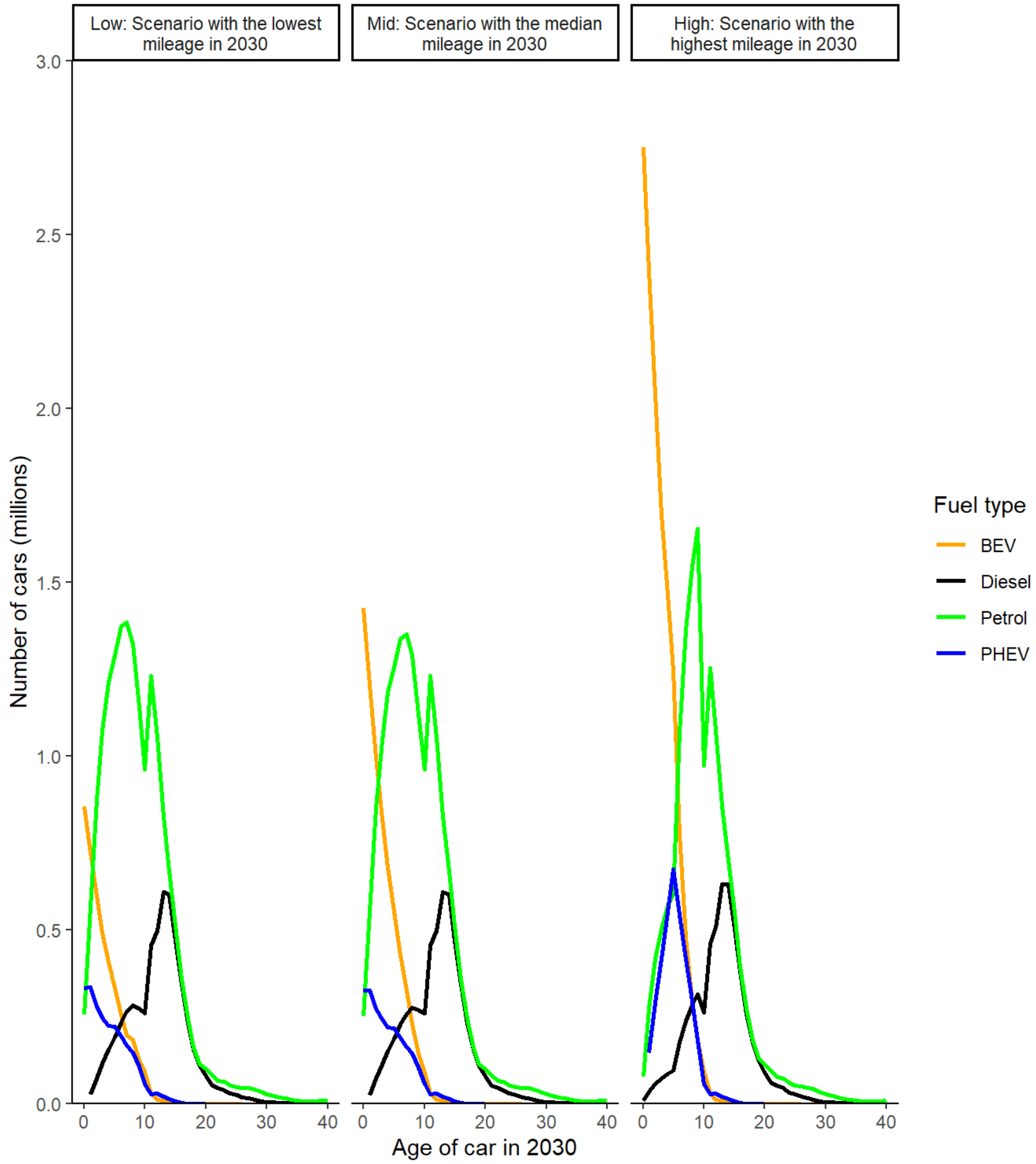


Figure 9.4: Total well to wheel CO2 emissions split by scenario and age of car (up to 40 years old) in 2030



Source: Authors own

Figure 9.5: The number of cars in the parc by fuel type and age of car (up to 40 years old) in 2030 (WTW)

Table 9.8: Total mileage split by fuel type (WTW)

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Low	2020	111,283,548,454	109,984,468,708	1,427,970,161	1,264,225,086	223,960,212,409
Low	2021	105,023,859,686	98,922,795,641	2,068,959,223	2,049,153,188	208,064,767,739
Low	2022	100,095,107,315	88,514,238,380	2,890,778,203	3,108,268,864	194,608,392,762
Low	2023	96,180,390,455	78,911,967,571	3,710,306,766	4,079,958,834	182,882,623,625
Low	2024	92,339,162,253	69,748,215,912	4,554,053,227	5,260,023,336	171,901,454,727
Low	2025	88,203,106,968	60,948,367,498	5,408,173,504	6,639,656,165	161,199,304,136

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2026	83,868,709,514	52,628,489,765	6,147,743,533	8,215,683,965	150,860,626,776
Low	2027	79,074,656,675	44,802,452,806	6,879,446,669	9,983,265,459	140,739,821,609
Low	2028	73,487,345,195	37,491,463,793	7,590,321,366	11,889,673,605	130,458,803,960
Low	2029	66,917,966,674	30,728,836,275	8,387,353,379	14,015,237,371	120,049,393,699
Low	2030	59,521,260,037	24,712,689,826	9,039,418,842	16,350,927,801	109,624,296,505
Mid	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Mid	2020	111,869,251,340	110,563,334,332	2,346,617,643	2,095,596,254	226,874,799,569
Mid	2021	105,973,897,718	99,905,267,012	3,383,221,694	3,675,807,049	212,938,193,474
Mid	2022	101,330,992,849	89,787,780,215	4,725,305,695	5,949,396,781	201,793,475,539
Mid	2023	97,673,123,289	80,392,957,531	6,076,583,710	8,881,652,368	193,024,316,897
Mid	2024	94,082,254,880	71,366,998,853	7,459,954,426	12,375,927,585	185,285,135,744
Mid	2025	90,181,052,909	62,637,375,758	8,843,422,049	16,508,910,252	178,170,760,967
Mid	2026	86,062,550,051	54,325,395,694	10,026,283,270	21,129,695,872	171,543,924,887
Mid	2027	81,445,939,652	46,449,883,677	11,204,863,862	26,319,994,285	165,420,681,475
Mid	2028	75,986,441,097	39,040,162,051	12,349,761,036	31,915,333,791	159,291,697,976
Mid	2029	69,479,924,461	32,138,676,979	13,654,228,990	38,149,738,993	153,422,569,423
Mid	2030	62,064,868,621	25,958,513,292	14,725,494,771	45,006,304,917	147,755,181,600
High	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
High	2020	113,550,313,160	112,037,683,560	2,373,251,427	2,121,524,718	230,082,772,866
High	2021	112,703,665,150	103,062,100,538	4,345,759,251	4,156,278,523	224,267,803,461
High	2022	110,841,788,559	93,918,609,068	7,412,659,170	7,266,401,212	219,439,458,011
High	2023	108,380,099,965	85,009,550,962	11,492,593,608	11,962,165,085	216,844,409,621
High	2024	103,683,651,459	75,913,999,081	16,348,632,540	19,079,477,346	215,025,760,426
High	2025	96,688,071,596	66,602,080,525	21,874,122,252	29,938,451,905	215,102,726,278
High	2026	89,805,606,870	57,834,701,970	25,653,493,864	41,731,756,438	215,025,559,142
High	2027	82,836,806,151	49,611,127,890	27,748,885,675	54,504,398,753	214,701,218,469
High	2028	75,879,783,210	42,017,974,753	28,121,865,469	68,024,999,121	214,044,622,552
High	2029	68,511,203,120	35,000,862,094	27,126,427,553	82,657,986,669	213,296,479,436
High	2030	60,609,638,264	28,602,103,879	24,911,124,272	98,566,044,594	212,688,911,008

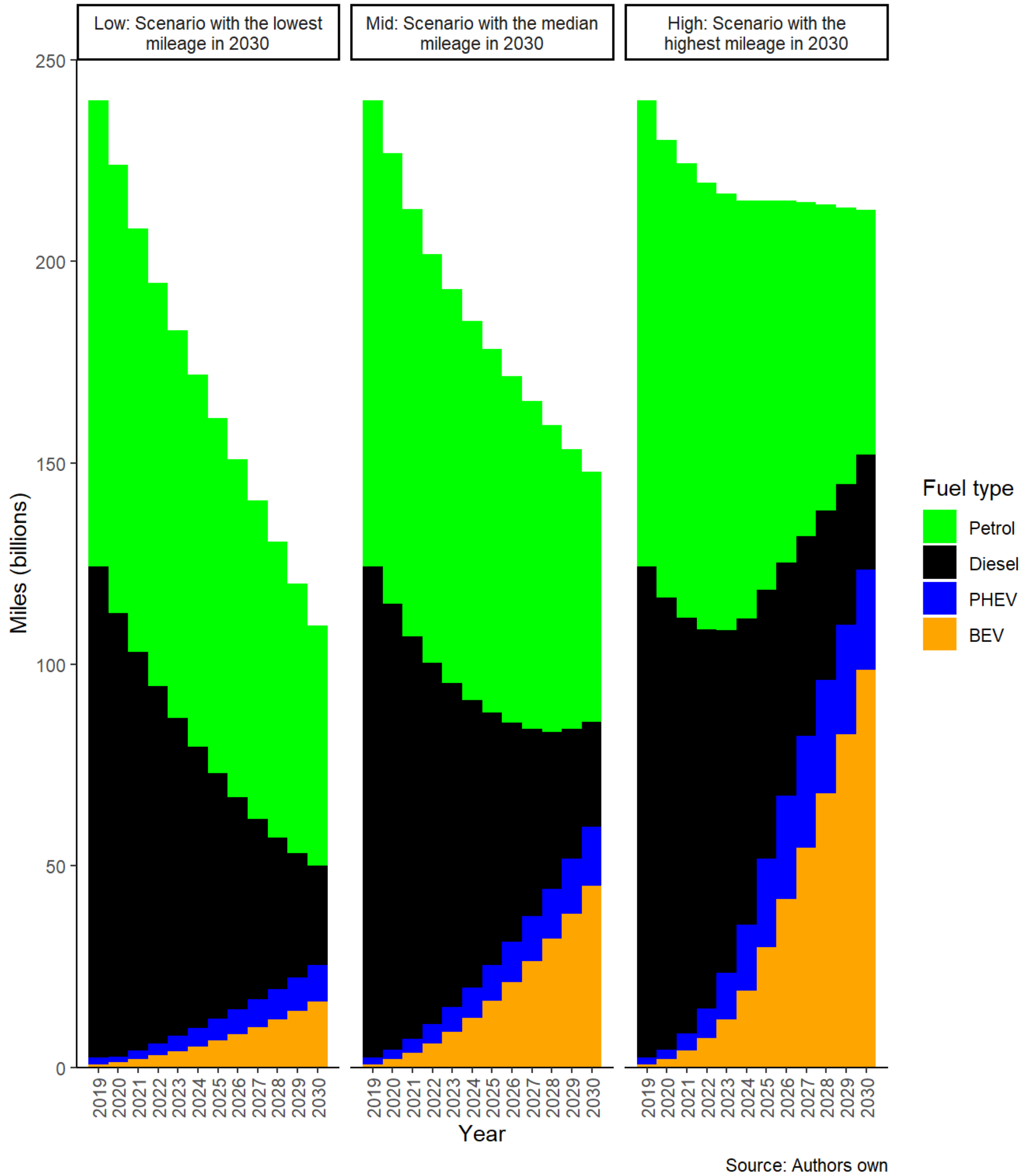


Figure 9.6: Total car parc mileage split by scenarios and fuel type (WTW)

Table 9.9: Total number of cars split by fuel type from 2019 - 2030 (WTW)

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Low	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Low	2021	19,262,598	11,997,213	341,192	337,500	31,938,504
Low	2022	19,328,295	11,518,654	501,084	535,304	31,883,336
Low	2023	19,500,287	10,992,934	675,838	740,552	31,909,611
Low	2024	19,674,241	10,399,548	873,891	1,004,214	31,951,895
Low	2025	19,773,598	9,734,572	1,095,330	1,339,650	31,943,150
Low	2026	19,801,460	9,009,282	1,313,671	1,747,542	31,871,956

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2027	19,694,426	8,228,181	1,552,116	2,239,657	31,714,380
Low	2028	19,339,837	7,397,102	1,810,810	2,814,792	31,362,541
Low	2029	18,653,808	6,531,884	2,114,015	3,500,946	30,800,652
Low	2030	17,640,168	5,676,312	2,408,124	4,309,963	30,034,566
Mid	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Mid	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Mid	2021	19,236,634	11,991,178	338,192	362,500	31,928,505
Mid	2022	19,267,718	11,505,163	494,078	610,355	31,877,314
Mid	2023	19,403,710	10,972,560	664,843	955,548	31,996,661
Mid	2024	19,542,671	10,373,372	858,009	1,398,379	32,172,431
Mid	2025	19,610,002	9,703,733	1,073,571	1,961,867	32,349,173
Mid	2026	19,609,049	8,974,827	1,286,059	2,644,716	32,514,651
Mid	2027	19,475,685	8,191,076	1,518,738	3,470,364	32,655,864
Mid	2028	19,101,074	7,358,558	1,770,753	4,435,957	32,666,342
Mid	2029	18,404,398	6,493,233	2,066,356	5,588,606	32,552,592
Mid	2030	17,388,417	5,638,311	2,353,001	6,948,612	32,328,342
High	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
High	2020	19,523,143	12,486,741	222,191	198,718	32,430,794
High	2021	20,025,938	12,122,440	423,724	401,174	32,973,277
High	2022	20,414,026	11,676,328	746,443	722,527	33,559,323
High	2023	20,617,970	11,148,631	1,190,490	1,231,492	34,188,583
High	2024	20,498,087	10,519,464	1,755,062	2,039,545	34,812,158
High	2025	19,921,489	9,778,359	2,442,874	3,323,350	35,466,072
High	2026	19,317,920	9,002,082	2,990,248	4,811,072	36,121,322
High	2027	18,657,376	8,194,369	3,388,300	6,528,366	36,768,411
High	2028	17,893,990	7,362,493	3,633,617	8,510,240	37,400,341
High	2029	16,964,607	6,516,087	3,729,301	10,808,603	38,018,598
High	2030	15,827,132	5,673,785	3,667,223	13,467,885	38,636,024

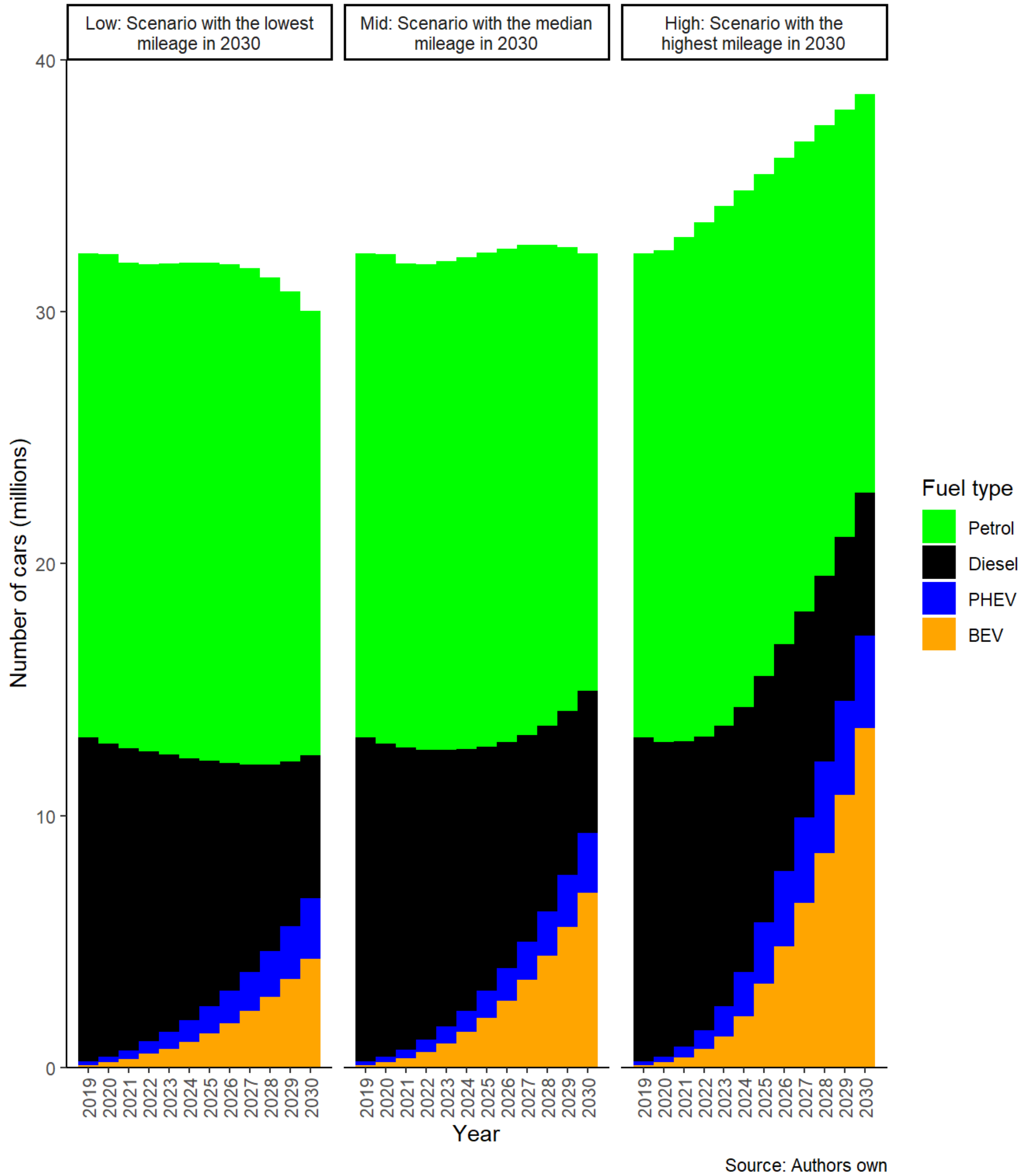


Figure 9.7: Total number of cars in the parc split by scenario and fuel type (WTW)

9.2.2 CCC

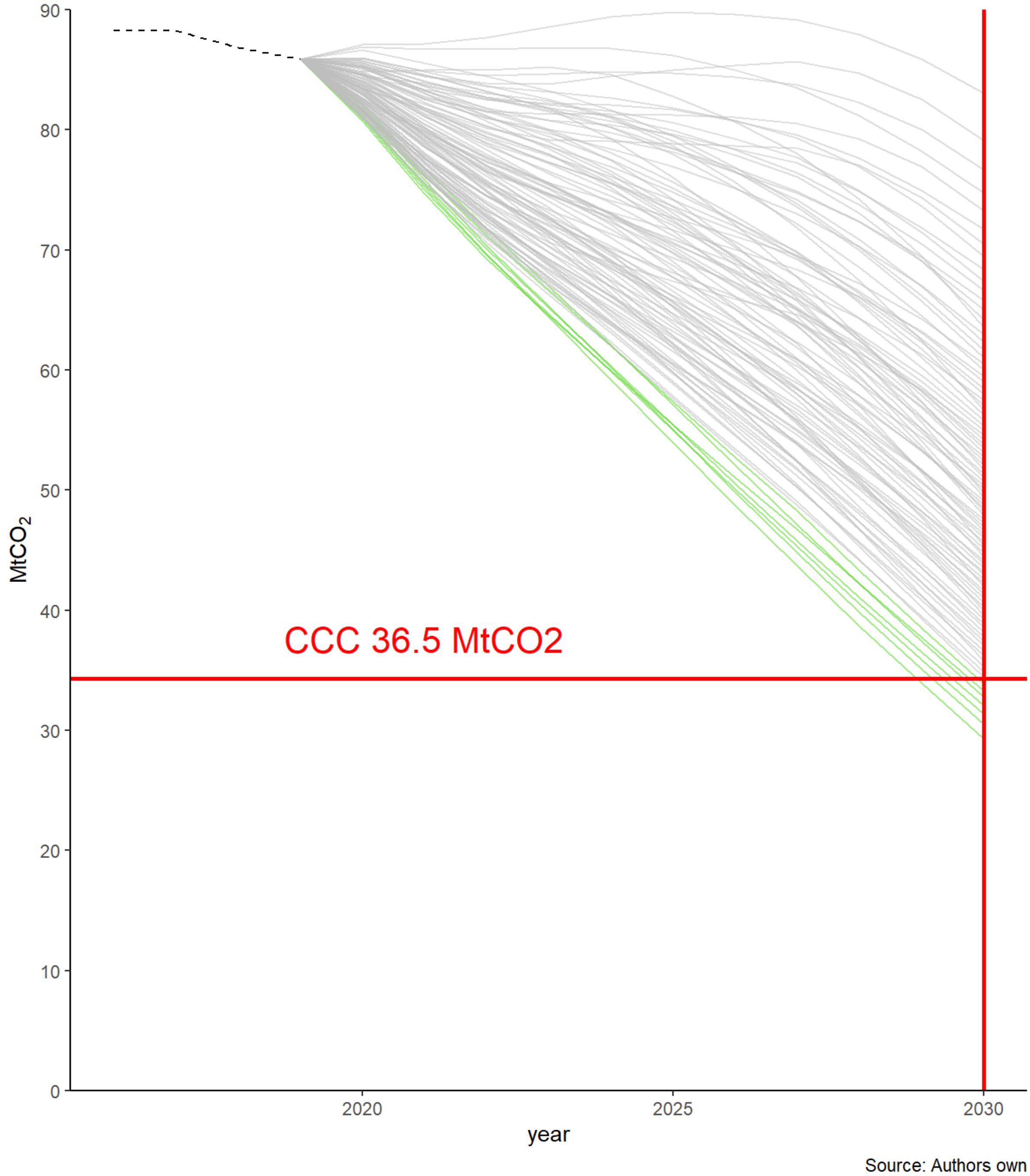


Figure 9.8: Total car well to wheel CO2 emissions from all scenarios

Note: each line (or scenario) does not have an equal likelihood of becoming true, 2,308 number of, 29,700 scenarios were successful in meeting the target, but this is not a measure of likelihood of success.

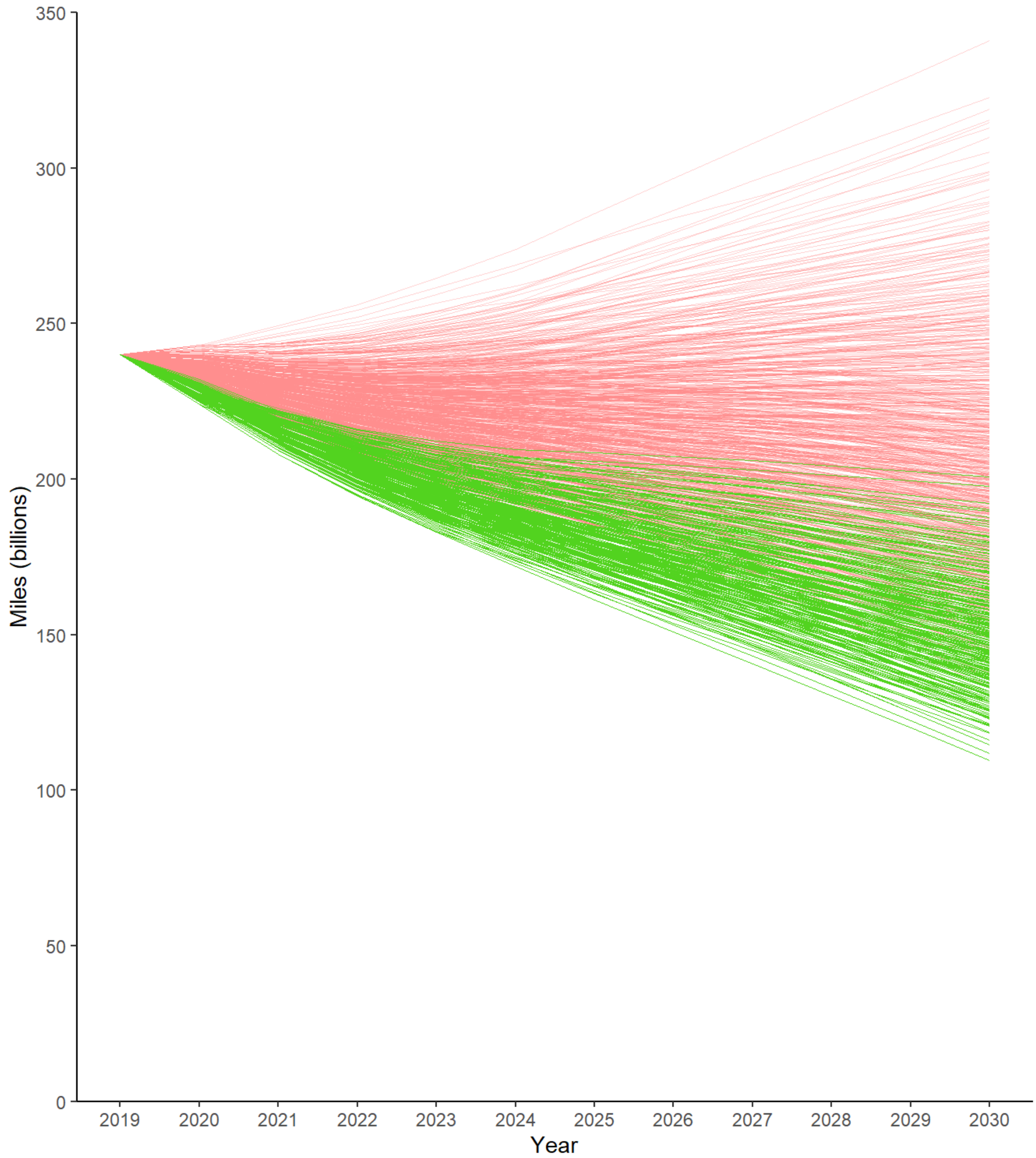


Figure 9.9: Total parc mileage from all scenarios in the model from cars only (WTW)

Table 9.10: CCC total well to wheel emissions split by fuel type

Scenario	Year	Petrol	Diesel	PHEV	Total
Low	2020	40.41	38.98	0.50	79.95
Low	2021	37.62	34.95	0.71	73.34
Low	2022	35.21	31.10	0.95	67.35
Low	2023	33.14	27.54	1.18	61.97
Low	2024	31.09	24.16	1.39	56.78
Low	2025	28.99	20.94	1.59	51.69
Low	2026	26.87	17.93	1.75	46.76

Scenario	Year	Petrol	Diesel	PHEV	Total
Low	2027	24.69	15.12	1.88	41.98
Low	2028	22.38	12.55	1.99	37.17
Low	2029	19.95	10.21	2.11	32.48
Low	2030	17.43	8.16	2.18	27.97
Mid	2020	41.40	39.74	0.50	81.69
Mid	2021	39.27	36.31	0.71	76.35
Mid	2022	37.19	32.91	0.89	71.09
Mid	2023	35.18	29.65	1.05	66.06
Mid	2024	33.13	26.47	1.21	61.06
Mid	2025	30.88	23.35	1.36	55.89
Mid	2026	28.51	20.34	1.48	50.70
Mid	2027	26.16	17.51	1.58	45.64
Mid	2028	23.70	14.85	1.68	40.66
Mid	2029	21.18	12.39	1.77	35.78
Mid	2030	18.67	10.18	1.84	31.12
High	2020	41.04	39.51	0.91	81.54
High	2021	39.87	36.04	1.60	77.61
High	2022	38.27	32.50	2.60	73.50
High	2023	36.50	29.08	3.83	69.61
High	2024	34.11	25.67	5.18	65.20
High	2025	31.20	22.30	6.60	60.46
High	2026	28.41	19.16	7.44	55.40
High	2027	25.68	16.26	7.79	50.18
High	2028	23.04	13.62	7.70	44.83
High	2029	20.41	11.22	7.29	39.42
High	2030	17.78	9.07	6.64	34.13

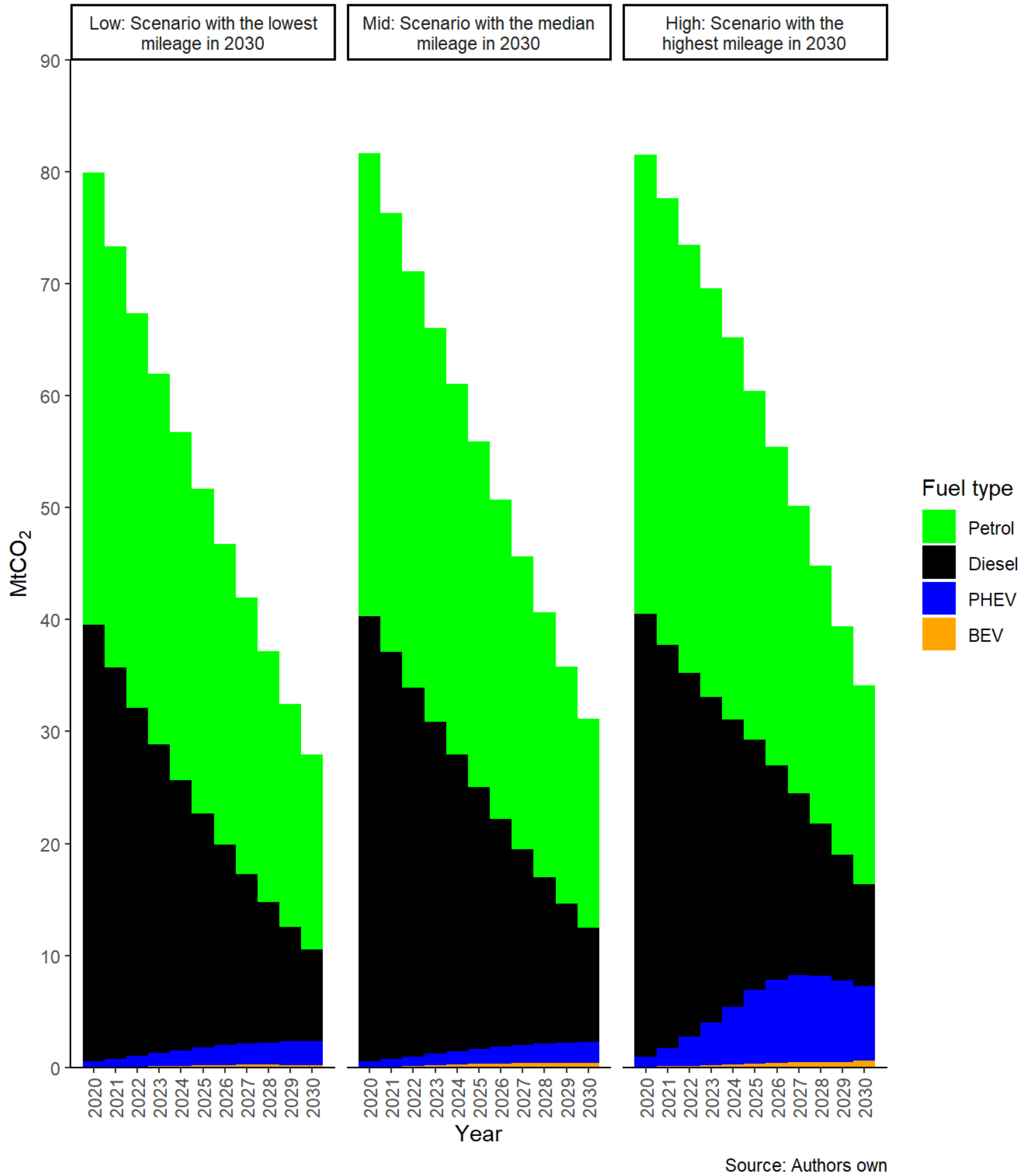
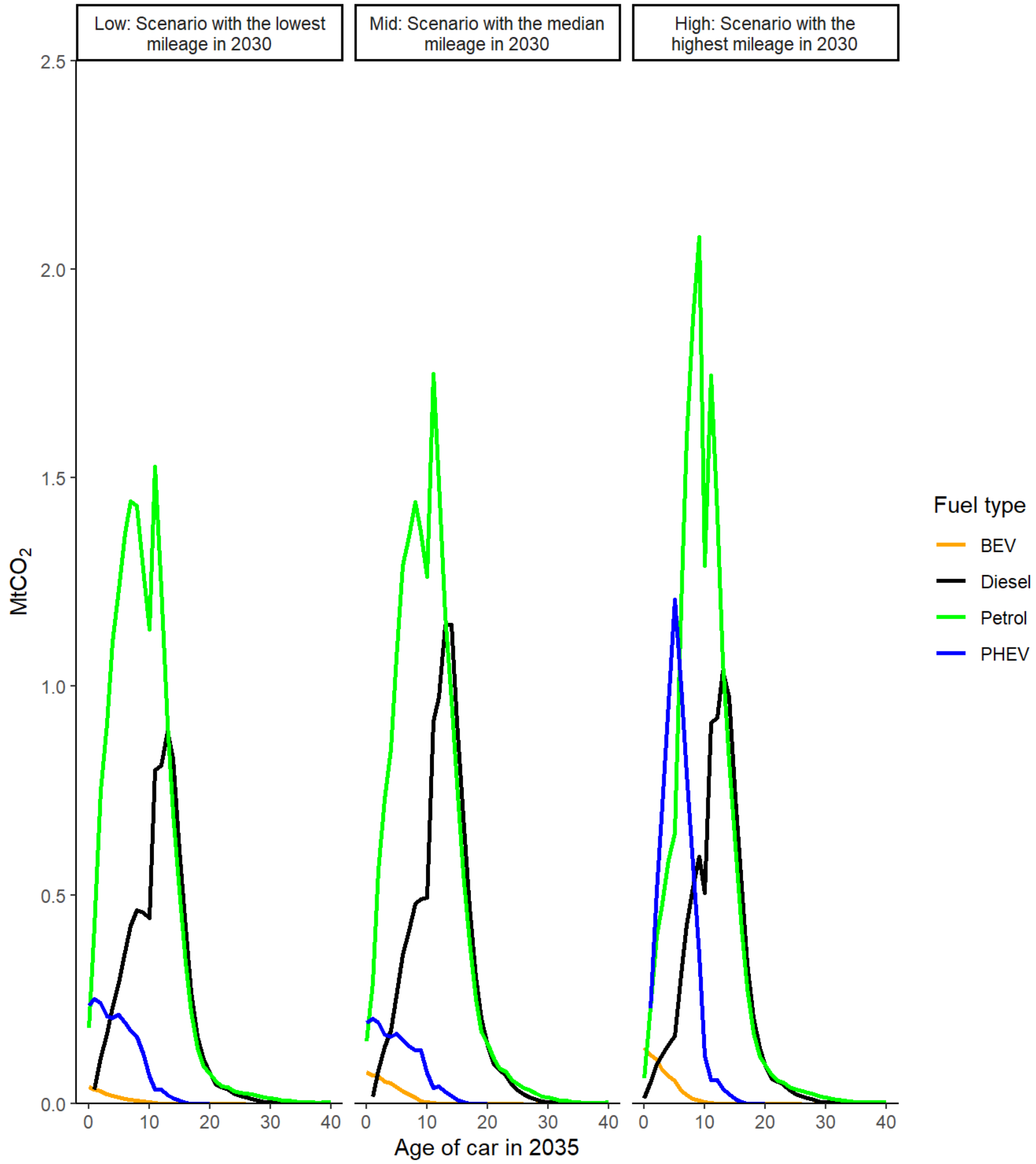


Figure 9.10: CCC total well to wheel CO2 emissions split by scenario and fuel type



Source: Authors own

Figure 9.11: Total well to wheel CO2 emissions split by scenario and age of car (up to 40 years old) in 2030

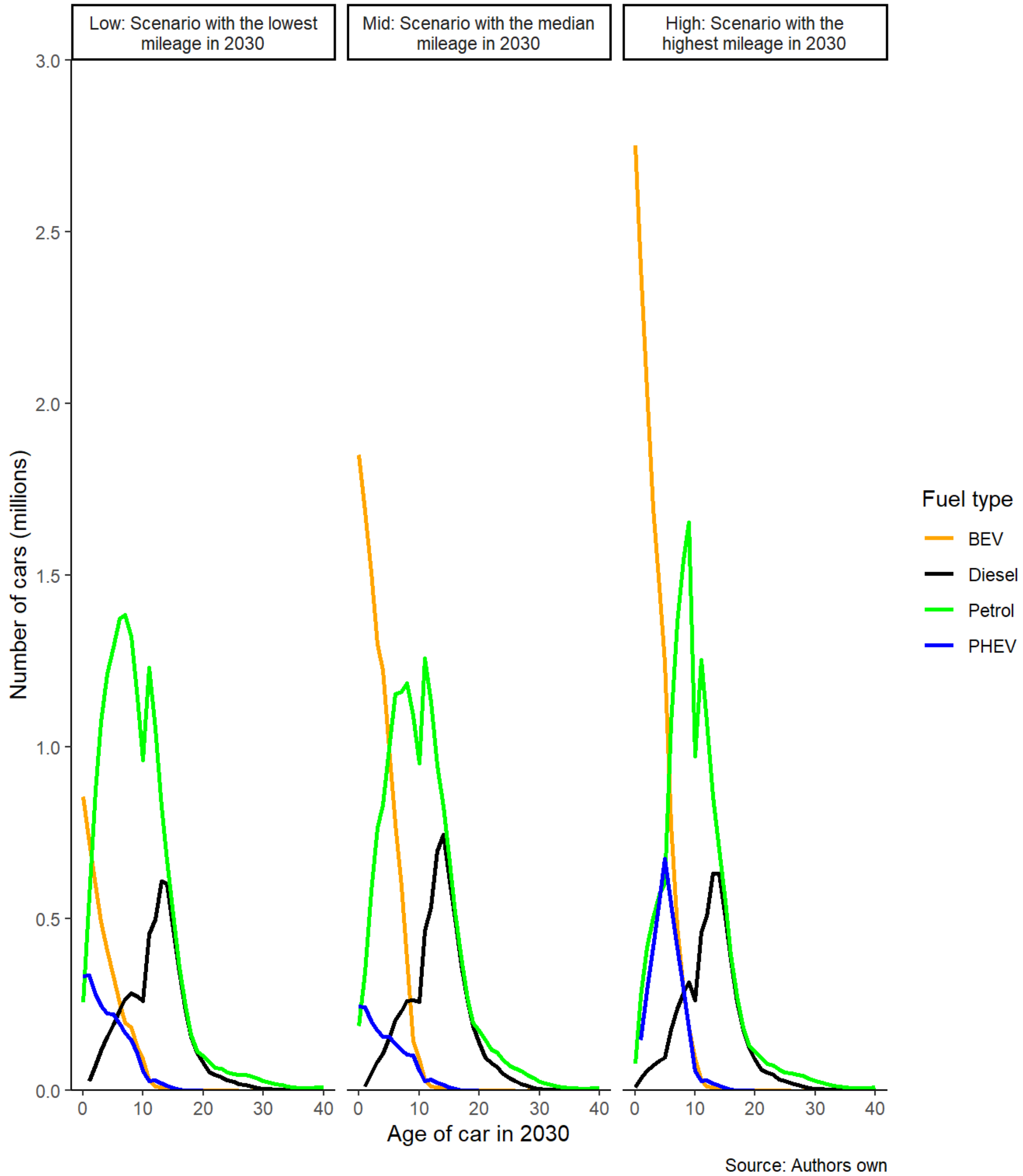
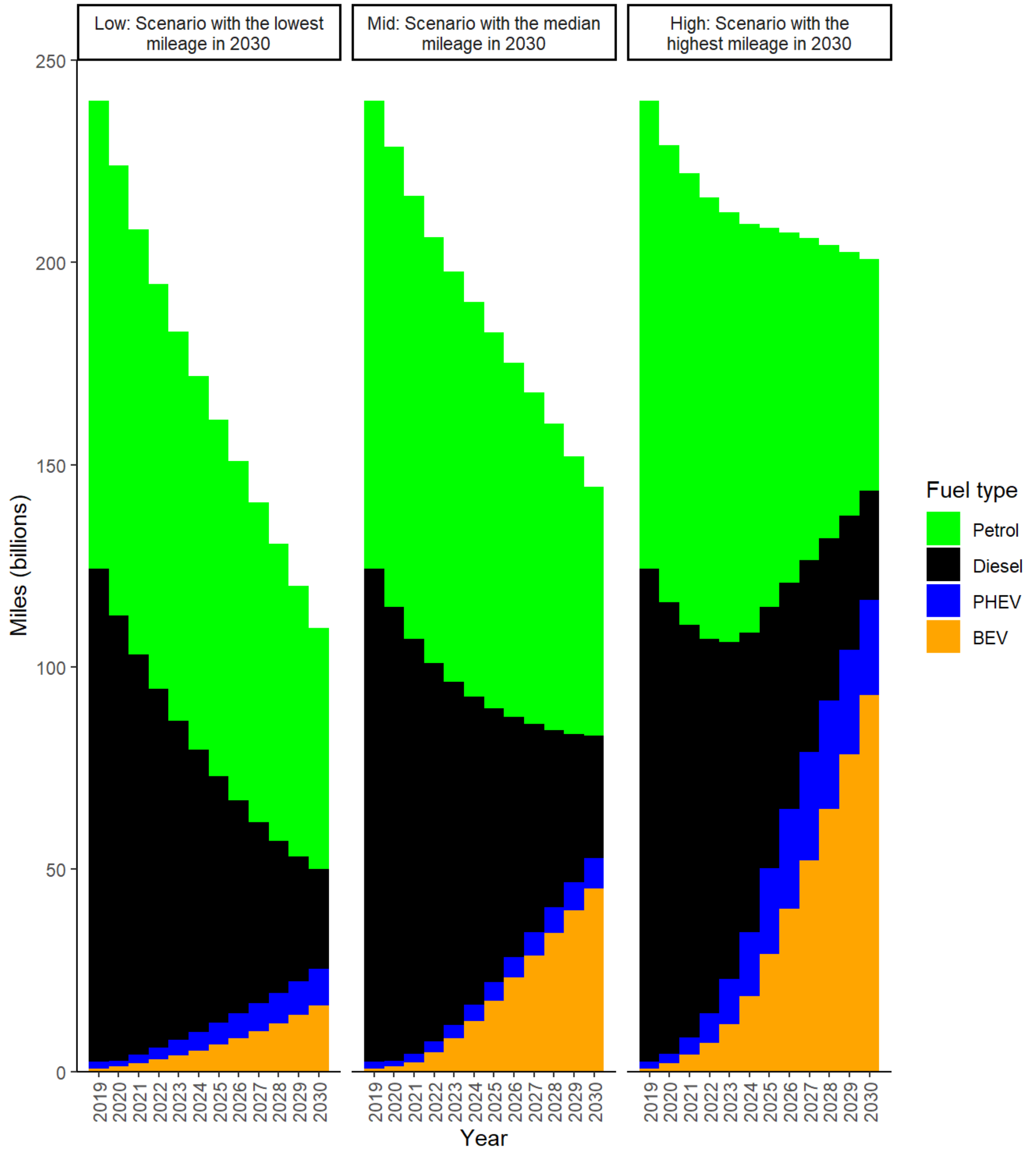


Figure 9.12: The number of cars in the parc by fuel type and age of car (up to 40 years old) in 2030 (WTW)

Table 9.11: Total mileage split by fuel type (WTW)

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Low	2020	111,283,548,454	109,984,468,708	1,427,970,161	1,264,225,086	223,960,212,409
Low	2021	105,023,859,686	98,922,795,641	2,068,959,223	2,049,153,188	208,064,767,739
Low	2022	100,095,107,315	88,514,238,380	2,890,778,203	3,108,268,864	194,608,392,762
Low	2023	96,180,390,455	78,911,967,571	3,710,306,766	4,079,958,834	182,882,623,625
Low	2024	92,339,162,253	69,748,215,912	4,554,053,227	5,260,023,336	171,901,454,727
Low	2025	88,203,106,968	60,948,367,498	5,408,173,504	6,639,656,165	161,199,304,136

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2026	83,868,709,514	52,628,489,765	6,147,743,533	8,215,683,965	150,860,626,776
Low	2027	79,074,656,675	44,802,452,806	6,879,446,669	9,983,265,459	140,739,821,609
Low	2028	73,487,345,195	37,491,463,793	7,590,321,366	11,889,673,605	130,458,803,960
Low	2029	66,917,966,674	30,728,836,275	8,387,353,379	14,015,237,371	120,049,393,699
Low	2030	59,521,260,037	24,712,689,826	9,039,418,842	16,350,927,801	109,624,296,505
Mid	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
Mid	2020	113,857,768,690	112,059,364,201	1,433,143,798	1,272,296,023	228,622,572,711
Mid	2021	109,360,880,762	102,681,125,605	2,072,914,920	2,229,673,809	216,344,595,095
Mid	2022	105,301,176,451	93,563,352,277	2,673,738,838	4,713,918,238	206,252,185,804
Mid	2023	101,454,570,043	84,799,913,438	3,277,042,229	8,244,241,351	197,775,767,062
Mid	2024	97,559,978,890	76,255,618,725	3,891,658,319	12,556,308,584	190,263,564,519
Mid	2025	92,829,441,903	67,709,105,840	4,544,953,235	17,577,441,986	182,660,942,964
Mid	2026	87,449,742,593	59,352,528,166	5,118,958,167	23,262,285,827	175,183,514,753
Mid	2027	81,928,197,092	51,418,990,210	5,704,687,732	28,739,826,491	167,791,701,525
Mid	2028	75,654,964,676	43,844,543,571	6,284,570,644	34,286,010,945	160,070,089,836
Mid	2029	68,672,695,707	36,719,786,176	6,952,474,745	39,791,264,250	152,136,220,878
Mid	2030	61,356,127,840	30,268,126,854	7,517,542,456	45,298,264,969	144,440,062,119
High	2019	115,786,476,095	121,829,205,113	1,669,923,769	743,999,598	240,029,604,575
High	2020	112,961,969,569	111,457,177,428	2,360,954,787	2,110,532,362	228,890,634,146
High	2021	111,538,777,204	101,996,866,338	4,300,842,144	4,113,319,860	221,949,805,546
High	2022	109,127,770,881	92,466,285,370	7,298,032,467	7,154,036,189	216,046,124,906
High	2023	106,151,277,718	83,261,340,927	11,256,249,959	11,716,164,762	212,385,033,366
High	2024	101,025,237,933	73,967,589,987	15,929,459,167	18,590,286,042	209,512,573,129
High	2025	93,720,892,706	64,558,185,305	21,202,845,716	29,019,695,941	208,501,619,668
High	2026	86,598,603,756	55,769,395,851	24,737,394,774	40,241,494,555	207,346,888,935
High	2027	79,464,783,314	47,591,616,709	26,619,316,821	52,285,698,083	205,961,414,927
High	2028	72,413,803,417	40,098,709,235	26,837,336,002	64,917,804,261	204,267,652,916
High	2029	65,043,033,997	33,229,051,008	25,753,235,518	78,473,680,102	202,499,000,625
High	2030	57,243,319,292	27,013,514,874	23,527,535,908	93,091,589,451	200,875,959,525



Source: Authors own

Figure 9.13: Total car parc mileage split by scenarios and fuel type (WTW)

Table 9.12: Total number of cars split by fuel type from 2019 - 2030 (WTW)

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Low	2020	19,409,402	12,441,368	222,000	198,347	32,271,117
Low	2021	19,262,598	11,997,213	341,192	337,500	31,938,504
Low	2022	19,328,295	11,518,654	501,084	535,304	31,883,336
Low	2023	19,500,287	10,992,934	675,838	740,552	31,909,611
Low	2024	19,674,241	10,399,548	873,891	1,004,214	31,951,895
Low	2025	19,773,598	9,734,572	1,095,330	1,339,650	31,943,150
Low	2026	19,801,460	9,009,282	1,313,671	1,747,542	31,871,956

Scenario	Year	Petrol	Diesel	PHEV	BEV	Total
Low	2027	19,694,426	8,228,181	1,552,116	2,239,657	31,714,380
Low	2028	19,339,837	7,397,102	1,810,810	2,814,792	31,362,541
Low	2029	18,653,808	6,531,884	2,114,015	3,500,946	30,800,652
Low	2030	17,640,168	5,676,312	2,408,124	4,309,963	30,034,566
Mid	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
Mid	2020	19,711,135	12,593,431	220,503	197,549	32,722,618
Mid	2021	19,764,560	12,290,063	334,795	359,828	32,749,245
Mid	2022	19,891,228	11,935,001	448,943	790,085	33,065,257
Mid	2023	19,983,691	11,505,690	572,067	1,441,310	33,502,759
Mid	2024	20,048,789	11,002,665	710,990	2,273,370	34,035,814
Mid	2025	19,931,505	10,404,244	867,284	3,313,926	34,516,958
Mid	2026	19,635,454	9,723,733	1,020,567	4,574,066	34,953,821
Mid	2027	19,268,449	8,991,486	1,188,972	5,893,140	35,342,047
Mid	2028	18,674,056	8,199,373	1,370,894	7,338,469	35,582,792
Mid	2029	17,824,905	7,363,220	1,585,948	8,908,135	35,682,208
Mid	2030	16,809,230	6,525,361	1,794,093	10,603,508	35,732,191
High	2019	19,240,316	12,852,290	146,414	90,812	32,329,832
High	2020	19,523,143	12,486,741	222,191	198,718	32,430,794
High	2021	20,025,938	12,122,440	423,724	401,174	32,973,277
High	2022	20,414,026	11,676,328	746,443	722,527	33,559,323
High	2023	20,617,970	11,148,631	1,190,490	1,231,492	34,188,583
High	2024	20,498,087	10,519,464	1,755,062	2,039,545	34,812,158
High	2025	19,921,489	9,778,359	2,442,874	3,323,350	35,466,072
High	2026	19,317,920	9,002,082	2,990,248	4,811,072	36,121,322
High	2027	18,657,376	8,194,369	3,388,300	6,528,366	36,768,411
High	2028	17,893,990	7,362,493	3,633,617	8,510,240	37,400,341
High	2029	16,964,607	6,516,087	3,729,301	10,808,603	38,018,598
High	2030	15,827,132	5,673,785	3,667,223	13,467,885	38,636,024

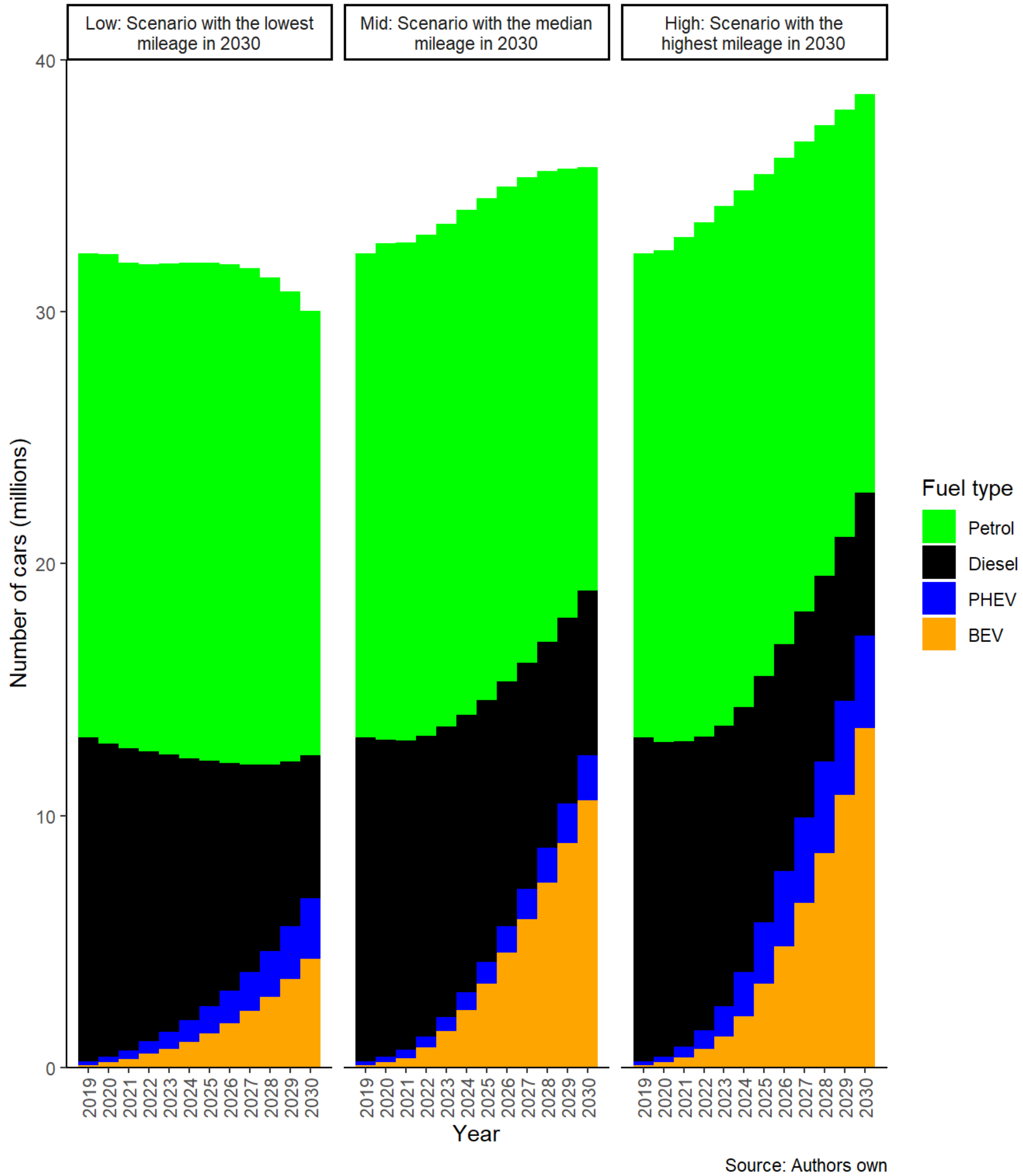


Figure 9.14: Total number of cars in the parc split by scenario and fuel type (WTW)

---

1. ‘Parc’ is the industry term for the population consisting of all the cars on the road.↩
2. The ‘departure rate’ is the rate and pattern of disappearance from the parc of the older cars as they are retired, with the options being taken from recent DfT data tables, which show a slowing down since 2016.↩

3. There are 29,700 in a the deeper well-to-wheel analysis detailed in the appendix.↩

4. https://www.gov.uk/guidance/carbon-budgets↩

5. Spritmonitor.de is a German Internet-based service that collects and delivers information about the fuel consumption of vehicles under real-world conditions.↩

6. Please note that fuel economy, although conventionally measured in miles per gallon or litres per kilometre, is often referred to in this report in terms of the emissions figure, thus in gCO_2/km. Fuel economy and emissions are of course directly proportional to each other.↩

7. https://www.gov.uk/government/statistical-data-sets/road-traffic-statistics-tra↩

8. The MOT Project was an EPSRC-funded initiative, undertaken in 2016, which analysed MOT test result data for environmental and social research purposes. Its aim was to reduce emissions from car travel by understanding car ownership patterns and the effects of policy measures. See https://environment.leeds.ac.uk/transport-research/dir-record/research-projects/754/mot-motoring-and-vehicle-ownership-trends-in-the-uk↩

9. Note that this in all mileage driven by all cars, summed; it is not per-vehicle mileage, and the two do not vary in fixed proportion to each other from scenario to scenario, as the number and age of cars making up that total mileage also varies.↩


RAC
Foundation