Applied Research and Smart Technology (ARSTech) Vol. 4 No. 2 (2023) 72–91

ARS Tech

Applied Research and Smart Technology (ARSTech)

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Journal homepage: https://journals2.ums.ac.id/index.php/arstech

ISSN 2722-9645

Review Article

The effects of higher bioethanol blends on greenhouse gas emissions from the UK passenger car fleet at various time horizons during the transition to net zero: A review

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Permalink (DOI): https://doi.org/10.23917/arstech.v4i2.2714

ARTICLE INFO

Article history:

Received 23 August 2023
Revised 08 September 2023
Accepted 15 September 2023
Available online 30 November 2023
Published regularly 31 December 2023

Keywords:

Bioethanol
Environment
Greenhouse gas emissions
Passenger car
Vehicle fleet turnover model

ABSTRACT

There is a need to minimise the Greenhouse Gas Emissions (GHG) of petrol-powered cars during the transition to net zero. This research examines the effects on GHG from the recent adoption of E10 as the standard 95-octane petrol grade in the United Kingdom (UK). Also, it considers the potential of using higher bioethanol blends within the national car fleet and the effect of increased lifetime mileage due to the growing incidence of extended vehicle ownership. A comprehensive fleet turnover model and a separate numerical model to predict the GHG emissions for various powertrain types using different bioethanol blends were developed. Sensitivity studies that model the effects of different annual mileage using E10 and applying the proposed UK fleet composition scenarios at 10-year intervals from 2020 to 2050 were conducted. The results support the claimed percentage reduction of GHG emissions arising from the UK petrol car fleet using E10 when compared to E5 and establish that using a higher bioethanol blend such as E15 would provide still further reductions in most instances except in the case of plug-in hybrid vehicles where an increase in GHG emissions was observed at the 2030 and 2040 time horizons. An increase in annual mileage creates a linear increase in GHG emissions, although the rate of increase is not the same for each propulsion type. Such an increase can potentially disrupt the achievement of the UK's 2050 net zero target and future periodic carbon budgets.

1. INTRODUCTION

To support efforts to reduce carbon tailpipe emissions from internal combustion engine vehicles (ICEV) during the transition to zero-emission technologies, e.g., battery electric vehicles (BEV), and the achievement of the net zero goal in 2050, the UK government introduced E10 as the standard 95-octane petrol grade in Great Britain (GB) in September 2021 [1-2]. Information provided by the Department for Transport (DfT) claims that switching to E10 can reduce tailpipe CO_2 emissions by around 2% compared to E5 and approximately 4% compared to petrol, E0. Further, to maximise the carbon savings gained from introducing E10, the UK government proposed, during 2021, an increase to the principal obligation of the Renewable Transport Fuel Obligation (RTFO) of an extra 1.5% in 2022, and then gradually between 2023–2032, by a further 1% [3] raising the main RTFO obligation level from 9.6% to 14.6% by 2032. The 1.5% increase was subsequently implemented in 2022 [4].

The government claim that the savings from the introduction of E10, combined with an increase to the overall renewable fuel targets, could cut overall transport CO_2 emissions by a further 750,000 tonnes a year, which they estimate is the equivalent of taking around 350,000 cars off the road [2] as well as helping to achieve compliance with future UK carbon budgets. The sixth carbon budget [5] states that the scenarios assumed widespread use of E10 from 2021 and that this use could result in up to a 1% reduction of car emissions ($0.3MtCO_2e$/year) by 2030. The value that the government places on biofuels and their importance in achieving GHG savings during the transition to zero tailpipe emission vehicles is demonstrated by their commitment to developing a strategy to explore how carbon savings can be maximised sustainably. This commitment is set out in the 'Decarbonising Transport' document published in 2021 [6] and carried forward in the 'Decarbonising Transport: A Better, Greener Britain One Year On' document [7].

A review of the current literature suggests that no independent research has been undertaken to investigate these specific claims by the DfT and whether a 2% reduction in tailpipe CO_2 emissions is realisable, or indeed if the adoption of E10 instead of E5 could reduce the CO_2 emissions of a passenger car. In particular, an analysis based on average calorific values of fossil petrol and E10 suggests fuel economy could be reduced by 1-2 % when using E10, depending on driving style and other factors [8]. This is important as any reduction in fuel economy can potentially increase the cost of use to the consumer and may also pressure the availability of feedstock, such as corn and wheat, used for ethanol production.

Recent data from the UK Department for Transport Driver and Vehicle Licensing Agency and the Society of Motor Manufacturers and Traders (SMMT) shows that the average age of passenger cars in the UK has increased, with the potential for an increase in lifetime mileage. The average age of a UK-registered passenger car in 2020 was 9.3 years for petrol and eight years for diesel [9]. Suppose this extension to ownership is significant and polluting vehicles remain in use for longer. In that case, there is a likelihood that the achievement of the government's net zero target and periodic carbon budgets, which have been set using historical annual mileage and vehicle lifetime data, could be delayed.

Lifetime mileage is a critical component in Life-cycle Assessment modelling (LCA) [10], and in most studies, a simplified approach based on fixed annual mileage profiles and lifetime activity is used [11]. Weymar et al. [12] assert that "best guess" lifetime mileages provided by industry associations and car manufacturers are currently applied in automotive LCA. Wang et al. [13] conclude that the energy efficiency and emissions in the total life cycle of different vehicle types is highly dependent on the driving mileage. Limited attention has been placed on research in this area or modelling the effect that changes in lifetime mileage may have on achieving the UK's net zero targets.

The current work aims to address the gaps mentioned above through the development of a numerical model to calculate GHG emissions and a separate fleet turnover model, the main objective being to model the effects of adopting E10 and a higher bioethanol blend (E15) in the UK passenger car fleet at different time horizons, to determine what contribution the different blends can make to reducing GHG emissions and, consequentially, to meeting the UK government's road transport decarbonisation goal of net zero by 2050.

In addition, to model the likely impact of extended vehicle lifetime and mileage sensitivity on GHG emissions from the UK petrol-powered car fleet using E10 at different time horizons from 2020-2050 and to evaluate the claim made by the UK government that the use of E10 instead of E5 could provide further reductions of CO_2 emissions from a passenger car by the percentage stated. The work will also attempt to identify key factors and critical uncertainties, including changing consumer behaviour, likely to accelerate or delay the achievement of the 2050 transport net zero target and future periodic carbon budgets, highlighting any interventions that may be relevant to current policy and to be a source of information for the Department for Transport.

2. OVERVIEW

Central to this research was developing a comprehensive fuel modelling tool and novel fleet turnover model. The development of a bespoke fuel modelling tool was preferred over the adoption of proprietary software such as the greenhouse gases, regulated emissions, and energy use in transportation (GREET) or motor vehicle emission simulator (MOVES) models [14-17] as the authors wanted to create a tool that was designed specifically for the UK and which could be replicated using the information within this manuscript. Section 1.0 provides a general introduction and background to the issues, and section 2 sets out the aim and objectives of the study. Section 4.0 provides a detailed description of the fuel modelling analytical framework as well as gives a brief introduction to the characterisation of bioethanol and how the issue of carbon emissions resulting from indirect land-use change is addressed. The remaining sub-sections consider the energy density and fuel consumption, blend walls, and vehicle compatibility and set out the detailed bioethanol modelling input assumptions. Section 5.0 describes the methodology, input data and assumptions used to construct the Fleet Turnover Model, in general and at each time horizon, and includes a discussion about the number of licenced cars, scrappage rates and parc composition. Section 6.0 considers the average age of licenced cars, the importance of lifetime mileage concerning GHG emissions, and how these factors are considered in the modelling. In section 7, the results are presented and discussed, and conclusions are provided in section 8, where some recommendations are also included.

3. FUEL MODELLING ANALYTICAL FRAMEWORK AND INPUTS

A comprehensive numerical model was constructed using Microsoft Excel to calculate the overall CO_2e/year for the assumed passenger car fleet at different time horizons, taking into account the various powertrain types within the fleet. The model was designed to accommodate different bioethanol blends and lifetime mileages using fleet size and composition data from the separate fleet turnover model. The following subsections describe the factors considered when building the model and detail the input data used for the calculations.

3.1. Bioethanol

Three generations can characterise bioethanol: first, second and third. First-generation bioethanol is derived from food or animal feed crops such as maise (corn, wheat) [18]. In contrast, second-generation bioethanol is derived from cellulosic biomass, e.g., perennial grasses, and third-generation bioethanol is derived from algae. In this study, only first-generation bioethanol is considered the predominant type used in the UK, with 52% of UK ethanol in 2021 being produced from corn [19].

The issue of how to deal with Carbon emissions resulting from indirect land-use change (ILUC) has been a source of debate within the European Parliament for some years [20], resulting in the introduction of a 60% minimum GHG-saving threshold [1][21] and the requirement for member states and fuel suppliers to report ILUC by adding a $12gCO_2e/MJ$ emissions factor for crop bioethanol. The outputs from the modelling in this work include well-to-tank (WTT) and tank-to-wheel (TTW) GHG emissions factors, where WTT GHG emissions are the result of fuel production activities and TTW GHG emissions are derived during the use stage from combustion within the vehicle.

3.2. Energy density and fuel consumption considerations

The energy density of ethanol is approximately one-third lower than that of petrol, resulting in higher fuel consumption. Studies have found that the reduction in fuel economy when using ethanol blends is generally consistent with their lower energy density, meaning that a vehicle will achieve the same distance per unit of energy, whether running on petrol or an ethanol blend [22]. The effect of this higher fuel consumption with the varying blends [23] has been considered within the present study, and representative fuel consumption figures taken from the DfT, International Energy Agency (IEA) [24], and the Which Organisation [25] have been adopted for the various blends and powertrain types as shown in Table 1. Consumption figures sourced from the DfT have already been weighted to account for the relative sales of different models, e.g., saloon, hatchback, sports utility, etc. [26].

For cars powered solely by an internal combustion engine, consumption figures were sourced from DfT data [26], with percentage adjustments being applied to account for the different bioethanol blends, a 2% increase for E10 and an additional 2% increase for E15. For cars with hybrid electric powertrains, an average fuel consumption figure was sourced from IEA data [24] and adjusted for each bioethanol blend in line with the adjustments for ICE cars. Fuel consumption figures for passenger cars with plug-in hybrid electric powertrains are more difficult to precisely quantify due to the need to account for the state of charge of the battery in order to gain an accurate consumption figure that is representative of actual on-road driving conditions [27].

Manufacturer consumption figures are based on the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) and are therefore unable to consider all possible driving styles, weather, traffic conditions and consumer behaviour. Real-world consumption figures for vehicles with plug-in hybrid electric powertrains are highly dependent on the state of charge of the battery [25], and the utility factor (UF) used [28]. The UF is the proportion of distance travelled in the electric mode and is directly influenced by the battery capacity, driving conditions, frequency of recharging and type of journey. The UK government provides advisory fuel rates (AFR) for petrol ICE-powered cars, which set a per-mile rate for reclaiming fuel expenses for business users. AFR's are based on the pump price and the average fuel efficiency for vehicles in three engine capacity bands for the different fuel types, i.e., petrol, diesel and liquefied petroleum gas (LPG). However, whilst the UK government has introduced an equivalent advisory electric rate (AER) specifically for electric vehicles, there is no explicit rate for Hybrid Electric Vehicles (HEV) or Plug-in Hybrid Electric Vehicles (PHEV), which are currently reimbursed at the same rates as a petrol or diesel car, based on their engine size. As a result, the UK government do not publish any fuel efficiency figures for PHEV's.

Research conducted by Transport and Environment [29] shows that the CO_2 emissions from the PHEV's tested in their study were higher than the manufacturer-published WLTP values. Therefore, in the absence of accurate data and in order to achieve the most realistic output from the research model used in the present study, an average consumption figure was calculated as described below.

A popular plug-in hybrid car in the UK is the Toyota Prius; hence, this model was chosen, and an average fuel consumption figure of 151.35mpg or 1.87l/100km was used in the calculations. This figure is the average value between the manufacturer's claimed minimum based on WLTP of 188.3mpg or 1.5l/100km and the independently tested results of 114.4mpg or 2.5l/100km [25]. This assumed value, which is 80% of the WLTP value, compares reasonably with the 133mpg or 2.1l/100km officially stated by the United States Department of Energy, Office of Energy Efficiency and Renewable Energy for a similar Prius vehicle [30], but lower than the findings of a study by the International Council on Clean Energy (ICCT) who noted that real-world driving emissions were two to four times higher than the type approved New European Driving Cycle (NEDC) or WLTP values for the vehicles studied [31].

Table 1. Fuel consumption values.

	E10	E15
ICE	5.5l/100km	5.6l/100km
HEV	4.8l/100km	4.9l/100km
PHEV	1.9l/100km	2.0l/100km

3.3. Blend wall assumptions

A blend wall may be defined as a regulatory threshold prohibiting biofuel blending with fossil fuels beyond a given dilution. The present study assumes the theoretical maximum of 5, 10, and 15% blend levels. In reality, it would be challenging for suppliers to blend to these percentages; hence, the UK government has set minimum blends for each commercially available blender - E5 and E10 - to consumers. For E10, the minimum is 5.5% bioethanol. It should be noted that the UK government's claim regarding the benefits of E10 and the percentage reduction in CO_2 tailpipe emissions are based on the theoretical maximum blends.

3.4. Vehicle compatibility modelling assumptions

E10 has been the reference fuel for new car emissions tests since 2016, and nearly all cars manufactured since 2011 have been approved to use E10 [1]. The DfT states, based on unpublished compatibility data from analysis conducted by the SMMT, that an estimated 96.6% of petrol cars in use in the UK during 2019 were E10 compatible, the remaining 3.4% being classified as incompatible [1]. In the 2020 time horizon modelling, it is assumed that 100% of the estimated compatible fleet, including HEV and PHEV cars, will use E10 and the 649,240 vehicles (3.4%) of the fleet incompatible with the higher blend will use the E5 grade. For the 2030, 2040, and 2050 time horizons, the modelling assumes that all compatible cars, including HEV and PHEV types, will use E10 and the small number of incompatible vehicles, estimated to be 279,000 for 2030 and 250,00 for 2040 and 2050, will use E5. The same assumptions are made regarding incompatible vehicles in the case of E15 for the 2020, 2030, 2040, and 2050 time horizons. The total number of incompatible vehicles for 2030 was derived from data provided by the DfT [1] and where, for the 2040 and 2050 time horizons, the total number was assumed to be 90% of the 2030 total, i.e., 90% of 279,000 = 251,100 rounded to 250,000. For these later time horizons, it was assumed that the number of incompatible vehicles would stabilise as most of the remaining vehicles would be classic cars produced before 1985. This number broadly agrees with the DfT data [1] for 2017-2031, where the total number of pre-1985 cars was considered to be constant at approximately 260,000.

E15 is not commercially available to the general public in the UK, and most vehicle fleets are incompatible with the blend. Ethanol is corrosive to rubber and certain metals. It absorbs moisture from the surrounding air, which can separate and cause internal rusting to fuel tanks and damage filters, seals and injectors. Fuel blends with a higher ethanol blend are more likely to cause damage if the vehicle is not designed for use with the particular fuel. E15 is also thought to cause an increase in smog during hot weather [32]. In the United States of America (USA), sales of E15 are prohibited from June to mid-September. Despite these potential air quality issues, E15 offers reduced carbon emissions compared to lower ethanol/ petrol blends [33].

The UK government proposed increasing the Renewable Transport Fuel Obligation (RTFO), which is the key measure to incentivise the supply of low-carbon fuels, to supply 14.6% of renewable fuel in transport by 2032 [34]. Stakeholders say that liquid low-carbon fuels in higher blends than are presently incentivised through the RTFO can play a key role in decarbonising road transport. In the present work, E15 was explicitly chosen as whilst most vehicles in the current UK fleet were not originally designed to run on this blend, future new vehicles, including HEV and PHEV's produced until the respective sales bans come into force, could easily be equipped to use E15 thus potentially helping to accelerate the reduction in GHG emissions and align with the governments transport decarbonisation plan to maximise the benefits of renewable, low carbon fuels.

3.5. Bioethanol modelling input assumptions

One of the objectives of the research was to establish if the claims made by the UK government that the introduction of E10 would provide reductions in CO_2 emissions by 2% when compared to E5 and approximately 4% when compared to petrol, E0. In order to establish this, it was necessary to examine the data used by the government and determine its accuracy and creditability. Data was sourced from the DfT Measures for the introduction of E10 petrol - Impact Assessment paper [1] and validated by using the Renewable Energy Directive (Annex III, p.49) [35] for the energy content values for both biofuel and fossil fuel, expressed as lower calorific values. Fossil fuel GHG emissions were sourced from the Government's Greenhouse gas reporting: conversion factors 2019 full dataset [36], and biofuel greenhouse gas emissions are based upon the year 10 (full year) RTFO statistics (sheet RTFO_05) [37] and ILUC was sourced from DIRECTIVE (EU) 2015/151338 (Annex V) [38].

Following validation from these sources and the knowledge that all data had been published and thoroughly scrutinised by the scientific community, it was concluded that the data was credible and suitable for use in the current research. Data used in the fuel model is summarised as follows:

Table 2. Fossil fuel GHG emissions factors.

Fuel		gCO_2e/MJ
Petrol	Well to tank	17.3
	Tank to wheel	70.5
	Total	87.8

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Table 3. Crop bioethanol GHG intensities.

Fuel		gCO_2e/MJ
Crop bioethanol (post-adjustment)*	Well to tank	31
	Tank to wheel	0**
	ILUC	12
	Total	43

** Crop bioethanol and crop biodiesel emissions factors have been adjusted upwards to reflect the recently introduced 60% minimum GHG saving sustainability criteria. [1][21]*

*** A TTW figure of 0 is given for bioethanol as it is only burnt when blended with petrol. Refer to tables 9, 10 and 11.*

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Table 4. Energy content values for petrol & ethanol.

Fuel	MJ/litre
Petrol	32
Ethanol	21

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Table 5. E5 energy content breakdown.

E5	Volume (%)	Blended fuel energy content (MJ/litre)	Energy content (%)
Petrol	95%	30.4	97%
Ethanol	5%	1.1	3%
Total	100%	31.5	100%

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Table 6. E10 energy content breakdown.

E10	Volume (%)	Blended fuel energy content (MJ/litre)	Energy content (%)
Petrol	90%	28.8	93%
Ethanol	10%	2.1	7%
Total	100%	30.9	100%

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Table 7. E15 energy content breakdown.

E15	Volume (%)	Blended fuel energy content (MJ/litre)	Energy content (%)
Petrol	85%	27.2	89%
Ethanol	15%	3.2	11%
Total	100%	30.4	100%

Table 8. GHG emissions factors for petrol & ethanol.

Fuel	gCO$_2$e/MJ
Petrol	87.8
Ethanol	43

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Table 9. GHG emissions factor for E5.

E5	% energy	gCO$_2$e/MJ
Petrol	97%	84.9
Ethanol	3%	1.4
Total		86.3

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Table 10. GHG emissions factor for E10.

E10	% energy	gCO$_2$e/MJ
Petrol	93%	81.8
Ethanol	7%	2.9
Total		84.7

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Table 11. GHG emissions factor for E15.

E15	% energy	gCO$_2$e/MJ
Petrol	89%	78.1
Ethanol	11%	4.7
Total		82.8

4. METHODS - FLEET TURNOVER MODEL

A Fleet Turnover model confined to passenger cars and including all powertrain types except Range-Extended Electric Vehicles (REEV) was developed using Microsoft Excel. REEV's were excluded as there are none currently available to purchase new in the UK, and the number of licenced vehicles is insignificant at less than 0.03% of the total number of licensed cars in the UK at the end of 2020 [39]. Powertrain types included in the model are ICEV, HEV, PHEV, and BEVs.

4.1. Estimating the number of licenced cars

The number of licenced passenger cars had been rising annually until 2019, as seen in Figure 1, which covers the twenty years 2001–2020. However, new car sales in 2020 and 2021 were severely impacted by the effects of the Covid-19 pandemic and the subsequent national lockdowns and general supply issues caused by the worldwide disruption to manufacturing and export/import operations. The new car registrations for 2020 were 1.656 million, down 29% on the 2019 figure of 2.346 million, and whilst there was a slight increase in new car registrations in 2021 to 1.677 million, representing a 1.3% increase in 2020, new car registrations were still 28.5% lower than the 2019 figure [40].

The underlying assumptions used in the fleet turnover model for the number of new car annual registrations take account of the continuing effects of the Covid-19 pandemic, the global shortage of microchips [41] combined with the downturn in the economy caused by rising energy prices and the multitude of adverse effects arising from the war in Ukraine. In particular, the downturn in the UK economy, rising cost of living and increase in interest rates combined with government policies to encourage active travel can reduce the number of new car registrations in the short, medium and possibly longer term. The fleet turnover model assumes the size of the UK licensed passenger car fleet increases by the difference between the new vehicle registrations and the number of vehicles scrapped each year, supposing current vehicle survival rates are maintained. This is captured in stock-flow simulations for each ten-year interval up to 2050 that account for the existing fleet of cars and the inward and outward flows represented by sales and end-of-life when a car is scrapped [42-44].

Examination of the total number of passenger cars licensed in the UK at the end of each year from 2014 until 2020, inclusive, as shown in Figure 2, indicates that the fleet grew by approximately 500,000 units per year until 2020, when new registrations fell due to the effects of the Covid-19 pandemic. It is recognised that many socio-economic factors can influence the annual growth of the vehicle fleet, but these factors are beyond the scope of this work. Given that a small annual sales growth is currently predicted, set against a background of near linear growth over the past seven years, the current research proposes a scenario where growth of 500,000 cars per year is assumed in the fleet turnover model, as shown in Table 12. A forecast by the SMMT for 2022 [45] suggests that there could be an increase in new car registrations of 4.5% when compared to the 2021 total. It is also possible that there may be a slight drop in new vehicle registrations at each cut-off point, i.e., cessation of ICE manufacture in 2030 and HEV/ PHEV in 2035. New vehicle sales growth in the UK from December 2006 to December 2021 has been approximately 1.1% [46], and previous research into renewable energy implementation scenarios conducted by the Joint Research Centre assumed a 1.5% average annual sales growth [47].

Considering all these factors, a scenario is used where new car registrations are assumed to be constant at 1.8 million per annum, approximately 10% greater than the 2021 total of 1.64 million and equating to approximately 1.4% average growth for each year of the ten years 2021–2030, 1.2% average growth for each year of the ten years 2031–2040 and a 1% average growth for each year of the period 2041–2050. The number of scrapped vehicles is assumed to be a fixed 1.3 million per year for every year until, including 2050.

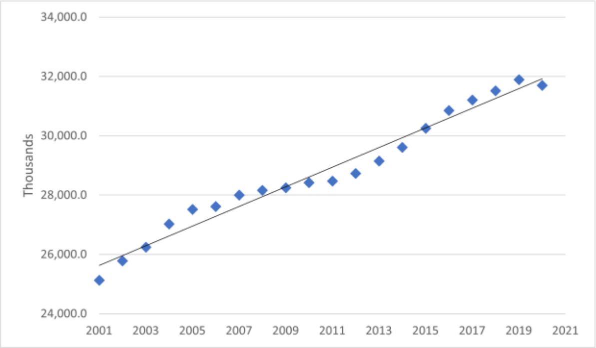

Figure 1. Total number of licensed cars in Great Britain at the end of the year (2001–2020).

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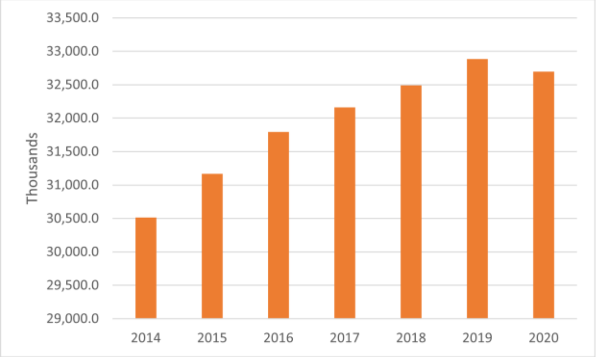

Figure 2. Licensed cars at the end of the year: United Kingdom from 2014.

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Table 12. Fleet turnover model parameters.

Year	Total Fleet Size (end of year)	New sales/ registrations	Number of scrap vehicles	% of ICE (Petrol)	% of HEV (Petrol)	% of PHEV (Petrol)
2020	32,697,400	1,640,200	No data	58.4	1.4	0.36
2030	37,698,000	1,800,000	1,300,000	30.0	10.5	6.0
2040	42,698,000	1,800,000	1,300,000	1.5	8.4	3.0
2050	47,698,000	1,800,000	1,300,000	0	1.1	0.3

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4.2. Calculating scrappage rates

Limited data is available on the number of passenger cars that are scrapped each year in the UK, and typically, data is published quoting reuse, recycling and recovery totals in tonnes. The most recent data from Eurostat for 2018 [48] shows that 1,589,882 tonnes were processed. Assuming that the average mass of a medium-sized saloon car, excluding fuel, occupants, and load, is 1250kg, then 1,589,882 tonnes is roughly equivalent to 1,271,905 vehicles. Recognising that the average vehicle mass may be greater or lower depending on the mix of cars being processed and that the tonnage will also vary and is likely to rise in line with the trends observed from the Eurostat data where tonnage has increased each year from 2015, the fleet turnover model assumes a fixed number of 1,300,000 cars.

4.3. Predicting the composition of different drivetrains

It can be seen from Figure 3 that the percentage of licenced petrol-powered passenger cars in the total UK fleet has been in decline since 2014, and all predictions point to this trend continuing in the years before the ban on pure combustion cars came into force in 2030. Whilst there are many predictions of the composition of the UK passenger car parc and the composition percentages vary widely, there are some common themes. Most observers predict that the number of new registrations for pure diesel-powered cars will drop more quickly than any other type and that there will be a significant rise in the number of new BEV's, whilst demand will exist for new HEV and PHEV cars until the cessation of production of these types in 2035. The Climate Change Committee (CCC) analysis predicts that the purchase cost of a BEV will reach parity with an equivalent ICE by 2030 [5], an essential factor as the higher purchase cost has been seen as a barrier holding back the take-up of BEV's. A recent survey by the Automobile Association (AA) published in the Fleet News publication [49] suggests that battery electric cars would represent 19% of all cars on the road in 2030.

It will take time for the composition of the fleet to change given, according to the CCC, the average car remains in service for approximately 14 years, and the average age of a licenced car is 8.6 years [39], with a petrol-powered car being, on average, older at 9.3 years than a pure diesel powered one [9]. Several vehicle manufacturers have confirmed that they will offer an electric car range to UK consumers before or by the 2030 date when new ICE sales will end. For example, Ford has confirmed that they will only sell electric cars in Europe from 2030 and that Jaguar will offer an entirely electric model range by 2025. In addition, in April 2022, the UK government launched a consultation to consider the introduction of a zero-emission mandate for cars and vans whereby a fixed percentage of vehicles registered every year until 2035 must be zero emission. The proposed commencement date for the mandate is 2024, after which time manufacturers will be required to sell a proportion of electric vehicles each year until the cessation of the sale of ICE cars (without significant zero emission capability) in 2030, and HEV and PHEV in 2035 [50].

The CCC estimates that BEVs will comprise 27–37% of the car and van fleet in 2030, rising to 81–88% by 2040, with central assumptions of 35% and 87%, respectively [5]. The National Grid has also considered some scenarios and concluded that there could be 11–36% BEV penetration of the fleet in 2030, rising to 61% - 99% by 2040 [51]. Given the efforts of manufacturers to bring their BEV (cars) to the market and to establish a significant presence whilst also recovering the high development costs, set against the reduction in investment that is predicted for pure combustion-powered models, it is plausible that there could be a 30% penetration of BEV's in the vehicle fleet in 2030, despite the government withdrawing the plug-in car grant (PiCG) in June 2022. Conversely, the percentage of licenced petrol ICE-powered cars in GB fell by approximately 4.4% in the ten years 2011–2020 and 3.8% for diesel ICE-powered cars in the three years 2018–2020. The peak number of diesel-powered car registrations was achieved in 2018, after which there has been a steady decline [39]. The rate of decline of licenced diesel ICE-powered cars is predicted to accelerate rapidly between 2020 and 2030, with commentators suggesting there is a likelihood that new registrations for these types may start to decline even more rapidly between 2025 and 2030. However, given the worsening UK economic situation in 2022 and associated market uncertainties combined with the shortage of semiconductors, political difficulties arising from the war in Ukraine and the ongoing Covid-19 pandemic, accurate forecasts for the composition of future fleets at different time horizons could not be reliably predicted.

4.4. Fleet composition forecast for 2020

For the 2020 fleet composition forecast, actual data was used as given in Table 12, with an allowance being included for E10 incompatible cars.

4.5. Fleet composition forecast for 2030

The model used in the current research assumes a scenario for the passenger car parc in 2030 based on the assumed percentage decline of new ICE-powered car registrations given in Table 13 and Figures 4a and 4b, where there is a broadly linear reduction of new diesel and petrol ICE registrations from 2021 to 2030 and a more rapid decline for diesel than petrol types. The 2021 figures in the table are the actual new registrations taken from SMMT data in the public domain [52]. It is assumed that there is a 90% survival rate and that the petrol-powered

ICEs will remain in service for 14 years. In 2020, approximately 22% of the licenced passenger car fleet was older than 13 years. Therefore, an allowance was made to recognise this within the background calculations, with a cut-off of 20 years from the first registration. Non-E10 compatible, pre-1985 cherished vehicles are considered separately, and alternative propulsion fuels/ types such as Fuel Cell, Electric and Gas have not been included as the number of licenced vehicles of this type is insignificant.

Figure 5 shows the assumed parc composition for 2030 where, at the end of the year, petrol ICE cars account for 30% of the licenced fleet, diesel ICE cars account for 15%, BEV 30%, PHEV 10% and HEV 15%. This scenario assumes a BEV penetration higher than suggested by some forecasters and within the percentage ranges suggested by others, e.g., the CCC and National Grid. The percentage of petrol and diesel HEV's was calculated using an assumed proportion of 70% petrol and 30% diesel. Similarly, the percentage of petrol and diesel PHEV's was calculated using an assumed proportion of 60% petrol and 40% diesel.

Using unpublished data owned by the SMMT, the DfT states that in 2019, approximately 3.4% (around 700,000) of petrol cars were classified as incompatible with E10 fuel [1]. From this number, approximately 25% were pre-1985 cherished vehicles. Using information from the Driver and Vehicle Licensing Agency (DVLA) on car scrappage rates, the DfT forecast that by 2030 the number of incompatible cars was expected to fall to 279,000 in 2030, with over 80% of this total being pre-1985 cars. The model makes allowance for these incompatible vehicles at each time horizon by proposing a likely total remaining and calculating the potential GHG arising from them using E5.

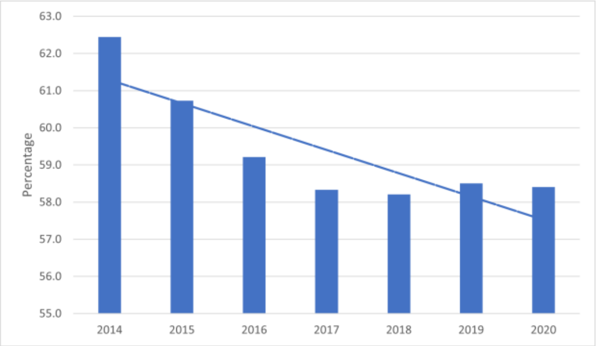

Figure 3. Licensed petrol ICE-powered cars at the end of the year as a percentage of all licenced cars in the UK from 2014.

Adapted using data with permission from the Department for Transport Driver and Vehicle Licensing Agency [39] Contains public sector information licensed under the Open Government Licence v3.0. Open Government Licence v3.0

Table 13: Scenario for the decline of ICE-powered cars, end 2021 – end 2030

Petrol ICE			Diesel ICE		
Year	% decline	New Registrations (end of year)	Year	% decline	New Registrations (end of year)
2016		1318707*			1285188*
2017		1354917*			1065879*
2018		1466024*			746332*
2019		1498640*			583488*
2020		903961*			261772*
2021		762103*	2021		135773*
2022	30%	533472**	2022	40%	81464**
2023	30%	373430**	2023	50%	40732**
2024	40%	224058**	2024	60%	16293**
2025	40%	134435**	2025	70%	4888**
2026	50%	67217**	2026	80%	978**
2027	50%	33609**	2027	90%	98**
2028	70%	10083	2028	100%	0
2029	70%	3025	2029		
2030	90%	302	2030		

*Actual values - taken from SMMT data in the public domain [52]
**Predicted values

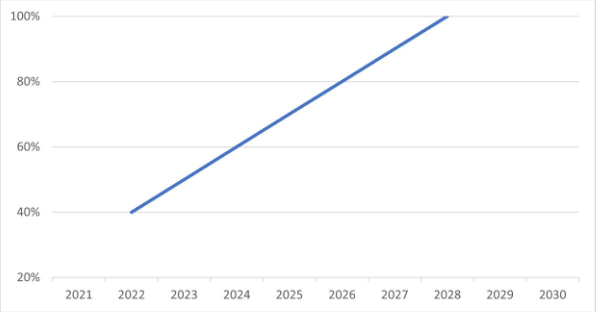

Figure 4a. Predicted percentage reduction of new diesel ICE car registrations, end 2021 – end 2030

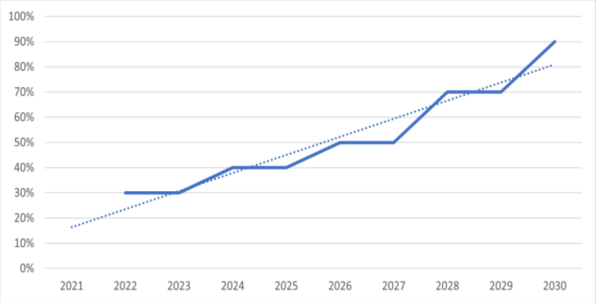

Figure 4b. Predicted percentage reduction of new petrol ICE car registrations, end 2021 – end 2030

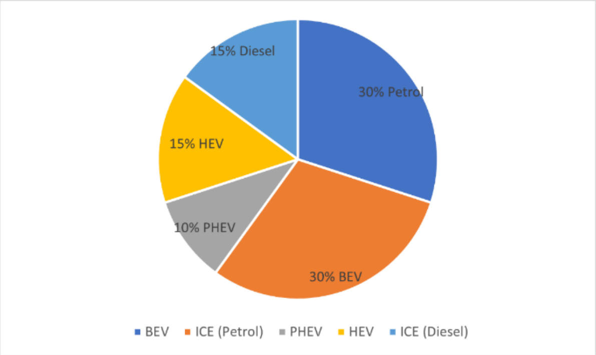

Figure 5. Predicted UK passenger car parc at the end of year, 2030.

4.5. Fleet composition forecast for 2040

The scenario for the assumed contribution of pure petrol and diesel ICE passenger cars to the parc at the end of 2040 was calculated using the total of assumed new vehicle registrations from 2027 to 2030, as given in table 13 and figures 4a and 4b, adjusted by a survival factor of 90% adopted for ICE vehicles of up to 14 years of age. This figure was added to an assumed total of licenced ICE cars aged between 15 and 20 years (inclusive) remaining in the fleet at the end of 2040. Table 14 provides the assumed total of licenced ICE cars surviving at the end of the year in 2040, calculated from the presumed number of new registrations in the respective years multiplied by percentage survival factors for each year. The scenario assumes that the fleet at the end of 2040 will include approximately 20% of cars older than 13 years and adopt a cut-off of 20 years from the date of original registration in the calculations. It was calculated that pure petrol-powered ICE cars will comprise 1.2% of the passenger car fleet at the end of 2040, and pure diesel-powered ICE cars will comprise 0.2%. In the chart (Figure 6), these percentages have been adjusted to 1.5% and 0.5% respectively.

Given that no actual survival rate data is currently available or published for any power vector, the assumed percentages used in tables 16, 18, 19 and 20 below were derived from historical data from the DfT for petrol and diesel-powered cars. Specifically, information about the number of licensed cars at the end of the year by year of first registration obtained from table VEH0211 was used [39]. Data from the DfT is only available for Great Britain (GB) from 1994 and the United Kingdom (UK) from 2014. As the research pertains to the UK, calculations were performed using the 2020 GB dataset, with the percentages adjusted marginally upwards and rounded to allow for the higher UK totals.

Table 14: An assumed total of licenced ICE cars surviving (at the end of the year) in 2040 from each registration year.

Petrol ICE		Diesel ICE	
Year	Total	Year	Total
2021	76210	2021	13577
2022	80021	2022	12220
2023	93358	2023	10183
2024	78420	2024	5702
2025	53774	2025	1955
2026	33609	2026	489

In the case of HEV cars, the scenario assumes that there will be a rise in new registrations of 20% per year from the 2021 year-end figure - obtained from SMMT data in the public domain [52] up to and including 2030. From 2030 until the end of 2035, when the sale of new HEV cars will cease, the scenario assumes a decline in new registrations of 15% per year, as shown in Table 15. A survival factor of 90% for HEV passenger cars up to 14 years of age was applied to the 2027–2035 registrations, which were, in turn, added to an assumed total of licenced HEV passenger cars aged between 15 and 20 years (inclusive) remaining in the fleet at the end of the year, 2040. As with the ICE approach, the scenario assumes that the fleet at the end of 2040 will include approximately 20% of cars older than 13 years and adopt a cut-off of 20 years from the original registration date in the calculations. The survival rate of vehicles registered in 2021 – 2026 was calculated assuming the percentage survival factors for each year, as given in Table 16. It was calculated that HEV's will comprise 11.5% of the passenger car fleet at the end of 2040. Rounded to 12% in the chart (Figure 6).

Table 15: An assumed total of new HEV car registrations at the end of each registration year.

Year	New Registrations
2021	147246
2022	176695
2023	212034
2024	254441
2025	305329
2026	366395
2027	439674
2028	527609
2029	633131
2030	759757
2031	645793
2032	548924
2033	466586
2034	396598
2035	337108

Table 16: An assumed total of licenced HEV cars surviving (at the end of the year) in 2040 from each registration year.

Years	Predicted registrations	Numbers surviving	Assumed survival %
2021	147246	14725	10%
2022	176695	35339	20%
2023	212034	63610	30%
2024	254441	101776	40%
2025	305329	152665	50%
2026	366395	219837	60%

The process used to determine the assumed percentage of HEV passenger cars in the overall parc for the end of the year 2040 was adopted to calculate the assumed percentage of PHEV passenger cars. However, whilst it was assumed that there would be a rise in new registrations between 2022 and 2030 (inclusive) and a decline between 2031 and the cessation of production in 2035, the percentages used differed from those adopted for HEV's, this being to reflect the reduced popularity of the type and historical differences in sales performance up to the end of 2021. Table 17 provides the assumed total of new PHEV car registrations at the end of each registration year, and Table 18 provides details of the assumed total, from each registration year, of licenced PHEV cars aged between 15 and 20 years (inclusive) surviving at the end of the year in 2040. It was calculated that PHEV's will comprise 4.6% of the passenger car fleet at the end of year 2040, rounded to 5% in the chart (Figure 6).

Table 17: An assumed total of new PHEV car registrations at the end of each registration year.

Year	New Registrations
2020	67134
2021	114554
2022	126009
2023	138610
2024	152471
2025	167719
2026	184490
2027	202939
2028	223233
2029	245557
2030	270112
2031	229595
2032	195156
2033	165883
2034	141000
2035	119850

Table 18: An assumed total of licenced PHEV cars surviving (at the end of the year) in 2040 from each registration year.

Years	Predicted registrations	Numbers surviving	Assumed survival %
2021	114554	11455	10%
2022	126009	25202	20%
2023	138610	41583	30%
2024	152471	60989	40%
2025	167719	83859	50%
2026	184490	110694	60%

The model, shown in Figure 6, assumes a scenario where BEV's will comprise 81% of the 2040 passenger vehicle fleet, this percentage being in good agreement with the prediction of 81% - 88% by the CCC [5] and 61% - 99% predicted by the National Grid [51]. As with the 2030 model, the percentage of petrol and diesel HEV's was calculated using an assumed proportion of 70% petrol and 30% diesel. Similarly, the percentage of petrol and diesel PHEV's was calculated using an assumed proportion of 60% petrol and 40% diesel.

In terms of the number of licenced E10 incompatible cars, a scenario is assumed where 90% of the 2030 end-of-year total remains in use. This figure is rounded to 250,000 and assumed to remain broadly stable as most of these cars comprise cherished, classic and vintage vehicles.

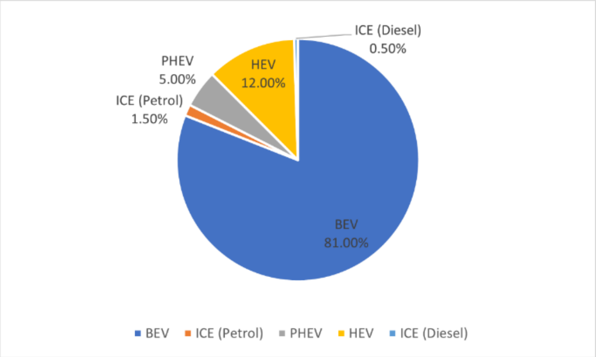

Figure 6. Predicted UK passenger car parc at the end of year, 2040.

4.7. Fleet composition forecast for 2050

In 2050, a scenario is assumed where only classic and cherished pure ICE-powered cars exist and a small number of HEV and PHEV remain in use. To calculate the likely percentage of the HEV and PHEV in the parc, the assumed total of licenced HEV and PHEV cars surviving from each registration year, 2031–2035, was calculated based on the same assumed percentage survival rates as used for HEV's and PHEV's in the 2040 parc prediction. A cut-off of 20 years since the first registration was used in line with the 2030 and 2040 predictions, i.e., back to 2031. Table 19 details the total number of licenced HEV cars surviving from each registration year at the end of 2050. Table 20 details the assumed total number of licenced PHEV cars surviving from each registration year at the end of 2050.

Table 19: An assumed total of licenced HEV cars surviving (at the end of the year) in 2050 from each registration year.

Years	Predicted registrations	Numbers surviving	Assumed survival %
2031	645793	64579	10%
2032	548924	109785	20%
2033	466586	139976	30%
2034	396598	158639	40%
2035	337108	168554	50%

Table 20: An assumed total of licenced PHEV cars surviving (at the end of the year) in 2050 from each registration year.

Years	Predicted registrations	Numbers surviving	Assumed survival %
2031	229595	22960	10%
2032	195156	39031	20%
2033	165883	49765	30%
2034	141000	56400	40%
2035	119850	59925	50%

The predicted passenger car parc at the end of 2050 assumes a scenario where HEV's comprise 1.3% of the parc, PHEV's 0.48% and BEV's dominate with a share of 98.22%. These percentages have been rounded as shown in the chart in figure 7, this being consistent with the practice used in the charts for 2030 and 2040. In keeping with the previous models, the percentage of petrol and diesel HEV's was calculated using an assumed proportion of 70% petrol and 30% diesel. Similarly, the percentage of petrol and diesel PHEV's was calculated using an assumed proportion of 60% petrol and 40% diesel. The number of incompatible cars was considered the same as for the 2040 model at 250,000 units.

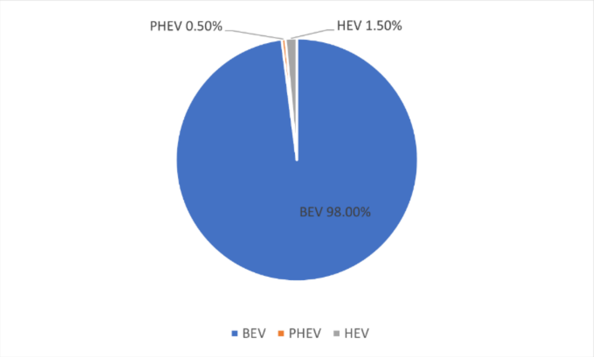

Figure 7. Predicted UK passenger car parc at the end of year 2050

5. AVERAGE AGE OF LICENCED CARS AND LIFETIME MILEAGE

Figure 8 provides data from the DfT, which shows that the average age of licensed cars in the UK has been increasing, and for the period 2014–2020, there was a rise from 7.9 years to 8.6 years. According to data published by the DfT [39], the average age of a pure petrol-powered car in 2020 was 9.3 years, and the CCC states that the average car remains in service for approximately 14 years. This increase in average age is significant as it will if combined with increased lifetime mileage, directly impact the amount of GHG emissions and could cause a considerable rise and potential threat to the achievement of the 2050 transport net zero target and periodic carbon budgets.

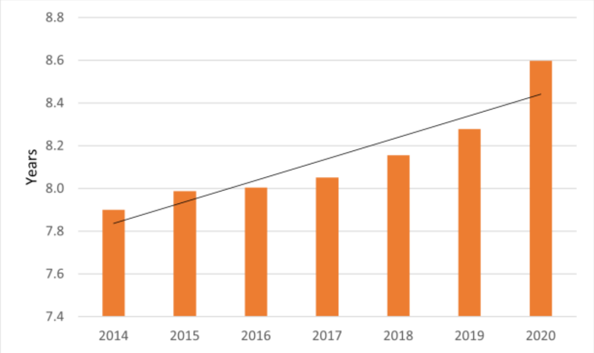

Figure 8. The average age of Licensed cars at the end of the year by several years since first registration (UK 2014–2020).

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Lifetime mileage is a critical component in Life-cycle Assessment modelling (LCA), and in most studies, a simplified approach based on fixed annual mileage profiles and lifetime activity is used. Weymar et al. [12] assert that "best guess" lifetime mileages provided by industry associations and car manufacturers are currently applied in automotive LCA. Wang et al. [13] conclude that the energy efficiency and emissions in the total life cycle of different vehicle types is highly dependent on the driving mileage. Some studies, such as that of Ternel et al. [53], have assumed a total lifetime mileage of 150,000 km and others [54] 200,000 km. Lifetime mileage has been decreasing in England since 2002, according to the DfT annual mileage of cars by ownership and trip purpose survey [55], with a rapid decline in 2020 due to the effects of the Covid-19 pandemic and associated lockdowns. Car usage picked up again during 2021, but the ongoing effects of the pandemic hindered a return to the usage levels recorded in 2019. While the evidence is still being collected, the switch to more home working and online meetings seems to have reduced car travel. With the rising cost of fuel in the first and second quarters of 2022 and the pressures on household finances due to rising inflation, many users are now choosing to drive less. The current research uses a default mileage of 12,000 km/year or approximately 7,400 miles per year, in harmony with the 2019 data published by the DfT. A range of higher annual mileages from 12,000km/year to 20,000km/year have also been modelled to examine the effects of mileage sensitivity on GHG emissions.

6. RESULTS AND DISCUSSION

Three different fuel models applied to the UK passenger car fleet, namely, E5 (petrol blended with no more than 5% bioethanol), E10 (petrol blended with no more than 10% bioethanol) and E15 (petrol blended with no more than 15% bioethanol) were modelled. A fleet turnover model was used to estimate the likely composition of the UK petrol-powered vehicle fleet, including hybrid types, at the 2030, 2040 and 2050 time horizons based on assumptions drawn from various forecasts as described in sections 4, 5 and 6. It was assumed in the modelling that the sale of new internal combustion powered vehicles and hybrid types will cease in 2030 and 2035, respectively, in line with the government policy and that all compatible vehicles will use the E10 or E15 bioethanol blends with allowances being made, via fuel consumption adjustments, to account for future technological developments to powertrain, vehicle structures and other relevant emissions reduction systems.

In general, assumptions are made conservatively in this study in order not to underestimate the impact of uncertain data. Additionally, the fleet composition model was not extended to identify Euro emission standards using vehicle age data or to account for less efficient, [56] worn or defective vehicles or different driver behaviour; instead, an average fuel consumption approach was adopted for each propulsion type across each time horizon. The forecasts for all time horizons are for the UK. However, it is recognised that E10 will not be introduced in Northern Ireland until November 2022. While E10 was adopted as the standard 95-octane petrol grade in the GB in September 2021, the model presents scenarios for ten-year intervals covering 2020 to 2050, inclusive, based on UK data. Hence, the 2020 results provide a retrospective insight into the effects of adopting E10 when applied to the 2020 year-end fleet.

6.1. Evaluating the claims made by the UK government (objective 3)

Figure 9 compares GHG emissions (MtCO₂e/year) for each propulsion type when 100% of the 2020 vehicle fleet uses E5 or E10. It can be seen from the information provided in Figure 10 and Table 21 that an overall reduction in emissions of 1.95% is achieved, with a reduction of 1.96% for ICE-powered vehicles. This percentage compares favourably with the UK government's claim that E10 would reduce CO_2 emissions by 2% compared to E5.

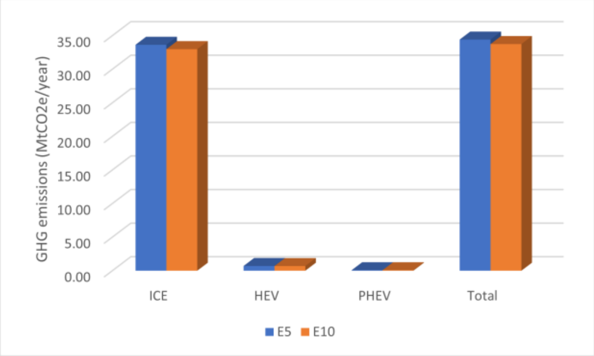

Figure 9. Comparison of GHG emissions (MtCO₂e/year) for each propulsion type when 100% of the vehicle fleet uses either E5 or E10.

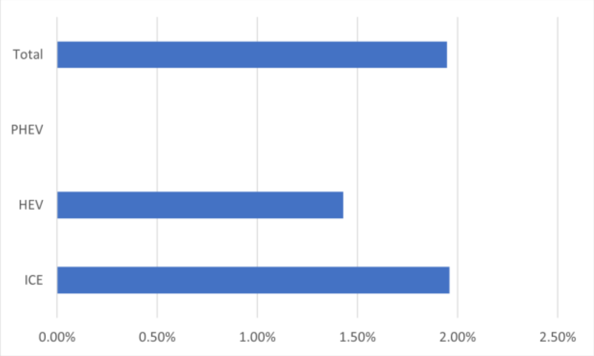

Figure 10. Percentage reduction of GHG (MtCO₂e/year) between E10 and E5 for each propulsion type (2020 model assuming 100% take-up).

Table 21: Percentage reduction of GHG (MtCO₂e/year) between E5 and E10 for each propulsion type (2020 model assuming 100% take-up).

	ICE	HEV	PHEV	Total
E5	33.64	0.70	0.07	34.41
E10	32.98	0.69	0.07	33.74
% Change	1.96%	1.43%	0.00%	1.95%

6.2. The effects of adopting E10 and a higher bioethanol blend (E15) – objective 1

The E10 and E15 blends were modelled for each time horizon, and Tables 22 and 23 show the assumed total GHG emissions (MtCO₂e/Year) for each propulsion type when all compatible vehicles use either E10 or E15. The GHG emissions from vehicles using E5 are negligible due to the low assumed number of incompatible vehicles. Table 24 provides details of the percentage change in GHG emissions that may be obtained if the fleet used E15 instead of E10. It can be seen in the majority of cases (excluding incompatible vehicles using E5) that there is a reduction in GHG emissions. However, in the case of PHEV vehicles in 2030 and 2040, an increase in GHG emissions of 1.48% and 1.32%, respectively, is seen. This increase is assumed to be due to the lower energy density and higher fuel consumption associated with using E15.

Table 22. Assumed total GHG emissions (MtCO₂e/Year) for each propulsion type when all compatible vehicles use E10 (2020–2050).

E10	ICE	HEV	PHEV	ICE using E5	Total
2020	31.86	0.69	0.07	1.14	33.77
2030	19.05	5.97	1.35	0.49	26.86
2040	0.67	5.41	0.76	0.44	7.29
2050	0.00	0.79	0.09	0.44	1.32

Table 23. Assumed total GHG emissions (MtCO₂e/Year) for each propulsion type when all compatible vehicles use E15 (2020–2050).

E15	ICE	HEV	PHEV	ICE using E5	Total
2020	31.20	0.68	0.07	1.14	33.09
2030	18.66	5.86	1.37	0.49	26.37
2040	0.66	5.31	0.77	0.44	7.18
2050	0.00	0.78	0.09	0.44	1.30

Figures 11 and 12 illustrate the GHG emissions for each propulsion type at each time horizon with the fleet using either E10 or E15. Cherished and incompatible vehicles are shown using E5. The plots look very similar, but data in Table 24 reveals percentage reductions in GHG emissions with the two exceptions described above. Figure 13 plots the total GHG emissions from the vehicle fleet using either E10 or E15 at each time horizon. The contribution to the total emissions arising from incompatible vehicles is included. It can be seen that there are advantages in using a higher blend such as E15 in the period 2020–2030 when there are a larger number of pure ICE-powered vehicles within the fleet. However, the reductions diminish in the years 2030–2050.

Table 24. Percentage change of GHG emissions between E10 and E15.

E10	ICE %	HEV %	PHEV %	ICE using E5 %	Total
2020	2.07	1.45	0.00	0.00	2.01
2030	2.05	1.84	1.48 (Increase)	0.00	1.82
2040	1.49	1.85	1.32 (Increase)	0.00	1.51
2050	0.00	1.27	0.00	0.00	1.52

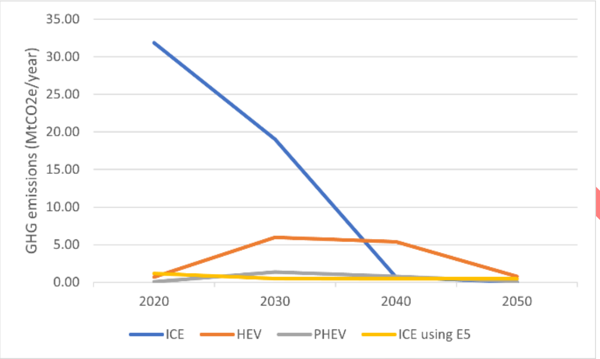

Figure 11. GHG emissions ($MtCO_2e$/Year) at each time horizon for each propulsion type, assuming all compatible vehicles use E10.

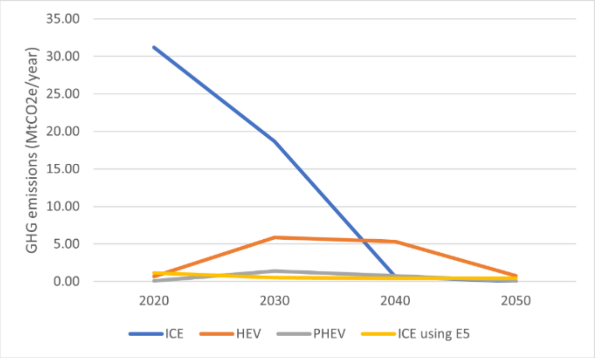

Figure 12. GHG emissions ($MtCO_2e$/Year) at each time horizon for each propulsion type, assuming all compatible vehicles use E15.

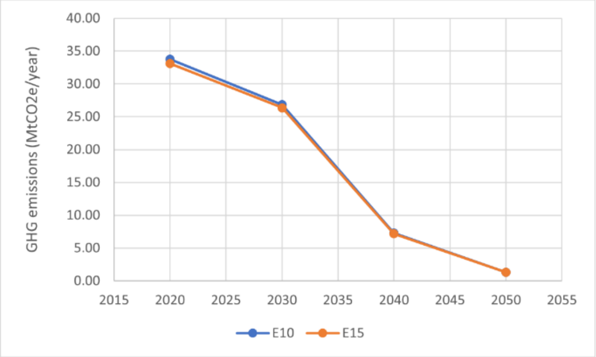

Figure 13. Comparison of GHG emissions emitted from the vehicle fleet at each time horizon when all compatible vehicles use either E10 or E15.

6.3. Impact of extended vehicle lifetime and mileage sensitivity – (objective 2)

The average GHG emissions (tonnes CO_2e/year) for one car travelling 12,000 km/year using E10 or E15 is shown in Figure 14. For an ICE-powered car using E10, this represents 143.95gCO_2e/km; for the same vehicle using E15, it is 140.96gCO_2e/km. For an HEV and PHEV using E10, the figures per kilometre are 125.6gCO_2e/km and 49.7gCO_2e/km, respectively. The figures for the identical vehicles using E15 are (HEV) 123.3gCO_2e/km and (PHEV) 50.3gCO_2e/km.

Figure 14 shows the GHG emissions for the range of propulsion types. It can be seen that a relatively small reduction in the average GHG emissions between the ICE and HEV cars is observed. This is attributed to a similarly modest difference in the average fuel consumption between the ICE and HEV vehicles of 12.7%. HEV vehicles may suffer a weight penalty compared to an equivalent ICE-powered one, resulting in fuel inefficiency offsetting some gains from using electric driving mode. PHEV's, on the other hand, can offer a much lower fuel consumption - subject to the UF used – resulting in lower average GHG emissions, as demonstrated in the results from this research.

The present work used the default annual mileage of 12,000 km/year. However, the influence on the amount of GHG emissions arising from higher annual mileage could be significant, as seen from the example in Figure 15. In this example, the GHG emissions for one vehicle using E10 fuel and powered by the various propulsion types are modelled at different annual mileages ranging from 12,000 to 20,000 km. It can be seen that there is an expected rise in emissions and that the increase is linear in all cases. However, the slopes of the three lines are different, with those of the ICE and HEV types being steeper than those of the PHEV type, indicating a more rapid rise in emissions from these types. An increase of 1.15 Tonnes CO_2e/year for a pure ICE-powered vehicle was recorded when the annual mileage increased from

12,000 to 20,000km/year. This represents a 66.5% increase. Similar increases were seen for HEV's, where an increase of 66.2% (1 Tonne CO_2e/year) was recorded and for PHEV's, where an increase of 66.7% (0.4 Tonne CO_2e/year) was recorded. From the results, it was seen that for each additional 1,000 km/year per vehicle, there would be approximately an extra 0.14 Tonnes CO_2e/year for an ICE-powered vehicle, 0.12 Tonnes CO_2e/year for a HEV and 0.05 Tonnes CO_2e/year for a PHEV. If the average vehicle lifetime continues to grow, the effect would be to create more damaging GHG emissions and spread them over a longer timeframe.

Figure 16 shows the effect on GHG emissions of changing the annual mileage for the vehicle fleet from 12,000 km/year to 19,000 km/year for each time horizon. The bar charts in Figure 17 show the scale of the increase in GHG emissions between the two scenarios, where the only change in the models is the annual mileage. The bars on the left side represent the results using a 19,000 km/year annual mileage, and the bars on the right represent the results obtained using a 12,000 km/year annual mileage. An annual mileage of 19,000 km/year was chosen for this example as it equates to approximately 11,800 miles/ year, a yearly mileage often used as a benchmark in used car pricing.

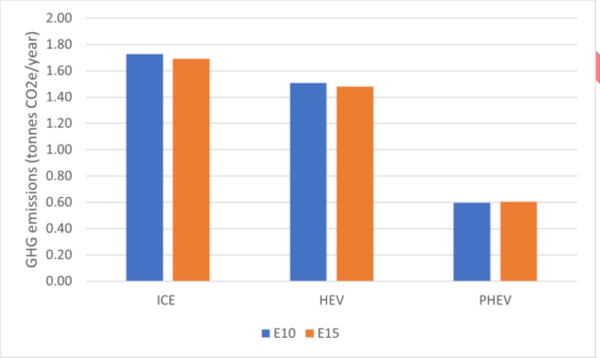

Figure 14. Average GHG emissions (tonnes CO_2e/year) from one car per 12000 km/year, using E10 or E15

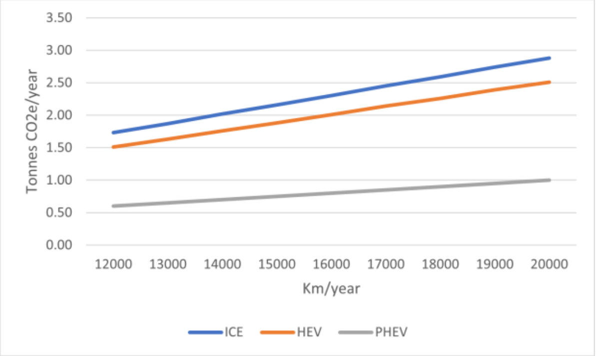

Figure 15. Effects of changes in annual mileage on GHG emissions for one car from each propulsion type using E10 fuel.

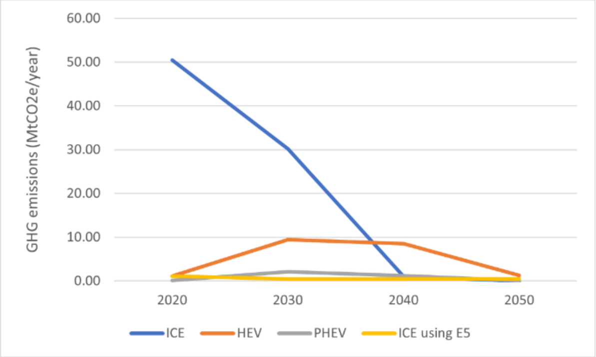

Figure 16. GHG emissions ($MtCO_2e$/Year) at each time horizon for each propulsion type, assuming all compatible vehicles use E10 and have an annual mileage of 19,000km/year.

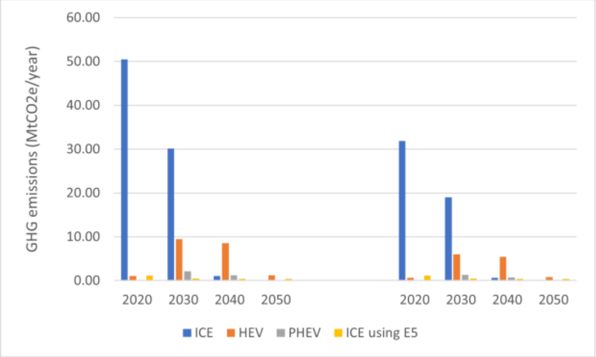

Figure 17. Comparison of GHG emissions for each propulsion type using E10 from different annual mileages 19,000 km/year Vs 12,000 km/year.

4. CONCLUSION

The research objectives of this work have been achieved. A novel fleet turnover model and a separate numerical model were developed to predict the GHG emissions for various powertrain types using different bioethanol blends. The contribution to reducing GHG emissions from using a higher bioethanol blend, the E15 blend, was investigated. GHG emissions reductions were recorded, although, in the fleet size and composition scenarios, the benefits were less after 2030, when the number of ICE-powered cars in the fleet significantly reduced. In the case of PHEV vehicles for the 2030 and 2040 time horizons, percentage increases in GHG emissions were unexpectedly noted when using E15 compared to E10. Sensitivity studies that model the effects of different annual mileage whilst using E10 and applying the proposed UK fleet composition scenarios at 10-year intervals up to 2050 show that an increase in yearly mileage will significantly increase GHG emissions.

The present study's final objective was to identify key factors and critical uncertainties, including changing consumer behaviour, that are likely to accelerate or delay the achievement of the 2050 transport net zero target and future periodic carbon budgets. It has been established that lifetime mileage has been decreasing since 2002. However, it is also the case that the average age of passenger cars in the UK has increased, with the potential for an increase in lifetime mileage. If this extension to ownership is significant, it can negatively impact the achievement of the legally binding periodic carbon budgets. Additionally, there is a risk that the rising food and energy costs could negatively impact the bioethanol supply or lead to a freeze on biofuel blending. Given the current challenging economic environment, there is also a risk that a freeze on biofuel blending could be considered to reduce the retail petrol price to the consumer. If this were to happen, there would be an inevitable rise in GHG emissions and the potential for carbon budgets to be missed.

The conclusions from this work may be a helpful reference for policymakers, and three key recommendations are proposed. Firstly, more needs to be done to inform PHEV drivers and owners about the need for regular charging to optimise fuel economy and GHG emissions from their vehicles. This might be a valuable recommendation for the DfT and vehicle manufacturers as correct PHEV technology use would help reduce GHG emissions, even if the additional contribution is modest. Secondly, the UK government should seek to ensure that consumer take-up and use of E10 is optimised by providing and maintaining incentives, e.g., a favourable cost differential between the cost of E10 and E5. Finally, fuel suppliers should be encouraged to provide blends as close as possible to the maximum dilutions for the particular blend wall, thus providing the maximum GHG emission savings from the blend.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENT

The authors would like to thank Coventry University for providing the resources to facilitate this work.

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