Second review of data and methods to calculate greenhouse gas emissions from alternative fuel transport

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Executive Summary

Greenhouse gas (GHG) emissions from the road transport sector are estimated to currently make up approximately 24% of domestic UK GHG emissions[1]. There are increasing demands to reduce the emissions arising from road transport, which is seen as one of the more challenging sectors in terms of climate change mitigation. One means of reducing emissions is through the use of alternative fuelled vehicles (AFVs). These vehicles are increasing in number in the UK and it is important, therefore, to understand the latest available data reflecting their use and impacts.

The National Atmospheric Emissions Inventory (NAEI) quantifies national emissions of a range of greenhouse gases and air quality pollutants, and this research forms part of the NAEI improvement programme. The aims of the project were to:

- Identify sources of information on the numbers and activity (mainly vehicle kilometres travelled) for the different alternative fuel vehicles (AFVs), historically and projected to 2035.
- Review the fuel consumption and emission factors available for AFVs. The study focus was on GHGs including Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O), but other regulated air quality pollutants such as nitrogen oxide (NO_x) and particulate matter (e.g. PM_{10}) were also considered. These were chosen because of their importance in the transport sector.
- Combine activity and emission factor data to estimate emissions from the different classes of AFVs to 2035.
- Review how other countries estimate emissions from AFVs, and make recommendations as to whether the UK could benefit from following similar approaches.

This project estimates emissions on a "by source" basis, which is consistent with international inventory reporting. Therefore, emissions from battery electric vehicles and hydrogen fuel cell vehicles are zero in this regard.

The key findings of the project were:

- As detailed in Chapter 6 of this report, AFVs currently contribute around 0.5% of UK road transport CO_2 emissions. This is an increase from around 0.3% in 2012. AFVs also currently contribute around 1% of UK total transport CH_4 emissions and 0.2% of UK total transport N_2O emissions. However, CO_2 emissions dominate GHG emissions, contributing more than 99% of total (CO_2e) UK transport emissions[2], and the overall contribution of CH_4 and N_2O is therefore very small. Whilst some caution is required given the greater uncertainty over AFV emission factors for these non-CO_2 gases, it is clear that, as with the transport sector more broadly, CO_2 emissions dominate total GHG emissions for AFVs.

- Accounting for AFVs in the UK inventory will therefore have little impact on historic and current emissions. However, CO_2 emission estimates from this sector will become increasingly important due to the expected continued increase in the numbers of AFVs. Looking at future projections, the contribution of AFVs to total road transport GHG emissions could be between 6-9% by 2035, as detailed in Chapter 7 of this report. The contribution is dependent on a number of factors, including assumptions on the continued inclusion of hybrids as AFVs, and the use of Plug-in Hybrid Electric Vehicles (PHEVs) in electric or petrol mode. It is important to view the projected

[1] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016
[2] Calculated from https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017

impacts through two mechanisms: 1) AFVs' contribution to emissions, and 2) The shift from conventional vehicles to AFVs and the associated reduction in transport's overall emissions.

- Point-of-use ('tailpipe') emissions from electric and hydrogen vehicles are currently treated as zero, consistent with international inventory reporting. However, the US are looking into the possibility of breaking out the electricity used to charge vehicles and reporting that electricity use under the transport sector. Reporting of electricity use in this way in the UK would increase AFVs total contribution to CO_2 emissions, and the extent to which would depend on the UK grid mix.

- There is increasing work being undertaken across Europe and internationally to better understand emission factors and activity data associated with AFVs. The UK is on a par with other countries in many respects, as illustrated in Table 1. However, improvements could be made to the UK's activity data. The US, for example, uses a vehicle km-based approach to calculate CH_4 and N_2O emissions for all AFVs, and is starting to capture AFV electricity use data, whilst the Japan inventory clearly sets out all assumptions and factors used.

Table 1: Summary of the Tier[3] approach to AFVs used in the inventories of selected countries

Aspect	Pollutants	Norway	Italy	Japan	Netherlands	United States	United Kingdom
Integration of LPG/CNG AFVs	CO_2	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)
	CH_4, N_2O	Yes (Tier 2)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 2/3)
Integration of bio-fuel AFVs	CO_2	Yes (Tier 2)	Yes (Tier 2)	No*	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 1)
	CH_4, N_2O	Yes (Tier 2)	Yes (Tier 2)	No*	Yes (Tier 2)	Yes (Tier 3)	Yes (Tier 2)
Integration of plug-in hybrid/ electric vehicles	CO_2 #	No	No	No	No	No	No
	CH_4, N_2O	No	Yes (Tier 3)	No	No	Yes (Tier 3)	No

* In Japan, the number of these vehicles is low and therefore considered negligible
# Calculating CO_2 emissions on a fuel basis incorporates any hybrid/electric vehicles implicitly, as these technologies directly impact the fuel use of the vehicle. In these cases, this row can therefore be read as whether or not the NIR explicitly acknowledges this dynamic

- Total CO_2 emissions from the transport sector can also be determined through fuel sales. However, improved understanding of activity data in terms of mileage and real-world use will be key to reconciling with the bottom-up estimates (activity data x emission factor) that are also employed in the UK. Furthermore, this improved understanding will continue to be important in terms of impacts of traffic-related emissions for other GHGs (CH_4 and N_2O) and air pollutants (NO_x and PM_{10}) which depend on engine load and speed.

- Whilst there is still uncertainty in the emission factor values, there is increasing literature and real-world data available. PHEVs could be considered to be the AFV vehicle type where the uncertainty is presently greatest, reflecting their significant uptake in recent years and the current limited understanding of real world use (petrol vs. electric mode). Increased

[3] A tier represents a level of methodological complexity. Usually three tiers are provided; with Tier 1 the most basic method, Tier 2 intermediate and Tier 3 the most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are typically considered to be the most accurate. Further details on the Tier approach is provided in Chapter 6

understanding of Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG) emissions could also be important, particularly in the context of the recent introduction of bio-LPG and bio-methane, although numbers of gas fuelled vehicles are decreasing. Data on N_2O and CH_4 emission factors is comparatively limited, however the extent to which effort is spent improving these factors needs to be seen in the context of their low overall contribution to GHG emissions.

The recommendations resulting from the project are:

Vehicle fleet statistics - it is recommended that continued improvements are made to the data collection processes for AFV fleet statistics, so that more reliable emission estimates can be made. This could include ensuring that projections start from the latest available statistics. In the future, more granular data could be provided on the size or segment categories of vehicles.

Activity data - understanding of real world use of PHEVs, electric and fuel cell vehicles is currently limited, which restricts the precision of analysis that can be applied. With respect to mileage odometer data, this is available from MOT test data and it is recommended that research using this source is undertaken to allow mileage data for AFVs to be improved. The UK National Travel Survey also offers opportunities to understand the use of these vehicles by trip purpose and road type. In terms of the consumption of liquid fuel vs. electricity in Plug-in Hybrid and Range Extender vehicles, the expected rise in increasingly connected vehicles could result in more data being available at fleet, manufacturer or software developer level. Consideration needs to be given on how best to access this data.

It will also be key to understand potential future societal changes on vehicle mileage. With the planned introduction of fully autonomous vehicles onto UK roads as soon as 2021, and the likely very high prevalence of electric vehicles within this autonomous roll-out, customer demands for vehicle ownership and hired transport services are expected to start shifting dramatically within the next 5-10 years. Combined, these factors could dramatically alter the annual mileages (and modes) driven by different vehicle types.

Emission factors - improvements have been made since the 2013 review. It is recommended that continued emission test work is supported and that the UK continues to work with other EU countries to build up an accessible database of emission factors. This is particularly relevant with the significant changes in manufacturer drive-cycle testing at EU level; increasing understanding of how emission levels can vary with speed; and the potential future impacts of introducing higher levels of biofuels.

Treatment of hybrid vehicles - the classification of hybrids as AFVs is increasingly a misnomer as variants of this technology are being generally adopted in many passenger cars in particular. Hybrid vehicles (without a separate means of charging) are essentially more efficient versions of standard internal combustion engine vehicles. Faced with stringent tailpipe CO_2 targets, most vehicle manufacturers are turning to various forms of hybridisation as a means to improve the efficiency of their products in the near term, with some also offering plug-in and full electric versions as well. In the latest US inventory, hybrids are classified as gasoline vehicles, whilst historically they have been treated as alternatively fuelled vehicles. Similarly, in the Committee for Climate Change's Fifth Carbon Budget report, hybrids are considered alongside conventional vehicles, whilst historically their impact has been detailed separately. In the UK NAEI, hybrid vehicles are not disaggregated per se, so the future treatment of hybrids reflects an issue over terminology rather than a quantifiable change in overall transport emissions.

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Glossary

AFVs	Alternatively fuelled vehicles
AQPI	Air quality pollutant inventory
BEVs	Battery Electric Vehicles
BEIS	Department for Business, Energy and Industrial Strategy
CCC	Committee on Climate Change
CH_4	Methane
CO_2	Carbon Dioxide
COPERT	COmputer Progamme for calculating Emissions from Road Transport
CNG	Compressed Natural Gas
CCC	Committee for Climate Change
DfT	Department for Transport
DUKES	Digest of UK Energy Statistics
EEA	European Environment Agency
EC	European Commission
EMEP	European Monitoring and Evaluation Programme
ETBE	Ethyl Tert-Butyl Ether
EU	European Union
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
GPS	Global Positioning System
HBFA	Handbook of Emission Factors
HEVs	Hybrid Electric Vehicles
HMRC	Her Majesty's Revenue and Customs
IPCC	Intergovernmental Panel on Climate Change
JAMA	Japan Automobile Manufacturers Association
Kg	kilogram
LGV	Light Goods Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NAEI	National Atmospheric Emissions Inventory
NIR	National Inventory Report
OLEV	Office for Low Emission Vehicles
N_2O	Nitrous Oxide
NO_x	Nitrogen oxides
PHEVs	Plug-in hybrid electric vehicles
PM10	Particulate matter of 10 micrometres or less in diameter
REEV	Range extended electric vehicle
RTFO	Renewable Transport Fuel Obligation
TJ	TeraJoule
UNFCCC	United Nations Framework Convention on Climate Change
vkm	Vehicle kilometre

1 Introduction

Greenhouse gas (GHG) emissions from the road transport sector are estimated to make up approximately 24% of domestic UK GHG emissions[4]. There are increasing demands to reduce the emissions arising from this sector, which is seen as one of the more challenging sectors in terms of climate change mitigation. The UK has a legally binding carbon target to reduce GHG emissions by 80% by 2050 (relative to 1990 levels)[5]. Periodic budgets to meet this target are set and monitored by the Committee on Climate Change (CCC). In their Fifth Carbon Budget report, the CCC described how emissions from the transport sector could be reduced by 2035[6], and identified alternative fuels and vehicle technologies as an important component of the emissions reduction potential. The road transport sector is also a key source of air quality pollutant emissions.

The National Atmospheric Emissions Inventory (NAEI) quantifies national emissions of a range of greenhouse gases and air quality pollutants. The key output of the NAEI is the provision of high quality and consistent data on emissions for policy and public information. This information must be reported annually as the UK Greenhouse Gas Inventory (GHGI) and the UK Air Quality Pollutant Inventory (AQPI), to fulfil the UK's national, European and global reporting obligations on climate change and air quality.

This research forms part of the NAEI improvement programme. The aims of the project were to:

- Identify sources of information on the numbers and activity (mainly vehicle kilometres travelled) for the different alternative fuel vehicles (AFVs), both historically and projected to 2030.
- Review the fuel consumption and emission factors available for AFVs. The study focus was on GHGs including Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O), but other regulated air quality pollutants such as NO_x and PM_{10} were also considered. These were chosen because of their importance in the transport sector.
- Combine activity and emission factor data to estimate fuel consumption and emissions from the different classes of AFVs to 2030.
- Review how other countries estimate emissions from AFVs, and make recommendations as to whether the UK could benefit from following similar approaches.

The UK's current approach to AFVs in the context of the NAEI is detailed in Section 2.

The project was undertaken by E4tech and Aether. E4tech is a strategic consultancy working in sustainable energy and vehicles, with offices in UK and Switzerland. Since 1997 the firm has supported companies, governments and investors on alternative fuel and vehicle topics, amongst others. Aether is an environmental consultancy working on air quality and climate change emission inventories, forecasting and policy analysis. The research project is a follow-on from a review undertaken in 2013 by Aether, and is undertaken under the Department for Business, Energy and Industrial Strategy (BEIS) Lot 22 Transport framework.

The review only covers emissions arising from the 'tailpipe' (i.e. at point of use); life-cycle emissions are outside the scope of the report and would require a much more detailed study. This is in

[4] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016
[5] https://www.gov.uk/government/policies/reducing-the-uk-s-greenhouse-gas-emissions-by-80-by-2050/supporting-pages/carbon-budgets
[6] https://www.theccc.org.uk/publication/the-fifth-carbon-budget-the-next-step-towards-a-low-carbon-economy/

accordance with the reporting in the NAEI, which reports emissions 'by source'[7] for international submissions.

A spreadsheet model has been developed that allows GHG emissions to be estimated over the time period 1990 to 2017 and under different future scenarios. Further detail is provided in the following sections:

- Section 2 - introduces alternatively fuelled vehicles; provides information on current numbers in the UK context; and the approach currently used in the NAEI
- Section 3 - details activity data, historic and future projections as well as assumptions on mileage undertaken
- Section 4 - provides information on fuel consumption and emission factors including uncertainties
- Section 5 - details the results, both historic and future projections
- Section 6 - considers the approaches used in other countries
- Section 7 - provides conclusions and recommendations

[7] 'By source' refers to emissions being attributed to the sector that emits them directly. The opposite is 'end user' which refers to emissions being reallocated from the fuel producers to the fuel users.

2 Alternatively fuelled vehicles

An alternative fuel vehicle is a generic term that covers vehicles which:

- are powered by fuels other than conventional petrol or diesel; and/or
- utilise new propulsion technologies; note that some of these are not 'fuelled' in the strict sense but the term alternative *fuel* vehicle nevertheless applies in general parlance.

The following fuel and technology types have been covered in this project. Emission factors are provided for all of the AFVs described below, but historic vehicle numbers and projected numbers are not available for all of these vehicle technology and fuel types.

In referencing the NAEI it is important to note that a top-down and bottom-up approach are used to capture emissions. The top-down approach is based on fuel sales while the bottom-up approach is based on a combination of vehicle kilometre data and emission factor data.

2.1 Gas

This sub-section covers vehicles running on Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG). Although Liquified Natural Gas (LNG) is another potential alternative fuel, it is not considered in this study. LPG is a blend of propane and butane, and is sold in certain fuel stations in the UK for use in converted cars and commercial fleet. CNG is methane (CH_4) in compressed gaseous form. Renewable versions of these fuels have also been developed (see the section 2.6 on biofuels), with bioCNG from anaerobic digestion facilities already used in UK transport, including sales via the gas grid. BioLPG has recently been introduced, and will initially be sold in small volumes at a 40% blend with fossil LPG[8]. However, the majority of LPG and CNG today is still fossil-based.

2.1.1 LPG

In the UK GHG inventory[9,10], emissions from vehicles which run on LPG are estimated on the basis of national figures (from Digest of UK Energy Statistics - DUKES) relating to the use of this fuel in the road transport sector and fuel-based factors given in the National Inventory Report.

The inventory suggests that CO_2 emissions from LPG consumption cannot be disaggregated by vehicle type because there are no reliable figures available on the total number or types of vehicles using this fuel. It is believed that many vehicles running on LPG are cars and vans converted by their owners and that these conversions are not necessarily reported to vehicle licensing agencies.

In terms of impact, data from DUKES suggest that since 2001, the annual consumption of LPG is only around 0.2% of the total amount of petrol and diesel consumed by road transport[11]. Vehicle licensing data suggests that a similar percentage of light duty vehicles registered since 2004 run on LPG.

Data obtained for the purposes of this project[12] suggest that there are approximately 120,000 LPG vehicles on the UK LPG register. Whereas data from DfT statistics suggests that in 2017 there were

[8] https://www.calor.co.uk/lpg
[9] https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/submissions/national-inventory-submissions-2017
[10] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804121004_Road_transport_emissions_methodology_report_2018_v1.1.pdf
[11] Page 24 https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804121004_Road_transport_emissions_methodology_report_2018_v1.1.pdf

around 32,000 gas-fuelled cars and 6,800 vans (noting that DfT statistics include gas bi-fuel, petrol/gas and gas-diesel vehicles)[13]. It is assumed that the differences between these data sets are due to variations in registering approaches.

In the UK, LPG use is incentivised through a lower fuel duty applied to LPG compared with petrol, with the 2017 annual statement providing confirmation that this differential will not change before 2025. With regard to road tax/vehicle excise duty, some LPG vehicles are eligible for the Alternative Fuel car reduced rate[14].

In the NAEI, emissions of CH_4 and N_2O from the consumption of LPG are calculated from vehicle km data and emission factors from COPERT 4[15]. Reliable data on vkm is not readily available and this was confirmed in the data collection for this project. In order to calculate these figures in the NAEI it is assumed that all vehicles using LPG are Light Goods Vehicles (LGVs), then data on fuel efficiency factors for these vehicles is combined with total LPG consumption to provide the km figure. This km figure is then combined with the COPERT 4 factors.

2.1.2 CNG

The NAEI does not currently estimate emissions from vehicles running on natural gas[16]. The number of such vehicles in the UK is suggested to be small, with most believed to be running in captive commercial fleets on a trial basis in a few areas. Estimates are therefore not made in the inventory, with the rationale being that there are no separate figures from BEIS on the amount of natural gas used by road transport, nor are there useable data on the total numbers and types of vehicles equipped to run on natural gas from vehicle licensing sources. In terms of potential impacts, the small amount of gas that is used in the road transport sector would currently be allocated to other sources in DUKES, and therefore the omission of this source does not represent an underestimate in the current UK inventory. In terms of future data availability, it was noted that DfT Renewable Transport Fuel Obligation (RTFO) statistics report on the amount of bio-CNG used in transport.

In the UK, CNG use is incentivised through a lower fuel duty and this differential will not change before 2025.

Data from DfT suggests that there over 6,800 gas powered vans[13], over 300 HGVs and over 280 buses[17]. It is important to note that this can include, gas bi-fuel, petrol/ gas and gas-diesel vehicles.

2.2 Hybrid

Hybrid Electric Vehicles (HEVs) are powered by a combination of a conventional internal combustion engine (either running on petrol or diesel) and an electric motor.

Cars are the most common form of HEV, with over 320,000 petrol hybrid electric cars in operation in the UK in 2017[17]. The Toyota Prius is the highest selling hybrid car. Hybrid buses (diesel-electric) are

[12] UK LPG register, personal communication 04/04/2018
[13] Based on DfT Transport Statistics Table VEH 0403 (2017) Licensed Light Goods Vehicles at the end of the year by propulsion fuel / type and Table VEH 0203 (2017) Licensed Cars at the end of year by propulsion fuel / type
[14] https://www.drivelpg.co.uk/about-autogas/what-are-the-benefits/
[15] COPERT is a software tool used to estimate air quality and greenhouse gas emissions from road transport. It is funded by the European Environment Agency. http://emisia.com/products/copert
[16] Page 24 https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804121004_Road_transport_emissions_methodology_report_2018_v1.1.pdf
[17] Department for Transport, 2017 Vehicle Stock output. Sent through for the purposes of this project.

increasing in popularity in cities in a bid to reduce air pollution and comply with Low Emission Zones. There are currently over 2,500 hybrid buses[18] in use in the UK, which usually utilise regenerative braking, whereby kinetic energy is recovered when braking and stored as electricity.

Incentives for hybrids reflect the lower CO_2 emissions these vehicles can offer. For example, historically[19] hybrid vehicles were effectively exempt from the London congestion charge. Hybrid buses which meet Low Emission Bus[20] criteria are eligible for a low emission bus grant.

In terms of the current NAEI[21], for CO_2, CH_4 and N_2O for all petrol and diesel vehicles, calculations are based on a top down and bottom up approach. Top down data on fuel consumption is compared with bottom up data (activity data combined with emission factors). Results are reconciled. There is no explicit consideration of hybrid vehicles since their primary energy source is fuel rather than electricity. For traffic-based emissions reference is made to Murrells and Pang (2013) which provides information on scaling factors[22] / emission factors to be used for PM and NO_x. Information on uptake rates of hybrid vehicles based on information provided by DfT.

2.3 Plug-in hybrid

Plug-in Hybrid Electric Vehicles (PHEVs) are hybrid electric vehicles containing batteries that can be recharged by plugging them in to an electric power source. They are typically driven in electric mode over short-medium ranges, with the combustion engine working as a back-up once the batteries are depleted or when more power is required – for example when accelerating or driving at high speeds.

Range-extended electric vehicles (REEVs) are battery electric vehicles equipped with internal combustion engines acting as an onboard generator to provide additional energy when battery charge is low. Driving ranges similar to conventional vehicles are therefore facilitated.

There are currently around 78,000 PHEV cars in the UK[23]. The leading PHEV is the Mitsubishi Outlander and the leading REEV is the BMW i3. There are currently limited REEV makes and models on offer in the UK, which results in low numbers. DfT forecasts reference PHEVs and REEVs together.

PHEVs and REEVs can be eligible for a grant towards their cost – for example through the Office for Low Emission Vehicles' (OLEV's) plug-in car grant. Other incentives can include exemptions from parking charges.

In the NAEI, PHEVs could be considered to be captured through reference to alternative fuelled vehicles, in which case the approach is consistent with that used for hybrid and electric vehicles.

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[18] Data compiled from TfL's fleet audit (September 2017) and https://www.lowcvp.org.uk/assets/reports/A%20Green%20Bus%20for%20Every%20Journey.pdf as well as bus company websites

[19] From 2003 to 2010 under the Alternative Fuel Discount, and to 2013 under the Greener Vehicle Discount. Note for the Greener Vehicle Discount, Toyota Prius vehicles manufactured later than 2009 would be eligible, but not earlier versions, reflecting that the discount required that vehicles produce CO_2 emissions of 100g/km or less.

[20] LowCVP low emission bus guide https://www.lowcvp.org.uk/assets/reports/LowCVP%20LEB%20Guide%202016%20interactive%20V3.pdf

[21] Ricardo-AEA, 2018. Methodology for the UK's Road Transport Emission Inventory. Version for the 2016 National Atmospheric Emissions Inventory. Report to BEIS. Page 52.

[22] Scaling factors are used to adjust emission factors upwards or downwards compared with a conventional vehicle

[23] There are approximately 124,000 'plug-in electric' cars in the UK in 2017 (plug-in grant eligible and non plug-in grant eligible), from DfT vehicle stats Table 0130. This would cover battery electric and plug-in hybrid electric vehicles / REEVs (note that REEVs are limited in number). There are approximately 46,000 battery electric vehicles in the UK, from DfT vehicle stats Table 0203. There are therefore around 78,000 PHEVs in the UK. Out of the total number of 'plug-in' vehicles (BEV and PHEV) this is a current ratio of approximately 1/3rd BEV to 2/3rds PHEV. Overall numbers are consistent with the broader literature, e.g. http://www.eafo.eu/content/united-kingdom

PHEV and REEVs emission factors (g/km) depend on assumptions with regard to use in electric or petrol mode. At the level of the inventory data on fuel sale use would ensure that assumptions were reconciled with the overall picture.

2.4 Battery electric

Battery electric vehicles (BEVs) run on electricity stored in rechargeable batteries, using electric motors for power, rather than an internal combustion engine.

There are currently around 46,000 battery electric cars in the UK[23], covering a wide range of manufacturers and vehicle sizes, with Nissan Leaf the sales leader. There are over 300 electric buses[17] and over 6,000 vans.

BEIS provides support for further EV battery development, with £246m funding for the Faraday Challenge[24], and a series of OLEV grant schemes exist to support EV charging infrastructure[25].BEVs can be eligible for a grant towards their cost e.g. through OLEV's plug-in car grant.

BEVs are referenced in the current NAEI methodology document. They are assumed to have no tail-pipe emissions and so have the potential to greatly reduce emissions from road transport. When reporting 'by source', emissions from this technology are zero – for CO_2, CH_4, N_2O and air quality pollutants[26].

2.5 Hydrogen fuel cell electric vehicles

Fuel cell electric vehicles (FCEVs) work on the same principles as a battery electric vehicle, producing electricity to run an electric motor. However, the electricity is generated in a fuel cell which consumes hydrogen fuel. This hydrogen is stored on-board in a tank. The range (in kilometres driven) and refuelling time (in minutes) of a fuel cell vehicle are comparable with a conventional vehicle – two of the main advantages compared with BEVs.

There are currently two FCEV car models available to own in the UK (Hyundai's ix35 fuel cell and the Toyota Mirai)[27] and these will be joined by Honda's Clarity Fuel Cell later in 2018, though total sales to date are barely in the hundreds. Transport for London has currently eight hydrogen fuel cell buses in use on route RV1. Fuel cell taxis have also been trialled[28].

Emissions relating to the production and supply of hydrogen fuel are outside of the scope of the study; however, significant investment is needed to produce low carbon hydrogen at scale. The UK H_2Mobility project is a partnership of UK industry leaders and government, working to support the introduction of hydrogen as a transport fuel. In March, 2018 OLEV awarded £8.8 million for the purchase of hydrogen fuel cell cars and to support the expansion of the UK's hydrogen refuelling infrastructure. The investment will include trials of 200 hydrogen cars with police fleets and Europcar

[24] BEIS (2017) "The Faraday Challenge – part of the Industrial Strategy Challenge Fund", Available at: https://innovateuk.blog.gov.uk/2017/07/24/the-faraday-challenge-part-of-the-industrial-strategy-challenge-fund/
[25] OLEV (2018) "Grant schemes for electric vehicle charging infrastructure", Available at: https://www.gov.uk/government/collections/government-grants-for-low-emission-vehicles
[26] For example, Murrells and Pang (2013) Reference PM and NO_x as zero in the context of electric vehicles
[27] http://www.nextgreencar.com/fuelcellcars/
[28] https://www.london.gov.uk/sites/default/files/exec_summary_-_london_-_a_capital_for_hfc_technologies.pdf

amongst partners who will operate the vehicles. Manufacturers who will participate in the project include Toyota, Honda and Hyundai[29].

In terms of the current NAEI[30], though there is no explicit mention of fuel cell vehicles, they could be considered to be captured through the use of 'alternative fuels'. As with electric vehicles, all emissions would be treated as zero at source (since hydrogen fuel cells only produce water from the 'tailpipe').

2.6 Biofuels

Biofuels include:

- bioethanol, an alcohol made most commonly from sugar cane, sugar beet and cereals, along with wastes/residues such as starch slurry
- biodiesel, which is produced by the esterification or hydro-processing of oils such as used cooking oil, waste animal fats, rape seed and palm oil
- biomethane, which is produced from aerobic digestion of manures, food waste and sewage sludge, and crops such as grass and silage maize
- less commercially mature routes for converting municipal solid waste, industrial, agricultural and forestry residues into alcohols, methane, petrol, diesel and jet fuel, amongst others

Biofuels can be attractive for reducing emissions as theoretically the CO_2 emitted during vehicle use are balanced by the carbon sink of the feedstock's growth. However, there are often significant upstream GHG emissions arising from the use of fertilisers and fossil fuels in cultivation, harvesting, processing, and distribution of the feedstocks, particularly if including land-use change impacts. To limit sustainability concerns, the revised EU Renewable Energy Directive to 2030 is setting a cap on crop-based biofuels, and promoting the use of waste/residue-based biofuels.

The RTFO requires UK road transport fuel suppliers to supply a certain percentage of fuels from renewable, sustainable sources (or else a pay a buy-out penalty). The obligation was set at 4.75% for several years, although changes to the RTFO made in early 2018 will see this rise to 9.75% by 2020, and then to 12.4% by 2032[31], with an increasing focus on waste/residue based fuels.

There are no reliable figures on the number of vehicles running solely on biofuels in the UK (e.g. 100% biodiesel, B100), or at high-blends (e.g. 85% ethanol in petrol, E85, or 30% biodiesel, B30). Whilst the total volumes of bioethanol, biodiesel, biomethane and other renewable fuels supplied in the UK are reported annually, the blending levels and vehicles they are used in are not reported.

There is some anecdotal evidence of around 5,000 vehicles in the UK currently running on high-blends of biodiesel, as well as a few hundred vehicles running on B100[32]. These bus and HGV fleets buy their biodiesel from a small handful of UK fuel suppliers and refuel at industrial/commercial outlets. Very few, if any, conventional petrol stations sell B30 or B100 to the UK motoring public[33]. There are no estimates available for the number of UK vehicles running on high-blend bioethanol,

[29] DfT (2017) "£23 million boost for hydrogen-powered vehicles and infrastructure", Available at: https://www.gov.uk/government/news/23-million-boost-for-hydrogen-powered-vehicles-and-infrastructure
[30] Ricardo-AEA, 2018. Methodology for the UK's Road Transport Emission Inventory. Version for the 2016 National Atmospheric Emissions Inventory. Report to BEIS. Page 52.
[31] DfT (2018) "Renewable Transport Fuel Obligation (RTFO) guidance: Year 11", Available at: https://www.gov.uk/government/publications/renewable-transport-fuel-obligation-rtfo-guidance-year-11
[32] Argent Energy, personal communication 28/06/2018
[33] http://www.biodieselfillingstations.co.uk/alloutlets.htm

although there were apparently 21 filling stations in the UK selling E85 in 2015 (unclear whether these are conventional petrol stations for the public, or industrial/commercial outlets)[34].

The NAEI currently assumes that all biofuels are consumed as weak blends with fossil fuels[10], with uptake rates of biofuels based on annual figures from HMRC. Bioethanol is typically blended with fossil petrol at up to 5% by volume in the UK, and biodiesel blended with fossil diesel at up to 7% by volume, but across the UK, average annual blending rates have previously been around 3% due to double counting incentives within the RTFO[35].

The CO_2 emissions associated with biofuel combustion are estimated and reported as memo items but not included in national totals, in line with international reporting requirements. For a valid comparison with DUKEs, the amount of petrol and diesel displaced by biofuel consumption is used to correct the calculated consumption of petrol and diesel.

CH_4 and N_2O emission are included[36] with an implicit assumption that the emissions of CH_4 and N_2O from bioethanol and biodiesel are the same as emissions from fossil fuel petrol and diesel, respectively by energy content. The effects of biofuel (bioethanol and biodiesel) on other (non GHG) tailpipe emissions are represented by a set of scaling factors given by Murrells and Li (2008). Biofuel scaling factors for PM were updated with values given in a report by Ricardo Energy & Environment for Defra following a review of the literature in 2017[37]. For 5% biofuel blends, these scaling factors were 0.925 and 0.948 for older petrol and diesel vehicles respectively (i.e. the use of biofuels slightly reduces PM emissions). No scaling factors are applied for motorcycles, nor for more recent Euro 5 and 6 light duty vehicles, and Euro IV, V or VI heavy duty vehicles. A combined scaling factor was applied to the emission factors according to both the emission effects of the biofuel and its uptake rate. The NAEI methodology indicates that the effects on these pollutants are generally rather small for these weak blends.

[34] https://epure.org/about-ethanol/fuel-market/fuel-blends/
[35] DfT (2018) Biofuel statistics: Year 10 (2017 to 2018), report 3, Available at: https://www.gov.uk/government/statistics/biofuel-statistics-year-10-2017-to-2018-report-3
[36] Here total traffic-based emissions for CH_4 and N_2O are divided by the total traffic consumption estimates for each vehicle type. The implied emission factors thus take into account the mix of vehicle technologies affecting emissions of each of these pollutants each year. The implied emission factors are then multiplied by the fuel sales assigned to the vehicle type including estimates of the amount of fossil fuel displaced by the sale of bioethanol and biodiesel each (taking into account the different energy contents of the biofuels). The allocation of biofuels to each vehicle type is done pro-rata to the distribution of fossil fuels to vehicle types.
[37] As referenced in Brown et al (2018) Methodology for the UK's Road Transport Emissions Inventory, No reference for report provided.

3 Activity data

A review was undertaken of the historic activity data (for 1990 – 2017, with the latter being the latest year available) that was available for road vehicles using alternative fuels and technologies. In addition, various road transport scenarios were obtained to provide an indication on the possible uptake rates in the future.

3.1 Historic data

3.1.1 Historic licensed stock

Data on the numbers of registered vehicles by propulsion type (including AFVs) from 1994 onwards was obtained from DfT and other sources[38]. In order to cover the period of reporting for the UK's Greenhouse Gas Inventory, data was required from 1990 onwards. Therefore data was extrapolated linearly prior to 1994. Information is for 2017 is presented below in Table 2.

Table 2: UK 2017 vehicle numbers by propulsion type

Vehicle	Fuel	Licensed stock	Percentage of vehicle type
Car	Petrol	18,760,152	58.4%
	Diesel	12,901,544	40.1%
	Hybrid petrol	320,130	1.0%
	Hybrid diesel	10,585	0.0%
	Gas	31,773	0.1%
	Electric	46,229	0.1%
	Plug-in Hybrid electric	78,182	0.2%
Bus	Petrol	4,032	2.4%
	Diesel	159,354	95.7%
	Hybrid diesel	2,555	1.5%
	Gas	283	0.2%
	Electric	302	0.2%
LGVs	Diesel	3,868,401	96.4%
	Petrol	128,910	3.2%
	Gas	6,812	0.2%
	Electric	6,293	0.2%
	Plug-in hybrid electric	144	0.0%
	Hybrid petrol	53	0.0%
HGVs	Diesel	520,626	99.5%
	Petrol	1,877	0.4%
	Gas	335	0.1%
	Electric	386	0.1%

*Note: for the percentage of vehicle type column, the sum of the components may not exactly equal 100% due to rounding
Data in italics reflects that sensitivity testing could be undertaken. Reflecting LGVs definitions could change in 2015.

[38] Note this included data direct from DfT as well as vehicle licensing statistics data in the form of Table 0130 Ultra Low Emission Vehicles licensed; Table 0203 Cars licensed by propulsion fuel / type and Table 0403 Light Goods Vehicles licensed by propulsion fuel / type. Information on buses is provided at http://content.tfl.gov.uk/fleet-audit-30-september-2017-final.pdf and https://www.lowcvp.org.uk/assets/reports/LowCVP%20LEB%20Guide%202016%20interactive%20V3.pdf

3.1.2 Annual distance travelled

No detailed information is available on the average annual distance travelled for all the AFVs - in total or split between urban roads, rural roads and motorways. It has therefore been assumed for this project that the distance travelled will be the same as an equivalent conventional vehicle for the year of concern.

The annual distance travelled by conventional vehicles has been calculated by dividing the total number of vehicle kilometres by vehicle type undertaken on each road type in Great Britain by the total number of licensed vehicles in Great Britain each year. This therefore differentiates between the mileage undertaken by petrol and diesel vehicles, with diesel vehicles typically having higher mileage. It is recognised that this is a simplified approach; for more accurate data to be obtained, a vehicle stock turnover and mileage model would need to be developed. Due to the currently low numbers of AFVs, this will only have a small impact on the results.

The exception to this would be for electric vehicles and a discussion of key issues is provided below. It is important to note that as this review only compiles estimates on a 'by source' basis, the emission outcomes are zero for electric vehicles.

Discussion on electric vehicle mileage

In the original review it was suggested that an electric vehicle could be around 50% of a conventional vehicle's mileage[39]. As a check on these assumptions, available data from the NAEI UK fleet composition projections on the proportion (%) of vehicle kilometres of:

- Electric vehicles in urban areas

was used for comparison (noting only reference is made to urban areas). For example, for England (outside of London) it is suggested that electric vehicles would be 4.4% of urban distance driven in 2035. Comparing this data with projections for electric vehicle uptake suggests a figure that is consistent with around 50% of a conventional vehicle use.

There is, however, an increasing literature on electric vehicle mileage[40,41] which suggests that the novelty value of new vehicles and an emphasis on recouping costs could result in higher mileage, rather than EVs being a secondary car purchase that does not see as much use. Electric vehicle mileage will also need to be seen in the context of continued developments in battery range and recharging availability which in turn may influence/ increase mileage driven.

Reflecting these uncertainties, it is important to understand potential future data sources. A new possible data source on the average annual distance travelled by cars, other light duty vehicles (including light goods vehicles), private buses and motorcycles became available in June 2013 in the form of DfT experimental statistics. One of the items of information recorded by the Nominated Tester during an MOT test is the vehicle odometer reading. Although it is not currently mandatory, it is recorded in around 95% of cases. The MOT database therefore contains mileage information for a very large proportion of Great Britain registered vehicles that are subject to an annual test. Analysis

[39] This assumption was made following discussions with the Low Carbon Vehicle Partnership and Emisia. However, as this report only compiles estimates on a 'by source' basis, emission estimates are zero for both electric and fuel cell vehicles and therefore this assumption is not actually used.
[40] Jensen and Mabit (2017) The use of electric vehicles: A case study on adding an electric car to a household. Transportation Research Part A 106 2017 89-99
[41] Langbroek et al (2017) Electric Vehicle Users and their travel patterns in Greater Stockholm. Transportation Research Part d 52 (2017)

of this data has been undertaken through the Motoring and Vehicle Ownership trends in the UK (MOT) project[42]. However, data in the form of AFVs has not yet been disaggregated. This data – average annual distance travelled by AFVs – could be provided if bespoke permission was provided by DfT to extract it and resourcing were available[43]. It is important to note that there is a three-year time lag before mileages across the first three years of a vehicle's life can be calculated.

There is also the potential for the National Travel Survey (NTS) to include a question on car make and model. The NTS[44] is a household survey designed to monitor long-term trends in personal travel and to inform the development of policy. It is the primary source of data on personal travel patterns by residents of England. The survey collects information on how, why, when and where people travel as well as factors affecting travel. Approximately 16,000 individuals, in 7,000 households in England, participate in the NTS each year. The richness of this data source could therefore be invaluable in understanding travel patterns as they relate to the real-world use of AFVs. Given the comparatively limited number of respondents who will own AFVs, appropriate means of ensuring confidentiality will need to be considered in the short to medium term.

Heavy goods vehicles (over 3.5 tonnes) and large buses and coaches are subject to a separate testing regime so would not be covered by this dataset. Dedicated monitoring of vehicle use patterns would therefore be required. The use of Global Positioning System data, for example could be explored.

3.2 Projections

Scenarios of the numbers of AFVs travelling on UK roads in future years are detailed below.

For some vehicle technologies there is a considerable range in the predicted number of future vehicles, particularly if the technology is currently in its very early stages. The different scenarios also focus on different specific vehicle technology types and do not present a complete coverage of vehicle types and future technologies. Government policies, infrastructure investment, consumer behaviour, the economic climate, and conflicting pressures will all affect the future numbers of AFVs, and the scenarios all assume different priorities. These are described below.

Emission projections based on these scenarios are detailed in section 7. It should be noted that these are based on only two scenarios, the CCC's Fifth Carbon Budget and the DfT's latest projection, as these are believed to be the most relevant, recent and complete projections currently available.

3.2.1 UK Department for Transport

The 2018 projection used in this analysis covers the time period from 2025 to 2035 for Great Britain (but not Northern Ireland), and includes electric cars, electric vans, plug-in hybrid cars and plug-in hybrid vans. There are therefore only selected vehicle and fuel /technology types covered in this set of projections. The source for this data is the DfT's fleet fuel efficiency model. The results suggest the following in:

2025

- 1.5% of the UK car fleet would be BEVs and 1.8% PHEVs or REEVs
- 2.1% of the UK van fleet would be BEVs and 1.4% of all PHEVs

[42] http://www.its.leeds.ac.uk/research/featured-projects/mot/
[43] Professor Jillian Anable - Principal Investigator on the MOT project - personal communication
[44] https://www.gov.uk/government/collections/national-travel-survey-statistics

2035

- 3.6% of the UK car fleet would be BEVs and 8.3% PHEVs or REEVs
- 7.0% of the UK van fleet would be BEVs and 8.5% PHEVs

It is important to note that the UK Government will shortly publish a zero emission road transport strategy, which may impact on the above projections.

The Government's Clean Growth Strategy references that at least 30% of new car sales are expected to be ULEVs by 2030, and possibly as many as 70%. For new vans, up to 40% of sales could be ULEVs by 2030. HGVs should be up to 15% more efficient by 2030 and there should be significant uptake of ultra-low and zero emission buses.

3.2.2 Committee for Climate Change Fifth Carbon budget

The CCC's Fifth Carbon budget report was published in November 2015. There are a number of key differences between this and the Fourth Carbon budget review, which was published in 2013.

- Road transport demand is projected to be higher in 2030. Total vehicle kms in 2030 are 6% above the 2013 projection.
- Plug-in electric small HGVs were not included in the CCC's previous scenario, but new evidence suggests that these could be a feasible and cost-effective measure.

The Fifth Carbon budget provides information on a central, barriers and max scenario for each sector. The 'barriers' scenario represents unfavourable conditions for key measures[45], while the 'max' scenario represents maximum feasible deployment of these measures. The 'barriers' scenario could, therefore, potentially be considered a low and the 'max' scenario a high. The approach demonstrates the flexibility in how the fifth carbon budget could be met.

In terms AFV vehicle sales under the central scenario in 2030:

- 61% of new car and van sales will be electric in 2030 (38% PHEV and 23% EV).
- 40% of new small rigid HGVs sales are electric in 2030 (30% PHEV and 10% BEV).
- 5% of new bus sales are hydrogen fuel cell buses, and 25% are electric.

Analysis undertaken for the purposes of this review using DfT data on forecast total numbers of cars and vans and CCC underpinning data sets, the following outcomes in terms of vehicles follows:

2030

- 8.9% of the UK car fleet are BEVs, 21.8% are PHEVs
- 18.3% of the UK van fleet are BEVs, 18.8% are PHEVs

2035

- 17.5% of the UK car fleet are BEVs, 35.2% are PHEVs
- 29.4% of the UK van fleet are BEVs, 25.9% are PHEVs

Biofuels volume:

[45] Technological barriers, failure to achieve cost reductions, or market barriers.

- Under the central scenario, there would be 3.89 billion litres consumed in 2020 and 3.30 billion litres consumed in 2030. Under the 'barriers' scenario, this would reduce to 1.8 billion litres in 2030.

The scenarios also relate to different levels of demand side measures.

One or more Alternative scenarios are also developed in each sector, representing deployment of different measures to those in barriers, central and max.

The Alternative scenarios involve either (i) hydrogen transport technologies achieving widespread deployment across all vehicle types; (ii) use of Liquefied Natural Gas to fuel HGVs with only modest emissions savings; or (iii) a greater role for demand reduction compensating for barriers to electric vehicle deployment. This demonstrates some robustness within sectors to uncertainty over the types of abatement options that will ultimately prove to be better-performing and cost-effective.

3.2.3 European Union Reference Scenario 2016

The European Union (EU) 2016 reference scenario considers energy, transport and GHG emission trends to 2050. It provides a model-derived simulation of one of its possible future states given certain conditions. It assumes that the legally binding GHG and Renewable Energy Source targets will be met and that the policies agreed at EU and Member State level as at December 2014 will be implemented. The reference scenario is therefore seen as helping the EU identify where existing policies might lead the EU and where further policy development may be required. This is in contrast to, for example, the approach used by the CCC which is target driven. The reference scenario modelling suite includes the energy system model PRIMES, which is the core element of the modelling framework for transport (PRIMES-TREMOVE), energy and CO_2 emissions. The GAINS model is used for non-CO_2 emissions. Transport activity projections are validated using indicators such as GDP per capita.

Results are provided for the EU as a whole and for the individual Member States. For the UK, the results suggest that electricity use in road transport would be 1.7% in 2035 and 3.3% in 2050. Biofuels use in total transport fuel would be 2.7% in 2015, 4.9% in 2035 and 5.5% in 2050. These numbers appear low in comparison to both the DfT and the CCC projections and reflect the focus on existing policies as of 2014 (e.g. before the recent updates to the RTFO).

3.2.4 The European Commission Impact Analysis

The European Commission 2011 impact analysis[46] for the uptake of electric vehicles provides three scenarios for battery electric cars, plug-in hybrids, and range extender electric cars:

- Scenario 1 was intended to provide the 'most realistic' projections of electric vehicles, and assumes government incentives continuing roughly as they are currently, high consumer reluctance to switch to electric vehicles, and production capacity and charging opportunities to limit market uptake until 2025. In 2030, of the EU passenger car fleet, 3% are assumed to be BEV, 11% PHEV and 4% REEV.
- Scenario 2 predicts the continuing dominance of internal combustion engine vehicles, with relatively limited technological progress in electric batteries, significant CO_2 efficiency improvements for combustion engines at reasonable cost, government incentives for electric

[46] Impacts of electric vehicles – Deliverable 5. Impact analysis for market uptake scenarios and policy implications. April 2011. https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/d5_en.pdf

vehicles reduce over time and are insufficient to compensate for the relative high cost of ownership, and consumer interest remains limited. In 2030, of the EU passenger car fleet, 1% are assumed to be BEV, 5% PHEV and 1% REEV.

- Scenario 3 is the most optimistic, assuming research and development leads to a rapid decrease in the cost of electric batteries and increase in their lifetime after 2015, government incentives are high at first and then rapidly reduced as costs come down, fast charging is offered throughout the EU after 2025, and no significant breakthroughs in internal combustion engine technology. In 2030, of the EU passenger car fleet, 7% are assumed to be BEV, 18% PHEV and 8% REEV.

3.2.5 E4tech's Auto-Fuel Biofuel Roadmap

E4tech's 2013 EU Auto-fuel Roadmap[47] assesses the potential contribution of biofuels in road transport to 2030 and includes four scenarios covering regulatory pressure on industries and economic capacity of industries to change. The roadmap only considers blends of biofuels; they do not foresee increasing the FAME biodiesel blend beyond 7% as worthwhile because of the engineering challenge associated with making engines that use biodiesel blends higher than B7[48] compatible with Euro 4/IV air quality requirements. In terms of gasoline, the recommendation is to continue to aim for maximal E10 roll-out by 2020, followed by the introduction of E20 in 2025. The scenarios also cover fuel-flex vehicles using niche volumes of high blends of biofuels, along with electric, plug-in hybrids, hydrogen fuel cell vehicles and vehicles running on LPG and CNG. However, numbers are only given at EU level, and not for the UK.

- Scenario A predicts minimal change at least cost, due to low regulatory pressure and limited economic resources. By 2030, the EU car fleet is expected to contain 4.8m PHEVs, 2.8m FFVs, 8.7m LPG cars, 4.0m NG cars, 2.5m BEVs and 1.2 FCEVs.
- Scenario B assumes low regulatory pressure but high economic capacity, resulting in a focus on attributes other than environmental protection, such as luxury and comfort. Low export capacity to the EU. By 2030, the EU car fleet is expected to contain 10.4m PHEVs, 2.7m FFVs, 8.4m LPG cars, 3.9m NG cars, 7.6m BEVs and 2.9 FCEVs.
- Scenario C foresees an economically constrained world but with high regulatory pressure to deliver energy secure environmental improvements. Medium technology efficiency improvements. By 2030, the EU car fleet is expected to contain 9.7m PHEVs, 0.5m FFVs, 8.7m LPG cars, 13.4m NG cars, 4.9m BEVs and 2.3 FCEVs.
- Scenario D, with high regulatory pressure and economic capacity, sees greater long-term investment in new technologies with higher initial costs but a more transformational long-term impact for environment and security targets. High environmental conservation, large technological cumulative installed capacity. By 2030, the EU car fleet is expected to contain 20.8m PHEVs, 0.5m FFVs, 8.3m LPG cars, 13.2m NG cars, 15.4m BEVs and 5.8m FCEVs.

3.2.6 Roland Berger Integrated Fuels and Vehicles roadmap to 2030 and beyond

A coalition of automotive companies and fuel suppliers commissioned Roland Berger[49] to define and produce an Integrated Roadmap for EU Road Transport Decarbonization to 2030 and beyond, building on the earlier E4tech work. The roadmap took into account the feasibility of all fuel and vehicle technologies along with infrastructure needs and the recommended policy framework beyond 2020, with a key consideration being the identification of a roadmap with the lowest,

[47] E4tech (2013) A harmonised auto fuel biofuels road map for the EU to 2030. http://www.e4tech.com/PDF/EU_Auto-Fuel-report.pdf
[48] B7 refers to a fuel containing 7% biodiesel in fossil diesel by volume. E10/E20 refers to a fuel with 10%/20% bioethanol in fossil petrol
[49] https://www.rolandberger.com/en/Publications/pub_integrated_fuels_and_vehicles_roadmap_2030.html

achievable GHG abatement costs to society. Two scenarios are provided and reference is made to the EU's Climate and Energy Policy Framework which aims to achieve a 30% reduction in GHG emissions (below 2005 levels) by 2030 in non-ETS sectors. The key messages from the study are as follows:

A 29% reduction in GHG emissions below the 2005 level (i.e. close to the EU Framework aims) could be achieved with key aspects as follows:

- Optimised ICEs (gasoline and diesel) would be the major contributor to the reduction of passenger car GHG emissions with significant improvements until 2020 and the subsequent penetration of effective technologies into the fleet.
- Alternative technologies are anticipated to comprise a relatively small share of new car sales, despite a reduction in cost. It is suggested that their influence on overall emissions remains marginal. The more ambitious scenario suggests that 2030 car sales could be up to 4% BEV, 6% PHEV, 1% full hybrid, 12% mild hybrid, but stock numbers in 2030 are not given. The less ambitious scenario has 2030 car sales as 3% BEV, 3% PHEV, 1% full hybrid, 11% mild hybrid. These numbers are EU wide, and not specific to the UK.
- Efficiency technologies employed in commercial vehicles as well as use of Liquefied Natural Gas (LNG) are estimated to likely over-compensate for the effect of significant increases of transport volumes on the GHG emissions side based on the modelling scenarios.
- Biofuels are expected to contribute significantly to the reductions in GHG emissions of passenger cars and commercial vehicles.

In terms of further abatement additional measures, those identified include:

- Full deployment of the E10 grade, to reach the 7% energy cap of conventional biofuels
- Higher advanced ethanol blends for gasoline such as E20
- Drop-in advanced biofuels for diesel such as R339
- Hybridized powertrains, such as mild hybrids and full hybrids
- In commercial vehicle segments, additional cost-efficient GHG abatement is possible through:
    - Higher uptake of drop-in advanced biofuels for diesel in all segments
    - New heavy duty truck (HDT) concepts with increased gross vehicle weight and higher maximal length for improved aerodynamics (having negative GHG abatement costs)
    - Improved efficiencies of current ICEs and hybridization of powertrains for Light Commercial Vehicles

3.2.7 E4tech and Element Energy (2016) Hydrogen and Fuel Cells: Opportunities for Growth – A roadmap for the UK

E4tech and Element Energy's 2016 roadmap for the UK[50] considers the opportunities for hydrogen and fuel cells, aiming to drive sustainable economic growth in the hydrogen and fuel cell industry from now to 2025 and beyond.

The application of hydrogen in passenger cars is considered important, but hydrogen could also be well suited to heavier vehicles operating daily duty cycles. The research suggests that the UK could benefit from a focus on buses, vans, trucks and even boats.

[50] http://www.e4tech.com/wp-content/uploads/2016/11/UKHFC-Roadmap-Final-Main-Report-171116.pdf

The central scenario of the roadmap suggests that by 2025 there could be 25,000 FCEV cars and 500 buses powered by hydrogen. In order for this to occur, the research identifies several required actions. These include:

- Industry to prioritise establishment of the very early fleet using available public funds and coordinated procurement projects.
- Industry and public sector collaboration on rollout
  - Focus on high volume hydrogen users and UK produced vehicles
  - Inclusion of FCEVs in existing OLEV scheme
- Tightened regulations which encourage use of zero emission vehicles in UK cities
- Coordination of policy efforts at EU, national and regional levels

3.2.8 Transport for London projections

Transport for London (TfL) provided 2018 projections of the uptake of hybrid and electric buses in London. There are currently, approximately 2,922 hybrid, 73 electric and 8 hydrogen buses in London[51]. The projections cover to 2020 to 2037. From 2037, the fleet is assumed to be fully zero emission vehicles. The exact fleet composition will depend on whether the vehicles are in use in Central, Inner, or Outer London. In Central London for example, in 2035 it is projected that:

- 6.4% of the bus fleet will be single decker electric / fuel cell vehicles
- 78% double decker electric / fuel cell vehicles
- 15.6% double decker hybrid electric vehicles

The use of a mixture of electric and hydrogen fuel cell vehicles in the fleet reflects the dependency on cost, infrastructure and Well to Wheel GHG considerations.

3.2.9 Future assumptions on annual distance travelled

In terms of the annual distance travelled, it has been assumed that the average annual mileage undertaken in future years is the same as in 2017, except for electric vehicles. This is a short research project to scope out the information available on AFVs and this was deemed to be appropriate at this stage. Further work in the form of a vehicle stock and mileage model would need to be developed for more accurate results to be obtained.

3.2.10 Consideration of other vehicle types

The study has analysed AFVs in the context of cars, buses, LGVs and HGVs. This reflects the availability of activity and emission factor data as well as the contribution these modes will make to overall emissions. Further work could potentially capture the role of electric scooters and bicycles. Note, as above, this would have an impact by shifting mileage from conventional vehicles, rather than emissions from the electric vehicles themselves.

[51] http://content.tfl.gov.uk/fleet-audit-30-september-2017-final.pdf

4 Fuel consumption and emission factors

Fuel consumption factors and CO_2, CH_4 and N_2O emission factors have been sourced for each alternative fuel and technology where available. The emission factors for each AFV are provided for different road types; urban, rural, and motorway (apart from buses which are solely urban).

In the first instance, UK data has been sourced where possible and then gap filling has been undertaken using European data. Emission factors were available either in:

- absolute terms (grams per kilometre); or
- the form of scaling factors relative to the equivalent conventional vehicle

In only a few cases UK specific data was available. For example, emission factors for hybrid buses from the emission tests undertaken at Millbrook. Even in UK projects and research reports[52], the emission factors referred to tend to be based on international[53] research programmes for which the results are reported in the EMEP / EEA Guidebook and used in COPERT. Where appropriate, reference is made to the BEIS Greenhouse Gas reporting conversion factors. These factors are used to report on 2017 GHG emissions by UK based organisations of all sizes and by international organisations reporting on UK operations. Similarities and differences to outcomes are referenced. However, the data categories are different from those used in this review. For example, reference in the BEIS Greenhouse Gas reporting conversion factors is made to small, medium and large car vehicle size but information on Euro Standards is not provided. Disaggregation by size could be a useful future step and is discussed further in recommendations. It is important to note that this disaggregation would also need to include data or assumptions on vehicle mileage by size.

4.1 Uncertainties

4.1.1 Causes of uncertainties

There can be uncertainty in the emission factors due to several factors:

- Few measurements have been undertaken on alternative fuelled vehicles, which therefore leads to a high uncertainty in the emission factors.
- In some cases the emission factors have been obtained from studies where little information is available on the exact vehicle type and drive cycle the emissions were measured over. This makes it difficult to undertake a meaningful analysis compared to a conventional vehicle.
- There can be a large variation in the engineering design for the same technology, which can lead to a large deviation in emissions. An example of this is hybrid technology for which there are different types; these include parallel and series hybrids[54] as well as mild and full hybrids[55]. These technologies may offer similar benefits in terms of fuel consumption and therefore carbon emissions, but may have very different emissions of other gases and pollutants, making it difficult to draw general conclusions.
- The uncertainty in activity levels, in particular for electric vehicles (battery and plug-in hybrid). For example, for PHEVs the fraction of the total mileage driven in electric or internal

[52] For example, approach used for NAEI road transport
[53] Carried out at JRC Ispra, TNO in the Netherlands and the USA and other locations
[54] In parallel drivetrains, the electric motor and the internal combustion engine can provide mechanical power at the same time. In a series drivetrain, power is only provided by an electric motor (with the electricity coming from a battery and a petrol/diesel powered generator).
[55] A mild hybrid has a smaller battery and electric motor that will typically only provide limited mechanical assistance to the main drivetrain (a petrol or diesel engine), allowing the engine to be turned off when coasting, braking or stationary. A full hybrid has a larger battery and electric motor, allowing running in electric-only mode, or petrol-only mode, or with both the electric motor and engine working together.

combustion engine (ICE) mode depends on the daily trip patterns, for which very little information is available. As an example, a plug-in hybrid or REEV with a fully-loaded battery driven for 30-40 kilometres primarily operates in electric mode and hence emission factors (in g/km) are extremely low (close to zero). Emission factors increase considerably when the ICE is used – for example, for driving over longer distances.
- Over time there will be technology improvements in the different vehicle types.

It is recommended that the emission factors and activity data assumptions presented in this project are reviewed regularly as new data emerges to ensure the best information is always being used.

CO_2 emissions can often be calculated from the fuel consumed and the fuel carbon content and this is a relatively straightforward approach with low uncertainty since the carbon content of the fuels is known. For PHEV, the overall emission factor will depend on assumptions with regard to its use of ICE and electric vehicle modes. For electric and fuel cell vehicles, the source emissions are treated as zero without any uncertainty (uncertainties in activity levels are discussed in Section 4.2.2).

CH_4, N_2O and air quality pollutant emissions can be more difficult to estimate since there is not a direct link between fuel and emissions. Emissions of these gases and pollutants are dependent on a number of factors including vehicle type, age, whether the vehicle has an exhaust catalyst, and the vehicle operating characteristics. For CH_4 and N_2O the uncertainty is high, but the contribution to the total GHG emissions from road transport is small (<1.5%). Overall GHG emissions uncertainty in the road transport sector was calculated to be +/- 1.9%, as a 95% confidence interval for 2015.

4.1.2 Dealing with uncertainties in the inventory

Greenhouse gas and air quality pollutant emission estimates will always have an element of uncertainty associated with them. The UK reports the uncertainty of its emission estimates alongside the inventory when it is published. This is calculated by quantifying uncertainties on emission factors and activity data, which therefore provides an overall uncertainty in the emission estimates.

For AFVs, there is uncertainty surrounding the emission factor data and therefore where possible low, medium and high values have been provided. The uncertainty of the emission factors originates from the variability of the underlying experimental data as discussed. In some cases, in the absence of more than one emission factor being available for a particular fuel and technology, the same emission factor has been assumed for the low, medium and high cases. In addition, for some vehicle and technology combinations, emission factors were not available and therefore the data has been gap filled using emission factors for conventional vehicles.

Information on the emission factors is provided for Euro Standard V for the urban road type consistent with the approach used in the previous 2013 review. It is important to note the impact of:

- The use of the urban road type. For example, for PHEVs the emission factor for the CO_2 urban road type is much lower than for motorway and rural driving reflecting the potential for greater electricity use in urban areas.
- The representation of the emission factor as 'hot' or 'cold', referring to whether trips start with the engine at ambient temperature. This is a particular concern for hybrid vehicles which also utilise a combustion engine, as the intermittent use of the combustion engine may increase the impact of cold-start emissions[56].

[56] Cold-start emissions control in hybrid vehicles equipped with a passive adsorber for hydrocarbons and nitrogen oxides, Gao et al (2015), available at: https://www.researchgate.net/publication/258177745

Figure 1: CO_2 Emission Factors Euro Standard V Urban driving

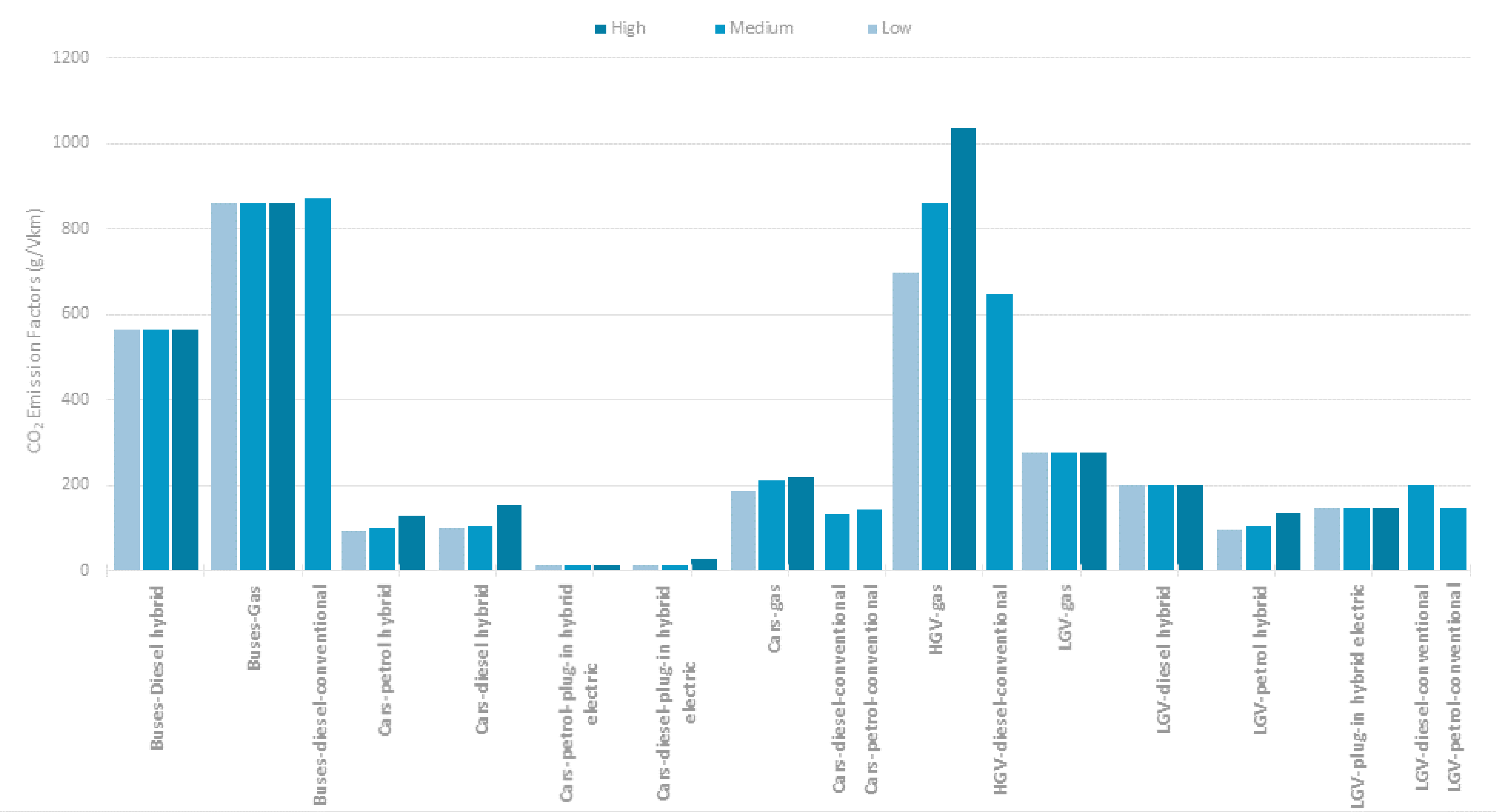


Figure 2: CH_4 Emission Factors Euro Standard V Urban driving

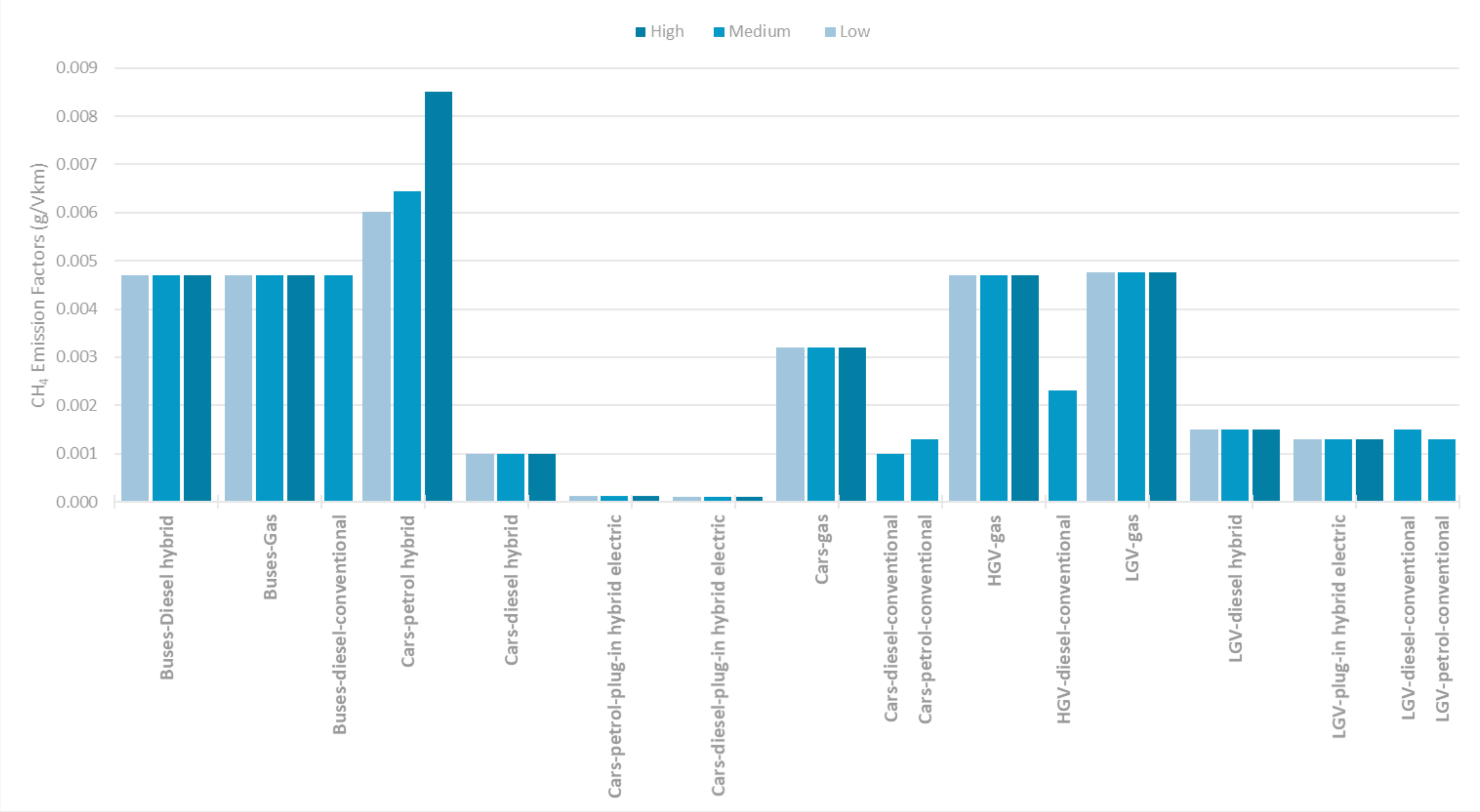
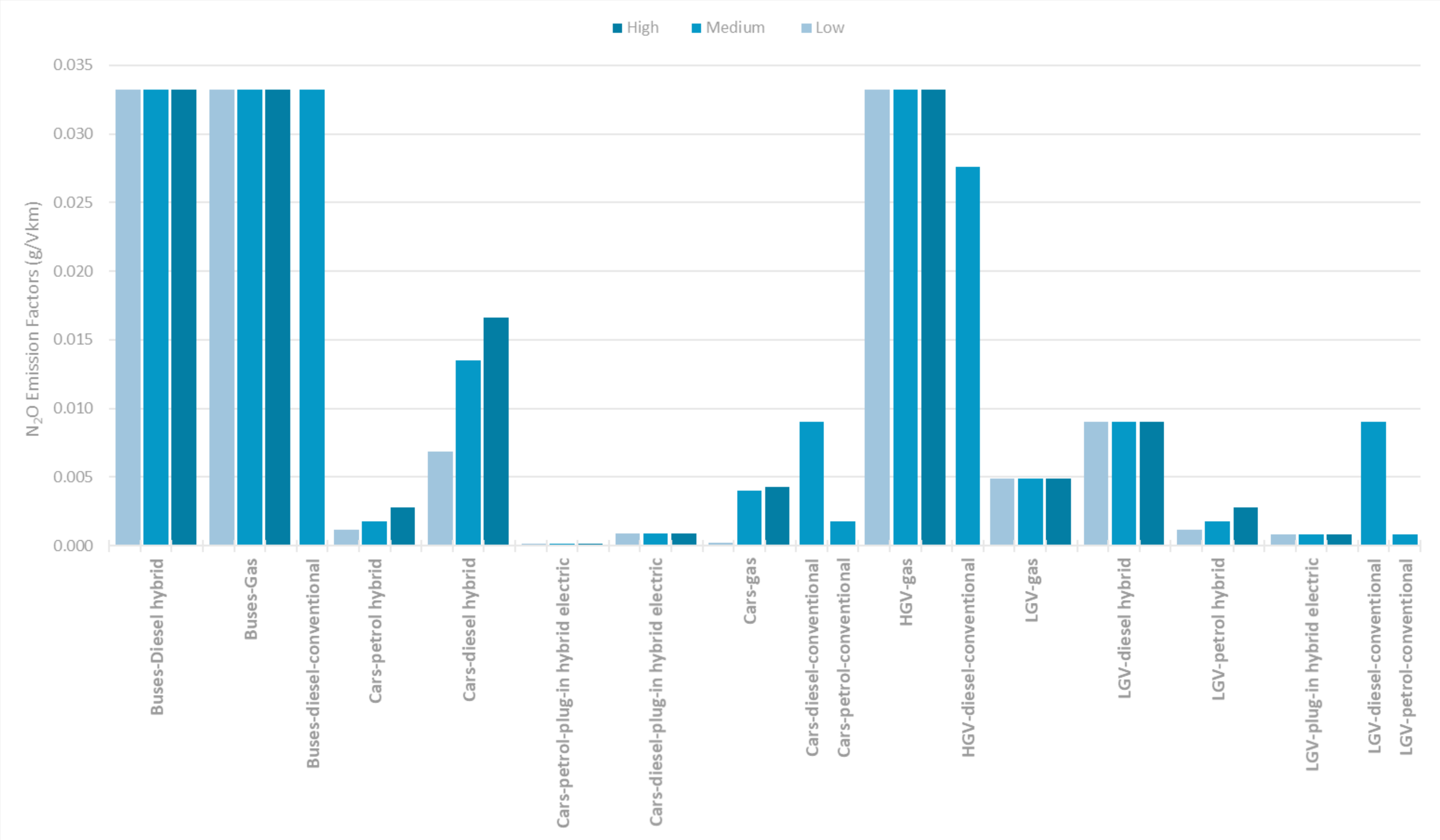


Figure 3: N_2O Emission Factors Euro Standard V Urban driving



4.1.3 Uncertainty regarding activity levels

Vehicles fuelled by CNG, LPG, biofuels, PHEVS and REEVs and hydrogen are assumed to have the same annual mileage as conventionally fuelled vehicles, although with differences captured in the split between petrol and diesel vehicles. Activity levels of Battery Electric Vehicles (and in turn displacement of conventional vehicle mileage) will impact on overall emissions. These overall emissions are not explicitly captured here, since in line with the 2013 review, data on transport total emissions (current and projected) is obtained from the BEIS 2017 Updated Energy and Emission Projections. Importantly, increased levels of electric vehicles would result (especially in the longer term) in lower petrol and diesel fuel sales which would be captured in the NAEI.

4.2 Gas – LPG and CNG

The CO_2 Emission factors for cars running on LPG are based on the original review and calculated with COPERT 4 v10. COPERT is the most recognised and widely used tool for road transport emission inventories. It is supported by the European Environment Agency and the Joint Research Centre, while it has been developed, maintained and updated by Emisia[57] researchers. The emission factors are consistent with the 2016 update to the EMEP / EEA Emission Inventory Guidebook.

It is useful to note that the CO_2 emission factors are lower (~15%) than those used in the 2017 'GHG Conversion factors for company reporting' and this could be attributed to different assumptions with regard to the size of LPG vehicles as well as differences in the calculation approach[58].

The recent, broader, literature[59,60] also suggests emission factors lower than the current Conversion factor guidelines, and lower than the COPERT data.

For the assessment of uncertainty, emission factors for CO_2 for cars from 2017 GHG conversion factors for company reporting are used as a high scenario and factors from the recent, broader literature are used in the low scenario.

For CO_2 from LPG cars, new emission factors for the assessment of uncertainty are included and reflect increased data availability.

For CH_4, factors in the original 2013 review for LPG cars were revised downwards in line with those used in the 2017 GHG Conversion factors (where CH_4 emission factors were also reduced substantially from 2013 data) and EMEP/EEA 2016 guidelines. This latest available data is adjusted to take into account the road type and Euro standards approach used in this review.

For CH_4 from LPG cars, revised emission factors were used reflecting the latest available data

[57] Emisia is a spin-off company of the Aristotle University of Thessaloniki / Laboratory of Applied Thermodynamics
[58] BEIS GHG Conversion Factors for Company Reporting. "Due to the significant size and weight of the LPG and CNG fuel tanks it is assumed only medium and large sized vehicles are available. In the 2017 GHG Conversion Factors, CO_2 emission factors for CNG and LPG medium and large cars are derived by multiplying the equivalent petrol EF by the ratio of CNG (and LPG) to petrol emission factors on a unit energy (Net CV) basis"
[59] EEA, 2017 Monitoring CO2 emission factors from new passenger cars and vans
[60] European Autogas, 2017 Measuring the Emission of Performance of Autocars

For N_2O, emission factors in the original 2013 review for LPG cars were based on COPERT data and these are consistent with those used in the 2017 GHG Conversion factors guidelines, which uses data from the NAEI. The same values from the previous project are therefore used.

For CO_2 emissions, for LGVs running on LPG or CNG, limited information was available in the original 2013 review. These factors were therefore updated using the latest available data which includes research undertaken for the LowCVP and the 2017 GHG conversion factors for company reporting. Note reflecting data availability LPG use in LGVs is used.

For CH_4 and N_2O, emissions factors for LGVs in the original 2013 review were based on comparatively limited information. These emission factors have therefore been updated using the latest available data which includes research undertaken for the LowCVP and the 2017 GHG conversion factors for company reporting. This latest available data is adjusted to take into account the road type and euro standards approach used in this review.

The emission factors for LPG use in LGVs for CO_2, CH_4 and N_2O are updated reflecting increased data availability.

For CNG use in HGVs in the previous review there was limited data availability and estimates were based on CNG use in buses. Comparison with more recent literature suggests indicates that the results are overall consistent. CO_2 levels could be considered to reflect the breadth and type of size of vehicle. Understanding of CH_4 and N_2O assumptions in relation to Euro 4 standards warrants further consideration.

4.3 Hybrids

The CO_2 Emission factors for petrol hybrid cars running are based on the original 2013 review and calculated with COPERT 4 v10. In the original review, reasonable assumptions on the emission levels of diesel hybrid cars were made using Emisia's expert judgement. These assumptions are based on the differences between the conventional petrol and the diesel vehicles, applying simple scaling factors to the emissions of hybrid petrol cars. The overall results are consistent with the outcomes of the 2017 Greenhouse Gas reporting conversion factors and therefore the original results are used.

For CH_4, the emission factors data were also taken from COPERT and expert judgement. They are also, overall, consistent with those used in the 2017 Greenhouse Gas reporting conversion factors taking into account broader literature[61]. This latest available data is adjusted to take into account the road type and euro standards approach used in this review.

For N_2O, the emission factors data were also taken from COPERT and expert judgement. Overall numbers are consistent with the GHG reporting conversion factors. However, there are differences between petrol and diesel hybrids which would warrant further consideration.

For hybrid LGVs, emission factor data was also taken from COPERT and expert judgement. Hybrid LGVs are not included in the BEIS Company GHG reporting guidelines, so comparison and verification of these emission factors is limited, however the number of hybrid LGVs in the UK is extremely low.

[61] e.g. https://www.aecc.eu/wp-content/uploads/2016/08/SAE-2013-24-0154-ICE2013.pdf

For hybrid buses, emission factor data is taken from Transport for London. For CH_4 and N_2O, data is assumed to be the same as the conventional equivalent, reflecting limited data, and in turn this data reflects NAEI hot exhaust factors.

4.4 Plug-in hybrids and electric vehicles with a range extender

The CO_2 Emission factors for plug-in hybrids and electric vehicles with a range extender are based on the original review. For these advanced powertrain technologies, which are not included in COPERT, emission factors have been obtained from the SIBYL model[62]. The related fuel/energy consumption factors and resulting CO_2 emission factors have been based on extensive simulations, employing custom-designed models and powertrain system level simulation tools, as well as reasonable modelling assumptions.

An overall utility factor of around 0.60 is used (i.e. PHEVs would be used in electric mode around 60% of the time) and this is consistent with the broader literature[63]. The results are in line with the 2017 Greenhouse Gas Reporting conversion factors (assuming a focus on Euro 6 vehicles). It is important to note that use of utility factor varies across urban, motorway and rural driving.

Real life data[64] suggests that the in-world use of the electric mode can be lower. We thus include a higher emissions value (assuming a lower utility value) in the uncertainty analysis.

For CH_4 in the original review there was limited data available. These emission factors have, therefore, been updated using the latest available data which includes the 2017 Greenhouse Gas Reporting conversion factors and international research[65]. This latest available data is adjusted to take into account the road type and euro standards approach used in this review.

For N_2O, the emission factors data were also taken from COPERT and expert judgement. Overall numbers are consistent with the GHG Gas reporting conversion factors. However, there are differences between petrol and diesel plug-in hybrids which would warrant further consideration.

> The emission factors for CH_4 have been updated in line with the latest available information. For CO_2, a new high value is introduced in the uncertainty analysis.

4.5 Electric vehicles

The emissions inventory reports emissions at point of use (at source) and therefore emissions are deemed to be zero from this vehicle type. However, for an 'end user' inventory, emissions from this category would be required since emissions are reallocated from the fuel producers to the fuel user.

[62] http://www.emisia.com/utilities/sibyl/
[63] Davies and Kurani, 2013 Moving from Assumption to Observation: Implications for energy and emissions impacts of plug-in hybrid electric vehicles. Energy Policy 62 (2013) 550-560
[64] https://themilesconsultancy.com/new-analysis-plug-hybrid-car-mpg-emissions-expected-spark-debate-suitability-fleet-operation/
[65] Lang et al (2013) Energy and Environmental Implications of Hybrid and Electric Vehicles in China. Energies 2013, 6, 2663-2685; doi:10.3390/en6052663

4.6 Hydrogen fuel celled vehicles

The emissions inventory reports emissions at point of use and therefore emissions are deemed to be zero from this vehicle type. However, for an 'end user' inventory, emissions from this category would be required since emissions are reallocated from the fuel producers to the fuel user.

4.7 Biofuels

As discussed earlier, most biofuels are currently consumed in the UK in the form of a weak blend in vehicles with conventional petrol and diesel engines. This has been driven by the RTFO. The effect of weak biofuels blends on CH_4, N_2O and air quality pollutant emissions is already accounted for in the NAEI via the approaches discussed in Section 2.6.

When reporting carbon emissions, only the fossil fuel consumption element should be taken into account in the calculation. This is consistent with the 1996 and 2006 IPCC Guidelines, which state:

'the emissions associated with the production of biofuels should be attributed to the Land Use, Land Use Change and Forestry sector under IPCC. Although carbon emissions from biogenic carbon are not included in national totals, the combustion of biofuels in mobile sources generates methane, nitrous oxide and air quality pollutant emissions and these should be calculated and reported in the emission estimates'.

Emission factors are provided for B100 (pure biodiesel) and E85 (85% ethanol and 15% petrol by volume). Biodiesel typically contains 10% fossil carbon from the methanol (made from natural gas) used in the esterification process. However, due to the uncertainty surrounding the manufacture of the biodiesel consumed in the UK (there are a few sources of renewable methanol available globally), carbon emissions from biodiesel are assumed to be zero. In contrast, the biogenic portion of ethanol is 100%. The emission factors provided for E85 were obtained from the 2013 update to the EMEP/EEA Emissions Inventory Guidebook and these are consistent with the 2016 update.

5 Compatibility with the 2006 IPCC Guidelines

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories provide an update to the 1996 Guidelines and associated Good Practice Guidance, which provides internationally agreed methodologies for use by countries to estimate greenhouse gas emission inventories for reporting to the United Nations Framework Convention on Climate Change.

The fundamental methodology for estimating GHG emissions from road vehicles has not been modified since the publication of the 1996 IPCC Guidelines and the 2000 Good Practice Guidance, except that the emission factors now assume full oxidation of the fuel to be consistent with emission estimates for stationary combustion[66]. The method for estimating carbon emissions from catalytic converters using urea is also included for the first time.

Volume 2, Chapter 3 of the IPCC 2006 Guidelines contains information on estimating emissions from biofuels. The majority of the text relates to the issue of avoiding double counting carbon emissions in estimates. Most alternatively fuelled vehicles are sufficiently covered, with the exception of hybrids, plug-in hybrids and REEVs, for which there is no information provided. Electric and hydrogen fuel cell vehicles are also not included, but these are not relevant for the road transport sector in the GHG inventory as they have zero emissions at point of use. The emissions arising from the electricity generation will be included under the IPCC source category 'public electricity generation' (and bulk hydrogen from the industrial sector).

[66] 2006 IPCC Guidelines. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

6 Results

6.1 Historic (2010 – 2017)

As outlined previously, alternative fuel vehicles still comprise a small proportion of the total road vehicle fleet. There were approximately 32.2 million cars registered in the UK in 2017[67]. Petrol hybrid cars are the most prevalent AFV with over 320,000 licensed in 2017 (1.1% of the total). There are now over 46,000 battery electric vehicles and 78,000 PHEVs registered, with numbers of both increasing over 100-fold in the past ten years.

Table 3, Table 4 and Table 5 show the estimated CO_2, CH_4 and N_2O emissions from AFVs from 2010 to 2017 based on DfT 2018 data for the number of registered vehicles and using the central ('medium') emission factors.

Allowing for uncertainty in the historic activity data, the estimates show that CO_2 emissions arising from AFVs are increasing year on year, as would be anticipated reflecting increasing adoption of these vehicles. In 2017, the estimated emissions were only the equivalent of approximately 0.5% of the road transport baseline emissions in the UK. The baseline scenario contains central price and growth assumptions but only policies that existed before the Low Carbon Transition Plan of July 2009. Information is also provided on the reference scenario which is based on central estimates of economic growth and fossil fuel prices. It contains all agreed policies where decisions on policy design are sufficiently advanced to allow robust estimates of impact. Note for $CO_{2,}$ information is disaggregated into road transport and other transport. For CH_4 and N_2O, information is provided for all transport. Information for CO_2 is provided for road transport in the main body of the report and all transport in appendix A. The overall impact is small.

It is again important to note that electric vehicles are treated as having zero emissions at point-of-use, due to the fact the any emissions arising are due to the generation of the electricity consumed, not emissions directly from the 'tailpipe'.

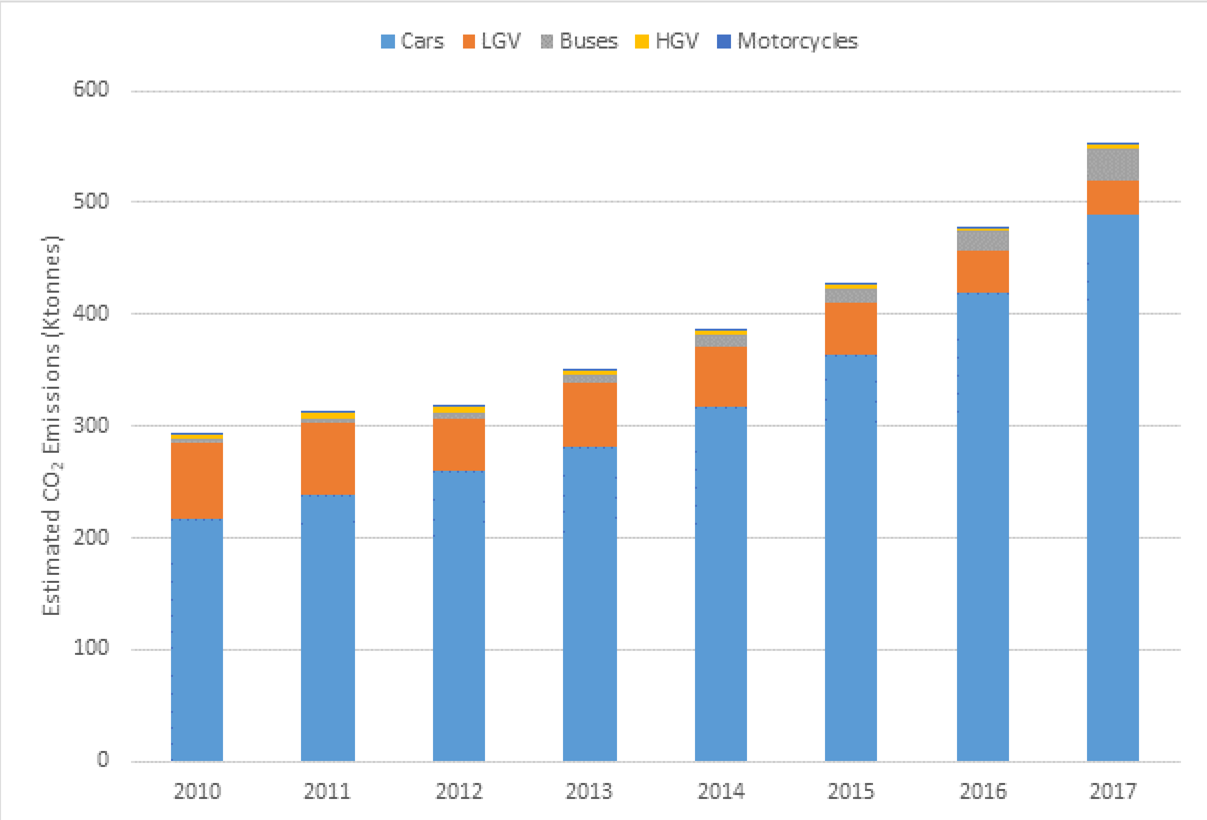
For CH_4 and N_2O, AFVs are estimated to emit the equivalent of approximately 0.98% and 0.16% respectively of the UK's total transport emissions of these gases in 2017. This is shown in Table 4 and Table 5.

[67] Based on DfT Transport Statistics Table VEH 0211 (2017) Licensed cars by year of first registration, propulsion and fuel type: Great Britain and United Kingdom

Table 3: Estimated CO_2 Emissions from AFVs by Vehicle Type (ktonnes)

Vehicle type	2010	2011	2012	2013	2014	2015	2016	2017
Cars	216.6	237.8	260.0	282.0	317.5	363.2	418.6	488.9
LGVs	68.3	65.9	46.5	55.9	53.0	47.3	39.0	31.6
Motorcycles	0.04	0.05	0.04	0.04	0.03	0.03	0.02	0.03
HGVs	4.2	4.2	4.4	3.4	3.6	3.0	2.0	2.1
Buses	3.8	3.5	5.6	7.5	10.9	12.8	18.0	28.6
Total AFV emissions	**293**	**311**	**317**	**349**	**385**	**426**	**478**	**551**
Total UK road transport emissions – baseline[68]	106,570	105,627	105,493	105,468	107,665	109,730	111,573	111,047
AFV % of total UK road transport – baseline	0.27%	0.29%	0.30%	0.33%	0.36%	0.39%	0.43%	0.50%
Total UK road transport emissions – reference[68]	109,325	107,850	107,592	106,753	108,186	110,409	110,309	107,614
AFV % of total UK road transport – reference	0.27%	0.29%	0.29%	0.33%	0.36%	0.39%	0.43%	0.51%

Figure 4: Estimated CO_2 Emissions from AFVs by Vehicle Type (ktonnes)



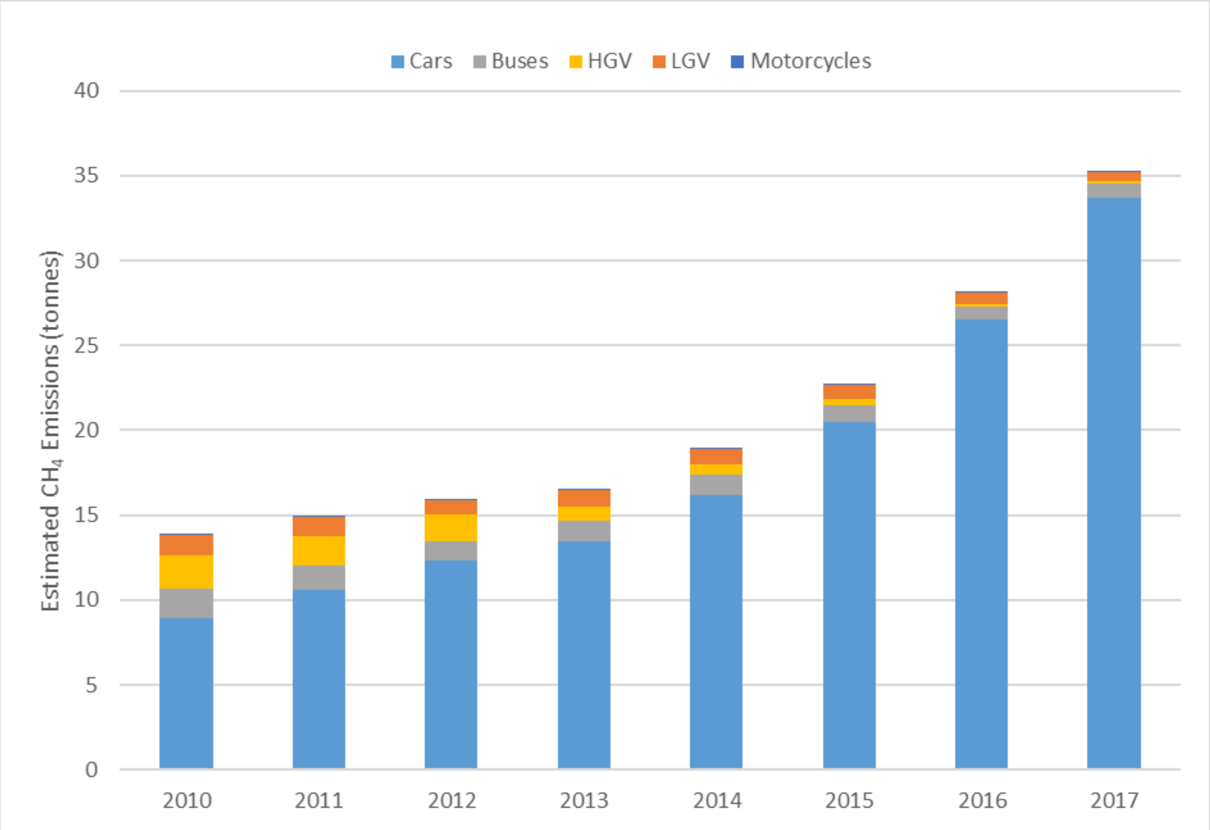
Overall the results are consistent with the 2013 review. Cars continue to dominate the overall CO_2 emission from AFVs reflecting the increased levels of petrol hybrid vehicles.

[68] Road transport, Annex B: Carbon dioxide emissions by source, Projections of greenhouse gas emissions and energy demand from 2017 to 2035, BEIS, available at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017

Table 4: Estimated CH_4 emissions from AFVs by Vehicle Type (tonnes)

	2010	2011	2012	2013	2014	2015	2016	2017
Cars	8.9	10.6	12.3	13.5	16.1	20.5	26.5	33.7
LGVs	1.2	1.1	0.8	1.0	0.9	0.8	0.7	0.5
Motorcycles	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.01
HGVs	2.0	1.7	1.6	0.8	0.6	0.4	0.2	0.1
Buses	1.8	1.4	1.1	1.2	1.3	1.0	0.8	0.8
Total AFV emissions	**14**	**15**	**16**	**16**	**19**	**23**	**28**	**35**
Total UK transport emissions baseline	7,038	6,376	5,757	5,155	4,904	4,679	3,818	3,638
AFV % of total UK transport emissions - baseline[69]	0.20%	0.23%	0.28%	0.32%	0.39%	0.48%	0.74%	0.97%
Total UK transport emissions – reference	7,038	6,376	5,757	5,155	4,904	4,679	3,758	3,579
AFV % of total UK transport emissions - reference[69]	0.20%	0.23%	0.28%	0.32%	0.39%	0.48%	0.75%	0.99%

Figure 5: Estimated CH_4 emissions from AFVs by Vehicle Type (tonnes)

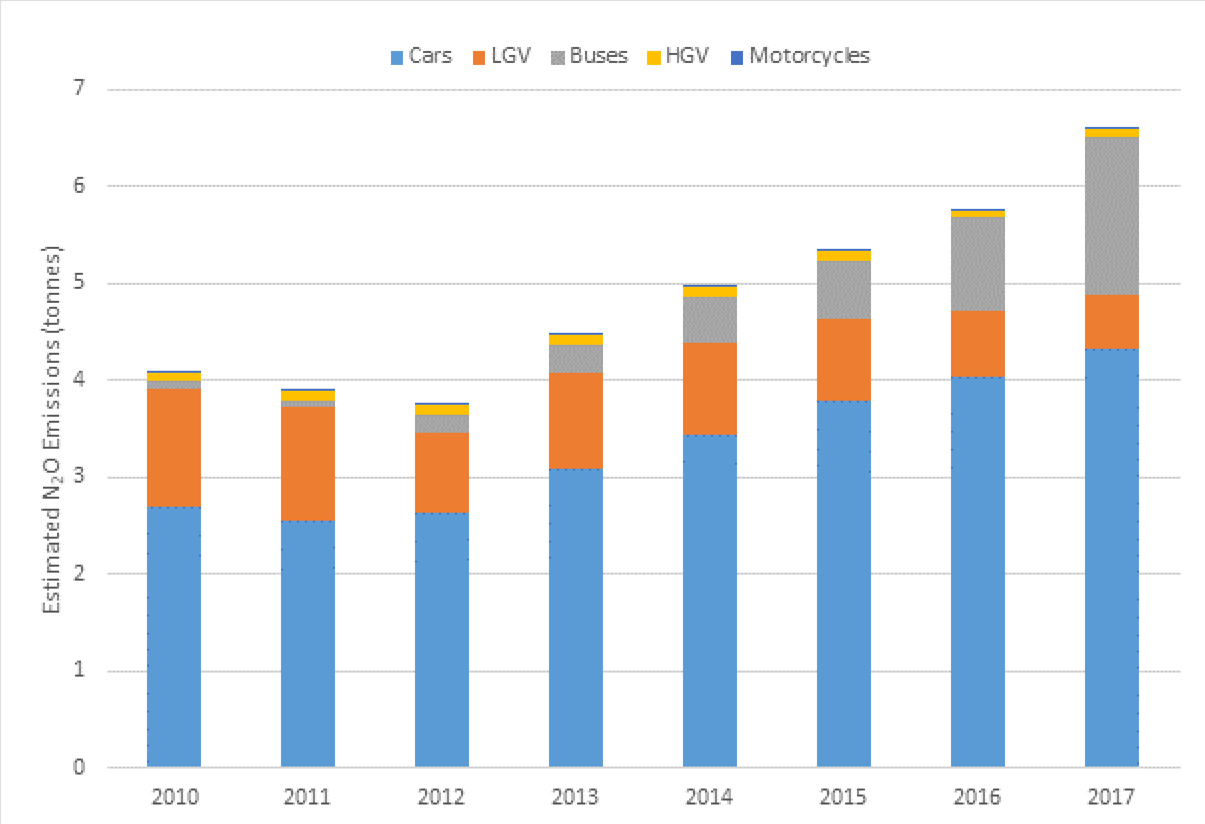


[69] Annex A: Greenhouse Gas emissions by source, Projections of greenhouse gas emissions and energy demand from 2017 to 2035, BEIS, available at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017

Table 5: Estimated N_2O emissions from AFVs by Vehicle Type (tonnes)

	2010	2011	2012	2013	2014	2015	2016	2017
Cars	2.7	2.5	2.6	3.1	3.4	3.8	4.0	4.3
LGVs	1.22	1.17	0.82	1.00	0.95	0.84	0.69	0.56
Motorcycles	0.0009	0.0010	0.0008	0.0008	0.0007	0.0005	0.0004	0.0005
HGVs	0.08	0.09	0.11	0.10	0.11	0.10	0.07	0.08
Buses	0.1	0.1	0.2	0.3	0.5	0.6	1.0	1.6
Total AFV emissions	**4.1**	**3.9**	**3.8**	**4.5**	**5.0**	**5.3**	**5.8**	**6.6**
Total UK road transport emissions - baseline	3,193	3,266	3,366	3,495	3,662	3,812	4,003	4,129
AFV % of total UK transport emissions - baseline[69]	0.13%	0.12%	0.11%	0.13%	0.14%	0.14%	0.14%	0.16%
Total UK road transport emissions – reference	3,193	3,266	3,366	3,495	3,662	3,812	3,990	4,116
AFV % of total UK transport emissions - reference[69]	0.13%	0.12%	0.11%	0.13	0.14%	0.14%	0.15%	0.16%

Figure 6: Estimated N_2O emissions from AFVs by Vehicle Type (tonnes)



Updated assumptions on N_2O result in slightly lower levels compared with the 2013 review.

6.2 Uncertainties

To assess the impact of the uncertainty in the emission factors, the low and high values were also used to compile estimated CO_2, CH_4 and N_2O emissions in 2017 from the alternative fuel car fleet. Cars were chosen as the most comprehensive data set is available for this vehicle type and they comprise the majority of the AFV emissions. The estimates are shown in Table 6, Table 7 and Table 8.

Table 6: Estimated CO_2 emissions from alternative fuelled cars in 2017 using low, medium and high emission factors (ktonnes)

L/M/H	ktonnes CO_2
Low estimate	522
Medium estimate	551
High estimate	619

Table 7: Estimated CH_4 emissions from alternative fuelled cars in 2017 using low, medium and high emission factors (tonnes)

L/M/H	tonnes CH_4
Low estimate	33.5
Medium estimate	35.3
High estimate	39.3

Table 8: Estimated N_2O emissions from alternative fuelled cars in 2017 using low, medium and high emission factors (tonnes)

L/M/H	tonnes N_2O
Low estimate	5.04
Medium estimate	6.58
High estimate	8.20

The estimates show that there is a range of approximately 97 ktonnes between the low and high estimate for CO_2. The relative uncertainty ranges for CH_4 and N_2O emissions are greater (but not in absolute terms of total GHG emissions).

7 Projections

Various projection scenarios have been presented in the AFV emission spreadsheet. These include those provided by DfT, which solely covers cars and LGVs, and those such as the E4tech Auto-Fuel roadmap and CCC Fifth Budget scenarios, which are the only ones to cover heavy goods vehicles. All the scenarios obtained have tended to focus on particular vehicle or technology types and no source was obtained that covered all the main vehicle technology types.

By way of example, two of the projection scenario results are presented in this review to provide an indication of the range of CO_2 emissions that may be expected in the future. This is consistent with the approach used in the 2013 review.

7.1 DfT Projections

The DfT projections[70] cover the following vehicle and technology types:

1. Petrol and diesel hybrid cars
2. Petrol plug-in hybrid cars / range extender cars
3. Electric cars
4. Electric LGVs
5. Plug-in hybrid LGVs

Some alternative fuel technologies such as gas and hydrogen fuel cell cars and gas and hybrid LGVs do not feature in the DfT projections, despite there being historical data for these vehicle types. Therefore the projections are a sub-set of the alternative fuelled car and LGVs.

Table 9: Estimated CO_2 emissions from AFVs under the DfT scenario by vehicle and technology type (ktonnes)

	2025	2030	2035
Car-diesel-hybrid	1,308	2,033	2,675
Car-petrol-hybrid	1,461	1,950	2,372
Car-plug in hybrid / range extender	354	985	1,730
Car electric	0	0	0
LGV-petrol-plug-in hybrid	178	562	1,051
LGV electric	0	0	0
Total AFV emissions	**3,302**	**5,530**	**7,829**
Total UK projected road transport emissions - baseline[68]	115,372	118,931	123,244
AFV % of total UK road transport – baseline	2.86%	4.65%	6.35%
Total UK projected road transport emissions - reference[68]	96,794	93,555	91,925
AFV % of total UK road transport – reference	3.41%	5.91%	8.52%

The DfT car and LGV projections forecast an increase in the numbers of alternative fuelled vehicles and hence CO_2 emissions from the AFV sector are also expected to increase by 2035. The increase in numbers and hence emissions is particularly noticeable for PHEV/REEV cars.

[70] Department for Transport, 2017 output from the '131024 Van Fleet Model' and the '130110 car fleet fuel efficiency model'. Provided by DfT on 18th April 2018 for the purposes of this project.

7.2 CCC projections

The CCC Fifth Budget review scenario provides a more optimistic view of the uptake of alternative fuelled vehicles out to 2030. The scenario covers the following vehicles and technologies:

1. Petrol plug-in hybrid cars
2. Plug-in hybrid petrol LGVs
3. Electric cars
4. Electric LGVs
5. Hydrogen fuel cell buses
6. Hydrogen fuel cell large rigids
7. Plug in hybrid – small rigids
8. Electric small rigids

As shown in the list above, it is important to note that in the Fifth Carbon Budget hybrid vehicles are not disaggregated and are instead included alongside ICEs (and associated efficiency improvements). Assuming the same contribution from hybrids as in the Fourth Carbon Budget (17,735 ktonnes CO_2) would more than double the total emissions in 2030.

Table 10: Estimated CO_2 emissions from AFVs under the CCC scenario by vehicle and technology type (ktonnes)

	2020	2025	2030	2035
Car-petrol - plug in hybrid	298.5	1,689	4,308.5	7,375.5
Car-Electric	0	0	0	0
LGV-petrol-plug-in hybrid	47	756	1,880	2,944
LGV electric	0	0	0	0
Total AFV emissions	**345.5**	**2,445**	**6,188.5**	**10,319.5**
Total UK projected road transport emissions - baseline[68]	112,430	115,372	118,931	123,244
AFV % of total UK road transport – baseline	0.3%	2.1%	5.2%	8.4%
Total UK projected road transport emissions - reference[68]	101,092	96,794	93,555	91,925
AFV % of total UK road transport – reference	0.3%	2.5%	6.6%	11.2%

7.3 Sensitivity of uptake rates

As none of the projection scenarios obtained provided a complete coverage of all vehicle types and technologies, a sensitivity analysis has been undertaken using predicted uptake rates of PHEVs.

Table 11: Estimated CO_2 emissions (ktonnes) at 5 yearly intervals to 2035 from PHEVs (cars) under the three scenarios which cover this vehicle and technology type

	2025	2030	2035
DfT projection	354	985	7,375.5
CCC 5th budget review – central scenario	1,689	4,308.5	1,730
E4tech auto-fuel study	995.6	2,030.1	NA

The focus was on PHEVs reflecting that while there can be large variation with regard to assumptions on take up of electric and hydrogen fuelled vehicles the treatment of these vehicles emissions as being at source outcomes in terms of transport CO_2 would be zero.

8 Lessons learnt from other countries

Five countries were analysed to determine how AFVs are represented in their national inventories. The countries reviewed were Norway, Italy, Japan, Netherlands, and the United States. These were chosen because of their high level of AFV uptake and to provide a mix of European and non-European approaches.

A brief description of the IPCC Tiers[71] is useful context before presenting the methodologies used in each country. A tier represents a level of methodological complexity. Usually three tiers are provided; with Tier 1 the most basic method, Tier 2 intermediate and Tier 3 the most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are typically considered to be the most accurate.

Tier 1 methods for all categories are designed to use readily available national or international statistics in combination with default emission factors. Tier 2 uses more specific emission factors developed on the basis of knowledge of the conditions that apply in the country for which the inventory is being developed. Tier 3 is defined as any methodology more detailed than Tier 2; hence there is a wide range of Tier 3 methodologies. This can include methodologies similar to Tier 2 but with a greater disaggregation of activity data and emission factors as well as more complex dynamic models.

For reference, the current UK GHG inventory uses a Tier 3 methodology to calculate emissions from conventional vehicles in road transport[72]. The integration of AFVs within the inventory is limited, with the estimation of CO_2 emissions from vehicles running on LPG, calculated by applying fuel based factors to national total consumption, derived from the UK's energy balance or DUKES (Digest of UK Energy Statistics)[72]. CH_4 and N_2O are also calculated via a traffic-based approach using emission factors from COPERT 4, however, due to the lack of specific vkm data, all LPG vehicles are assumed to be LGVs. Natural gas vehicles are thought to exist within the UK fleet, but available data is believed to be inaccurate, and therefore limits any estimation[10]. Emissions from the consumption of biofuels are also estimated using a Tier 1 methodology for CO_2 and Tier 2 for CH_4 and N_2O, referring primarily to the presence of bio-fuels blended with conventional fossil fuels[72].

8.1 Norway

The Norwegian inventory integrates a range of AFVs into its road transportation emission estimates. For CO_2, emissions from the road transport sector for conventional petrol and diesel vehicles are estimated from the total consumption of fuel using country-specific emission factors on the carbon content of each fuel. This is consistent with a Tier 2 approach as outlined in the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines. CNG and LPG are estimated via bottom-up approaches, although the source of this data is not stated. The use of bioethanol and biodiesel, which has grown substantially in consumption since 2006, is also estimated. CO_2 emissions are then allocated across vehicles classes based on the outputs from the emission model of the Handbook of Emission Factors (HBFA), which is an internal document operated by Statistics Norway.

For conventional vehicles, the HBFA emissions model is also used to estimate emissions from other greenhouse gases (GHG) e.g. CH_4, N_2O via a mileage approach split by vehicle class and vehicle

[71] EMEP/EEA Air Pollutant Emission Inventory Guidebook
[72] Methodology for the UK's Road Transport Emissions Inventory, Ricardo Energy & Environment, (2018), available at: https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1804121004_Road_transport_emissions_methodology_report_2018_v1.1.pdf

technology, consistent with a Tier 3 approach from the IPCC 2006 guidelines. The model combines the number of vehicles within each class with driving lengths for the same classes to produce annual national mileage per vehicle class. This is then combined with emission factors in grams per kilometre to derive emissions.

For LPG and CNG however, the CH_4 and N_2O emission factors stated in the NIR are given in terms of kg/TJ and reference either COPERT 5 or the IPCC 2006 guidelines. Such units imply a fuel-based approach, consistent with a Tier 2 methodology, analogous to the methodology used for CO_2. Similarly, for biofuels, CH_4 and N_2O emissions factors used within the inventory for bio-diesel and bioethanol are the same as the emission factors for gasoline and auto-diesel. The units for these emission factors also indicate a Tier 2 fuel-based approach. This implies the Norwegian inventory is yet to estimate GHG emissions for AFVs via a mileage approach.

It is noted within the NIR that the HFBA emissions model is due to be updated in 2017, specifically to include emission factors from new technologies, however the evidence of this update in report format could not be found. It should be noted that there is no specific mention of hybrid diesel or hybrid petrol vehicles.

8.2 Italy

Within the Italian inventory, road transport CO_2 emissions are calculated by combining the total fuel consumption (obtained from the national energy balance) with IPCC 2006 and country-specific emission factors. These estimates include emissions from the consumption of LPG and CNG. Emissions are then allocated according to traffic data for each vehicle class.

The emissions from the consumption of bioethanol and biodiesel are reported under the respective categories for petrol and diesel fuel. The exact emission factors used are not provided but it is implied that the resulting CO_2, CH_4 and N_2O emissions are calculated on a fuel-basis (so following a Tier 2 methodology). Biofuels are observed to have increased over the timeseries, with biodiesel being used in testing before entering production in 1998. Bioethanol was first used within the road transport sector by passenger cars in 2008.

For CNG passenger cars, LPG passenger cars, hybrid gasoline passenger cars and CNG buses, the emissions of other GHGs including CH_4 and N_2O are estimated using a mileage approach utilising the COPERT 4 transport emissions model. This could be described as a Tier 3 approach. Detailed classifications for these vehicles and their populations are obtained from the Ministry of Transport (MIT). Emission factors are assumed to be those available for these technologies within the COPERT 4 model; however this is not stated explicitly within the NIR.

8.3 Japan

CO_2 emissions from road transport are estimated using a Tier 2 fuel-based approach, using country-specific emission factors on the carbon content of each fuel. From the description in the NIR, it is not clear whether CO_2 emissions from AFVs are calculated via this methodology. However, emission factors are supplied for LPG and CNG, and therefore imply this to be the case.

The Japanese Inventory estimates CH_4 and N_2O emissions using a mileage-based methodology consistent with Tier 3 of the IPCC 2006 guidelines. For AFVs specifically, this approach has been used to estimate emissions for LPG and CNG passenger vehicles, CNG buses and CNG 'cargo' trucks. For CNG vehicles, emission factors for CH_4 have been developed based on data available from the Japan Automobile Manufacturers Association (JAMA). For N_2O, the emission factors are based upon specific measurement data for CNG cargo trucks, and then applied to other vehicle classes by correcting the EF by vehicle weight. Emission factors for LPG for the same pollutants have been assumed to be the same as for gasoline. Emission are calculated with activity data in the form of annual distances travelled by each vehicle type and by each fuel type, supplied by the Road Transport Census (MLIT) Statistical Yearbook of Motor Vehicle Transport.

The NIR recognises that the number of vehicles which run on methanol was negligible (only 9 vehicles) in 2016. Therefore emissions are considered negligible and not included in the inventory. However, it is unclear from the NIR whether this is fossil or biogenic methanol. Very small amounts of biodiesel and bioethanol are blended into the respective diesel and gasoline pools in Japan[73], with only a modest amount of imported bio-based ETBE being blended into the gasoline pool. It is therefore likely the number of AFVs that run on high-blends of biofuels is extremely small in Japan.

8.4 Netherlands

For CO_2, road transport emissions are calculated using a Tier 2 approach, based on the fuel consumed, utilising country specific emission factors. This includes emission factors for alternative fuels, such as LPG and CNG. These appear to be derived from a study in 2017, but refer to fuel samples from 2004.

For LPG and CNG vehicles, a Tier 3, traffic-based approach is followed for estimating CH_4 and N_2O emissions, utilising data on vehicle kilometres travelled. CH_4 and N_2O emissions from biofuel vehicles are also calculated but are calculated using the same emission factors for diesel and gasoline based on figures for bio-diesel or bio-ethanol respectively, calculated according to a Tier 2, fuel-based methodology. The NIR referenced, several times, a study by Klein et al 2017, which addresses emissions from alternative vehicles specifically. This is explored further in the annex to this report.

8.5 United States

For emissions from AFVs, the US NIR includes a detailed methodology within Annex 3.2. This annex discusses the methodologies used for the transport sector alongside the various complications and data sources. CO_2 emissions from the road transport sector are derived via a Tier 2 fuel-based approach – therefore combining total fuel consumption with country-specific emission factors. Fuel consumption of gasoline and diesel across the transport sector is determined via a top-down and bottom-up approach (the main report references a top down approach, and the annexes reference a bottom-up approach). CNG and LPG emissions are also derived via a top-down and bottom-up approach. Emission factors are calculated based upon country specific characteristics of the fuel provided by the Energy Information Administration (EIA). CO_2 emissions from the consumption of biodiesel and bioethanol, which has grown substantially in the US, is estimated similarly by applying country-specific emission factors to fuel consumption.

Emissions of CH_4 and N_2O from conventional vehicles are estimated based on a mileage-based approach. The methodology for AFVs mirrors this approach by calculating the vehicle kilometres travelled for LPG, CNG, bioethanol, biodiesel and hydrogen fuelled vehicles via the EIA. Data on electric vehicles and plug-in hybrid electric vehicles (PHEVS) are compiled separately via the Electric Drive Transportation Association.

[73] USDA FAS (2017) "Japan Biofuels Annual 2017", GAIN report number: JA7100, Available at: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Tokyo_Japan_8-15-2017.pdf

The fuel economy for each AFV type is expressed in 'gasoline equivalents' (the amount of gasoline that contains the same amount of energy as the alternative fuel). Energy economy ratios (the ratio of the gasoline equivalent fuel economy of a given technology to that of conventional gasoline or diesel vehicles) were taken from the Argonne National Laboratory's GREET2016 model. These ratios were used to estimate fuel economy in miles per gasoline gallon equivalent for each alternative fuel and vehicle type. Energy use per fuel type was then divided among the various weight categories and vehicle technologies that use that fuel. Total vehicle kilometres travelled per vehicle type for each calendar year was then determined by dividing the energy usage by the fuel economy.

CH_4 and N_2O emission factors for AFVs are calculated according to studies by Argonne National Laboratory and the Lipman & Delucchi (2002) study and are reported in ICF (2006a). In these studies, CH_4 and N_2O emissions for AFVs were expressed as a multiplier corresponding to conventional vehicle counterpart emissions (Tier 1). Emissions of CH_4 and N_2O were calculated by multiplying the vehicle kilometres travelled by the calculated emission factors. It should be noted that emission factors for PHEVs were not listed alongside the emission factors for other AFVs. It is therefore unclear how the US methodology handles PHEVs.

Improvements that the US are looking into include the possibility of breaking out the electricity used to charge vehicles and reporting that electricity use under the transport sector.

8.6 Summary

The research identifies that the countries selected for review have now developed methodologies for integrating specific AFV technologies, most notably LPG and CNG fuelled vehicles into their national GHG inventories. These methodologies tend to vary between the IPCC Tier 2 and Tier 3. For the use of biofuels, the methodologies, in comparison are simpler, with more countries using a Tier 2 methodology to estimate CH_4 and N_2O emissions, and in some cases using the emission factors for conventional gasoline or diesel. Methodologies to handle electric vehicles are sparse in comparison, however it is important to recognise that 'tailpipe' emissions are zero from this vehicle type and their upstream emissions are allocated under the power station sector.

Table 12: Summary table of treatment of AFVs in different country inventories

Aspect	Pollutants	Norway	Italy	Japan	Netherlands	US	UK
Integration of LPG/CNG AFVs	CO_2	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 2)
	CH_4, N_2O	Yes (Tier 2)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 3)	Yes (Tier 2/3)
Integration of bio-fuel AFVs	CO_2	Yes (Tier 2)	Yes (Tier 2)	No*	Yes (Tier 2)	Yes (Tier 2)	Yes (Tier 1)
	CH_4, N_2O	Yes (Tier 2)	Yes (Tier 2)	No*	Yes (Tier 2)	Yes (Tier 3)	Yes (Tier 2)
Integration of plug-in hybrid/ electric vehicles	CO_2[#]	No	No	No	No	No	No
	CH_4, N_2O	No	Yes (Tier 3)	No	No	Yes (Tier 3)	No

* In Japan, the number of these vehicles is low and therefore considered negligible
[#] Calculating CO_2 emissions on a fuel basis incorporates any hybrid/electric vehicles implicitly, as these technologies directly impact the fuel use of the vehicle. In these cases, this row can therefore be read as whether or not the NIR explicitly acknowledges this dynamic

9 Conclusions and recommendations

The data collected and analysed in this project shows that alternative fuelled vehicles are an increasingly important sub-sector of road transport in the National Atmospheric Emissions Inventory.

9.1 Key findings

AFVs currently contribute around 0.5% of road transport CO_2 emissions. This is an increase from around 0.3% in 2012. CO_2 is the dominant transport GHG, contributing 99% of total (CO_2e) emissions. The overall contribution of CH_4 and N_2O is therefore small. AFVs currently contribute around 1% of transport CH_4 emissions and 0.2% of transport N_2O emissions. Whilst some caution is required given the greater uncertainty over emission factors for these gases it is clear that, as with the transport sector more broadly, CO_2 emissions dominate total GHGs for AFVs.

Accounting for AFVs in the UK inventory will therefore have little impact on historic and current emissions. However, CO_2 emission estimates from this sector will become increasingly important due to the expected continued increase in the numbers of AFVs. Looking at future projections, the contribution of AFVs to total road transport GHG emissions could be between ~6-9% by 2035. The contribution is dependent on a number of factors, including assumptions on the continued inclusion of hybrids as AFVs, and the use of Plug-in Hybrid Electric Vehicles (PHEVs) in electric or petrol mode. It is important to view the projected impacts through two mechanisms: 1) AFVs' contribution to emissions, and 2) The shift from conventional vehicles to AFVs and the associated reduction in transport's overall emissions.

Emissions from electric and hydrogen vehicles are currently treated as zero, consistent with international inventory reporting. However, the US are looking into the possibility of breaking out the electricity used to charge vehicles and reporting that electricity use under the transport sector. Reporting of electric use in this way in the UK would increase AFVs total contribution to CO_2 emissions, the extent to which would depend on the UK grid mix.

There is increasing work being undertaken across Europe and internationally to better understand emission factors and activity data associated with AFVs. The UK is on a par with other countries in many respects. However, improvements could be made to the UK's activity data. The US, for example, uses a vehicle km based approach to calculate CH_4 and N_2O emissions for all AFVs.

Total CO_2 emissions from the transport sector can be determined through fuel sales. However, improved understanding of activity data in terms of mileage and real-world use will be key to reconciling with bottom-up estimates (activity data x emission factor) which are also employed. Furthermore, this improved understanding will continue to be important in terms of impacts of traffic related emissions for GHGs – CH_4 and N_2O and air pollutants – NO_x and PM_{10} which depend on engine load and speed.

Whilst there is still uncertainty in the emission factor values, there is increasing literature and real-world data available. PHEVs could be considered to be the AFV vehicle type where the uncertainty is presently greatest, reflecting their significant uptake in recent years and the current limited understanding of real world use (petrol vs. electric mode). Increased understanding of Liquefied Petroleum Gas and Compressed Natural Gas emissions could also be important, particularly in the context of the recent introduction of bio-LPG and bio-methane.

9.2 Recommendations

Vehicle fleet statistics - it is recommended that continued improvements are made to the data collection processes for AFV fleet statistics, so that more reliable emission estimates can be made. In the future more granular data could be provided on the size or segment categories of vehicles.

Activity data - understanding of real world use of PHEVs, electric and fuel cell vehicles is currently limited, which restricts the precision of analysis that can be applied. With respect to mileage odometer data, this is available from MOT test data and it is recommended that research using this source is undertaken to allow mileage data for AFVs to be improved. The UK National Travel Survey also offers opportunities to understand the use of these vehicles by trip purpose and road type. In terms of the consumption of liquid fuel vs. electricity in Plug-in Hybrid and Range Extender vehicles, the expected rise in increasingly connected vehicles could result in more data being available at fleet, manufacturer or software developer level. Consideration needs to be given on how best to access this data.

It will also be important to understand potential future societal changes on vehicle mileage. With the planned introduction of fully autonomous vehicles onto UK roads as soon as 2021, and the likely very high prevalence of electric vehicles within this autonomous roll-out, customer demands for vehicle ownership and hired transport services are expected to shift dramatically within the next 5-10 years, and combined, these factors could dramatically alter the annual mileages (and modes) driven by different vehicle types.

Emission factors - improvements have been made since the 2013 review. It is recommended that continued emission test work is supported and that the UK continues to work with other EU countries to build up an accessible database of emission factors. This is particularly relevant with the significant changes in manufacturer drive-cycle testing at EU level; increasing understanding of how emission levels can vary with speed; and the potential future impacts of introducing higher levels of biofuel inclusion.

Treatment of hybrid vehicles - the classification of hybrids as AFVs is increasingly a misnomer as variants of this technology are being generally adopted in many passenger cars in particular. Hybrid vehicles (without a separate means of charging) are essentially more efficient versions of standard internal combustion engine vehicles. Faced with stringent tailpipe CO_2 targets, most vehicle manufacturers are turning to various forms of hybridisation to improve the efficiency of their products in the near term, with some also offering plug-in and full electric versions as well. In the latest US inventory, hybrids are classified as gasoline vehicles, whilst historically they have been treated as alternatively fuelled vehicles. Similarly, in the Committee for Climate Change's Fifth Carbon Budget report, hybrids are considered alongside conventional vehicles, whilst historically their impact has been detailed separately. In the UK NAEI, hybrid vehicles are not disaggregated per se, so the future treatment of hybrids reflects an issue over terminology rather than a quantifiable change in overall transport emissions.

Appendix A

Table 13: Estimated CO_2 Emissions from AFVs by Vehicle Type (ktonnes), using total UK transport emissions instead of total UK road transport emissions for comparison

Vehicle type	2010	2011	2012	2013	2014	2015	2016	2017
Cars	216.6	237.8	260.0	282.0	317.5	363.2	418.6	488.9
LGVs	68.3	65.9	46.5	55.9	53.0	47.3	39.0	31.6
Motorcycles	0.04	0.05	0.04	0.04	0.03	0.03	0.02	0.03
HGVs	4.2	4.2	4.4	3.4	3.6	3.0	2.0	2.1
Buses	3.8	3.5	5.6	7.5	10.9	12.8	18.0	28.6
Total AFV emissions	**293**	**311**	**317**	**349**	**385**	**426**	**478**	**551**
Total UK transport emissions - baseline[68]	117,376	116,426	116,140	115,946	118,087	120,058	121,964	121,616
AFV % of total UK transport - baseline	0.25%	0.27%	0.27%.	0.30%	0.33%	0.36%	0.39%	0.45%
Total UK transport emissions - reference[68]	120,079	118,261	117,696	116,548	117,781	120,022	119,812	117,300
AFV % of total UK transport - reference	0.24%	0.26%	0.27%	0.30%	0.33%	0.36%	0.40%	0.47%

Table 14: Estimated CO_2 emissions from AFVs under the CCC scenario by vehicle and technology type (ktonnes), using total UK transport emissions instead of total UK road transport emissions for comparison

	2020	2025	2030	2035
Car-petrol - plug in hybrid	298.5	1689	4308.5	7375.5
Car-Electric	0	0	0	0
LGV-petrol-plug-in hybrid	47	756	1,880	2,944
LGV electric	0	0	0	0
Total AFV emissions	**345.5**	**2,445**	**6,188.5**	**10,319.5**
Total UK projected all transport emissions - baseline[68]	112,430	115,372	118,931	123,244
AFV % of total UK transport - baseline	0.31%	2.12%	5.20%	8.37%
Total UK projected all transport emissions - reference[68]	110,982	106,995	103,999	102,619
AFV % of total UK transport - reference	0.31%	2.29%	5.95%	10.06%