ENGLAND'S ECONOMIC HEARTLAND

Pathways to decarbonisation

A technical report produced by the University of Oxford and the University of Southampton for the EEH evidence base

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Authors:

Adrian Hickford	University of Southampton.
Simon Blainey	University of Southampton.
Tom Russell	University of Oxford.

With contributions from:

James Golding-Graham	England’s Economic Heartland.
Jim Hall	University of Oxford.
Christian Brand	University of Oxford.
John Preston	University of Southampton.
Milan Lovric	University of Southampton.

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1. Introduction.

One of the main ambitions set out in England's Economic Heartland's (EEH) Transport Strategy is for the region's transport system to be 'net-zero carbon' by 2050[1], by substantially reducing vehicle emissions in the region. This will require a substantial change in the vehicle fleet towards zero-emission vehicles, coupled with technological solutions to improve vehicle efficiencies and the use of the road and rail networks, and promoting behaviour change of drivers and passengers to reduce the number and nature of motorised trips in the region.

As defined by the Committee on Climate Change (2019), the net-zero carbon target applies to the UK economy, and "requires deep reductions in emissions, with any remaining sources offset by removals of CO_2 from the atmosphere (e.g. by afforestation)". It is a challenging target for the transport sector, the largest carbon-emitting sector of the UK economy (accounting for 28% of greenhouse gas emissions, and 33% of carbon emissions in the UK in 2018[2, 3]), and still heavily dependent on fossil fuels.

In February 2020, the UK government laid out plans to bring forward the ban on selling new petrol, diesel or hybrid cars in the UK from 2040 to 2035 at the latest, in order to reach its target of emitting virtually zero carbon by 2050.

Consultation on this target is currently underway[4], and while vehicle manufacturers claim there is insufficient time to prepare the network for charging infrastructure[5], there are suggestions that even a 2035 ban on new conventionally-fuelled vehicles will not be soon enough to reduce carbon emissions by the 2050 target[6, 7], and will require substantial disruption to the energy system[8].

There are other societal pressures which make this a challenging target. In recent years, the SUV has become more popular[9, 10, 11], while the general public is still relatively uncertain of the merits of electric vehicles[12]. However, with vigorous policy interventions and timely infrastructure investments, these challenges can potentially be overcome. These interventions need to be purposeful, coordinated and measured if they are to achieve the target of net-zero carbon emissions by 2050. It is therefore necessary to carefully analyse the potential impacts of different policy interventions and examine their sensitivity to future changes in society, the economy and technology that are impossible to predict with certainty. By adopting a 'pathways' approach, we have sought to analyse how a range of policy options could be ramped up, coordinated and adapted between now and 2050 in order to achieve the zero-carbon goal.

1 As recommended in Committee on Climate Change (2019) Net Zero: The UK's contribution to stopping global warming.
2 BEIS. (2019). Digest of UK Energy Statistics. Department for Business, Energy and Industrial Strategy.
3 Committee on Climate Change (2018). Reducing UK emissions. 2018 Progress report to Parliament.
4 https://www.gov.uk/government/consultations/consulting-on-ending-the-sale-of-new-petrol-diesel-and-hybrid-cars-and-vans
5 https://www.theguardian.com/business/2020/feb/04/car-industry-petrol-diesel-ban-uk-electric-vehicles
6 Brand, C., Anable, J., Ketsopoulou, I., & Watson, J. (2020). Road to zero or road to nowhere? Disrupting transport and energy in a zero carbon world. Energy Policy, 139(February).
7 https://friendsoftheearth.uk/climate-change/government-accelerate-ban-new-petrol-and-diesel-cars
8 UKERC. (2019). Disrupting the UK energy system: causes, impacts and policy implications.
9 UKERC. (2019). Review of Energy Policy 2019. http://www.ukerc.ac.uk/publications/rep19.html
10 https://www.bbc.co.uk/news/business-50713616
11 https://ukerc.ac.uk/news/suvs-sabotage-green-revolution/
12 Bennett, R., & Vijaygopal, R. (2018). An assessment of UK drivers' attitudes regarding the forthcoming ban on the sale of petrol and diesel vehicles. Transportation Research Part D: Transport and Environment, 62(March), 330–344.

This report assesses outputs from a strategic transport model – part of the NISMOD modelling suite (National Infrastructure Systems Models) developed by the Infrastructure Transitions Research Consortium (ITRC) – to investigate the impact of different sets of options, or 'Pathways', to help achieve the zero-carbon target for transport in EEH by 2050, given expected population growth in the region.

The report is structured as follows: Section 2 provides a brief overview of the transport model used in this assessment, and its application to the EEH region. Section 3 sets out the housing and population growth scenario we are testing; Sections 4 and 5 describe the Pathways to decarbonisation, while Section 6 provides an overview of results for some key metrics: vehicle kilometres, CO_2 emissions and electricity use for each of the Pathways. Section 7 provides a brief summary and conclusions.

2. Modelling the EEH transport network.

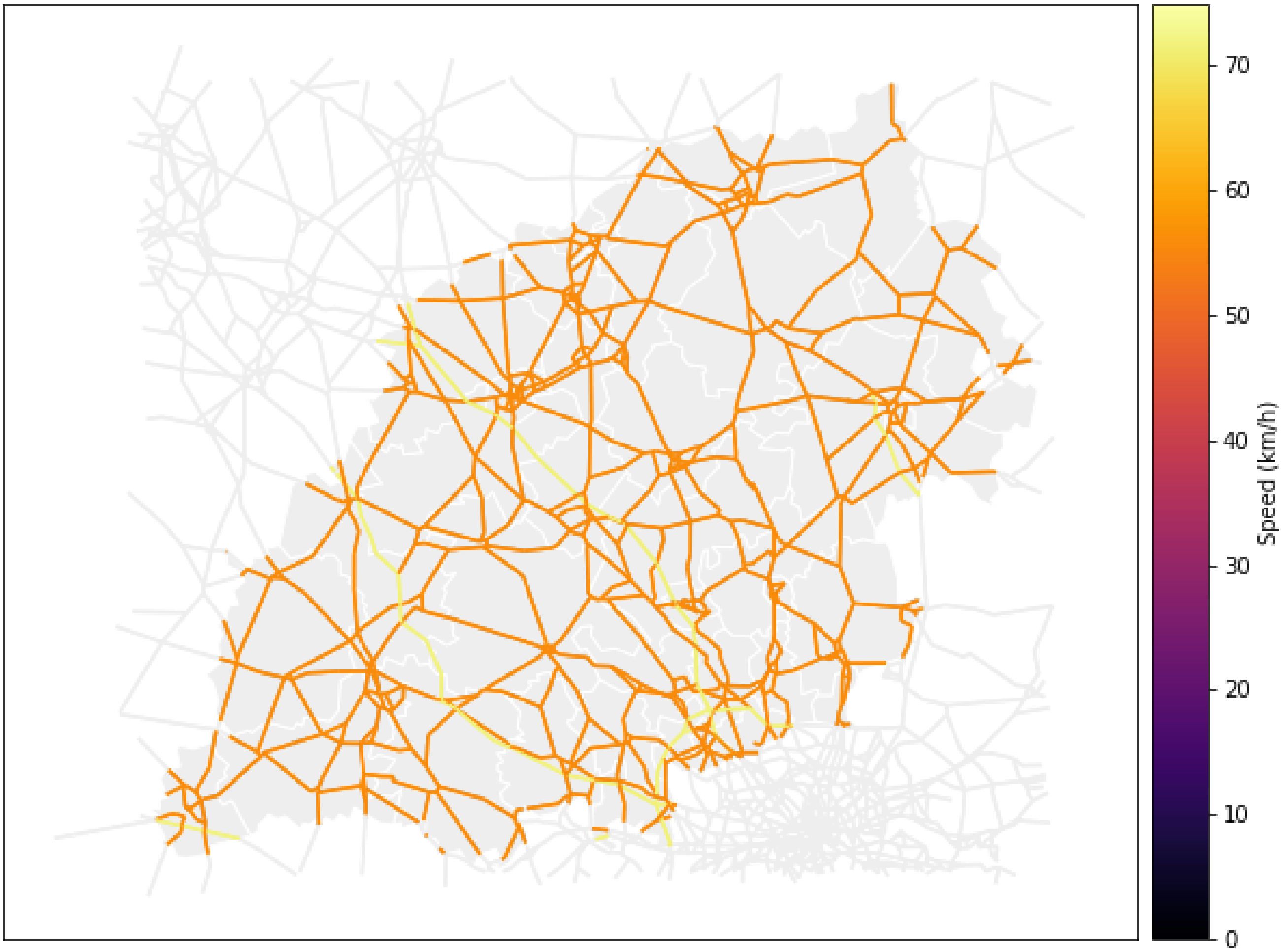
The NISMOD v2 Transport Model[13] is a national-scale (Great Britain) model of the road and rail network, developed to support policy making regarding future infrastructure. It forecasts the impact of various factors that influence transport demand, trip generation and utilisation of the road and rail networks. For a given scenario, the model predicts a range of metrics including travel times, energy use, emissions and capacity utilisation. A detailed description of the road and rail models is provided in Appendix A.

The strategic road network we are considering is shown in Figure 1, colour-coded by speed limits. There are 2,774 separate major road links in the EEH network, most of which are A-roads, while the motorways passing through the region are also included.

The model also generates trips on minor roads, so outputs represent all road vehicle trips on the entire network.

13 Lovric, M. et al. (2019). 'NISMOD Transport v2.2.1' Available online: https://github.com/nismod/transport doi: 10.5281/zenodo.3583128.

Figure 1: EEH trunk road network assessed in this report.



For this report, we model the effects on travel demand of population change between 2015 and 2050 (based on housing growth as collected from local authority, Local Plans in the region at the end of 2019), assessing the impacts of a range of diverse routes or pathways towards a decarbonised transport system. The next section introduces the scenario of population change used in this assessment.

3. Scenario generation.

Using a set of assumptions about housing development and occupancy over time, we have developed a scenario of population change specific to this study, which contributes to changes in transport demand.

3.1 Housing growth.

EEH has provided data on planned housing developments provided by each local authority in the region. These are generally 20-year growth forecasts (e.g. 2013-2033)[14], giving an average annual estimated growth for each local authority. These annual estimates are summarised in Table 1, which also shows the total number of new houses between 2019 and 2050 if the annual growth trend was to continue. Local Plan housing growth averages 27,822 new houses per year across the region, resulting in a total of around 862,000 new houses in those 30 years.

14 EEH Databank and EEH_Databank_Development_Sites_2.0.

Table 1: New dwellings per year, by region, according to EEH Databank figures.

	Annual housing growth	Total new dwellings EEH 2020-2050
Buckinghamshire	2,343	72,633
Cambridgeshire	3,604	111,724
Hertfordshire	5,113	158,503
Northamptonshire	4,231	131,161
Oxfordshire	4,962	153,822
Bedford	970	30,070
Central Bedfordshire	1,968	61,008
Luton	425	13,175
Milton Keynes	1,767	54,777
Peterborough	972	30,132
Swindon	1,467	45,477
Total	**27,822**	**862,482**

3.2 EEH population growth assumptions.

These estimated housing figures can be combined with projected changes in household occupancy levels[15] to generate the EEH future population growth scenario.

According to ONS data projections, household occupancy in the UK is decreasing over time. In the EEH, this average is 2.49 people per household in 2015, which is projected to decrease to 2.27 people per household in 2041. The average occupancy figures for each area can be combined with the EEH housing estimates to provide an estimate of future population change in the region. The estimated population in each area is given in Table 2.

Table 2: EEH Population change, given by expected changes in household growth.

	AREA	2015	2020	2030	2040	2050
Buckinghamshire	Aylesbury Vale	193,632	211,464	241,934	267,956	302,635
	Chiltern	98,504	100,133	98,908	98,118	101,088
	South Bucks	71,910	73,458	71,495	70,376	73,081
	Wycombe	180,883	183,277	185,492	188,710	200,063
Cambridgeshire	Cambridge	140,112	158,451	177,258	189,785	207,982
	East Cambridgeshire	89,062	92,160	102,414	112,380	125,011
	Fenland	102,597	108,687	121,396	132,061	144,611
	Huntingdonshire	178,979	183,731	194,200	205,412	222,473
	South Cambridgeshire	159,750	166,968	180,800	194,049	214,827
Hertfordshire	Broxbourne	98,732	100,120	104,892	109,029	119,111
	Dacorum	152,953	156,643	158,568	159,917	168,401
	East Hertfordshire	146,518	150,871	161,585	171,499	188,549
	Hertsmere	107,075	110,068	110,175	110,042	115,425
	North Hertfordshire	134,135	137,040	143,774	150,448	164,203
	St Albans	150,795	155,279	166,183	177,348	196,639
	Stevenage	86,893	89,202	92,575	95,584	103,106
	Three Rivers	92,199	91,533	88,062	85,869	89,097
	Watford	96,744	95,997	93,599	92,858	97,656
	Welwyn Hatfield	119,086	123,320	131,777	137,604	150,879

15 Based on data from the following sources:
MHCLG: Table 125: Dwelling stock estimates by local authority district: 2001-2018
ONS: Table 406 Household projections, mid-2001 to mid-2041
ONS: 2018-based subnational population projections, Table 2

	AREA	2015	2020	2030	2040	2050
Northamptonshire	Corby	69,084	75,569	85,298	93,109	103,700
	Daventry	81,765	93,407	116,405	137,438	156,581
	East Northamptonshire	93,364	99,455	109,065	117,589	127,438
	Kettering	101,472	108,374	120,150	130,908	142,908
	Northampton	226,974	231,483	239,279	247,666	268,235
	South Northamptonshire	91,552	100,599	115,643	129,066	143,877
	Wellingborough	80,059	84,393	93,500	102,052	112,400
Oxfordshire	Cherwell	152,257	169,961	203,431	235,029	268,566
	Oxford	162,012	167,008	173,682	178,927	191,701
	South Oxfordshire	146,322	155,737	174,509	192,281	214,724
	Vale of White Horse	129,288	150,428	186,887	219,251	251,703
	West Oxfordshire	112,499	118,654	136,717	154,593	173,304
Unitary Authorities	Bedford	174,342	184,208	197,676	208,635	228,802
	Central Bedfordshire	278,229	298,149	329,018	354,608	395,715
	Luton	213,830	212,826	199,313	190,877	198,649
	Milton Keynes	274,659	286,424	303,709	323,349	359,761
	Peterborough	204,617	220,751	243,242	261,001	284,716
	Swindon	223,809	239,847	270,427	298,216	331,346
	Total	**5,216,691**	**5,485,676**	**5,923,042**	**6,314,205**	**6,938,963**

Comparing this with ONS housing and population projections to 2041 (Figure 2), we see that the total EEH estimated growth is higher than ONS projections[16], with an estimated extra 600,000 people in the region in 2041 for the EEH scenario compared with ONS. However, the distribution of new housing is much more intensive and variable in the EEH projection than for ONS, as can be seen in Figure 3.

16 Note: there is a mismatch between ONS projection data and MHCLG numbers for 2015-2019 of around 60,000 dwellings, so this has been added to ONS figures to ensure lines begin at identical points

Figure 2: Comparison of EEH housing growth with ONS projections.

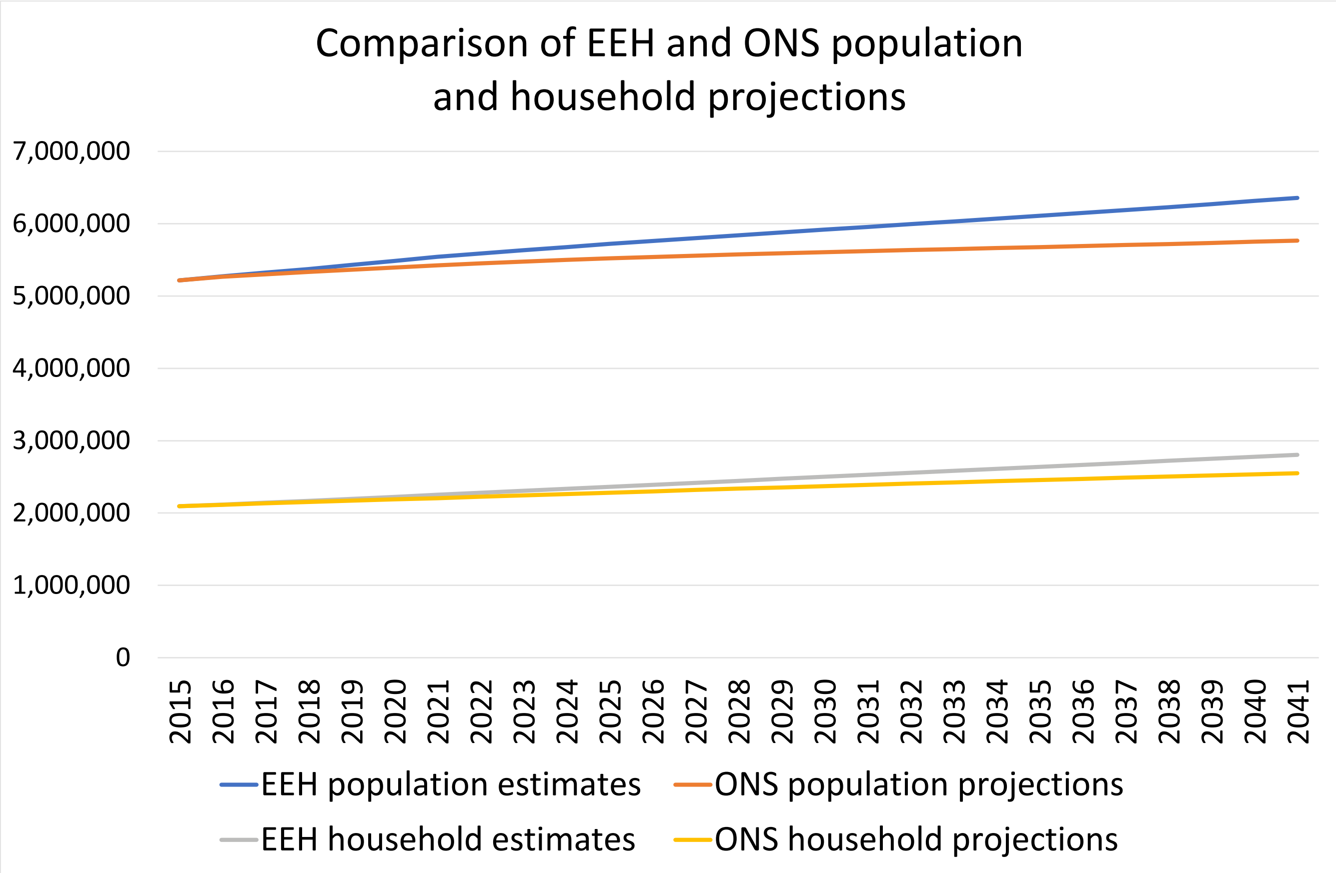
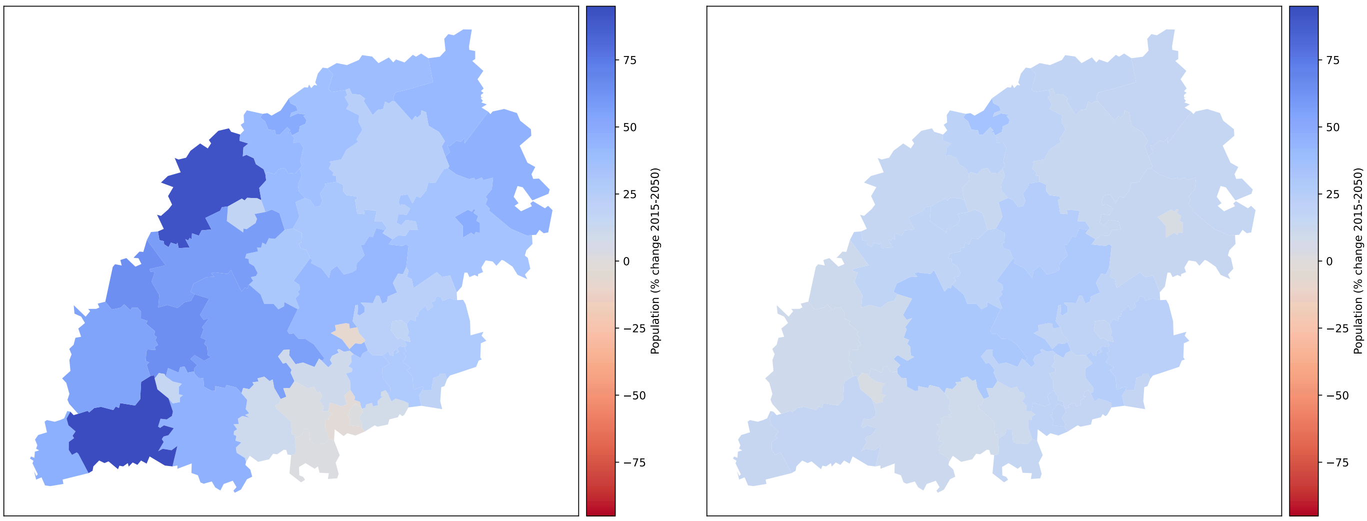


Figure 3: Population change comparison between EEH scenario and ONS population projections.



(a) EEH scenario.

(b) ONS projection.

The population for EEH shows more concentrated growth in the west of the region, although some areas to the south and centre of the region do not grow as much as projected by ONS figures.

4. Pathways to decarbonisation.

- Pathway 1: Business as Usual (BaU) – a 'baseline', based on recent (pre-COVID-19) trends in transport demand.
- Pathway 2: Highly Connected (HC) – increased use of digital communications and embedded technologies in the transport network.
- Pathway 3: Adapted Fleet (AF) – technological development of the vehicle stock.
- Pathway 4: Behaviour Shift (policy-led) (BSP) – behaviour change achieved through road pricing and education measures.
- Pathway 5: Behaviour Shift (results-led) (BSR) – assume that societal change takes place, regardless of policy choices.

This section introduces the proposed Pathways towards decarbonising transport in EEH. Each Pathway is comprised of a variety of strategic approaches towards decarbonisation by 2050, each with a different focus. These different approaches provide the narrative for each Pathway. The Pathways are modelled and assessed using the NISMOD Transport model, using the population growth scenario described in Section 3, and a summary of the model implementation is provided for each Pathway.

The model uses a baseline year of 2015. Results are available for the baseline year, 2020, 2030, 2040 and 2050. Note that we assume that the Expressway road does not feature in any of these analyses.

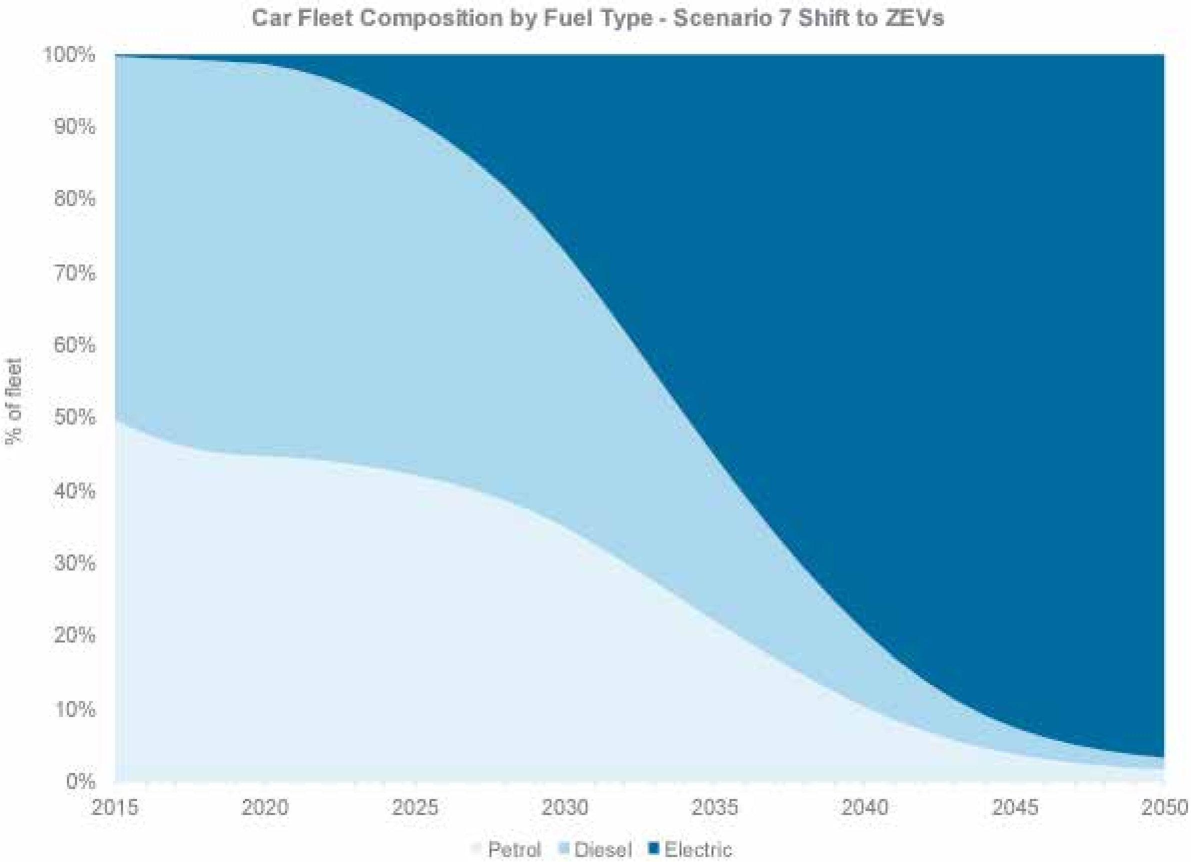
Before describing the Pathways in more detail, we first set out assumptions about some common themes for all the Pathways: the distribution and efficiency of fuels powering the fleet, and the percentage of autonomous vehicles (AVs).

4.1 Changing the fleet.

We are seeking to assess the impact of approaches which achieve the challenging target of zero carbon from the transport sector in EEH by 2050. While the government target is for net-zero carbon emissions by 2050, we assume for all Pathways (except BaU) that 100% of motor vehicle traffic in 2050 is made up of zero carbon vehicles (based on a modified DfT 'Shift to ZEVs' Scenario and CCC Net Zero 'Further Ambition' and 'Speculative' scenarios). For these analyses, we assume that there are differences in the rapidity and nature of technological change and capacity utilisation via autonomous vehicles, depending on the Pathway.

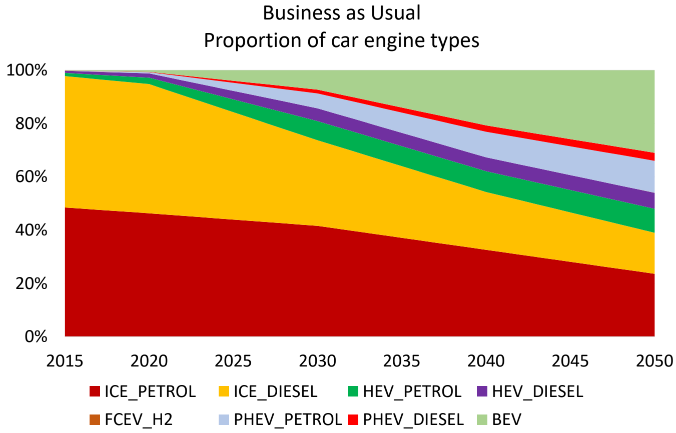
Figure 4 shows the assumed level of zero-emission powered vehicles in the car fleet for the DfT Scenario 7 Shift to ZEVs. These values are slightly adapted to create the timeline for cars and LGVs, resulting in 100% of zero-emission powered vehicles by 2050.

Figure 4: Car fleet composition by fuel types for S7 Shift to ZEVs (from DfT Road Traffic Forecasts 2018, p42).

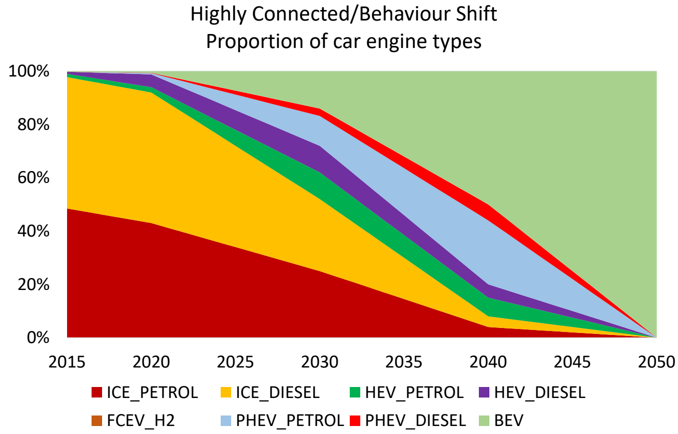


Timelines for decarbonising HGV and Public service Vehicle (PSVs) are included for each of the Pathways in Appendix B. Note that PSVs are not specifically modelled in NISMOD, so only form part of the Pathway narratives where appropriate. The differences between the Pathways for fuel types in cars are shown in Figure 5, and summarised in Table 3. The profile of changes for other vehicles types (LGV, HGV) differs slightly (not shown here, further details in Tables 7, 8 and 9, Appendix B).

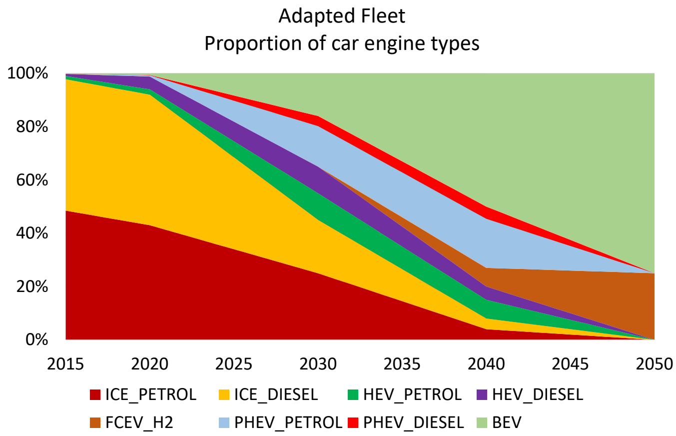
Figure 5: Proportion of car engine types for all Pathways.



(a)



(b)



(c)

For BaU, we assume that 31% of vehicles in 2050 are battery electric powered (BEV), 15% are hybrid ICE/battery (HEV), 15% are plug-in hybrids (PHEV), while 39% are petrol or diesel (ICE). For the other Pathways, we assume that all engine types are 'zero-carbon' by 2050, i.e. that all vehicles are powered entirely by batteries or hydrogen fuel cells, with zero tailpipe emissions. For Highly Connected and Behaviour Shift (both policy-led and results-led), we assume all cars in 2050 are BEV, while for Adapted Fleet, 25% of cars are powered by hydrogen fuel cell (FCEV_H2).

Table 3: Percentage PHEV and ZEV for each Pathway.

Percentage of Plug-in hybrid electric vehicle (PHEV)						Percentage of zero-emission vehicles (BEV and Hydrogen)					
BaU						BaU					
	2015	*2020*	*2030*	*2040*	*2050*		*2015*	*2020*	*2030*	*2040*	*2050*
Car	0	0.6	7	12	15	Car	0.2	0.6	7.3	20.7	31
LGV	0	0.1	2.9	7.7	10	LGV	0.1	0.1	3	8	15
HGV	0	0	0	0	0	HGV	0	0	1	1	1
PSV	0	0	0	0	0	PSV	0	0	1	2	4
Highly Connected / Behaviour Shift						Highly Connected / Behaviour Shift					
	2015	*2020*	*2030*	*2040*	*2050*		*2015*	*2020*	*2030*	*2040*	*2050*
Car	0	0.6	14	30	0	Car	0.2	0.6	14	50	100
LGV	0	0.1	10	20	0	LGV	0.1	0.1	10	30	100
HGV	0	0	0	0	0	HGV	0	5	20	50	100
PSV	0	5	15	15	0	PSV	1	5	20	45	100
Adapted Fleet						Adapted Fleet					
	2015	*2020*	*2030*	*2040*	*2050*		*2015*	*2020*	*2030*	*2040*	*2050*
Car	0	0.6	19	23	0	Car	0.2	0.6	21	57	100
LGV	0	0.1	10	20	0	LGV	0.1	0.1	15	50	100
HGV	0	0	0	0	0	HGV	0	5	20	50	100
PSV	0	5	15	15	0	PSV	1	5	20	45	100

We assume that the fuel efficiency improvements suggested by Brand et al. (2019)[17] apply in all Pathways except Adapted Fleet, as shown in Table 11. For Adapted Fleet, we assume there is an accelerated improvement, such that the 2040 efficiencies shown in Table 11 are achieved in 2030, and that 2050 efficiencies are brought forward to 2030. In this Pathway, no changes are made beyond 2040.

17 Brand, C., Anable, J., Philips, I., & Morton, C. (2019). Transport Energy Air pollution Model (TEAM): Methodology Guide – Appendices.

4.2 Autonomous vehicles.

Autonomous vehicles (AVs) are currently undergoing wide ranging testing around the world, and are likely to be part of future modern society. There is uncertainty regarding the impacts of AVs on energy consumption and carbon emissions[18]. However, for these analyses, we assume that the primary impact of changing the levels of autonomous vehicles (AVs) in the fleet will be to free up additional road capacity, since we assume AVs require 75% of the road space compared with non-AVs.

Using data modified from Litman (2020)[19], we assume that AVs make up 30% of the vehicle fleet in 2050 for the Highly Connected Pathway, while for Adapted Fleet and Behaviour Shift (policy-led), the penetration of AVs is assumed to be half as much, as set out in Table 4. To measure the impact of these capacity improvements, we assume there are no AVs for BaU.

Table 4: Percentage of Autonomous Vehicles in each Pathway.

	2015	2020	2030	2040	2050
BaU	0	0	0	0	0
Highly Connected	0	0	1.5	15	30
Adapted Fleet / Behaviour Shift	0	0	0.75	7.5	15

18 Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. Transportation Research Part A: Policy and Practice, 86, 1–18.

19 Todd Litman. (2020). Autonomous vehicle implementation predictions: implications for transport planning. Victoria Transport Policy Institute.

5. Pathway narratives.

The following section contains brief descriptive narratives and headline assumptions for the Pathways to decarbonisation. A summary of the differences in model implementation between Pathways is provided in Table 6.

5.1 Pathway 1: Business as Usual (BaU).

Headline assumption:

- 46% zero-emission powered cars and 25% zero-emission powered LGVs (by 2050).

The 'Business as usual' Pathway acts as a 'baseline', based on recent (pre-COVID-19) trends in transport demands. As set out in Section 4, this Pathway assumes that by 2050, 46% of cars and 25% LGVs are powered by zero emission technologies. A timeline for achieving these changes in fuel mix is set out in Table 7 (Appendix B), based on figures given in TAG Data book (2019), and previous ITRC Transport strategies.

5.2 Pathway 2: Highly Connected.

Headline assumptions:

- 100% zero-emission cars, LGVs, HGVs and PSVs (by 2050).
- 10% reduction in car trips (2015-2050).
- 20% increase in LGV trips (2015-2050).
- 30% AVs for all road vehicle types by 2050.
- GVA elasticity for all passenger modes is assumed to be progressively reduced by a total of 50% (2015-2050).

This Pathway is focused on the increasing use of digital communications to enhance the operation of transport systems, with a high and increasing level of embedded technology within vehicles and transport systems, connected to technologies in homes, businesses and mobile devices. This also impacts other passenger travel, reflected as a decoupling of GVA and passenger travel (see Table 10, Appendix B).

This Pathway represents a range of changes in the way the road network is used. Vehicle routing systems become more sophisticated, based on real time traffic information enhanced by traffic data from vehicle positioning systems and crowd-sourced mobile phone and sat-nav data. Automated vehicles (AVs) are increasingly prevalent, particularly on interurban trunk roads, where platoons of vehicles increase capacity utilisation and potentially increase maximum permitted speeds and the use of hard shoulder running. Cooperative traffic management systems help guide vehicles safely through urban centres, while smart logistics systems optimise freight movements.

Overall traffic volumes (and trip rates) are progressively reduced as increased use of video-conferencing, 3D printing, ultra-high-speed internet connections and hologram-based communications reduce the need for passenger transport. However, freight transport increases, particularly light goods vehicles, mostly due to an increase in home deliveries. These assumptions are linked to those for Behaviour Shift (policy-led) below, in that enhanced use of digital communications affects the amount of individual travel.

Model implementation.

As set out in Section 4, we assume that all vehicles are zero-emission vehicles (ZEVs) by 2050, following the timeline provided in Table 8.

We model the narrative above by assuming a 10% reduction in the number of car trips and 20% increase in LGV trips between 2015 and 2050 (HGV trips are unchanged). We assume that the GVA elasticity for all passenger modes is progressively reduced by a total of 50% between 2020 and 2050, implemented at each timestep as set out in Table 10.

We assume that autonomous vehicles become most prevalent in this Pathway, affecting capacity utilisation. The first AVs appearing during the 2020s, resulting in 1.5% of the fleet being AV in 2030, 15% in 2040 and 30% in 2050.

5.3 Pathway 3: Adapted Fleet.

Headline assumptions:

- 100% zero-emission cars, LGVs, HGVs and PSVs (by 2050).
- 15% AVs for all road vehicle types by 2050.

Rapid technological development in this Pathway allows wide-ranging modernisation of the vehicle stock for all modes at a faster rate than for the 'Highly Connected' Pathway. Increased engine efficiencies reduce energy consumption for all types of vehicle. Electrification is extended across the existing rail network and through the development of new tram and trolleybus networks[20]. Extensive deployment of hybrid transmissions and regenerative braking also reduce fuel consumption. Advances in materials science lead to the production of lighter construction materials for all vehicles, and trains become progressively lighter and faster with better acceleration and braking characteristics.

20 Note that this is narrative only, as NISMODv2 Transport Model does not actually model tram/trolleybus/psv.

Model implementation.

The focus on the rapid take-up of alternative vehicle fuels results in higher levels of zero emission vehicles and alternative fuels than for the 'Highly Connected' Pathway, and this is detailed in Table 9. We assume that fuel efficiency improvements are accelerated, so that the 2040 efficiencies shown in Table 11 are achieved in 2030, and that 2050 efficiencies are brought forward to 2030. No changes are made beyond 2040.

We assume that autonomous vehicles first appear during the 2020s, at half the rate of Highly Connected, with 0.75% of the fleet being AV in 2030, 7.5% in 2040 and 15% in 2050.

Improvements to rail rolling stock is assumed to lead to a reduction in rail journey times (by reducing generalised journey times (GJT) in the model by 10%) by 2050.

5.4 Pathway 4: Behaviour Shift (policy-led).

Headline assumptions:

- 100% zero-emission cars, LGVs, HGVs and PSVs (by 2050).
- 15% AVs for all road vehicle types by 2050.
- A general increase in the cost of car travel, achieved by applying road pricing in larger built-up areas as follows: 2015, 2020 no road pricing measures; 2030 £10 per vehicles 0700-1800 (£5 otherwise); 2040 £20 per vehicle 0700-1800 (£10 otherwise). The built-up areas where these pricing measures were tested for the scenario are set out in Table 5.

The focus of this Pathway is to achieve behavioural change away from single occupant car driving towards more intensive use of fewer vehicles, via car sharing and use of public transport[21]. The approach is likely to be a combination of road pricing measures and education measures to promote active travel and more sustainable transport modes. This will be assessed in our modelling through a steady increase in the financial cost of car travel by testing road pricing regimes in the larger built-up areas.

The assumptions underpinning this Pathway do not differentiate between demand management regimes, however, measures might in reality include higher road tax, national road pricing to disincentivise travel on congested routes at peak periods and workplace parking levies.

21 For further details see, for example, Marsden, G., Anable, J., Bray, J., Seagriff, E., & Spurling, N. (2019). Shared mobility – where now, where next? (www.creds.ac.uk/publications/where-now-where-next/).

This would be coupled with a concurrent national program of measures to influence and alter travel behaviour and freight logistics. A variety of 'soft' interventions relating to 'smarter choices'[22] would be used to promote more considerate and sustainable travel, including workplace travel plans, targeted discounts and promotional material, awareness-raising to encourage walking and cycling (including increased use of electric bikes), and promotion of public transport use and shared mobility. Such measures should help to reduce intra-zonal road congestion. Additional measures for freight transport might include drop off boxes and freight consolidation centres. Substitutes for travel, particularly those based on ICT, would also be promoted, similar to Pathway 2 Highly Connected.

Model implementation.

The timeline for changes to the fuel mix in the fleet for Pathway 4 is assumed to be the same as for Pathway 2 Highly Connected (see Table 8). We assume that autonomous vehicles first appear during the 2020s, at half the rate of Highly Connected, with 0.75% of the fleet being AV in 2030, 7.5% in 2040 and 15% in 2050.

The model uses pricing measures as a proxy for behaviour change, equivalent to road user charging and demand management for particular links within zones identified in Table 5, as follows:

2015: no road pricing charge.

2020: no road pricing charge.

2030: 0700-1800 £10 per vehicle to travel within the zones, other times £5 per vehicle.

2040: 0700-1800 £20 per vehicle to travel within the zone, other times £10 per vehicle.

The model does not discern between engine types for this road pricing scheme, and as we are testing the impact of general cost increases, the pricing regime applies regardless of engine type (i.e. there is no discount for low- and zero-emission vehicles).

The above narrative is achieved in the modelling by applying road pricing to particular road links in regions within EEH, identified as roads within any built-up area of >= 10 million hectares inside the EEH region, as shown in Table 5.

22 See for example Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A., & Goodwin, P. (2008). Smarter choices: Assessing the potential to achieve traffic reduction using "Soft measures." Transport Reviews, 28(5), 593–618.

Table 5: Conurbations/localities identified for demand management measures in Behaviour Shift (policy-led) pathway (road pricing measures used as a proxy measure for modelling purposes only).

Conurbation	Estimated population (2018)
Northampton	229,840
Luton	222,460
Swindon	192,600
Milton Keynes	185,580
Peterborough	176,890
Oxford	165,380
Cambridge	149,240
High Wycombe	123,990
Bedford	94,620
Stevenage	94,000
Aylesbury	87,100
Corby	61,100
Kettering	60,300
Wellingborough	53,010
Welwyn Garden City	51,180
Hertford/Ware	48,920
Amersham/Chesham	48,520
Banbury	47,200
Abingdon	39,610
Letchworth Garden City	34,470
Wisbech	34,400
Didcot	30,120

5.5 Pathway 5: Behaviour Shift (results-led).

Headline assumptions:

- 100% zero-emission cars, LGVs, HGVs and PSVs (by 2050).
- 15% AVs for all road vehicle types by 2050.
- 20% reduction in car trip rates; 5% increase in rail trip rates (both 2020-2040).

This Pathway is related to Pathway 4, but rather than implementing policies of pricing and behavioural shift, we assume that societal change takes place (regardless of the policy being implemented), resulting in a reduction in vehicle ownership and increased car sharing and modal shift to public transport.

Model implementation.

The timeline for changes to the fuel mix in the fleet for Pathway 5 is assumed to be the same as for Pathway 2 Highly Connected (see Table 8). We assume that autonomous vehicles first appear during the 2020s, at half the rate of Highly Connected, with 0.75% of the fleet being AV in 2030, 7.5% in 2040 and 15% in 2050.

Car ownership, vehicle occupancy, PSV trips and modal shift are not explicitly modelled, so for this Pathway we model the societal changes outlined above by adjusting trip rates for road and rail, such that there is a 20% reduction in car trip rates between 2020 and 2040, while rail trip rates are increased by 5% over the same period.

Table 6: Summary of model assumptions for EEH Pathways. An empty cell refers to no change from the initial model assumptions.

	BaU	Highly Connected	Adapted Fleet	Behaviour Shift (policy)	Behaviour Shift (results)
Engine types (cars) 2050	39% ICE, 15% HEV, 15% PHEV, 31% BEV	100% BEV	75% BEV, 25% H2FC	100% BEV	100% BEV
Autonomous vehicles 2050	0%	30%	15%	15%	15%
Cost of travel	—	—	—	Road user cost increase 2020-2040	—
Trip rates	—	-10% car trips +20% LGV trips 2015-2050	—	—	-20% car trips +5% rail trips 2020-2040
Fuel efficiencies	—	—	Accelerated	—	—
GVA elasticity	—	-50% car and rail 2020-2050	—	—	—
Rail GJT	—	—	-10% 2030-2050	—	—

6. Results.

The following section provides a set of comparisons between the Pathways. In particular, we assess the changes for road travel in terms of vehicles travelled, levels of congestion, CO_2 emissions and electricity consumption.

6.1 Vehicle kilometres.

The number of vehicle kilometres in each area is provided by the model. A comparison of the total for each Pathways is given in Figure 6, and regional variations are shown in Figure 7 (a to f).

Figure 6: Vehicle kilometres travelled in EEH by Pathway and year, cars, freight and combined.

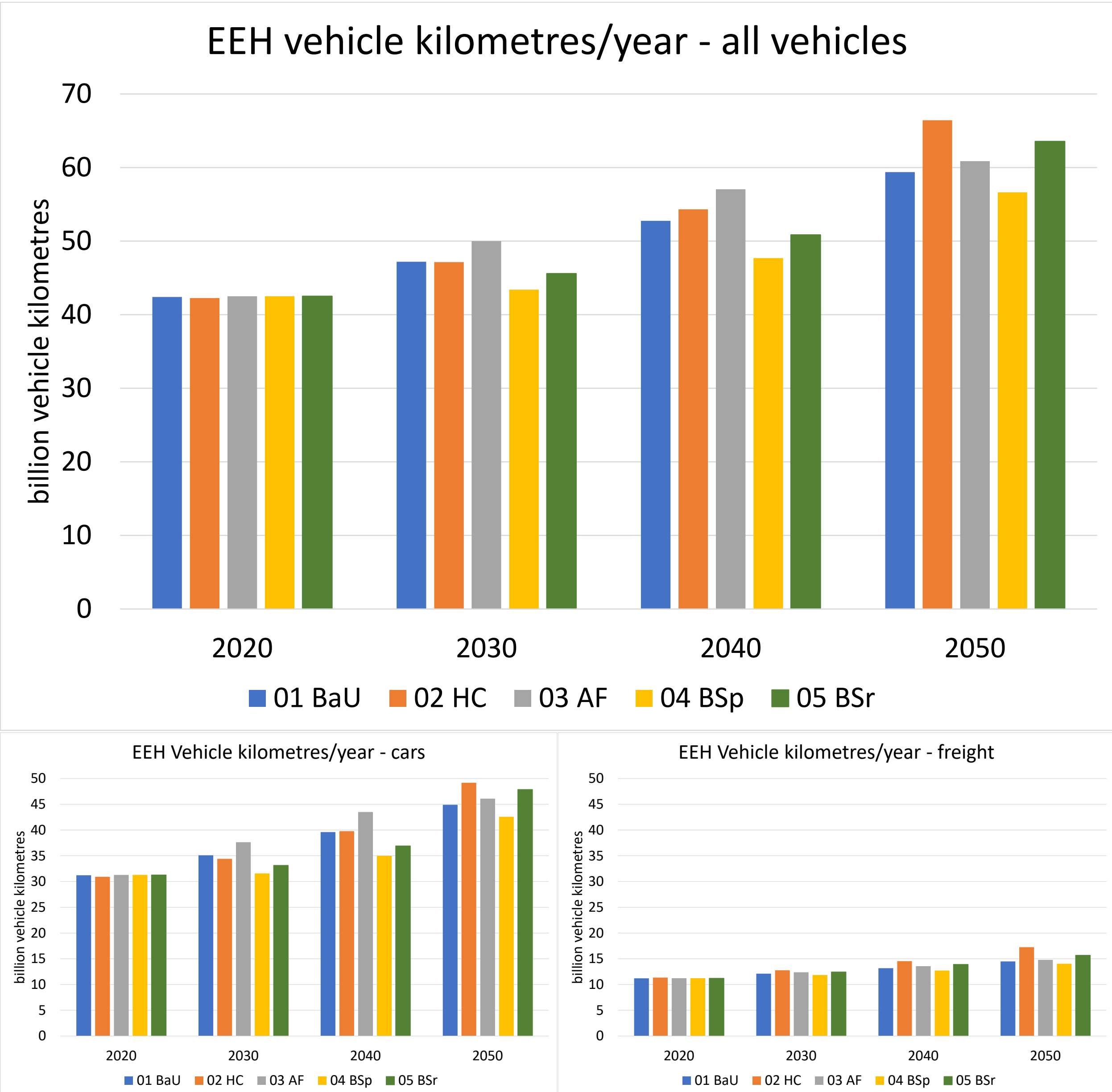
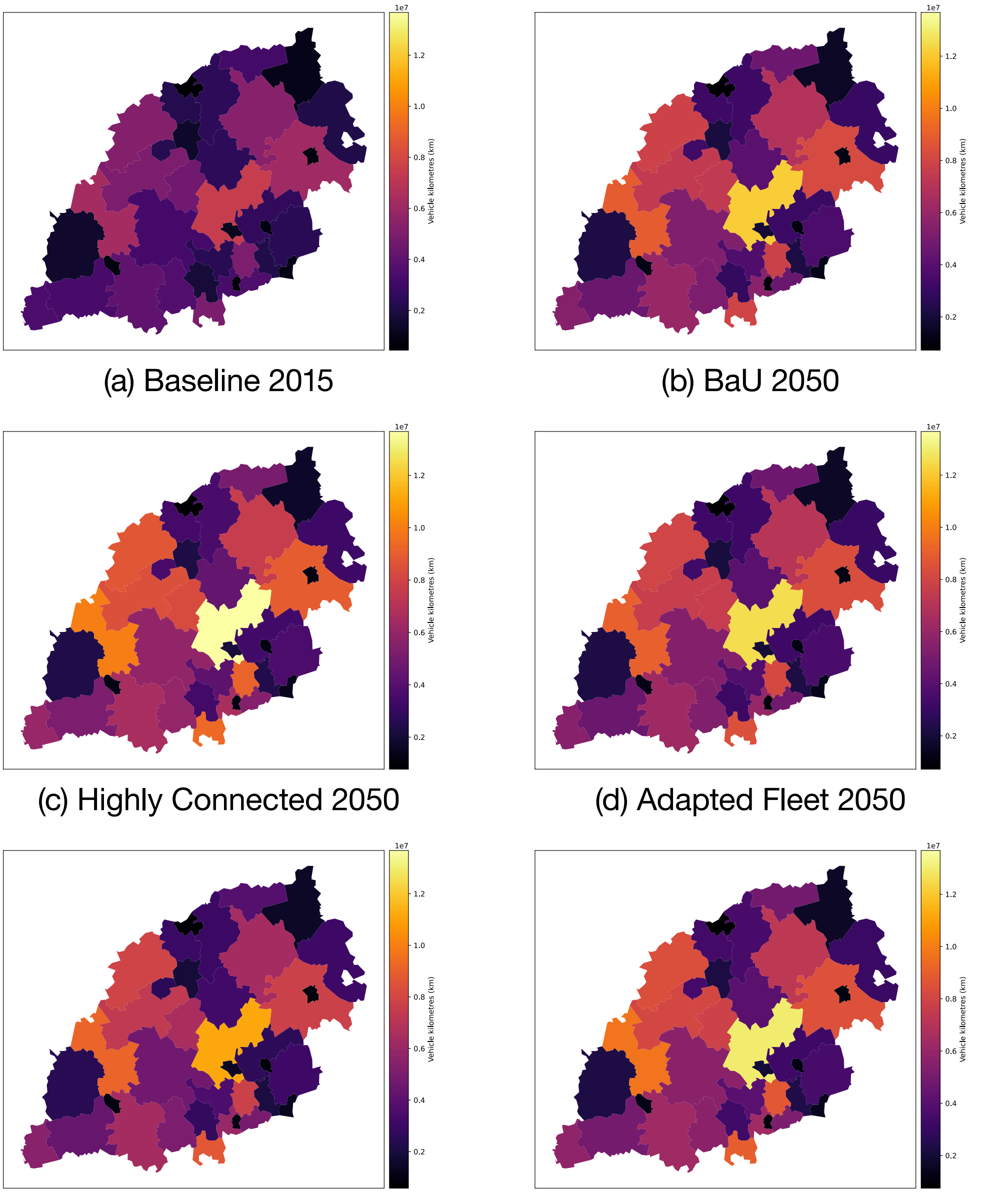


Figure 6 shows a steady increase in vehicle kilometres travelled for BaU, with no specific interventions introduced to change travel demand as population increases. The most effective measure seems to be for Behaviour Shift (policy-led), in which a charging regime is introduced between 2020 and 2040 in major urban areas, which deters travel demand somewhat compared to the other Pathways (see Figure 7(e) for an example of how this pathway is limiting vehicle use in urban centres), although the 10 years after 2040 shows significant growth for both BSp and BSr, when interventions remain at 2040 levels, but population change continues to affect demand at a higher rate than for BaU. It is unclear why this should be the result, and there is an underlying increase in vehicle kilometres per person which may be a constraint of the model, and merits further investigation. Nevertheless, the patterns to 2040 seem to reflect our expectations.

The reduction in car trips for HC can be seen up to 2040, as trip rates are reduced by 10%. However, the effect of this intervention is eroded as more autonomous vehicles are introduced to the fleet, and average road capacity increases. Freight movements for the Highly Connected Pathway are also higher, as LGV trips increase.

Figure 7: Vehicle kilometres for each area within EEH.



(a) Baseline 2015

(b) BaU 2050

(c) Highly Connected 2050

(d) Adapted Fleet 2050

(e) Behaviour Shift (Policy-led) 2050

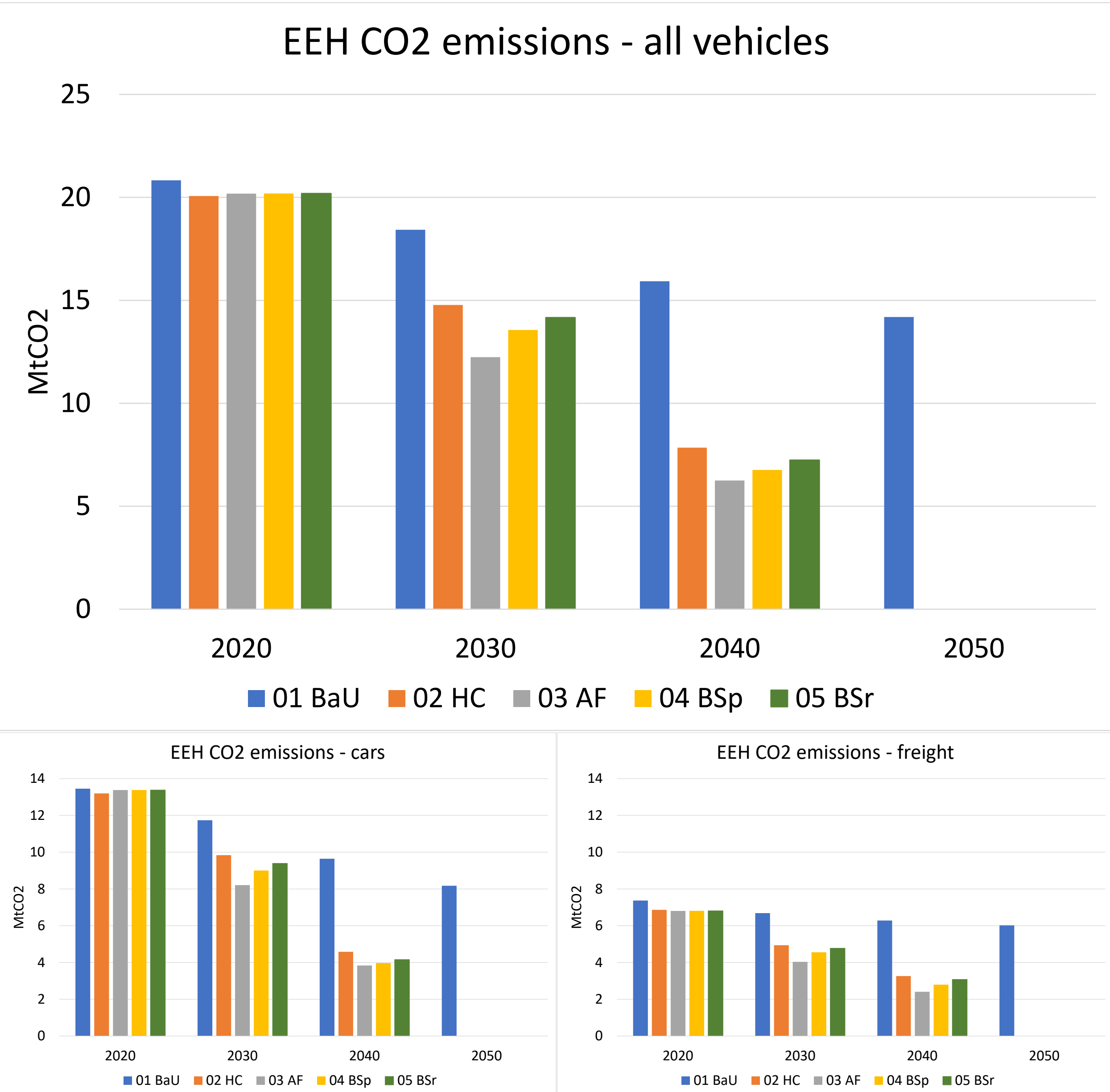
(f) Behaviour Shift (Results-led) 2050

6.2 CO_2 emissions.

The total CO_2 emissions[23] for the region are shown in Figure 8. The rate of decline is linked with the assumed levels of electric, hybrid and hydrogen fuel cell powered vehicles in the fleet, as well as fuel efficiencies, and as we assume that all vehicles in non-BaU Pathways are zero emission by 2050, there are no emissions in 2050 for these Pathways. Note that there is a steady reduction in CO_2 for BaU as vehicles become more fuel efficient and more electric vehicles enter the fleet.

The differences between the other Pathways are generally related to vehicle kilometres, although emissions drop off more rapidly for the Adapted Fleet Pathway, in which fuel efficiencies are improved more quickly, and there is a slightly more rapid conversion to zero-emitting vehicles.

Figure 8: CO_2 emissions in EEH by Pathway and year, cars, freight and combined.



The levels of CO_2 emissions in 2040 are at around 30-40% of 2020 levels, so there is still much

23 Note: in this section, we are referring specifically to tailpipe emissions.

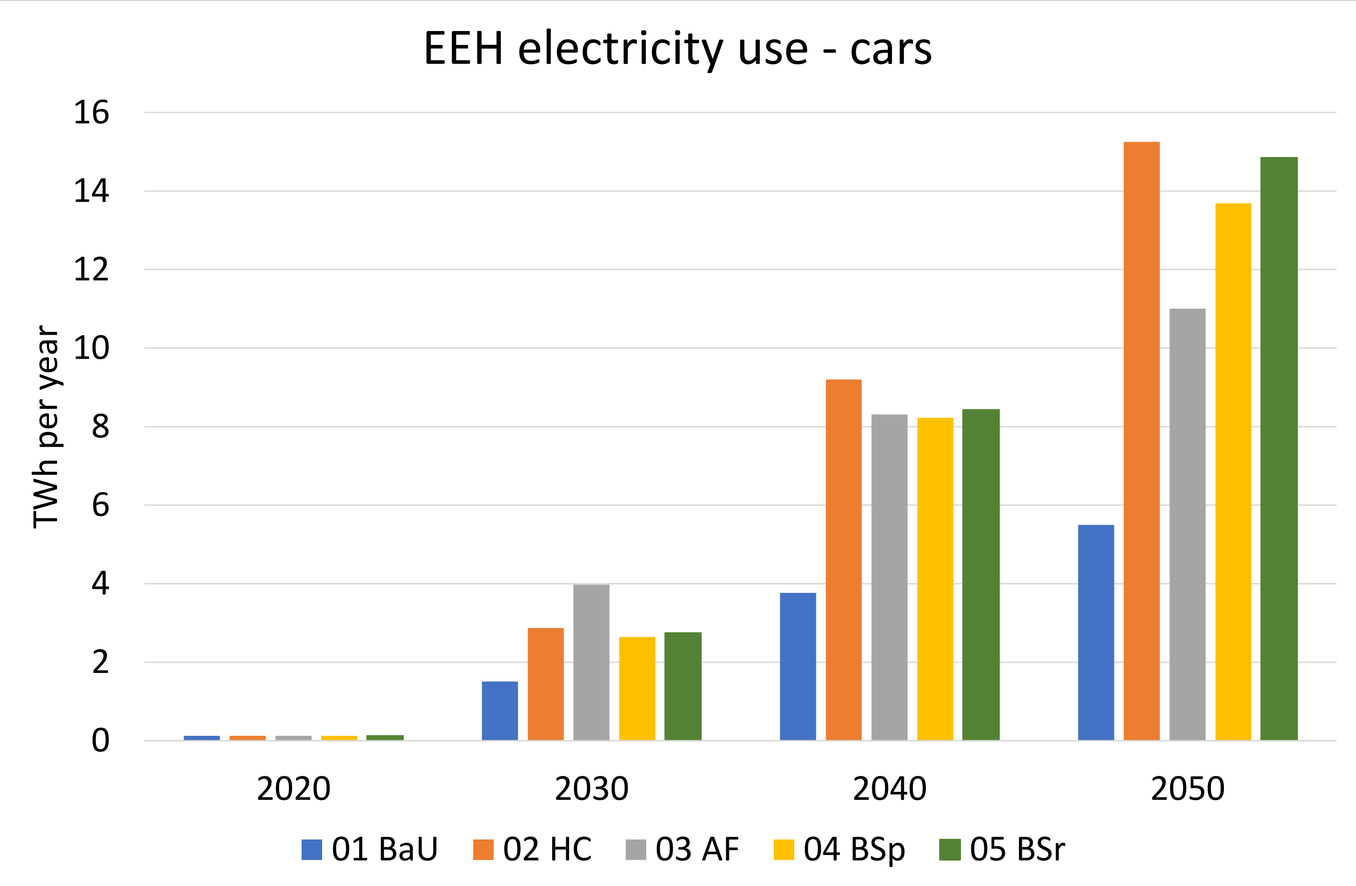
to achieve in the following decade as the fleet transforms to zero-emission vehicles.

6.3 Electricity use.

The projected electricity use for cars travelling within EEH for each study year is shown in Figure 9. As the vehicle fleet relies more on electricity for power, the requirements from the energy system increases accordingly, up to around 15 TWh per year for car transport in 2050 for HC and BSr Pathways. The amount of electricity used for domestic purposes in the EEH region in 2017 was 8.7 TWh[24], so nearly doubling the electricity use by powering vehicles at home will put considerable strain on the energy generation and transmission networks.

The trajectory is different for Adapted Fleet as the fleet is made up of more electric vehicles in 2030, but the impact of better fuel efficiencies and alternative zero-emitting non-electric vehicles (powered by hydrogen fuel cells) reduce the electricity requirements compared with the other Pathways.

Figure 9: Electricity demand for cars in EEH by Pathway and year.

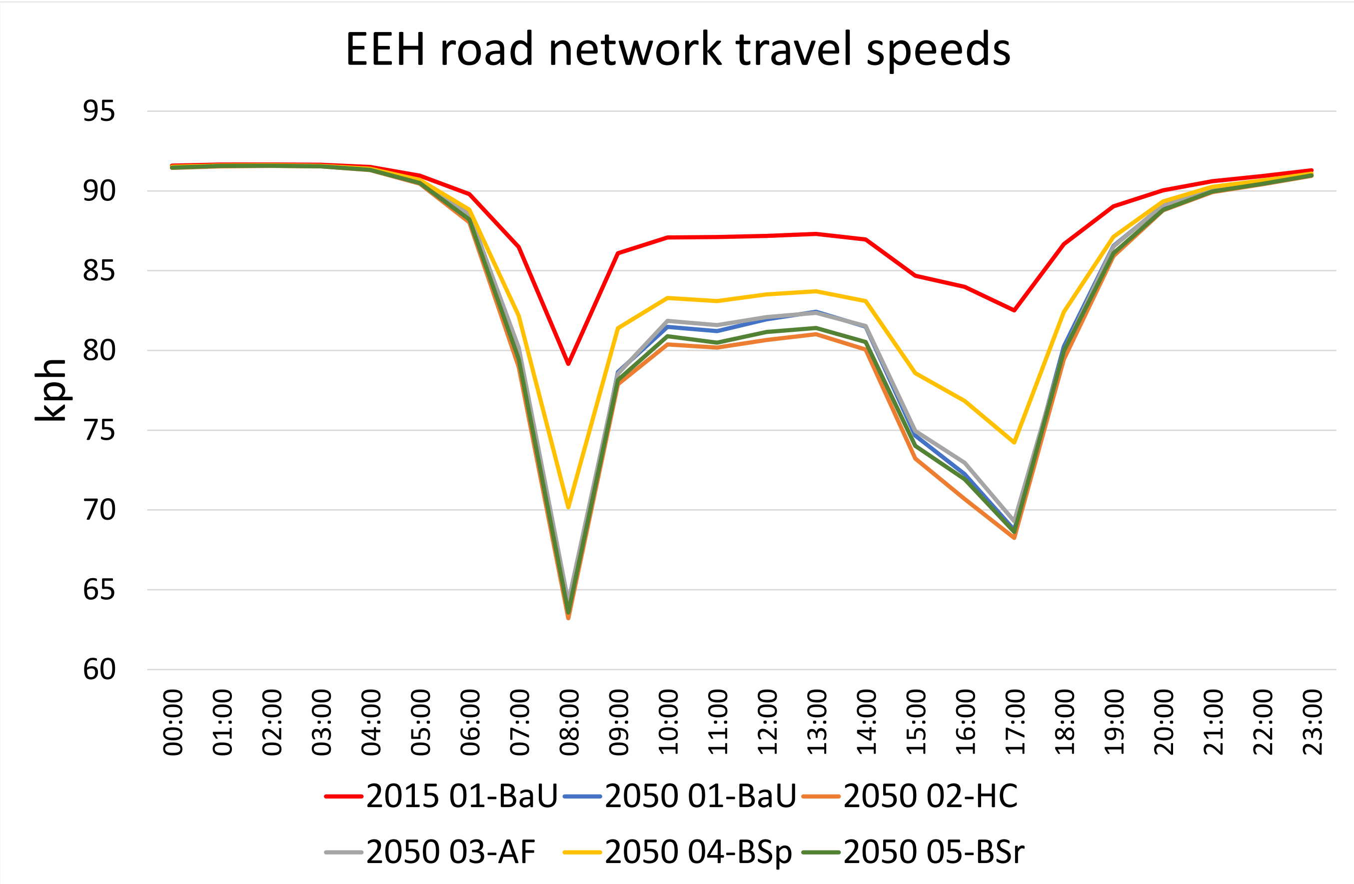


24 BEIS (2019) Sub-national total final energy consumption in the UK 2005-2017 database.

6.4 Congestion.

The transport model is able to produce average hourly estimates of link travel times and speeds, which can be compared with free-flowing traffic to give a representation of the levels of congestion within the network. Figure 10 shows the daily profile of average speeds in the EEH road network.

Figure 10: Average traffic speeds in the EEH road network, by Pathway.

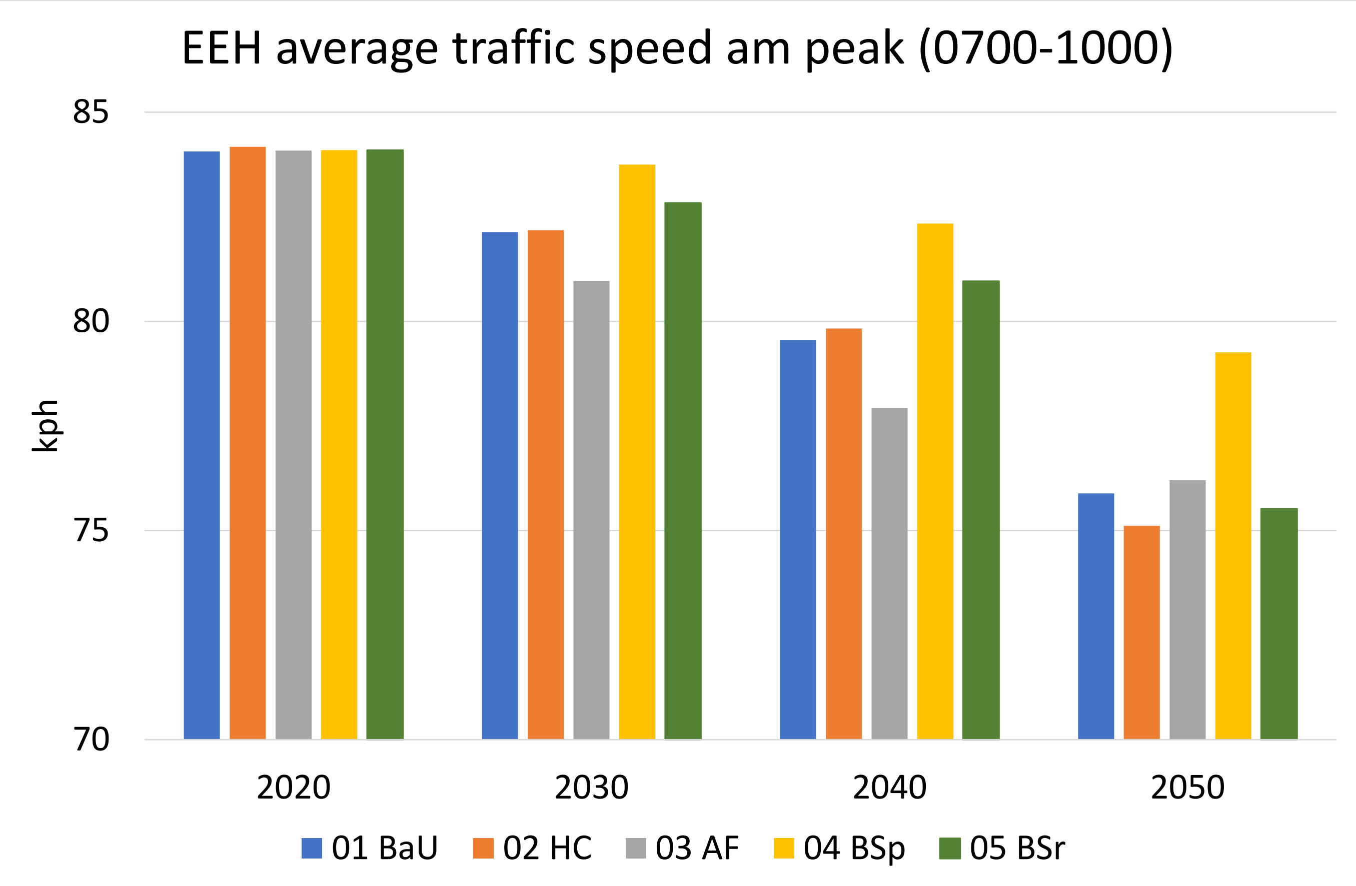


Compared with the 2015 baseline, the increased levels of traffic result in a generally slower network for all Pathways in 2050, with the morning peak average speed reduced to around 63 kph compared to around 80 kph in 2015. The effect of fewer vehicle kilometres in the Behaviour Shift (policy-led) Pathway can be seen, since the average speeds are slightly higher in 2050 compared with the other Pathways with higher traffic flows.

In relation to HC scenario, our assumptions regarding autonomous vehicles effectively provide higher road capacities, so more vehicles can use the same road network, resulting in higher flows and reductions in traffic speeds.

Comparing how the average speed profiles change over time, Figure 11 shows how BSp is more effective at keeping traffic flowing more freely in the morning peak, but still much more slowly than in 2015.

Figure 11: Average network speeds in morning peak by year for each Pathway.

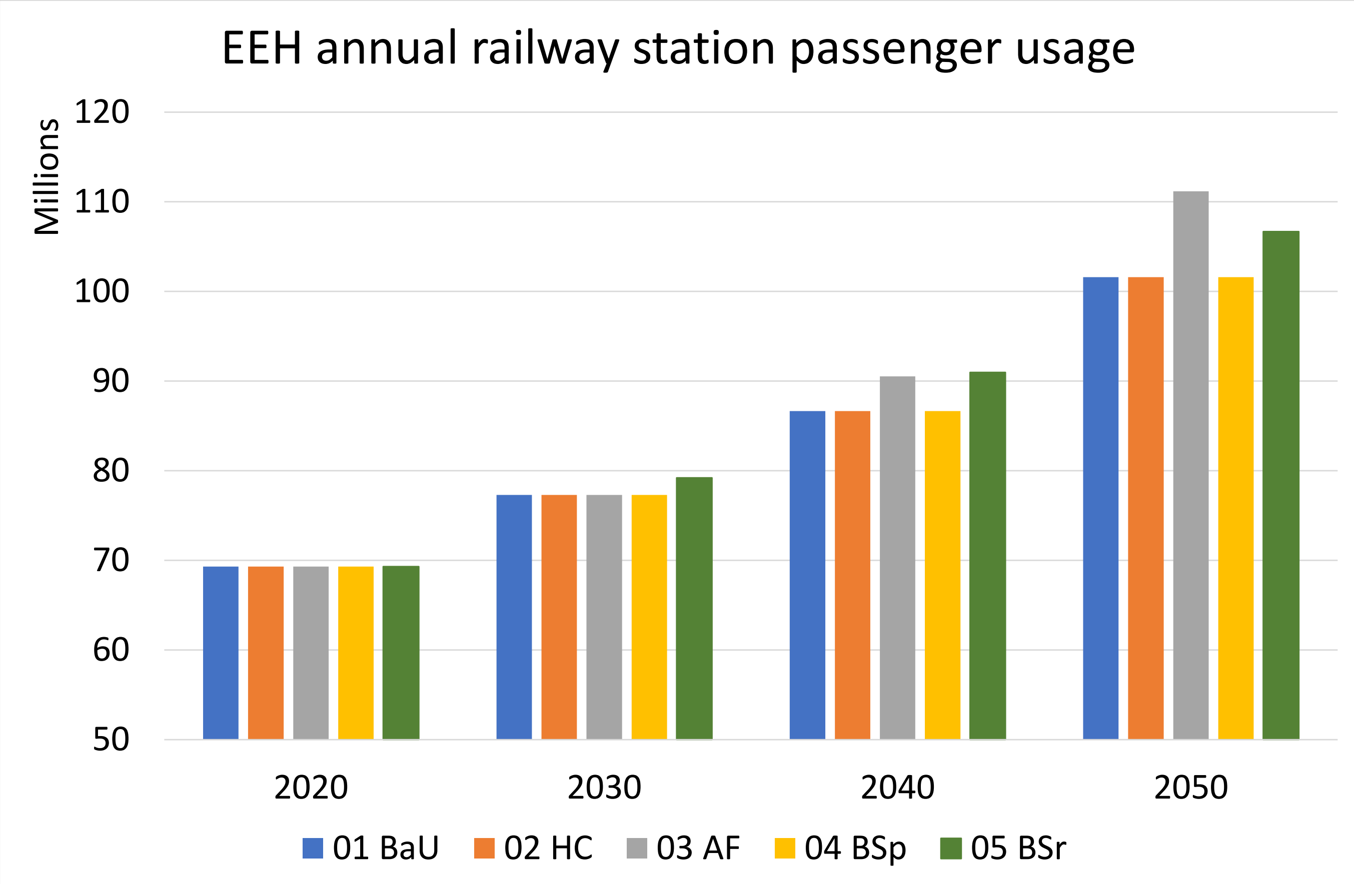


6.5 Rail.

In addition to the road network, the model is capable of modelling rail station usage over time. Note that the rail model does not interact with the road model, so this only represents the inputs to the model (-50% GJT for AF, +5% rail trips for BSr), rather than any representation of modal shift.

For the railway to achieve decarbonisation by 2050, full electrification (or alternative carbon-free power sources such as hydrogen) would need to be completed.

Figure 12: Annual estimate of railway station passenger usage in the EEH region, by year.



7. Summary and conclusion.

This report has provided details of different pathways to achieve the decarbonisation of transport in England's Economic Heartland. Given the current projected change in housing development across the region, and associated assumptions beyond 2030, we have assessed the impacts of future options regarding vehicle fuel types and efficiencies, levels of electric and autonomous vehicles, and the introduction of an urban-based road pricing scheme to promote behaviour change.

We have considered distinct Pathways to achieve decarbonisation – Highly Connected, reliant on digital communication technologies to change the way transport networks are used; Adapted Fleet, in which wide-ranging modernisation alters the natures of the vehicles using the transport network; and Behaviour Shift, in which pricing and educational measures are used to promote modal shift and reduce motorised trips. There are inevitably overlaps between these Pathways. The impact of more sophisticated interactions between vehicles, transport network, homes and businesses is likely to be a strong driver of future change, highlighted in both Behaviour Shift (policy-led) and Highly Connected Pathways.

For each Pathway (except BaU) we have assumed that the fleet comprises 100% zero-emission vehicles by 2050. Future investments, government policy and social attitudes will have to change and adapt considerably in order to reach this challenging target. A fleet comprising mostly electric vehicles will reduce the levels of emissions on the roads and rail, but will require significantly more electricity over time, which will put added pressure on energy supplies.

The measures and interventions contributing to each Pathway change travel demand. Road pricing helps to reduce demand in the areas where it is introduced, but our assumptions regarding autonomous vehicles effectively provide higher road capacities, so more vehicles can use the same road network, resulting in higher flows. Population growth adds continuing pressure to the transport network, and levels of congestion are expected to increase as population grows.

Rail use is expected to increase with population, and effective measures to promote sustainable travel are likely to increase rail's modal share in the longer term. However, decarbonisation of the rail system relies on a zero-carbon drive system (either through electrification or alternative carbon-free power sources). Lines that are currently reliant on fossil fuels will have to adapt to a carbon-free future.

This report has shown that delivering a zero-carbon transport system by 2050 is a challenging target. Measures to change travel behaviour, through increased costs or promoting of sustainable transport modes could help reduce the overall demand on the transport network, but it will require significant effort through governance, legislation and public will to effect such large scale changes.

This study has been mostly undertaken while the UK has been under lockdown in response to the COVID-19 pandemic. These months have shown that lifestyles and behaviours can change rapidly, but the long-term impact of such change is uncertain. To meet the challenging goals of decarbonising transport by 2050 or earlier, it seems likely that an approach involving elements of all the Pathways assessed in this study is likely to be the most successful path in the longer term.

Appendix A: The NISMODv2 Transport Model.

NISMOD v2 Transport Model[25] is a national-scale (Great Britain) model of the road and rail network, developed to support policy making regarding future infrastructure. It forecasts the impact of various factors that influence transport demand, trip generation and utilisation of the road and rail networks. For a given scenario, the model predicts a range of metrics including travel times, energy use, emissions and capacity utilisation

A1 Road transport model.

The NISMOD v2 Transport Model predicts vehicle demand for passenger and freight vehicles, and stochastically simulates road traffic on all major UK roads including A-roads and motorways. The number of lanes on each road segment has been estimated by map-matching AADF count point locations to the OpenRoads major road network. This has allowed a distinction between single and dual carriageway A-roads, which are then assumed to have 1 and 2 lanes per direction, respectively.

It is currently the only national-scale road traffic model capable of routing-based network assignment and provisioning a national-scale origin-destination matrix (on TEMPRo & LAD spatial zoning levels), while achieving a respectable match with AADF traffic counts, total vehicle kilometres, expected number of car trips, and the observed trip length distribution from the National Travel Survey. The freight model has been modelled after the DfT's 2006 Base-Year Freight Matrices model, which includes traffic flows for freight vehicles (vans, rigid HGVs, and articulated HGVs) between local authority districts (LADs), sea ports, selected airports, and major distribution centres. The accuracy of the freight model is mostly limited by the spatial zoning system (LAD).

Demand prediction for the transport model is given by an elasticity-based model that can predict future vehicle flows from exogenous (scenario-based) changes in population and GVA, and endogenously calculated changes in inter-zonal travel time and travel cost (but also dependent on exogenous interventions such as new road development and congestion charging policies).

Congested travel times on individual road links have been modelled separately for each hour of the day, using the speed-flow curves estimated on English roads (DfT's 2005 FORGE model), the overcapacity formula from WebTAG, and the passenger car unit (PCU) concept to capture different vehicle sizes.

The network assignment exists in two versions and has been implemented using state-of-the-art routing algorithms. The routing version uses an A* heuristic search algorithm to find the fastest path between two locations using congested link travel times, while the route-choice version uses an advanced discrete-choice model (path-size logit) to choose the optimal path based on distance, travel time, travel cost (fuel and road tolls), and the number of intersections.

25 Lovric, M. et al. (2019). 'NISMOD Transport v2.2.1' Available online: https://github.com/nismod/transport doi: 10.5281/zenodo.3583128.

The route-choice version of the network assignment uses a pre-generated route set, which consists of more than 90 million different route options, enabling the national-scale assignment to run within minutes, despite each individual vehicle trip being simulated separately (including time of day choice, engine type choice, route choice).

The model can assess different scenarios of fuel efficiency and engine type market share (i.e. internal combustion engines on petrol, diesel, LPG, hydrogen or CNG; hybrid EVs on petrol or diesel; plug-in hybrid EVs on petrol or diesel; fuel cell EVs on hydrogen, and battery EV). This scenario analysis can be used to test policies such as the fossil fuel phase-out.

Electricity and fuel consumption are calculated using the four-parameter formula from WebTAG. Behavioural assumptions are made for plug-in hybrid EVs (electricity on urban, fuel on rural road links).

Interventions such as new road development, road expansion with new lanes, and congestion charging zones can be dynamically implemented in each simulated year.

The model can output various metrics at the road link level (e.g. road capacity utilisation, peak hour travel times), zonal level (e.g. vehicle kilometres, EV electricity consumption), inter-zonal level (e.g. predicted vehicle flows, average travel times, average travel costs) and national level (e.g. total CO_2 emissions, total energy consumptions). The outputs are in csv and shapefile format, allowing them to be visualised with a software of choice.

A2 Rail model.

The NISMOD v2 Transport Model also includes a national-scale rail model for predicting future station usage, using base year data for 3054 stations covering National Rail, London Underground, Docklands Light Railway, London Trams (previously Croydon Tramlink), Manchester Metrolink, and Tyne & Wear (Newcastle) Metro.

The demand model is elasticity-based, and can predict station usage (entry + exit) from exogenous inputs including: population, GVA, rail fare index, generalised journey time (GJT) index and car trip costs (which can be provided as an input or calculated from the outputs of the NISMOD road model). Demand elasticities of rail fares and GJT vary between different areas of the country (London Travelcard, South-East, PTE, other).

The model capabilities include an assessment of building new rail stations in future years.

Appendix B: Data tables.

Table 7: Road vehicle fuel mix for EEH Pathway 1 BaU.

Vehicle type	Year	Petrol	Diesel	Petrol HEV	Diesel HEV	Petrol PHEV	Diesel PHEV	BEV	H2
Cars	2015	48.5	49.3	1.2	0.8	0.08	0.02	0.1	0
	2020	46.3	48.5	2.4	1.6	0.48	0.12	0.6	0
	2030	41.6	32.1	7.2	4.8	5.6	1.4	7.3	0
	2040	32.6	21.7	7.8	5.2	9.6	2.4	20.7	0
	2050	23.6	15.4	9.0	6.0	12.0	3.0	31.0	0
LGVs	2015	2.2	97.6	0	0.1	0	0	0.1	0
	2020	1.3	97.2	0	1.3	0.08	0.02	0.1	0
	2030	0.8	85.3	0	8.0	2.32	0.58	3.0	0
	2040	0.7	71.6	0	12.0	6.16	1.54	8.0	0
	2050	0.6	59.4	0	15.0	8.0	2.0	15.0	0
HGVs	2015	0	99	0	1	0	0	0	0
	2020	0	96	0	4	0	0	0	0
	2030	0	88	0	11	0	0	1	0
	2040	0	86	0	13	0	0	1	0
	2050	0	83	0	16	0	0	1	0
PSVs	2015	0	95	0	5	0	0	0	0
	2020	0	88	0	12	0	0	0	0
	2030	0	80	0	19	0	0	1	0
	2040	0	78	0	20	0	0	2	0
	2050	0	75	0	21	0	0	4	0
Motorcycles	2015	99	0	1	0	0	0	0	0
	2020	98	0	2	0	0	0	0	0
	2030	93	0	6	0	0	0	1	0
	2040	89	0	10	0	0	0	1	0
	2050	85	0	14	0	0	0	1	0

Table 8: Road vehicle fuel mix for EEH Pathway 2 Highly Connected.

Vehicle type	Year	Petrol	Diesel	Petrol HEV	Diesel HEV	Petrol PHEV	Diesel PHEV	BEV	H2
Cars	2015	48.5	49.3	1.2	0.8	0	0	0.2	0
	2020	43	49	2	4.8	0.48	0.12	0.6	0
	2030	25	27	10	10	11.2	2.8	14	0
	2040	4	4	7	5	24	6	50	0
	2050	0	0	0	0	0	0	100	0
LGVs	2015	2.2	97.6	0	0.1	0	0	0.1	0
	2020	1.3	97.2	0	1.3	0.08	0.02	0.1	0
	2030	0.8	71.2	0	8	8	2	10	0
	2040	0.7	37.3	0	12	16	4	30	0
	2050	0	0	0	0	0	0	100	0
HGVs	2015	0	98	0	2	0	0	0	0
	2020	0	80	0	15	0	0	5	0
	2030	0	40	0	40	0	0	20	0
	2040	0	20	0	30	0	0	40	10
	2050	0	0	0	0	0	0	75	25
PSVs	2015	0	92	0	7	0	0	1	0
	2020	0	70	0	20	5	0	5	0
	2030	0	40	0	25	15	0	20	0
	2040	0	20	0	20	15	0	35	10
	2050	0	0	0	0	0	0	75	25
Motorcycles	2015	98	0	0	0	0	0	2	0
	2020	75	0	0	0	0	0	25	0
	2030	25	0	0	0	0	0	75	0
	2040	10	0	0	0	0	0	85	5
	2050	0	0	0	0	0	0	80	20

Table 9: Road vehicle fuel mix for EEH Pathway 3 Adapted Fleet.

Vehicle type	Year	Petrol	Diesel	Petrol HEV	Diesel HEV	Petrol PHEV	Diesel PHEV	BEV	H2
Cars	2015	48.5	49.3	1.2	0.8	0	0	0.2	0
	2020	43	49	2	4.8	0.48	0.12	0.6	0
	2030	20	20	10	10	15.2	3.8	21	0
	2040	4	4	7	5	18.4	4.6	50	7
	2050	0	0	0	0	0	0	75	25
LGVs	2015	2.2	97.6	0	0.1	0	0	0.1	0
	2020	1.3	97.2	0	1.3	0.08	0.02	0.1	0
	2030	0.8	61.2	0	8	12	3	15	0
	2040	0.7	27.3	0	12	16	4	40	0
	2050	0	0	0	0	0	0	85	15
HGVs	2015	0	98	0	2	0	0	0	0
	2020	0	80	0	15	0	0	5	0
	2030	0	40	0	40	0	0	20	0
	2040	0	20	0	30	0	0	40	10
	2050	0	0	0	0	0	0	75	25
PSVs	2015	0	92	0	7	0	0	1	0
	2020	0	70	0	20	5	0	5	0
	2030	0	40	0	25	15	0	20	0
	2040	0	20	0	20	15	0	35	10
	2050	0	0	0	0	0	0	75	25
Motorcycles	2015	98	0	0	0	0	0	2	0
	2020	75	0	0	0	0	0	25	0
	2030	25	0	0	0	0	0	75	0
	2040	10	0	0	0	0	0	85	5
	2050	0	0	0	0	0	0	80	20

Table 10: GVA-based elasticities for Highly Connected.

Road (not freight)		2020	2030	2040	2050
GVA	elasticities.csv	0.6	0.5	0.4	0.3
Rail					
GVA LT	elasticitiesRail.csv	0.55	0.46	0.37	0.28
GVA SE	elasticitiesRail.csv	0.55	0.46	0.37	0.28
GVA PTE	elasticitiesRail.csv	0.55	0.46	0.37	0.28
GVA OTHER	elasticitiesRail.csv	0.55	0.46	0.37	0.28

Table 11: Changes in road vehicle fuel consumption 2010-2050 (from Brand, et al. 2019).

Year			2015	2020	2025	2030	2035	2040	2045	2050
Motorcycles	Petrol		100.0%	100%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	Electric		100.0%	85.8%	85.8%	85.8%	85.8%	85.8%	85.8%	85.8%
	Hydrogen fuel cell		100.0%	93.4%	86.8%	80.2%	80.2%	80.2%	80.2%	80.2%
Small cars	Petrol		100.0%	91.8%	85.2%	78.9%	73.2%	67.9%	62.9%	58.4%
	Petrol hybrid		100.0%	91.9%	85.3%	79.0%	73.3%	68.0%	62.9%	58.5%
	Petrol PHEV	Petrol	100.0%	93.1%	86.2%	80.2%	74.1%	69.0%	63.8%	60.1%
		Electric	100.0%	91.4%	84.7%	78.6%	72.8%	67.5%	62.6%	58.0%
	Diesel		100.0%	91.9%	85.3%	79.0%	73.3%	68.0%	62.9%	58.5%
	Battery EV		100.0%	91.4%	84.7%	78.6%	72.8%	67.5%	62.6%	58.0%
	LPG		100.0%	91.4%	84.7%	78.6%	72.9%	67.5%	62.6%	58.0%
	CNG		100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	Hydrogen fuel cell					100.0%	77.6%	77.6%	77.6%	77.6%

Year			2015	2020	2025	2030	2035	2040	2045	2050
Medium car	Petrol		100.0%	91.9%	85.3%	79.0%	73.3%	67.9%	63.0%	58.4%
	Petrol hybrid		100.0%	91.7%	85.2%	79.1%	73.1%	67.8%	62.8%	58.3%
	Petrol PHEV	Petrol	100.0%	93.3%	86.5%	80.3%	74.3%	69.1%	64.1%	60.1%
		Electric	100.0%	91.4%	84.7%	78.6%	72.8%	67.5%	62.6%	58.0%
	Biodiesel		100.0%	91.8%	85.2%	78.9%	73.3%	67.9%	63.0%	58.4%
	Bioethanol		100.0%	91.8%	85.2%	78.9%	73.1%	68.0%	62.8%	58.3%
	Diesel PHEV	Diesel	100.0%	93.4%	86.7%	80.3%	74.6%	69.1%	64.2%	60.1%
		Electric	100.0%	91.4%	84.7%	78.6%	72.8%	67.5%	62.6%	58.0%
	Biodiesel		100.0%	79.8%	79.8%	59.3%	59.3%	59.3%	59.3%	59.3%
	Bioethanol		100.0%	85.0%	78.8%	73.1%	67.8%	62.8%	58.3%	54.0%
	Battery EV		100.0%	91.4%	84.7%	78.6%	72.8%	67.5%	62.6%	58.0%
	LPG		100.0%	91.4%	84.8%	78.5%	72.8%	67.6%	62.6%	58.0%
	CNG		100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	Hydrogen fuel cell			100.0%	88.8%	77.6%	77.6%	77.6%	77.6%	77.6%

Year			2015	2020	2025	2030	2035	2040	2045	2050
Large car	Petrol		100.0%	91.8%	85.2%	79.0%	73.2%	67.9%	62.9%	58.4%
	Petrol hybrid		100.0%	91.8%	85.3%	79.0%	73.2%	67.9%	63.0%	58.3%
	Petrol PHEV	Petrol	100.0%	93.4%	86.6%	80.4%	74.3%	68.9%	63.9%	60.1%
		Electric	100.0%	93.3%	86.7%	80.0%	73.3%	66.7%	60.0%	53.3%
	Diesel		100.0%	91.9%	85.3%	79.0%	73.3%	67.9%	63.1%	58.5%
	Diesel hybrid		100.0%	91.8%	85.2%	79.1%	73.2%	68.0%	63.1%	58.4%
	Diesel PHEV	Diesel	100.0%	93.4%	86.7%	80.3%	74.6%	69.1%	64.2%	60.1%
		Electric	100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	Biodiesel		100.0%	80.7%	80.7%	59.8%	59.8%	59.8%	59.8%	59.8%
	Bioethanol		100.0%	85.0%	78.9%	73.1%	67.8%	62.9%	58.3%	54.1%
	BEV		100.0%	89.5%	84.2%	78.9%	71.1%	65.8%	63.1%	57.9%
	LPG		100.0%	91.3%	84.6%	78.5%	72.7%	67.4%	62.5%	58.1%
	CNG		100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	Hydrogen IC		100.0%	91.3%	84.7%	78.5%	72.8%	62.6%	62.6%	62.6%
	Hydrogen fuel cell		100.0%	100.0%	100.0%	100.0%	68.4%	68.4%	68.4%	68.4%
PSV	Diesel		100.0%	97.4%	95.0%	92.6%	90.3%	88.1%	85.9%	83.8%
	Diesel hybrid		100.0%	97.4%	95.0%	92.7%	90.4%	88.1%	86.0%	83.8%
	Diesel PHEV	Diesel	100.0%	97.4%	95.0%	92.7%	90.4%	88.1%	85.9%	83.8%
		Electric	100.0%	94.2%	89.5%	85.1%	81.0%	77.0%	73.2%	69.6%
	Biodiesel		100.0%	100.0%	93.1%	93.1%	93.1%	93.1%	93.1%	93.1%
	Bioethanol		100.0%	100.0%	95.1%	95.1%	73.6%	73.6%	73.6%	73.6%
	BEV		100.0%	94.2%	89.5%	85.1%	81.0%	77.0%	73.2%	69.6%
	LPG		100.0%	97.1%	94.7%	92.4%	90.1%	87.9%	85.7%	83.6%
	CNG		100.0%	86.3%	84.1%	82.1%	80.0%	78.0%	76.1%	74.2%
	Hydrogen fuel cell		100.0%	100.0%	95.1%	90.4%	86.0%	81.8%	77.8%	77.8%

Year			2015	2020	2025	2030	2035	2040	2045	2050
Coach	Diesel		100.0%	97.3%	95.0%	92.6%	90.3%	88.1%	85.9%	83.8%
	Diesel hybrid		100.0%	97.4%	95.0%	92.7%	90.4%	88.1%	86.0%	83.8%
	Biodiesel		100.0%	100.0%	93.1%	93.1%	93.1%	93.1%	93.1%	93.1%
	BEV		100.0%	94.1%	89.5%	85.1%	81.0%	77.0%	73.2%	69.6%
	LPG		100.0%	97.1%	94.7%	92.4%	90.1%	87.9%	85.7%	83.6%
	CNG		100.0%	97.1%	94.7%	92.4%	90.1%	87.8%	85.7%	83.6%
	Hydrogen fuel cell		100.0%	100.0%	100.0%	95.1%	90.4%	86.0%	81.8%	81.8%
LGV	Petrol		100.0%	92.1%	85.5%	79.3%	73.5%	68.1%	63.2%	58.6%
	Diesel		100.0%	92.1%	85.5%	79.3%	73.5%	68.1%	63.2%	58.6%
	Diesel hybrid		100.0%	92.2%	85.6%	79.4%	73.6%	68.2%	63.2%	58.7%
	Diesel PHEV	Diesel	100.0%	93.9%	87.1%	80.7%	74.8%	69.5%	64.3%	60.7%
		Electric	100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	Biodiesel		100.0%	79.2%	73.5%	68.1%	63.2%	58.6%	54.4%	50.3%
	Bioethanol		100.0%	72.4%	67.2%	62.3%	57.7%	53.5%	49.7%	46.1%
	BEV		100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	LPG		100.0%	91.3%	84.7%	78.5%	72.8%	67.5%	62.6%	58.0%
	CNG		100.0%	91.3%	84.6%	78.5%	72.8%	67.5%	62.6%	58.0%
	Hydrogen fuel cell		100.0%	100.0%	100.0%	85.9%	73.7%	63.3%	54.4%	46.7%
Medium truck	Diesel		100.0%	92.1%	85.4%	79.2%	73.4%	68.1%	63.1%	58.6%
	Diesel hybrid		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	BEV		100.0%	100.0%	100.0%	86.0%	86.0%	73.9%	73.9%	73.9%
	LPG		100.0%	82.6%	76.6%	71.0%	65.9%	61.1%	56.6%	52.5%
	CNG		100.0%	82.6%	76.6%	71.0%	65.8%	61.1%	56.6%	52.5%
	Hydrogen fuel cell				100.0%	77.3%	66.4%	57.0%	49.0%	42.0%
	Liquid hydrogen		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Year		2015	2020	2025	2030	2035	2040	2045	2050
HGV	Diesel	100.0%	92.1%	85.5%	79.2%	73.5%	68.1%	63.2%	58.6%
	Diesel hybrid	100.0%	85.2%	85.2%	85.2%	85.2%	85.2%	85.2%	85.2%
	LPG	100.0%	82.6%	76.6%	71.0%	65.9%	61.1%	56.6%	52.5%
	CNG	100.0%	82.6%	76.6%	71.0%	65.8%	61.1%	56.6%	52.5%
	Hydrogen fuel cell			100.0%	77.3%	66.4%	57.0%	49.0%	42.0%
	Liquid hydrogen	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%