Cumulative emissions reduction in the UK passenger car sector through near-term interventions in technology and use

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DAN CALVERLEY

SCHOOL OF MECHANICAL, AEROSPACE AND CIVIL ENGINEERING

Tyndall Centre for Climate Change Research

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PRINTING INSTRUCTIONS

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ABSTRACT

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Dan Calverley
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Responsible for one in eight tonnes of national CO_2 emissions, the passenger car sector is pivotal to delivering on UK climate change commitments to avoiding warming of more than 2°C. This thesis provides a clear and *quantitative framing* of emissions reduction at the sectoral level, by disaggregating global cumulative emissions budgets and pathways associated with a range of probabilities of exceeding 2°C. The relatively low level of abatement currently planned for the UK car sector, it is argued, needs to be significantly increased for the following reasons: (i) a scientific basis in *cumulative emissions* for sectoral mitigation makes carbon budgets, rather than end point targets (e.g. 2050), of the first importance; (ii) the currently high probability (63%) of exceeding 2°C underpinning the current UK carbon budgets is inconsistent with the UK government's commitment to avoiding 'dangerous climate change'; (iii) short-term emissions growth in industrialising countries considerably reduces remaining emissions space for industrialised countries; (iv) very limited scope exists for *any* large sector to cut emissions by less than the national mean rate of decarbonisation at higher rates of mitigation (around 10% p.a. by the 2020s). The consequences for emissions space in other sectors if international aviation and shipping mitigate less than the mean are quantified.

For UK car sector emissions to remain consistent with a *low probability* of exceeding 2°C while observing these limitations, this analysis finds that planned sectoral mitigation over the *coming decade* needs to be *increased* fourfold. Means to address this expected abatement shortfall using *readily available technology* are investigated using a fleet emissions model to compare the effect on cumulative emissions of changes in a range of fleet parameters (including mean new car bulk emissions factors, vehicle age-proportionate annual distance travelled, and rates of fleet growth and turnover). Pushing existing car technology to the limit of expected short term efficiency gains is found to be insufficient to deliver a pathway with better than 56% probability of exceeding 2°C. Without reduction in *aggregate demand* for vehicle kilometres in the short term, lower probabilities of 2°C are placed beyond reach. The possibility of rapid step changes in levels of per capita car use is explored in qualitative interviews using narrative storyline scenarios. A range of coercive and voluntary interventions is considered in relation to their potential to overcome the structural and behavioural constraints to rapid transformation of personal travel.

DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

COPYRIGHT STATEMENT

DEDICATION

Particular thanks first and foremost to my PhD supervisors, Kevin Anderson and Alice Bows, without whose encouragement and support this PhD would never have been started, let alone finished. This work, I hope, does at least some small justice to their insight and dedication to systems-level thinking, and their refusal to accept easy answers.

Very grateful thanks to the University of Manchester Alumni Fund for sponsoring this PhD, and for supporting and promoting my research throughout. This work would also not have been possible without the generosity of all those who participated in interviews.

Sincere thanks to all members of Tyndall-Manchester, past and present, who have been there with tea and talk over the last four years. Special thanks to Michael Traut, whose relentless good humour and badinage livened up many a dark day in the office, and to Carly McLachlan for feedback on early draughts.

I owe an enormous debt of gratitude to my mum, Jean Calverley. Words on a page are a poor substitute for those spoken face to face, but the following few thousand are a tribute to her for keeping me on track and teaching me what's important in life.

Finally, this PhD is dedicated to Hannah Austin, for whose patience and support (moral and practical) I am forever grateful. I am truly indebted to her for never appearing less than fascinated by the vagaries of vehicle stock replacement models and endless 'epistemological crises'. I promise it will all have been worth it.

GLOSSARY of all chapters

Term	Definition
Annex 1	Countries signatory to Annex 1 of the UNFCCC – industrialised countries and countries in transition
AFV	Alternative-fuel vehicle – i.e. powered by an energy source other than petroleum
AVO	'Average vehicle occupancy' – a measure of the number of persons (driver + passengers) conveyed, also know as the vehicle 'occupancy rate', 'occupation', 'load factor', or 'utilisation'. Primarily used in the literature to refer to mean occupancy per trip (or discrete journey), but also observed to refer to mean occupancy of 'all cars on the road'. For avoidance of doubt, the terms AVO_{trip} and AVO_{VKM} are preferred here.
AVO_{trip}	Mean vehicle occupancy per discrete trip. Used to express different occupancy rates for different trip purposes, e.g. commuting, shopping etc.
AVO_{VKM}	Mean occupancy per vehicle kilometre – also referred to as 'bulk occupancy'. Used to express mean occupancy rate for all vehicle kilometres driven on UK roads in a given year, regardless of trip purpose.
BEV	Battery electric vehicle
CBA	Cost benefit analysis
CCC	Committee on Climate Change
CEU	Council of the European Union
CO_2e	Carbon dioxide equivalent – common measure of greenhouse gases in terms of the amount of carbon dioxide that would produce the same global warming potential
DAI	‘Dangerous anthropogenic interference' (with the climate)
DECC	Department of Energy and Climate Change
Defra	Department for the Environment, Food and Rural Affairs
drivetrain	Transmission and related components of a car that transfer the power output of the engine into mechanical propulsion
DfT	Department for Transport
DICI	Direct injection compression ignition (diesel ICEs)
DISI	Direct injection spark ignition (modern petrol ICEs)
DRDNI	Department for Regional Development Northern Ireland
DUKES	Digest of UK Energy Statistics
EEA	European Environment Agency
EU ETS	European Union Emissions Trading Scheme
EV	Electric vehicle
FCV	Fuel cell vehicle
gCO_2/J	Grammes of carbon dioxide per joule – a measure of the carbon intensity of vehicle fuel or energy source. Also expressed as gCO_2/MJ – per megajoule (joules x 10^6)
gCO_2/km	Grammes of carbon dioxide per kilometre – a combined measure of vehicle–fuel carbon intensity
GHG	Greenhouse gas
GtC	Gigatonnes of carbon (tonnes x 10^9)
$GtCO_2$	Gigatonnes of carbon dioxide (tonnes x 10^9)

Term	Definition
HEV	Hybrid–electric vehicle
HGV	Heavy goods vehicle
HOVL	High occupancy vehicle lane (sometimes simply HOL)
HOTL	High occupancy toll lane (sometimes simply HOT)
IA&S	International aviation and shipping
ICE	Internal combustion engine
ICEV	Internal combustion engined–vehicle
ICT	Information and communications technology
IPCC	Intergovernmental Panel on Climate Change
IPCC–AR4	The Fourth Assessment Report of the IPCC
IPCC–SAR	The Second Assessment Report of the IPCC
IPCC–TAR	The Third Assessment Report of the IPCC
J/km	Joules per kilometre – a measure of vehicle–fuel- or energy-efficiency
$kgCO_2/kWh$	Kilogrammes of carbon dioxide per kilowatt hour – a measure of carbon intensity of an energy source
kmh	Kilometres per hour
l/100 km	Litres (of fuel consumed) per 100 kilometres
LCA	Lifecycle assessment (also referred to as lifecycle analysis)
LCT	*Low Carbon Transport* – 2009 Department for Transport white paper
LCTP	*Low Carbon Transition Plan* – 2009 government white paper
mpg	Miles per gallon (of fuel)
LGV	Light goods vehicle (commonly known as vans)
LDV	Light duty vehicle – including cars and light vans
mph	Miles per hour
MPT	Motorised private transport – the passenger car sector (see footnote 2, p.16)
MtC	Megatonnes of carbon (tonnes x 10^6)
$MtCO_2$	Megatonnes of carbon dioxide (tonnes x 10^6)
NAEI	National Atmospheric Emissions Inventory
NEDC	New European Driving Cycle
non-Annex 1	Countries not signatory to Annex 1 of the UNFCCC – industrialising countries
non-powertrain	Vehicle components and design aspects which do not form part of the powertrain
NTM	National Transport Model – the Department for Transport's econometric model of future transport end user demand, emissions and congestion
NTS	National Travel Survey (of Great Britain)
PCT	Personal carbon trading
PDF	Probability density function
PHEV	Plug-in hybrid–electric vehicle
PISI	Port injection spark ignition (older petrol ICEs)
PKM	Passenger kilometres
PLG	Private and light goods vehicles – includes cars, vans and taxis
powertrain	The engine and drivetrain of a car taken as a single entity

Term	Definition
ppm	Parts per million
PT	Public transport
RTF	Road Transport Forecasts – Department for Transport's annual forecast of various road transport metrics including total VKM, congestion and emissions.
RTFO	Renewable Transport Fuel Obligations Order 2007
RW	Real-world vehicle emissions, as distinct from TA values
SMMT	Society of Motor Manufacturers and Traders
TA	Type approval (of new vehicles), based on the NEDC
TDM	Travel demand management
TRL	The UK Transport Research Laboratory
TSGB	Transport Statistics Great Britain
TTW	Tank-to-wheels
UKERC	United Kingdom Energy Research Centre
UNFCCC	United National Federation Convention on Climate Change
VED	Vehicle excise duty
VKM	Vehicle kilometres. Often referred to in the literature as vehicle kilometres travelled ('VKT'). Sometimes referred to as car-kilometres for avoidance of doubt.
VKM_{fleet}	Total vehicle kilometres travelled by all cars in the fleet, usually in one year. Also referred to as ‘aggregate demand’, or traffic volume.
VKM_{veh}	Vehicle kilometres travelled by an individual vehicle or category of vehicles, usually in one year. Effectively a measure of annual driving distance per vehicle.
WTW	Well-to-wheels

CHAPTER ONE – INTRODUCTION

1.1 Rationale

The urgent need to reduce greenhouse gas emissions from all sectors is widely recognised, with broad agreement on the imperative of restricting warming to 2°C existing at various political levels[1]: international (Copenhagen Accord, UNFCCC 2009; Cancun Agreements, UNFCCC 2011), European (CEU 2007) and national (Climate Change Act 2008). Transport (including international aviation and shipping) accounts for almost one third of UK CO_2 emissions, with road transport a fifth of total UK CO_2 (CCC 2010a), second only to energy production in emissions from a single sector. Passenger cars form the bulk of emissions from road transport, responsible for one in eight tonnes of UK CO_2 (DECC 2011c). Decarbonising the passenger car sector, therefore, is a prerequisite of meeting national climate change mitigation objectives[2].

1.1.1 UK passenger car sector mitigation – technology and use

All sectors present their own particular problems for deep and rapid emissions cuts. Difficulties for decarbonising the car sector are conventionally portrayed as arising from the historically strong association between growth in motorised private transport and economic prosperity (expressed as increasing GDP, or other similar metric) (Eddington 2006b). Further problems are presented by limited (perceived and real) alternatives to car travel (King *et al* 2009) for many journeys.

Seeking to promote economic growth and support popular aspirations, successive UK governments have arguably accorded ‘special treatment’ to the car sector. Hence the UK has seen several decades of predict-and-provide road-building programmes (Goodwin 1999; Terry 2000), ‘car-friendly’ planning regulations for residential, retail and industrial developments (Banister 1999; Lucas 2004), and the shelving of the fuel duty escalator (Dresner *et al* 2006). Such policies, in combination with (*inter alia*) the high perceived levels of ‘net’ personal convenience and mobility offered by cars[3], have resulted in the private car becoming firmly embedded in UK infrastructure, lifestyles, patterns of employment and leisure (Rayner *et al* 2008; Lucas and Jones 2009).

Passenger car sector emissions may be reduced by one or a combination of the following approaches: (i) substitution of a lower-carbon energy source for petroleum, (ii)

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[1] Adopting 2°C (mean global surface warming above the preindustrial) as the threshold of ‘dangerous climate change’ and mitigating emissions to avoid exceeding it are essentially *political* goals rather than scientific principles. Nonetheless, as the *de facto* central tenet of national and international climate policy, preventing warming of more than 2°C may be regarded as the benchmark of effective mitigation (the validity of the 2°C target itself is explored in detail in Chapter 2).

[2] The passenger car sector is used throughout to stand for UK ‘motorised private transport’ (MPT). Strictly speaking, MPT comprises cars, taxis and two wheelers, although cars dominate energy demand and emissions from this sector: taxis and two wheelers contributing < 1% each, hence are excluded from the analysis in this research. All subsequent references to the car sector are specifically to the UK, unless otherwise stated.

[3] Or at least net benefit offered to car *drivers*. Car travel has achieved dominance *despite* its many ‘inconveniences’, such as the wider negative social and health consequences for individuals, communities and society (Jacobsen *et al* 2009; Douglas *et al* 2011).

hastening vehicle efficiency improvements, (iii) increasing penetration of more efficient vehicles in the fleet, (iv) decline in traffic volumes. Current mitigation policy for the UK car sector strongly emphasises supply side measures which do not challenge established patterns of car use (Anable and Shaw 2007) – primarily through approaches (i) and (ii), and to a lesser extent (iii). However, many promising technology-based measures (e.g. battery electric or hydrogen vehicles) will not reach maturity until well into the 2020s (CCC 2010d). On the other hand, end user demand for motorised private transport, expressed as traffic volumes or total vehicle kilometres, is expected to increase significantly by the mid-2020s (DfT 2012c). While the last four years have seen a slight drop off in traffic volumes, a return to pre-recession rates of demand growth is a distinct possibility – indeed government traffic forecasts consistently predict strong growth (DfT 2012c). The putative intractability of end user demand and reliance on medium to long term low-carbon technology innovation is reflected in relatively modest rates of emissions cuts envisaged for the car sector in the short term. As such, the 2009 government white paper, *Low Carbon Transport* (DfT 2009b), identifies 'opportunities' to achieve a 14% reduction in annual domestic transport[4] CO_2 emissions by 2020 (cf. 2008), largely from vehicle efficiency improvements.

1.1.2 Emissions pathways and budgets

The *Low Carbon Transport* measures form part of the UK government's strategy to deliver 29% to 40% reductions for UK domestic CO_2 emissions by 2020 (cf. 1990[5]), under the terms of the UK carbon budgets (Carbon Budgets Orders 2009 and 2011). The carbon budgets themselves are ground-breaking in acknowledging the importance of cumulative emissions with respect to climate change and in framing mitigation as *cumulative constraints*. Global warming is driven by cumulative emissions of greenhouse gases over time, so does not relate to the emissions in any specified future year, e.g. 2020 or 2050 (Anderson and Bows 2008; Allen *et al* 2009). The relationship between cumulative emissions and climate response is elaborated in §2.1.3., but it is important to recognise from the outset that, as the primary determinant of any given pathway's probability of exceeding a given warming threshold (see §2.1.3.2.), cumulative emissions are taken as the appropriate basis for analysis in this research.

While the importance of staying below the 2°C threshold is repeated throughout the UK policy literature[6], the UK's carbon budgets are not premised on a pathway associated with a *low probability of exceeding* 2°C average global surface warming over pre-industrial levels. Instead, the budgets are premised on a pathway (the CCC's *2016:3%*) derived from a global cumulative emissions budget associated with a 63% probability of exceeding 2°C warming by the end of the century (CCC 2008a).

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[4] Passenger cars comprise 57% of domestic transport CO_2 emissions (mean 2008–10) (DECC 2011a).

[5] See §2.2.4 for explanation of comparability between transport emissions in 1990 and 2008.

[6] For example in the DfT's *Low Carbon Transport* (DfT 2009b, p.18); in DECC's *Low Carbon Transition Plan* (DECC 2009b, p.5, pp.31-32 four times).

An emissions pathway that delivers a low probability of exceeding 2°C necessarily entails significantly greater emissions cuts from all major emitting sectors than one intended to deliver a 63% probability of exceeding 2°C. Therefore much more ambitious emissions abatement than is entailed by current UK legislation is necessary to reconcile the high level political goal of avoiding 'dangerous' climate change with the national and sector-level mitigation interventions planned to achieve it. Other than dividing the UK carbon budgets between the traded and non-traded sectors[7], the UK government and the CCC make no further distinction as to where in the UK economy the 'emissions savings' necessary to achieving the emissions budgets should be made – the expectation is that emissions cuts will be made where they cost least (CCC 2008a). Marginal abatement costs are typically estimated as being higher in the passenger car sector than in other more geographically consolidated and static sectors (van Vuuren *et al* 2007; Perrels 2010). The Department for Transport's non-binding 'target' of 14% reduction in annual emissions from road transport by 2022 is based on this 'least cost' approach. However, for any individual sector to reduce its emissions by less than the national rate of decarbonisation, equivalent additional savings from another sector must be made or the national pathway becomes unobtainable (§1.3.1 below introduces further discussion on 'apportioning' national budgets at the sectoral level).

1.1.3 Timeframes and rate of change

Under the current mix of policies and mitigation measures, emissions abatement from the car sector over the coming decade will not keep pace with even a national pathway associated with a 63% probability of exceeding 2°C – a likelihood of exceeding 2°C described by the IPCC as 'about as likely as not' (IPCC 2010). However, to delay reductions from any major emitting sector risks sacrificing all possibility of respecting UK cumulative emissions budgets and accompanying commitments on 2°C (Anderson *et al* 2008; CCC 2008a). Thus, early and ambitious abatement is essential for a pathway associated with a low probability of exceeding 2°C; gradual incremental rates of emissions reduction will be insufficient. Allowing for short term emissions growth in the industrialising nations (non-Annex 1, see §2.1.4.1), for even a 50:50 chance of exceeding 2°C, emissions cuts in the already industrialised nations (Annex 1) such as the UK need to be made in the order of 8% to 10% *per annum* (p.a.) with more or less immediate effect (Anderson and Bows 2011).

[7] i.e. between those parts of the economy which are included in the EU Emissions Trading Scheme and those that are not. Passenger cars are in the non-traded sector. The traded sector may obtain additional emissions 'rights' through participation in the Clean Development Mechanism established under the Kyoto Protocol. Since emissions cuts are not expected to be based on domestic effort alone, the possibility of carbon leakage, and likelihood of long term high carbon infrastructure lock-in are significant problems (Bows *et al* 2009).

1.1.4 Geographical remit

In passing the Climate Change Act 2008 and subsequent carbon budgets, the UK[8] was the first country to unilaterally adopt binding, statutory mitigation commitments. While the UK is sometimes portrayed as a 'small nation', whose global mitigation potential is insignificant, in reality it ranks as the seventh largest emitting nation globally, with only the USA, China, Japan, India, Russia and Germany having higher absolute consumption emissions[9]. Moreover, the UK's *per capita* consumption emissions are the second highest of any of this 'big seven' group of global emitters (Davis and Caldeira 2010, supplementary data). The UK's emissions profile is typical of many post-industrial nations, whose emissions from indigenous industry are outweighed by consumption of imported goods and by end user energy demand in the residential and transport sectors. As such, the UK serves as an illustrative case study of the potential for meeting political climate change goals by implementing scientifically-based emissions budgets.

The UK passenger car sector is part of an international market and global automotive industry, subject to numerous influences beyond the immediate control of the UK government. Most significantly, external pressure arises from the UK's membership of the European Union (EU) – arguably the main policies affecting emissions from the UK car sector come from the EU. While this research makes frequent reference to such international influences and constraints, the boundary of emissions reductions analysed is specifically the UK. Although the UK is taken to be broadly representative of its European neighbours and of Annex 1 nations in general, there are several important aspects in which the UK car sector is dissimilar to other industrialised nations.

1.2 **Research outline**

1.2.1 Aim

This research investigates the potential for non-marginal reductions in CO_2 emissions from the UK car sector in the next decade, consistent with a low probability of exceeding 2°C. In doing so, it quantifies the potential for radical emissions reductions from both technical improvements in the energy intensity of motorised private transport and changes in patterns of end use.

1.2.2 Core research questions

For the UK to follow an emissions pathway consistent with a given probability of exceeding 2°C, the following specific questions are addressed.

1. What cumulative emissions budget is required of the car sector in the next decade?
2. How much of the necessary mitigation could be achieved through new and existing technology?

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[8] The United Kingdom of Great Britain and Northern Ireland. Many official statistics refer to Great Britain (i.e. excluding Northern Ireland), or to England only. In these cases any necessary adjustment to scale up to UK level are made explicit.

[9] The UK emits around 5% of annual global CO_2 (CDIAC 2011), based on territorial emissions plus international aviation and shipping; or around 7% based on consumption accounting (DECC 2012).

3. What, if any, shortfall remains between budget-based sectoral mitigation goals and potential technology savings over the next decade?
4. What are the emissions implications of assumptions about future demand for car travel?
5. How might changes in patterns of car use contribute to or detract from meeting sectoral mitigation goals?
6. What are the implications for policy of findings from all of the above?

These core questions include both quantitative and qualitative elements. Adequately framing responses to questions about emissions pathways, budgets, associated probabilities of exceeding 2°C, and the emissions abatement potential of certain technologies or patterns of end use, requires accurate emissions accounting and quantification of mitigation potential. Questions 1, 3 and 4 are therefore largely quantitative in nature. By contrast, questions 5 and 6 investigate the possibility of interventions to manage demand in accordance with emissions objectives, taking an essentially qualitative approach to the roles of end users and 'upstream actors' (manufacturers, policymakers *et al*) in the car sector. Question 2 combines elements that are both quantitative and qualitative in nature, quantifying abatement potential based on critical judgement. Methods specifically appropriate to answering these types of questions are discussed in Chapters 5–7, but it is worth noting from the start that a necessarily *mixed methods* approach is used to tackle these issues. Thus, the more quantitative questions of emissions budgets, defining pathways and estimating the abatement potential of specific technology configurations and fleet dynamics are explored using desk-based numerical modelling. Questions about end user (driver) behaviour and practices, which are less amenable to purely quantitative research techniques, are explored using in-depth interviews with end users and qualitative analysis of gathered data.

The foregoing should not be taken to imply that technology and use (or behaviour) are distinct and isolable quantities. The complex, iterative and mutually reinforcing relationships that exist between technological artefacts and the people who interact with them are considered in more detail in §1.4.2 below, while the many and various factors that influence levels of demand for private transport are picked out in Chapter 4. However, it is expedient to observe here that the approach taken to answering the research questions above is to assume that there exists a preference both amongst the general public and in government for policies and measures which achieve the necessary emissions cuts[10]:

(i) while promoting rather than restricting personal mobility;
(ii) at 'least financial cost' to the state and to individual car users; and

[10] This approach is broadly in keeping with the King Review's position that "it will generally be preferable to reduce CO_2 by improving fuel, vehicle and driver efficiency rather than by reducing demand for travel" (King 2007: p.21, §2.10). However, while King's rationale is that growth in demand for *vehicle* kilometres (VKM) will bring economic prosperity and personal mobility, here the first priority is to promote *personal* mobility, expressed as passenger-kilometres (PKM).

(iii) where possible, minimising disruption to existing patterns of use[11].

Where all three conditions cannot be met, a preference is assumed for policies and measures which prioritise these considerations in the order presented.

The core research questions also proceed from an assumption that *a low probability* of exceeding 2°C is preferred to a higher probability – as stated in, for example, the UK *Low Carbon Transition Plan* (DECC 2009b). A full discussion of the history and selection of 2°C as a policy objective is provided in Chapter 2, but it should be noted here that radically different sets of answers emerge if higher probabilities of exceeding 2°C are accepted, or if the objective is not framed as a cumulative constraint on absolute emissions but as, say, an 80% reduction in annual emissions by 2050. A range of probabilities of exceeding 2°C is considered in the analysis presented, to allow comparisons between the policy implications that emerge.

The following sub-sections give a detailed breakdown of the key concepts, uncertainties and issues involved in each of the research questions listed above.

1.2.2.1 For a given probability of 2°C, what cumulative emissions budget is required of the car sector in the next decade?

The first question quantitatively grounds the research in the science of climate change and emissions accounting. Chapter 2's review of the state of the science with respect to global climatic response to anthropogenic inputs of greenhouse gases allows an appropriate conception of 'effective mitigation' to be defined. Key issues considered include treatment of uncertainty in climate sensitivity and associated probabilities of a given temperature increase, and in likely impacts of specified temperature increases. This part of the research follows a 'correlation trail' (Anderson and Bows 2008) back from a normatively determined level of global warming (2°C), via climate modelling and cumulative global emissions budgets, to apportionment of remaining twenty-first century emissions space between nations. Important points to recognise include: the differences between consumption and production-based emissions accounting; the relationship between emissions growth and welfare in industrialising nations and the limited short term potential for emissions reductions in those countries; along with the treatment of emissions from global deforestation and land use change. To move to the level of individual economic sectors[12], this research extends the correlation trail one step further, deriving sectoral emissions budgets from national budgets (see Chapter 5). This involves assessment of sectoral emissions accounting and inter-sectoral apportionment approaches, and evaluation of the potential for some sectors to make additional cuts to

[11] This may be construed as a third order preference for measures that are less rather than more interventionist, as recommended by, for example, Gunningham and Sinclair (1999). However, the overriding consideration here is the achievement of the necessary emissions cuts; the degree of 'interventionism' is taken as subordinate to this goal and priorities (i) and (ii). Interventions which affect patterns of use may be accorded a higher priority for their own sake if the overriding goal were different, i.e. if reasons other than an absolute reduction in emissions were the primary objective (e.g. public health, network congestion, road safety, or local amenity and environmental quality).

[12] Sectors in the sense of Standard Industrial Classification of Economic Activities (ONS 2007)

compensate for others which are not able to abate as easily. Alternative means of attributing emissions to the car sector are considered: on a tailpipe-only basis (tank-to-wheels); by total carbon released from fuel extraction, refinement, distribution and final use (well-to-wheels); and according to the total carbon released well-to-wheel from fuel plus vehicle manufacture, maintenance and disposal (full lifecycle carbon costs).

These considerations underpin the estimation of a series of quantified emissions 'pathways' for the UK and for the car sector specifically, derived from global pathways with associated probabilities of exceeding 2°C. An emissions pathway[13] describes a future trajectory of annual emissions, which cumulatively form an emissions budget for a given period of time. Figure 1.1 shows historical UK production emissions as a line plot (green), with two future emissions pathways: the CCC's *2016:3% low* (the current 'interim' pathway to an 80% reduction in emissions by 2050, adopted by the government in the current legislative carbon budgets) and the CCC's *2016:4% low* 'intended' pathway. The cumulative emissions budget is effectively represented by the area under the pathway curve (shaded pink for the interim pathway).

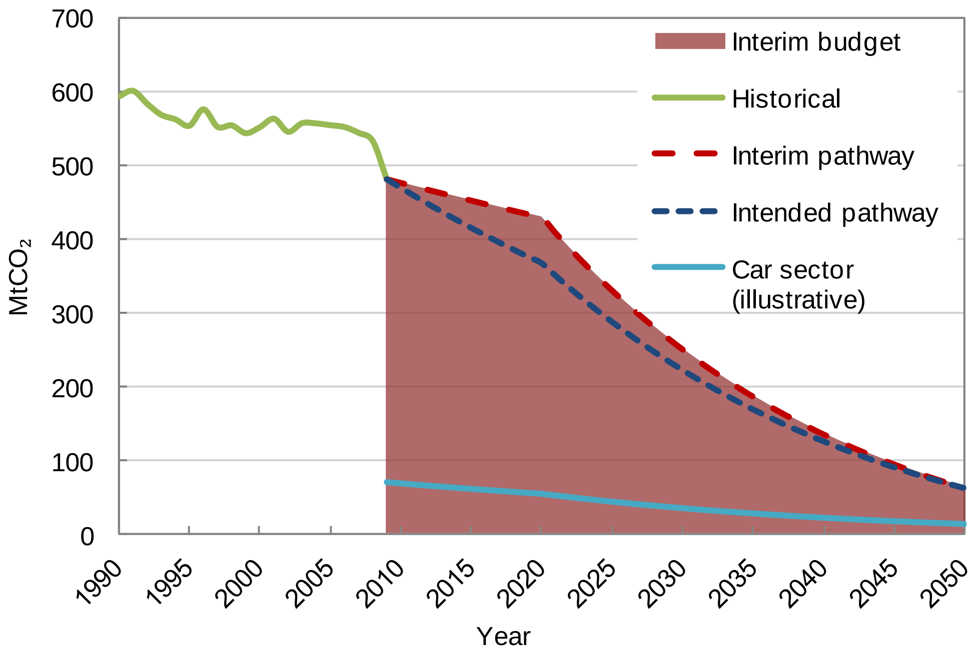

Figure 1.1: illustration of UK producer-based emissions pathways and budgets, based on CCC data (CCC 2008b). Car sector emissions pathway is shown for illustration only.

Budgets and pathways are significant concepts for this research because global warming correlates with *cumulative* emissions over the 21st century, not the emissions in a particular future year (so called 'end point' targets – see Chapter 2). In Figure 1.1, both interim and intended pathways arrive at an 80% reduction on 1990 emissions in 2050, but cumulative emissions under the intended pathway are significantly less than under

13 The CCC (and others) refer to emissions 'paths'; the terms path and pathway are used interchangeably here.

the interim. Thus the global pathway corresponding to the UK intended budget (*2016:4% low*) is associated with a lower probability of exceeding 2°C than the global pathway from which the interim budget is derived (*2016:3% low*). By extension, lower probabilities of exceeding 2°C demand smaller national budgets, with less aggregate emissions space available for use by individual sectors (e.g. passenger cars). Pathways with high emissions in early years may not be compatible with certain overall budgetary constraints, given that a minimum 'emissions floor' must remain (for food production, for example)[14]. As indicated in §1.1.3 above, if allowance is made for industrialising nations to increase their emissions in the short term, remaining emissions 'headroom' within the global budget for industrialised nations is consequently reduced. Therefore, in order to respect such constrained headroom, strong arguments exist for the UK's emissions pathway to decline with immediate effect, since emissions continue to accumulate for each year that mitigation is delayed.

1.2.2.2 How much of the required mitigation could be achieved from new and existing technology?

Emissions reductions may be achieved by intervening at various points in the system of supply and consumption of carbon intensive vehicles, fuels and feedstocks in the car sector. An 'intervention' in this sense refers to a strategically planned, coordinated and monitored action intended to reduce emissions by changing the relative influence of one or more factors of supply and / or demand. More precisely, changes to supply-side factors such as vehicle and fuel technology and infrastructure are referred to here as 'measures'; the term 'intervention' is reserved hereafter for attempts to alter demand-side or end-user factors.

Although supply measures are essentially technology-based, they need not be 'hi-tech', ranging from the simple (reducing vehicle mass, or tare weight), through more sophisticated design measures (reducing aerodynamic drag and rolling resistance, improving internal combustion efficiency) to system-wide infrastructural measures (reducing the carbon content of road fuel and innovative forms of propulsion and fuelling, or non-conventional vehicle design). Before estimating the mitigation potential of specific technology measures in the next decade, an assessment is first made of the market readiness of available measures, based on a detailed review of the academic and industry literature (see Chapter 3). Figure 1.2 shows how vehicle emissions per kilometre have reduced over the last decade as mean fuel efficiency has improved (based on type approval, or TA, legislative test cycle-based values), largely through refinements to internal combustion engines (ICEs).

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[14] Due to a lack of working, industrial-scale demonstrations of viable and dependable sequestration technology, 'negative emissions' and offsetting are excluded from this analysis.

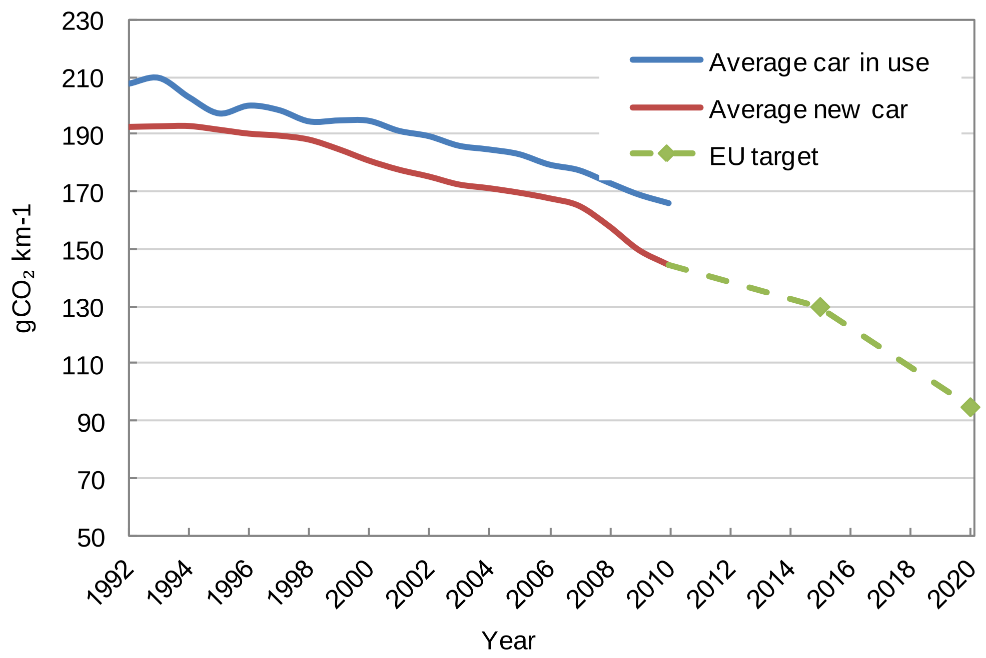


Figure 1.2: Mean CO_2 emissions in grammes per kilometre for all cars in use in the UK and for new registrations each year (based on idealised, 'type approval' test cycle data), with EU new car emissions targets for 2015 (130 gCO_2/km) and 2020 (95 gCO_2/km). Data source SMMT 2011.

A method for quantifying the potential fleet-wide abatement impacts of market-ready, or 'nearly ready', technology measures is elaborated in Chapter 6. The approach taken does not aim to 'pick winners' in terms of the types of technology likely to emerge, or attempt to precisely quantify the emissions savings potential of individual technological advances. Rather the findings from the literature are used to inform the creation of a series of fleet emissions scenarios, based on assumptions about fleet penetration of available technology, under various assumptions about demand (constant, growing, constrained). As noted above, emissions savings will depend heavily on the method selected for attributing lifecycle carbon from fuel and vehicles to end users or producers. Questions of the efficacy of policies intended to bring about reductions in vehicle emissions per kilometre are also pertinent here. Chapter 3 explores in detail concerns surrounding the current EU new car emissions regulations, in particular the effect of scaling emissions targets according to vehicle mass, and the significance for the UK's car sector abatement strategy of the EU regulation being based on average new car emissions across the EU27 group as a whole.

After screening out supply measures that are infeasible in the short term (based on assessment of the literature), car sector technology scenarios are modelled to allow comparison of resultant cumulative sectoral emissions with the various sectoral budgets (with named associated probabilities of exceeding 2°C) for the period to 2022. Although developed independently, a similar procedure to that used by Bristow *et al* (2008) is followed, with the important exception that the focus here is on absolute emissions budgets, whereas Bristow *et al* looked at percentage reductions in 2050.

1.2.2.3 What shortfall, if any, remains between budget-based sectoral mitigation goals and available technology savings in the next decade?

This part of the research will explore whether there is any discrepancy between (i) emissions reductions estimated within the next decade from the assessment of market-ready technology (core to question 2), and (ii) the sectoral budgets, which allow the car sector to follow a national pathway consistent with a low probability of exceeding 2°C (question 1).

As already noted, the UK government's climate change mitigation strategy, laid out in the *Low Carbon Transition Plan* (DECC 2009b) and other related white papers, does not specify emissions budgets for individual sectors of the UK economy – only for the UK as a whole. However, this strand of the research compares the government's estimated 'abatement opportunities' for the car sector with both the sectoral budgets derived under question 1 and the 'best case' technology savings assessed under question 2. This section involves assessment of the measures within the *Low Carbon Transport* strategy and comparison of their estimated cumulative reductions with the sectoral budgets derived for various probabilities of exceeding 2°C (the *LCT* measures are currently expressed as end point target levels of emissions for the year 2020).

Complicating factors to be explored in this section include uncertainties in methods of accounting, monitoring and reporting emissions from the car sector as a sub-set of the road transport sector. Car sector emissions are currently estimated using a bottom-up methodology, multiplying total vehicle kilometres travelled (estimated from automatic and manual roadside traffic counts (DfT 2007)) by emissions factors scaled for speed and vehicle type. The car sector bottom-up emissions estimate is then reconciled with estimates for all other road vehicle types to tally with total recorded road fuel sales as reported in the Digest of UK Energy Statistics (DUKES) (Brown *et al* 2012) – discussed in detail in §6.3.7. Key issues relate to the derivation and application of the emissions factors (expressed as gCO_2/km) themselves, as well as their sensitivity to real-world driving, as opposed to the standardised and rather artificial driving cycle currently used for the type approval of new vehicles under EU law (Weiss *et al* 2011). Taking these concerns into account (explored further in Chapter 3), an estimate can be made of any discrepancy between the 2°C-based sectoral budgets and (a) the technology savings estimated by this work, and (b) the UK government's current mitigation strategy.

1.2.2.4 What are the emissions implications of assumptions about future demand for car travel?

In some usages, demand may refer to the overall *demand for transport* within the wider system of mobility – i.e. total passenger kilometres. However, since total demand for transport can increase while 'demand for' specific types of vehicle kilometres falls (for instance by increasing vehicle occupancy, or by modal shift), when dealing with reductions in emissions in absolute terms it is helpful to look specifically at demand factors relating to carbon-intensive modes of transport – predominantly the private car. Further distinctions are drawn in Chapter 4, but henceforth, unless otherwise stated, demand refers to aggregate vehicle kilometres or total car traffic (VKM_{fleet}, sometimes referred to as 'traffic volume').

The planned emissions reductions in the *LCT* strategy are presented as occurring in parallel with strongly rising demand for car kilometres (Figure 1.3) – hence the relatively low level of abatement envisaged (compared with the 28–40% cuts in CO_2 nationally), as rising demand counteracts fuel efficiency savings. The DfT's forecasts of future demand growth are based on an econometric component of the National Transport Model, using exogenous values for personal incomes and fuel prices from other government macro-economic models (DfT 2012c). Looking at the past trajectory of demand for vehicle kilometres, future growth projections are well-founded in historical precedent – at least in terms of net effect – as annual vehicle kilometres increased steadily year on year for over five decades until the start of the economic recession in 2008–9 (Figure 1.3). Recent years have seen an unprecedented downturn in demand. Nevertheless, government forecasts of future demand are for a resumption of the previous upward trend within the next few years.

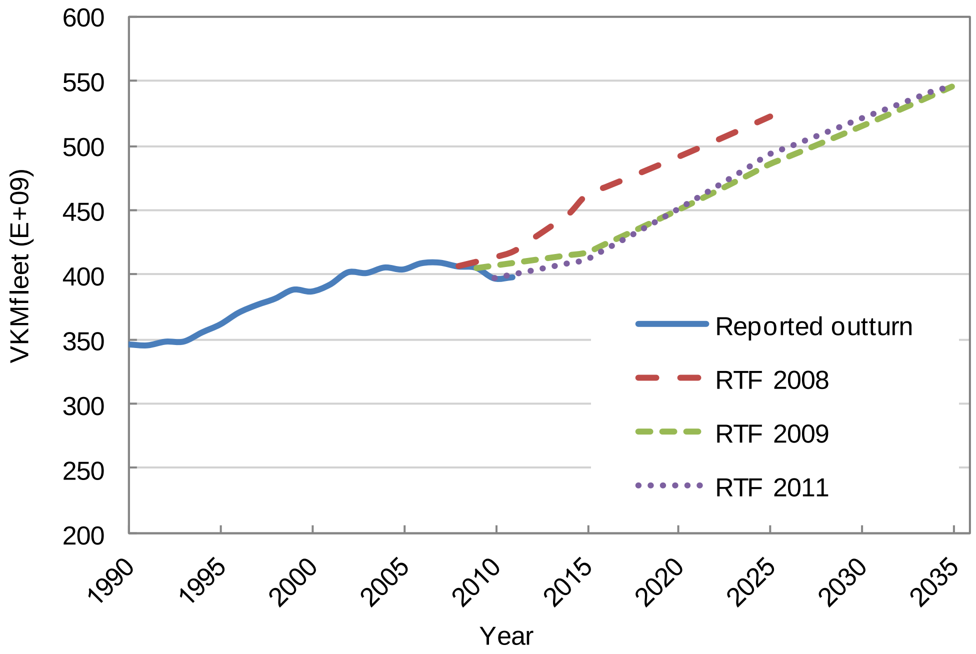


Figure 1.3: Historical total annual UK driving distance, or aggregate demand (billion vehicle kilometres travelled, VKM_{fleet}), with three future demand scenarios based on the Department for Transport's Road Transport Forecasts (RTF) 2008, 2009 and 2011. NB: RTF-2008 forecasts run to 2025 only. Later forecasts run to 2035. Outturn refers to recorded historical values.

However, to assume growth as a given is to assume that the conditions that brought it about will persist. Traffic volume is influenced to a large extent by the provision of infrastructure and services such as roads and parking facilities. Until the late 1990s these facilities were planned on a 'predict and provide' basis, whereby the expectation of future growth in demand warrants increased service provision, which in turn creates opportunities and inducements for further usage. This self-fulfilling aspect of traditional predict and provide transport planning is captured in the concept of 'induced travel demand' (Goodwin 1996).

As noted in §1.1.1, growth in car-based personal transport has in the past appeared to correspond with economic growth, leading some to suppose that a causal relationship obtains (e.g. Eddington 2006a). Hence, a return to pre-recession annual growth in traffic volumes is, in some quarters, seen as a *desirable* outcome for economic reasons (Hammond 2011). The complex nature of the relationship between passenger kilometres, car kilometres and economic prosperity is examined further in Chapter 4. Figure 1.4 shows how growth in car kilometres over recent decades has effectively cancelled out the emissions savings from improvements to car fuel efficiency (Figure 1.2) – sectoral emissions varying relatively little between 1990 and 2008.

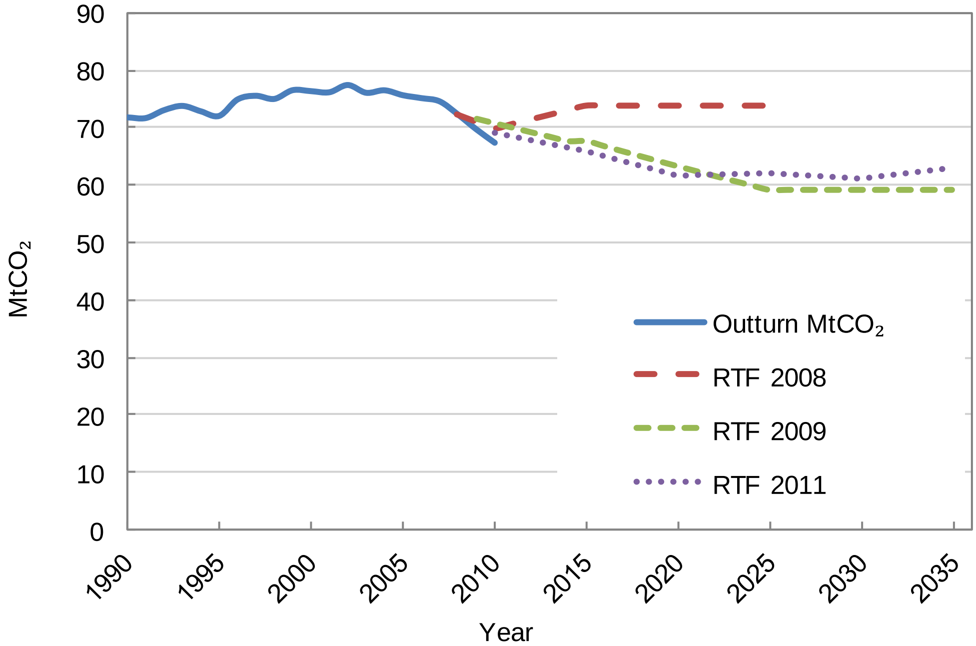


Figure 1.4: Historical car sector annual CO_2 emissions, with three future emission scenarios based on the Department for Transport's Road Transport Forecasts (RTF[15]) made in 2008, 2009 and 2011. NB: RTF 2008 forecasts run to 2025 only. Later forecasts run to 2035

[15] The DfT Road Transport Forecasts (RTF) present emissions scenarios for road transport as a whole, not disaggregated to specific vehicle types (e.g. car, light goods, etc). The approach taken here is to assume that, because they dominate road transport emissions, cars follow the mean trajectory implied by the RTF end point reductions in emissions for the specified years.

If demand were to revert to strong annual growth in line with the Department for Transport's central projections in their Road Transport Forecasts 2011, this would have consequences for the achievability of sectoral mitigation objectives (and by extension, for national objectives). To respect a given sectoral emissions budget, scenarios with increasing demand require a proportional increase either in the rate of vehicle efficiency improvements, or a proportional reduction in the carbon intensity of the energy source. Chapter 6 quantifies the emissions penalty entailed by various demand scenarios (*ceteris paribus*), as well as the additional mitigation burden that demand growth places on supply-side mitigation for given sectoral emissions budgets to be met.

1.2.2.5 How might changes in patterns of car use contribute to meeting sectoral mitigation goals?

This question considers the potential for emissions reductions to be delivered through interventions that affect aggregate demand (i.e. total vehicle kilometres, or VKM_{fleet}). While increasing the energy efficiency of vehicles is a relatively 'easy win' in terms of emissions savings, mitigation strategies that focus purely on supply-side factors can do only so much. There is consensus within the literature that the required level of emissions reduction from the car sector will not be achievable purely through technological improvements in the fleet, as the predicted growth in the sector will outweigh the possible emissions savings (Bristow *et al* 2004; Rajan 2006; Hickman and Banister 2007; Hensher 2008). It is also acknowledged that policies designed to affect travel behaviour and habits are as important – if not more important – than technological solutions, because of possible rebound effects and uptake of additional features that increase vehicle weight, reducing efficiency (Anable and Boardman 2005). Furthermore, driving behaviour is often more than a matter of just travelling from A to B; driving (or at least car ownership) has evolved into a practice laden with meaning that transcends the simple act of conveyance (Urry 1999; Sheller 2004). A key finding from Defra's environmental behaviours unit (2008) was that for one of the most 'impactful' headline pro-environmental behaviours – 'finding alternatives to car use for trips of under three miles' – only 18% of the sample population ('positive greens') were reported to find this behaviour goal at all acceptable. The 'unacceptability' of alternatives is left unqualified, but the finding nevertheless suggests that the majority do not currently contemplate public or non-motorised modes of transport even in cases where they may easily be substituted for the car. As a means to counteract the strong affective attachments and habitual behaviours and practices involved in driving for some population segments (Anable 2005), price instruments have been proposed as suitable measures to incentivise behaviour change (Bows *et al* 2006).

The available range of demand-side interventions that may be implemented to tackle emissions from personal transport is examined in detail in Chapter 4. Distinctions are drawn between demand management[16] interventions which (i) *modify end user access* to technology, services and institutions (e.g. home working, flexi-time, car clubs, public transport provision); (ii) *regulate use* (e.g. speed limits, minimum occupancy vehicle lanes); and (iii) *encourage* or *discourage* uptake of specific behaviours or technology by means that are '*rational*' (e.g. providing information about costs, driving more efficiently), '*ethical*' (e.g. appealing to social or environmental interests, e.g. carbon foot-printing) or '*economic*' (fuel-tax, personal carbon allowances, road-user charging, workplace parking levy, etc). An important concept in this strand of the research is vehicle occupancy, or load factor – i.e. the number of people in the car. Official statistics show a decline in trip occupancy rates over the last forty years, to the current 1.6 persons per car per trip (mean value for all journey purposes) (DfT 2011b, NTS0906). Closer inspection of the data reveals significantly lower rates of car occupancy for commuting and business journeys, which categories comprise a large proportion of longer distance trips, and consequently are responsible for a greater proportion of car sector emissions than shorter trips.

This part of the research also explores the interrelationship between technology and use. Technology and behaviour are not binary opposites; taking a broader view of technology itself than just 'physical things', technology configures and is configured by interaction with society (Rip and Kemp 1998). Mutual feedbacks that exist between behaviour and technology are highlighted: just as new technologies create new opportunities for use, so too patterns of use feed into shaping 'demand for' technology. Findings from the fleet emissions model and primary research interviews are discussed in relation to these ideas, drawing on the socio-technical transitions and practices literatures, in Chapter 9.

Building on these considerations, Chapter 7 elaborates a method using qualitative, in-depth interviews with car drivers to assess the potential for significant emissions reductions through similarly significant reductions in vehicle kilometres travelled. Interviews are based around narrative scenarios of personal mobility in the near future (eight years hence, i.e. 2020). In the scenarios, numerous hypothetical interventions have been introduced, some of which aim to constrain car use, some facilitate more efficient patterns of car use, while others aim to enhance options for non-car mobility.

The narrative scenarios include a wide range of demand management interventions, presented for discussion to ascertain which the respondent considers more likely to influence their personal car use in a way that most significantly reduces motorised private transport emissions, and to identify potential barriers to uptake of those

[16] Note that 'demand-management' is sometimes used within the literature to refer specifically to road-pricing / congestion charging / parking levy schemes. Litman (2003) defines *transportation demand management* (TDM), elsewhere referred to as travel demand management, in a broader sense as "a general term for strategies and programs that encourage more efficient use of transport resources (road and parking space, vehicle capacity, funding, energy, etc)". This is the sense in which the term is used here, to include all direct and indirect demand-side interventions.

interventions. Respondents' reactions to demand management measures provide qualitative data and understanding of the potential efficacy and equity of possible demand-side interventions.

1.2.2.6 What are the implications of findings from the previous questions for policy?

The final research question draws out the ramifications of each of the foregoing aspects of the research for transport and climate change policy in the UK. Findings from the numerical modelling of car sector emissions budgets (question 1) and technology scenarios (questions 2 and 3), along with findings from the primary research into potential barriers for demand management (questions 4 and 5) are discussed in relation to the relevant literature in Chapter 9. Chapter 10 frames the key issues which arise from this discussion as implications for policy and further work.

1.3 **Is the car sector a special case?**

1.3.1 Approaches to determining the sectoral balance of effort

The strategic importance for national mitigation of decarbonising the car sector is plain – as noted in §1.1, the transport sector as a whole accounts for a third of UK CO_2 emissions, private cars for around one eighth. Conventionally, the car sector has often been regarded as posing particularly difficult obstacles to decarbonisation (e.g. King 2007, p.11, citing Stern; McKinsey 2009, p.14). The supposed inertia arises from the automotive sector's widespread and well-established infrastructure, geared towards continued provision of fossil fuels. Then, supply-side 'fixes' must penetrate a fleet of tens of millions of individual units (vehicles), in contrast to a few dozen power stations (albeit each entailing massive costs). In addition to the physical features of fuel provision and the multitudinous car fleet, the car as an economic, cultural and social entity is also deeply embedded in the fabric of life in the UK, invariably at the heart of land use planning for housing, employment, industry, retail and leisure (Pooley 2010). Over the last half century, patterns of car use and mobility have evolved side by side with provision of car-based infrastructure, such that the private car is now widely considered a 'necessity' for personal mobility. In rural areas, public transport provision has in recent years contracted to make many communities accessible for much of time only by private car (Gray *et al* 2001; CfIT 2008). Furthermore, driving and car ownership are culturally associated with status and other affect-based values, as well as being practically related to employment and leisure opportunities. Demand-side behavioural change is therefore a contentious and emotive issue.

Few would claim that the car sector presents an *easy* target for decarbonisation, although as pointed out by Lutsey and Sperling (2009), when consistent assumptions are applied across *all* sectors, transport mitigation measures are as able to generate financial savings over the lifetime of the investment as elsewhere. Nevertheless, following the correlation trail back from politically selected climate warming goals to national emissions budgets (§1.2.2.1 and Chapter 2) demands that all sectors cut emissions rapidly and deeply, such that every sector is likely to find it difficult to envisage how such unprecedented cuts could be made without fundamentally changing the economy, not to mention lifestyles and practices. In this light it is reasonable to ask whether the car sector (or any major sector) presents greater or lesser challenges to decarbonisation than other major emitting sectors, in terms of costs and practicality – the implication being that there may be opportunities for certain sectors where mitigation is more difficult to offload some of their abatement effort to other sectors where cuts can be made more easily.

However, for any individual sector to reduce its emissions by less than the national rate of decarbonisation required for a given probability of exceeding 2°C, equivalent additional savings from another sector must be made or the national pathway becomes unobtainable. Notwithstanding that the planned 29–40% UK CO_2 reduction by 2020 is more ambitious than the 14% reduction proposed for domestic transport, the scale of the challenge is significantly greater when abating for lower probabilities of exceeding 2°C, particularly when accounting for realistic emissions growth from non-Annex 1 countries, the physical constraints on mitigation achievable from agriculture and whether deforestation is considered a 'global overhead'. Under such constraints, there would be little to no latitude for any high emitting sector to reduce its emissions by less than the national mean rate, since additional mitigation opportunities from other sectors would be minimal. With such a challenging mean rate in the first place (typically over 8% p.a.), it is difficult to envisage how a quantified case for special treatment of one sector, at the expense of yet more challenging reductions from other sectors, could be justified.

Therefore, this research proceeds from the position that significant asymmetry in the division of abatement effort between major emitting sectors is not an option when mitigating for lower probabilities of exceeding 2°C. Leighty *et al* advance a similar rationale with a more optimistic slant, stating that "while the transport sector may not need to meet the [80% emissions reduction by 2050] goal if other sectors exceed it, we develop scenarios assuming the [80%] goal must be met separately within the transportation sector, as well as in the economy as a whole" (Leighty *et al* 2012: p.52).

1.4 **Conceptual framing**

The spatial and temporal complexity of effectively mitigating climate change has led to it being referred to as a 'super-wicked' problem, referring to the diminishing time available to address the problem, identity between problem-solvers and problem-causers, lack of a central controlling authority and the tendency of policies to discount the future irrationally (Levin *et al* 2012). Mitigating passenger car sector emissions illustrates this complexity, with a diverse range of actors and influences all having bearing. As such, a conceptual framework for analysing the key contributory factors and identifying pathways for rapid emissions reduction must account for the intricate interplay of elements and actors which combine to form the 'automobility system'. The principal actor types may be characterised as:

i. product and service providers, comprising vehicle, fuel and component manufacturers, research and development teams (science), and ancillary industries such as insurance, maintenance and servicing etc;
ii. sales and marketing companies, including the in-house divisions of manufacturers themselves, but also mass media advertising agencies, motoring press, car dealerships;
iii. infrastructure providers, in both public and private sectors – civil engineering and construction, information and communications technology providers;
iv. governing bodies and regulators, as a multi-tiered governance hierarchy (local authorities, national government, European Union), as well as national and international trade organisations, and NGOs and industry analysts; and
v. vehicle end users, including private individual car drivers and corporate fleet users.

Each of these constituent elements has over time been subject to extensive disciplinary study, informed by a wide variety of analytical traditions. In the following subsections, perspectives are identified which lend useful insights to the problem of decarbonising the passenger car sector at the scale and rate of interest in this enquiry (i.e. for the UK to follow an emissions pathway consistent with a lower probability of exceeding 2°C than currently in train).

1.4.1 Automobility as a socio-technical regime

Of particular relevance to this research is the body of literature originating from science and technology studies, which has coalesced around the examination of the aforementioned groups of actors in terms of their comprising a 'socio-technical regime' (Geels 2004). Geels and Kemp (2012) suggest that each of these elements has its own set of rules and conventions, effectively separate regimes which are 'meta-coordinated' through a socio-technical regime – in this case automobility.

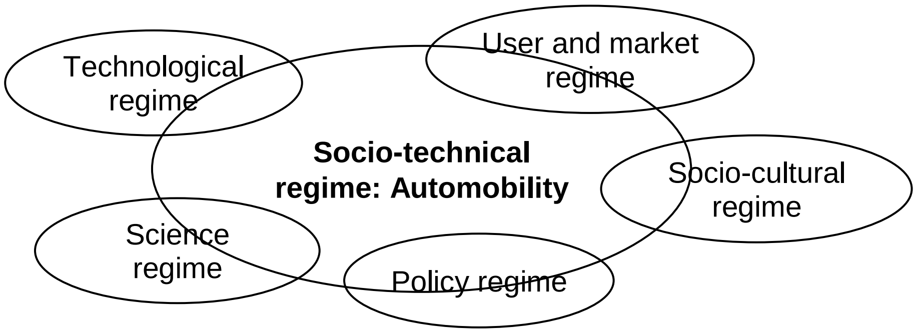


Figure 1.5: Meta-coordination of constituent regimes through a socio-technical regime (after Geels 2004)

Geels situates socio-technical regimes within the broader context of a socio-technical landscape, essentially the background infrastructure, political and cultural values, economic conditions and societal trends within which regimes operate. Underpinning regimes themselves, technological niches are constantly forming and reforming, some of which break through to emerge as new socio-technical regimes. The classic multi-level perspective (MLP) illustration of regime *transitions* depicts influence running both ways between landscape and regime, with landscape developments applying pressure on regimes, which in turn affords opportunities for niches to take hold, while new niches that emerge as dominant regimes exert influence on the wider landscape in turn (Geels 2002).

Geels (2012) lists the landscape pressures threatening to destabilise the automobility regime as:

i. public concerns and policy action which have led to the introduction of regulatory standards for new vehicles at EU level;
ii. peak oil production, or the threat thereof; and
iii. the move towards an increasingly information-based society, with opportunities for tele-presence.

Counteracting these disruptive influences, Geels also identifies a number of landscape characteristics that work to stabilise the dominant automobility regime:

i. culture of private property rather than communalism, favouring private car ownership and discouraging car-sharing;
ii. prioritisation of speed, time-saving and preferences for autonomy and privacy, giving the car advantages over public modes;
iii. established car-centric physical landscape;
iv. macro-economic growth creating sufficient disposable household income to run more than one car per household; and
v. growing demand for mobility arising from shift to a ‘network society’ with increased flows of goods and services.

Geels goes on to describe a number of ‘lock-in’ mechanisms, which stabilise the *de facto* automobility regime and mean that incremental rather than transformative changes are preferred by affected parties within the system. Lock-ins result from inertia within the technology, science, policy and socio-cultural regimes, from vested interests in the technology and market regimes and from “cultural values and positive discourses around the ‘joy of driving’ and ‘love affair with the car’” (Geels 2012, p.8).

The multi-level perspective is helpful to frame the approach taken in this research to analysing passenger car sector decarbonisation measures, offering a holistic, systematic view of the problem while recognising the complexity of interactions with elements within *and beyond* the immediate bounds of the socio-technical regime of automobility. Insofar as this research explores the potential for mitigation at the sectoral level, the conceptual framework underpinning analysis and discussion of the automobility regime (or system) is the multi-level perspective of socio-technical transitions, after Geels (2012) and Geels and Kemp (2012) *et al*. However, insofar as it considers the sensitivity of sectoral emissions to potential changes across all of the constituent regimes that comprise automobility, this research also recognises the value of disciplinary insights from relevant fields of research, which typically use more narrowly focused conceptual 'filters' than the systems level of MLP and socio-technical transitions.

1.4.2 Competing frameworks in demand-side research

Whereas epistemological issues tend not to arise as salient themes in the literature on supply side measures[17], the conceptual framing of demand-side issues is much more hotly contested (see for example Shove 2010; Whitmarsh *et al* 2011; Wilson and Chatterton 2011). Thus, a variety of disciplinary perspectives compete to situate and guide research into the 'user and market' and socio-cultural regimes including:

i. psychological approaches, particularly with respect to behaviour *change*
ii. economic approaches, particularly theories of random utility and decision making
iii. sociological approaches, including consumption and 'theory of practices'
iv. geographical approaches, including mobilities and 'time geography'

Broadly speaking, psychological and economical interpretations may be seen as essentially individualist and deterministic in their conceptualisation of behaviour; whereas sociological and geographical approaches are more structuralist and allow for emergent properties from the interaction of agents within social systems. A full discussion of the merits and limitations of each alternative interpretation is beyond the scope of this brief introduction. However, the following sub-sections give a brief overview of the key theories and tenets in each of these areas, with an eye to their applicability to the investigation of effective mitigation at the scale and rate of interest in this research.

1.4.2.1 Individualist behavioural framings

Individualist approaches have arguably exerted considerably greater influence on political thinking about demand-side interventions than structuralist approaches in recent history. Psychological theories of behaviour and behavioural change in particular have come to dominate contemporary policy debates about interventions. Psychological thinking and language permeate everyday discourses about people's actions and interactions with their environments; the first-person experience of having reasons and motivations which consequently determine our actions is hard to shake. Hence, due to

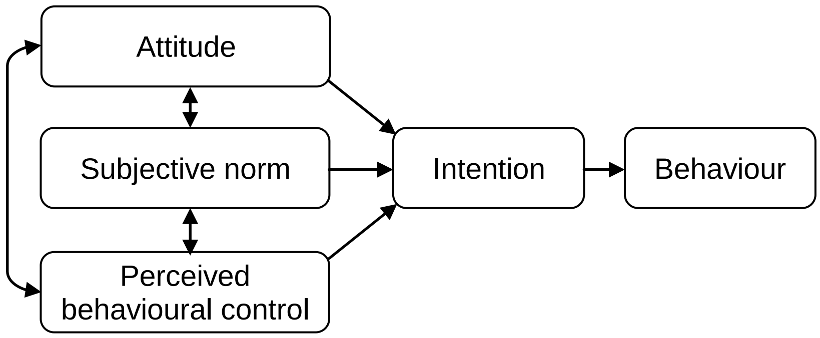
[17] Comprising a wide variety of technical specialisms, engineering is ostensibly united by a common, fundamentally positivist, perspective with hierarchical power relationships (Schwanen *et al* 2011). By contrast, with respect to demand, the divergent disciplinary and theoretical backgrounds of researchers and policy-makers alike guides the degree to which interventions are held to be possible, desirable or necessary.

people's strong subjective sense of individuality and autonomy, the appeal of psychological interpretations is undeniable. Related to this sense of agency is the age-old debate about free will versus determinism, but in explaining the sense of volition that emerges from behavioural antecedents such as values, beliefs etc, the causal chains invoked by psychology are highly deterministic. Thus policy research on 'pro-environmental behaviours' (PEB), embraced by government departments such as Defra and DfT, proceeds from psychological assumptions which situate the locus of intervention with individual choices and decisions, which can be targeted by interventions to produce the desired change in behaviour (Lucas *et al* 2008).

Behavioural determinism lends itself well to representation as theoretical models, which often focus on the interplay of the supposed antecedents of behaviour, such as attitudes, values and beliefs. Four of the most studied and debated psychological models of behaviour are summarised in Box 4.1. Such models have been criticised for portraying attitudes, beliefs and emotions, as *preceding* and *causing* behaviour. Setting aside for the moment the question of conscious and unconscious attitude and affect, this critique highlights that attitudes and beliefs are in some cases more likely to be the *result* of behaviour, rather than the other way round (Aarts *et al* 1998; Shove 2010). For instance, evidence suggests that people who routinely drive to work may give a convincing account of conscious reasons for doing so, but the reality may be that the routine itself has taken over from any such deliberation on a daily basis (Møller and Thøgersen 2008). Triandis' 1977 Theory of Interpersonal Behaviour includes habit on a parallel track to attitudes etc, recognising the powerful influence of routine, and its ability to *lock-in* patterns of behaviour (Schwanen and Lucas 2011).

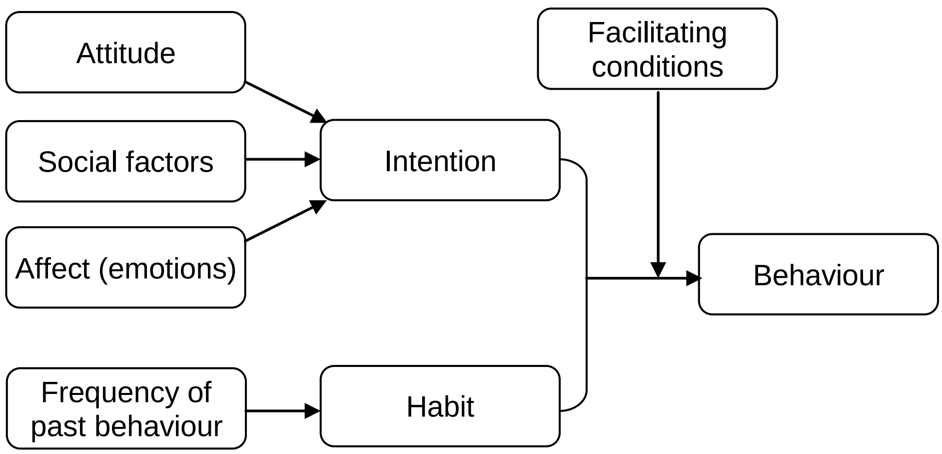
Box 4.1: Selected psychological models of behaviour

- Theory of Planned Behaviour (TPB) (Ajzen 1991)



Building on the earlier Theory of Reasoned Action (Ajzen and Fishbein 1980), Ajzen's 1991 model posits a behavioural intention as the immediate antecedent of action. Intentions are formed by the interplay of a person's attitudes (beliefs about the behaviour or some external stimulus), subjective norms (social influences and pressures towards particular behaviours) and perceived control (sense of ability to control relevant external factors which may assist or obstruct the action).

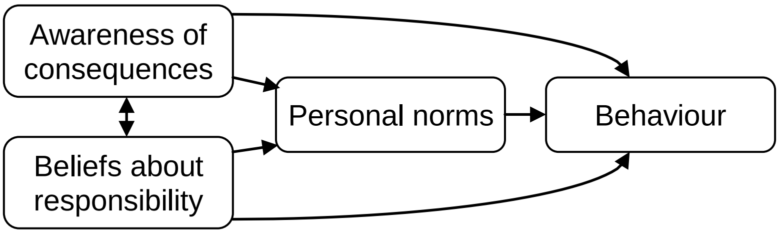
- Theory of Interpersonal Behaviour (TIB) (Triandis 1977)



Following a similar 'intentions as behavioural antecedents' logic as Ajzen's TPB, Triandis' model includes the important additional factor of habit. Significantly, habit is situated on a pathway to influencing behaviour separate from intention (Darnton 2011). This is important as it introduces the concept of automaticity, or uncritical doing-without-thinking, which is a feature of many repetitive or daily tasks. Habit is highly salient to travel, particularly to car driving, which not only depends on learning automatic responses in order to operate a vehicle and navigate traffic, but also because of the repetitive nature of many journeys (commuting to work, taking children to school, weekly shopping, social fixtures etc).

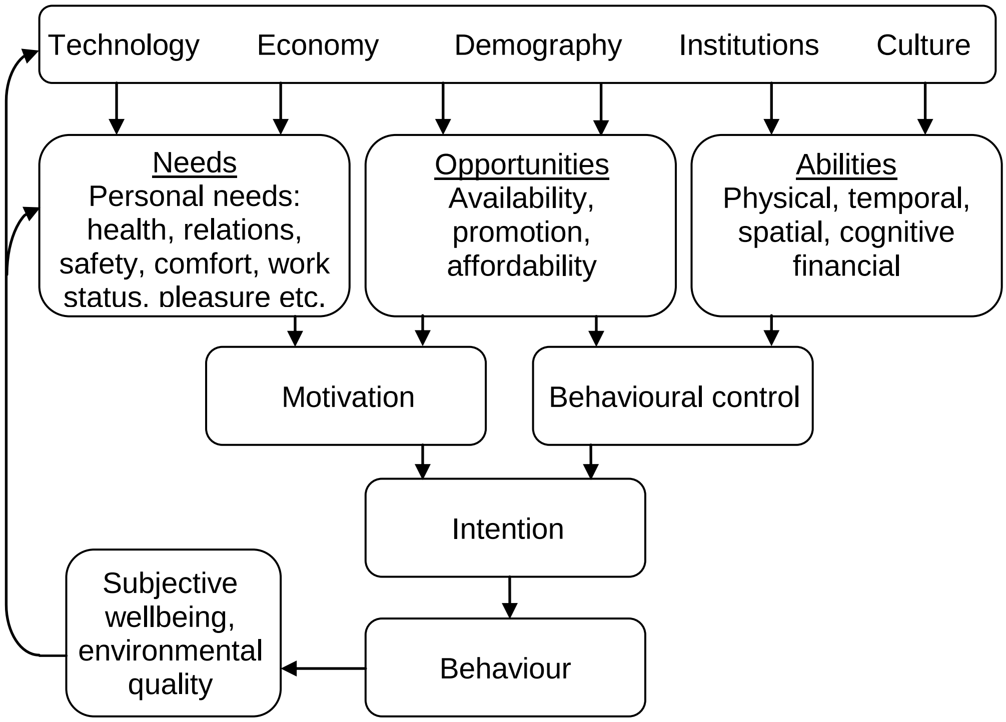
Box 4.1 continued

- Norm Activation Model (NAM) (Schwartz 1977)



Originally offered as an explanation of altruistic behaviour, Schwartz elevates the role of perceived social and cultural norms (in addition to personal norms) in the NAM model. Essentially a model of moral behaviour, NAM has clear applications in the field of environmentally significant behaviours. The possibility of ignorance or indifference to environmental or moral dimensions is captured by NAM in the two-way conversation between awareness of consequences and responsibility beliefs, which activate personal norms, or sense of duty. While not 'falsified' by habitual behaviour – such pathways yield low awareness of consequences – it does not give a particularly satisfying account of such non-moral behaviours.

- Needs–Opportunities–Abilities (NOA) (Gatersleben and Vlek 1998)



Situating a mental model of behavioural antecedents within a broader societal context, Gatersleben and Vlek's NOA model also incorporates the potential for individual behaviours to affect their environment. In this regard it goes beyond the purely psychological, opening up a bridge into sociology and science & technology studies.

Neo-classical economic approaches to understanding travel and driving behaviour based on random utility theory (RUT) have also enjoyed considerable political influence. At root, RUT assumes individuals select amongst a finite set of alternative behaviours according to principles of efficient resource allocation and minimisation of effort. The ‘utility’ of each alternative course of action is an abstract quantity reflecting how well the action satisfies the needs, desires and personal preferences of the individual, who is able to rank possible actions accordingly, selecting action to maximise (or optimise) utility. In recognition of the impossibility of perfect information and knowledge (bounded rationality), RUT builds in uncertainty by incorporating a stochastic or random component into the behavioural model, balancing the observable, deterministic component (Schwanen and Lucas 2011).

Qualitative attributes of the alternative courses of action (travel time, financial costs, level of forward planning required etc) and the broader situational context (purpose of travel, nature of origin and destination etc), along with demographic characteristics of the decision maker themselves (age, gender, income etc) are all widely applied to the deterministic component of RUT-based models (Schwanen and Lucas 2011, citing Ben-Akiva and Lerman, 1985). Co-efficients are estimated for each of the attributes, which allow elasticities to be estimated in turn for each independent variable of interest. Elasticities ostensibly permit researchers to assess the likely effect on the probability of any given behavioural outcome of a *marginal change* in a particular independent variable while holding all others constant. In case of non-marginal or ‘step’ changes, such elasticities are arguably invalid, both theoretically and practically, given the lack of appropriate historical analogues and the unknown scale of the costs of adapting to ‘dangerous climate change’ (Van Dender 2009).

1.4.2.2 Collectivist / structural framings

Whereas psychological and economic theories of behaviour focus on the individual, collectivist interpretations place the individual within a complex system of interconnected societal elements, which together exercise considerably more influence than personal attitudes, beliefs and values on ‘behavioural’ outcomes. Theories of practice have loosely coalesced around the writing of scholars such as Rip, Schatzki, Pred, Reckwitz, Giddens and Shove. These approaches, while gaining in prominence (see for example Darnton 2011), are still relatively marginal in terms of the sway exerted over actual on-the-ground policies and measures. Nevertheless, in acknowledging and embracing the real-world complexity of interactions constituting particular practices (for example car-commuting), such collectivist theories are arguably better suited to the systems level analytical approach pursued in this research.

Within such interpretations, repeated or habitual behaviours appear as a continuous flow of actions expressed as *practices,* of which people are *carriers,* rather than the end result of a causal chain of psychological antecedents. Shove *et al* (2012) distil the essential elements of a practice into: (i) materials (technology, artefacts, infrastructure), (ii) competences (skills, expertise, practical ability), and (iii) meanings (images, ideas, what is signified). Given the complexity involved in the emergence of practices from many carriers, practice theory does not offer easy answers with regard to changing demand for travel. Nevertheless a working model to operationalise the key tenets of the theory has been compiled by Shove and Darnton, reproduced in Figure 1.6. In this policy tool, the competences element becomes a component of 'procedures', which is disaggregated into competences plus two further constituent parts: schedules, which support the timetabling of the practice, and the policy frameworks or landscape within which the practice occurs.

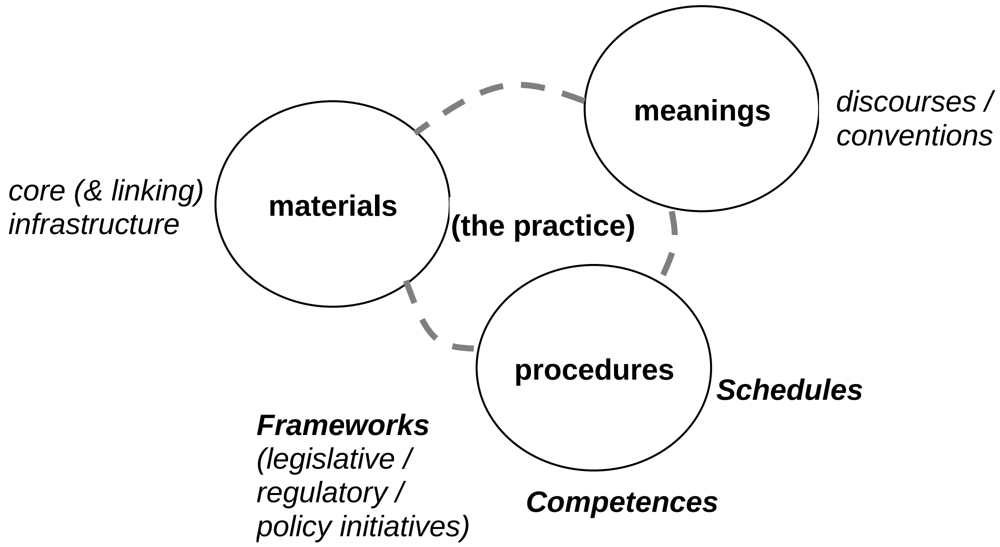


Figure 1.6: The three elements of practice 'tool', devised by Shove and Darnton – reproduced from Darnton 2011.

With respect to personal travel, practice-related theories have been dubbed the *New Mobilities Paradigm* (Sheller and Urry 2006; Urry 2008). Framing demand by situating driving activity as the emergent property of a nexus of personal, physical, cultural and political elements dovetails with the MLP approach to the system of automobility writ large, as described above. A further important feature of routinised behaviour recognised by the practice approach is the potential for lock-in to specific patterns of behaviour, whereby an "individual's choice not to undertake a particular behaviour is limited" (Darnton 2011: p.39). Thus the practice space is constrained not only by supply-side factors, but also 'lifestyle influences'.

1.4.3 Syncretic framing: overcoming structure–actor dualism

The role of *habits* in forming behaviour and creating the possibility for intervening in the contextual factors that cue the performance of certain habits has received growing attention in recent years (Verplanken and Wood 2006). Whereas the traditional psychological view of habits has been that they present a barrier or driver to action, sociological perspectives place habits at the centre, effectively taking the place of behaviour itself (Darnton 2011).

Maréchal (2010) proposes a theoretical framework within which to explore energy consumption, placing habits as the locus of interaction between structuralist / institutional accounts (such as the aforementioned theories of practices) and individualist interpretations (such as the social psychological theories in §1.4.2.1) (Figure 1.7). Darnton (2011) also notes the commonality of habits to both framings.

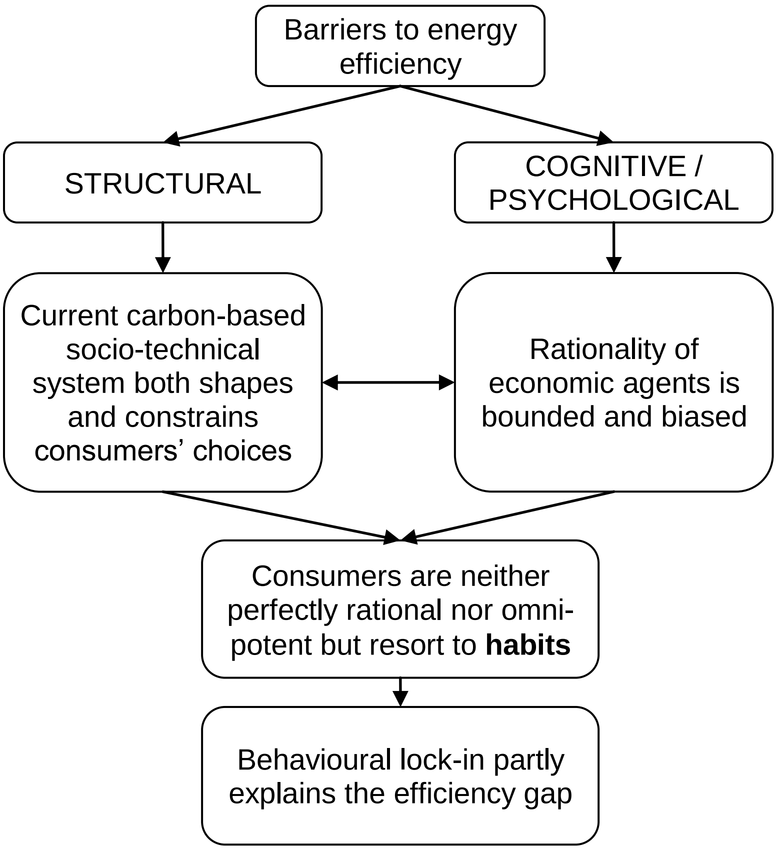


Figure 1.7: Complementary theoretical framing of the 'efficiency paradox', placing habits as the point at which structural and behavioural influences interact (i.e. the rebound effect, also known as Jevons' Paradox). Reproduced from Maréchal (2010).

Maréchal quotes Hodgson (2007: p.404) in suggesting that individuals and institutions "mutually constitute and condition each other"; elaborated elsewhere by Hodgson as "habits are the constitutive materials of institutions", while the existence of institutions themselves lead to "accordant habits...[being] further developed and reinforced among the population" (Hodgson 2007: p.107). Maréchal goes on to propose that, "the influencing institution to be accounted for... is what is termed the Socio-Technical System (STS)" (Maréchal 2010, p.1105).

Considering the role of individualised agency (or at least the individual's sense of agency), Røpke summarises Giddens theory of structuration, observing that:

"most routinized activities are carried out based on a practical consciousness that does not require conscious reflection. Instead of conceiving of actions as isolated events, agency is seen as a flow of activities in an ongoing process. Accordingly, intentionality is also seen in a processual perspective rather than as relating specific motivations to specific actions. Reasons for actions can be discursively formulated, however, for instance when agents are asked questions and upon reflection become open to change, which implies that agents are far from passive "slaves" of structural pressures" (Røpke 2009, p.2491).

1.4.4 Putting theory into practice

In the following Chapters 2 to 4, the diverse sets of issues particular to each constituent 'regime' (science, policy, user and market, socio-cultural etc) are considered in turn, and on their own terms. The mixed-method toolset assembled to address the core research questions 1–6 in §1.2.2 above and described in detail in Chapters 5–7, necessarily cuts across a number the theoretical frameworks native to each relevant academic discipline. The calculation of sectoral emissions budgets (Chapter 5) is essentially positivist in its application of the scientific principle of cumulative emissions, but also invokes a number of normative arguments with respect to selecting the 2°C temperature threshold and dividing emissions headroom amongst Annex 1 and non-Annex 1 nations. The conceptualisation of the fleet emissions model (Chapter 6) fits well with the framework of technology regimes as expounded by Rip and Kemp (Rip and Kemp 1998), given the embedding of changes to vehicle–fuel carbon efficiency within the institutions of automotive manufacturing and European Union emissions regulation. The decadal timescale over which changes are considered is consonant with *transformation* transition pathways, which occur "when there is moderate landscape pressure at a moment when niche-innovations have *not* yet been sufficiently developed, leading regime actors to respond by modifying the direction of development paths and innovation activities" (Geels and Kemp 2012, p.60).

The fleet modelling exercise estimates the effects of changes to mean new car vehicle–fuel efficiency (the technology regime) in combination with assumptions about levels of demand for vehicle kilometres (the user and market regime). The scale and rate of technology regime changes are grounded within the scientific literature on supply side measures available in the near term. Likewise, the potential for demand-side changes is grounded in the literature on interventions, but also investigated through primary research which explores the mutually constitutive relationship between travel habits and the institutions which enable and constrain them. The results from qualitative interviews with members of the driving public are presented in Chapter 8 in such a way as to reflect these complementary influences. Qualitative findings are subsequently discussed in relation to the emissions budgets and quantitative outputs from the fleet emissions scenarios in Chapter 9, taking into account the foregoing analytical framework of practices and agency.

CHAPTER 2 – CLIMATE AND TRANSPORT POLICY

2.1 General context: climate science and the political landscape

Before investigating the potential for policies or interventions to achieve certain emission reduction (or mitigation) targets, it is appropriate to stop and ask why specific targets have been selected and to make sure they are well founded in science. This chapter focuses first on the political process by which 2°C came to be adopted internationally as the threshold of concern, widely taken as synonymous with ‘preventing dangerous climate change’. While the overarching aim of restricting warming to 2°C is normative in origin, the level of mitigation required to deliver this goal must be determined by explicitly scientific means if it is to have real value.

2.1.1 Correlation trail

The following review of climate science and mitigation policy builds on the approach taken in Anderson *et al.* (2008), which highlights the strong correlation between cumulative emissions and temperature rise. The discussion follows the logical correlation trail of evidence shown in Figure 2.1, working back from a 2°C threshold to *scientifically consistent* global and national mitigation objectives. Thus debate is shifted away from long-term emissions reduction targets (such as ‘cutting 2050 emissions by 80% compared to 1990 levels’) onto absolute emission budgets derived from robust assessment of the available global emissions headroom.

The focus of the chapter then turns to national and passenger car sectoral mitigation policy as currently enacted in the UK, and reflects on the extent to which it is premised on a scientific approach. This allows the correlation trail to be extended to the individual sectoral level (a detailed methodology for quantification of a sectoral budget and pathway for the passenger car sector is presented in Chapter 5).

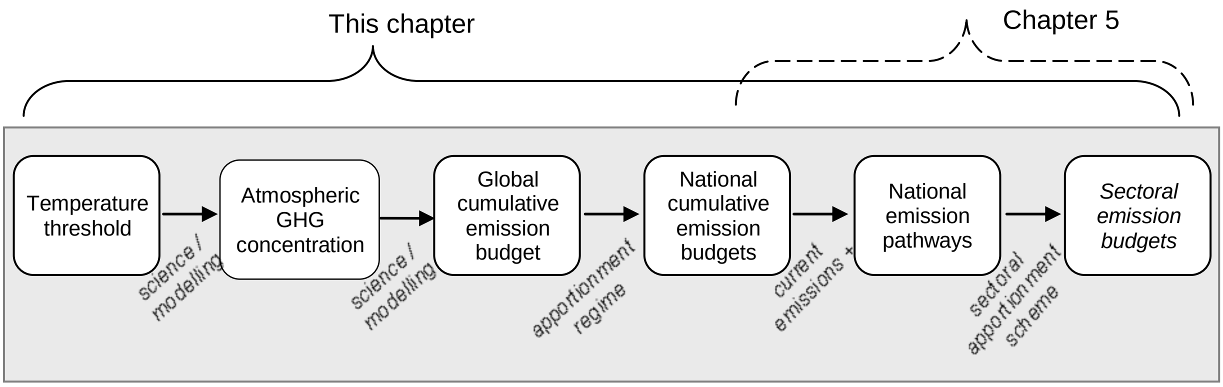


Figure 2.1: Correlation trail extended by an additional step to the level of individual national sectors. Adapted from Anderson and Bows (2007). Focusing on costs of mitigation and abatement, Hammit (1999) describes a similar causal chain linking GHG emissions to climate change and damages.

2.1.2 The origins of 2°C

Accepting as a starting point the UNFCCC's definition of climate change as "...*attributed directly or indirectly to human activity* that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC 1992: Article 1, §2 - italics added), there remains scope for debate as to the appropriate metric by which to quantify change. Adopting a broader definition of climate change, which includes natural (or non-anthropogenic) causes, the Intergovernmental Panel on Climate Change (IPCC) has become more confident since its Third Assessment Report ('TAR') of the human-induced contribution. The IPCC's Fourth Assessment Report ('AR4') states that the steady and unprecedented 0.74°C rise in global mean surface temperature witnessed over the last century (the rate of change itself increasing over the last fifty years) is *very likely* caused mostly by increases in atmospheric concentrations of greenhouse gases *from human activity* (anthropogenic GHGs) (IPCC 2007b, p.72).

Temperature increase as a metric of climate change has the advantage of obvious, observable effects, including sea-level rise due to thermal expansion of the oceans, vegetation shift and species loss due to ecosystem changes and an increase in the frequency and severity of extreme weather events. These effects in turn have severe and all too tangible implications for food and water security, especially in coastal, tropical and subtropical regions. This visibility of attributable effects means that temperature increase has emerged as the primary measure of climate change. The need to ground mitigation policy in publicly understandable terms has also served to recommend limiting increase in temperature as the headline political goal. Thus in 1996 the Council of the European Union specified an increase in global mean surface temperature (hereafter simply 'temperature') of 2°C over pre-industrial conditions as its 'line in the sand', and so began the construction of policy to address that goal:

> "The Council recognises that, according to the IPCC S.A.R. [Second Assessment Report], stabilisation of atmospheric concentrations of CO_2 at twice the pre-industrial level, i.e. 550ppm, will eventually require global emissions to be less than 50% of current levels of emissions; such a concentration level is likely to lead to an increase of the global average temperature of around 2°C above the pre-industrial level. Given the serious risk of such an increase and particularly the very high rate of change, the Council believes that global average temperatures should not exceed 2 degrees above pre-industrial level and that therefore concentration levels lower than 550 ppm CO_2 should guide global limitation and reduction efforts". (CEU 1996)

Hence the Council adopted as its overriding climate policy principle the avoidance of a 2°C rise effectively because the IPCC Second Assessment Report ('SAR') of the previous year had projected (modelled) such an increase in temperature for its mid-range emission scenario, assuming the (then) "best estimate" value of climate sensitivity

(IPCC 1995, section 2.7). In essence, the Council simply determined that a 2°C temperature increase should not be exceeded.

2.1.2.1 In support of 2°C – likely impacts

The Council's use of the normative term 'should' is significant and prompted criticism of the scientific foundations of EU climate policy[18]. For example, Tol (2007) criticises the EU's basis for selecting the 2°C threshold for lacking grounding in scientific assessment and quantification of acceptable and unacceptable risks to the human population and critical resources. Tol also decries the widespread acceptance of 2°C as a *de facto* threshold in the policy community, which he claims is evidence of ignorance of the absence of scientific grounding for such a threshold.

More recent research indicates that 2°C as a threshold to be avoided can in fact be supported scientifically. For instance, Richardson *et al* (2009) consider the sensitivity of ecosystems and societies to temperature rises, noting that beyond the 2°C 'guardrail' the potential for adaptation falls off sharply. Similarly, following a systematic review of the literature since 2001's IPCC–TAR, Smith *et al.* (2009) update the 'burning embers diagram' (a visual representation of the risk thresholds for five key 'reasons for concern' related to climate change), downwardly revising the temperature thresholds at which all five reasons for concern transition from 'moderately significant risks' (yellow) to 'substantial or severe risks' (red). New *et al* (2009) also present a strong case for restricting warming to 2°C, but soberingly highlight the prudential step of planning adaptation in readiness for likely exceedance.

Commenting on Smith *et al*'s work, Mann (2009) observes that due to continually emerging evidence about the risks inherent in rising temperature, the risk averse policy maker would be unlikely to accept a definition of dangerous anthropogenic interference (with the climate) of anything above +1°C over 1990 levels. Mann also notes that even a gambler would struggle to conscience a definition of dangerous anthropogenic interference in excess of 2°C above 1990 levels, where aggregate impacts are negative for all reasons of concern, and "the risk of large-scale discontinuities [abrupt and / or irreversible changes] becomes non-trivial" (Mann 2009: p.4006).

Lenton *et al.* (2008) found (through expert elicitation) that the temperature relating to the critical value of control for certain Earth system tipping elements (e.g. loss of Arctic Sea Ice, collapse of the Greenland Ice Sheet) is likely to be in the range 0.5–2°C above 1990 levels (i.e. 1.1–2.6°C above pre-industrial levels – temperatures having already increased by 0.6°C above preindustrial levels during 1900–1990 (Smith *et al* 2009)).

It is important to note that 2°C refers to the global *mean* surface temperature increase. Temperatures will not change uniformly around the world: increases greater than this

[18] This reasoning infracts 'Hume's law', (a.k.a. the 'fact–value distinction'), which forbids deriving an 'ought' from an 'is' (Hume 1975).

average will be experienced in some regions. Steffen's (2009) report for the Australian government highlights that while the current mean global temperature is 0.8°C higher than before industrialisation, Arctic temperatures have increased at about double that rate. Steffen cites evidence associating elimination by surface melting of the Greenland Ice Sheet with a 1.9–4.6°C increase in temperature above the pre-industrial. Due to the uneven warming of the Earth's surface, the polar region is already fast approaching this threshold. Similarly, in already water-stressed regions, increases of only 1°C have been found to adversely affect the availability of water resources (Steffen 2009). For many parts of South and South-East Asia and Sub-Saharan Africa, the detrimental effects of rising annual mean temperatures on crop yields, heat-waves and vector-borne disease means that an increase of less than 2°C above the pre-industrial may already be interpreted as constituting dangerous climate change (McMichael and Bertollini, in Richardson *et al* 2009).

Limiting the increase in temperature to 2°C, therefore, is arguably an appropriate policy objective, defensible in retrospect, since exceedance of this threshold can reasonably be said to correspond to 'dangerous anthropogenic interference' with the climate system, or, simply, 'dangerous climate change'. Remembering that, due to thermal inertia the climate is already committed to *further warming* of 0.3–0.7°C, a guardrail of 2°C above pre-industrial temperatures appears not only justified but extremely challenging given the 0.74°C increase already witnessed over the last century (see §2.1.2).

2.1.3 Atmospheric stabilisation

Although the causes of temperature increase are less tangible than its effects, there is now little question that the principal cause of the observed rate of increase in temperature over the last century is radiative forcing by long-lived GHGs *accumulating* in the atmosphere. By far the most important GHG is carbon dioxide (CO_2), due to its abundance and long atmospheric residence time (IPCC 2007b, p.36). Radiative forcing is a measure of the effect of external perturbations to the climate system, which affect the atmospheric balance of incoming solar and outgoing infrared radiation, which in turn controls the Earth's surface temperature (IPCC 2007a).

2.1.3.1 Climate sensitivity

Uncertainties in the sensitivity of the Earth's climate system to elevated concentrations of GHGs mean it is no simple task to determine the upper limit of the atmospheric concentration of GHGs that gives a 'good chance' of less than 2°C increase in equilibrium temperature. The IPCC estimates that stabilisation at 350–400 ppmv CO_2 (approximately 450 ppmv CO_2 equivalent[19] or CO_2e) is likely to result in temperature increase of approximately 2–2.4°C above pre-industrial levels, based on a 3°C best estimate of climate sensitivity, an early peak global emissions year (by 2015 – see

[19] The 'basket of six' Kyoto greenhouse gases are carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

§2.1.4.1 below) and with 60-85% emissions reduction by 2050 (IPCC 2007b, table 5.1, p.67)[20]. However, the appropriateness of conventional best estimates of climate sensitivity (Charney 1979) of 3°C ± 1.5°C for a doubling of pre-industrial atmospheric concentration of CO_2 (approximately 275ppm (EEA 2009a)) is increasingly questioned. Hansen *et al.* (2008) warn that once slow climate feedbacks are included, true sensitivity may be as much as twice the conventionally assumed 3°C. Climate modelling studies tend to use a range of probability density functions (PDFs) for climate sensitivity (Hare and Meinshausen 2006; Meinshausen *et al* 2009), to allow for the possibility that other mechanisms may increase true climate sensitivity, but higher values such as Hansen *et al*'s cannot be ruled out (Knutti and Hegerl 2008).

Furthermore, climate sensitivity itself is not in equilibrium (Cox *et al* 2006). The balance between GHG emissions and the absorptive capacity of carbon sinks (oceans and vegetation that absorb and store carbon), has been severely disrupted – exploitation of the planet's natural resources has led to removal and degradation of carbon sinks, and remaining sinks are believed to be nearing capacity (Falkowski *et al* 2000). Human activities currently release GHGs into the atmosphere faster than sinks can absorb them (and much faster than they decay[21]), hence net accumulation in the atmosphere occurs and concentration rises. Sinks currently absorb approximately 50% of the CO_2 emitted from human activities (Jones *et al* 2006). Beyond this, the increase in atmospheric GHG concentration and the point at which it eventually stabilises (for a given quantity of GHGs emitted over a fixed time) depends on complex interactions between carbon cycle feedbacks and the radiative forcing effect of the *accumulated GHGs* (Lenton 2000). Carbon cycle feedback mechanisms mean, for example, that as temperature rises the ability of the oceans and land to absorb carbon from the atmosphere decreases, thus a greater proportion of emitted GHGs is left to accumulate, which causes temperature to rise further, and so on (Fung *et al* 2005; IPCC 2007b). Such amplifying feedbacks have the potential to switch the response of sinks, for example causing the land biosphere to change from acting as a net sink of carbon to a net source, highlighting the non-linear effects of feedbacks in combination (Allison *et al* 2009).

2.1.3.2 Global cumulative emissions

Allen *et al* (2009) sidestep the problems posed by the uncertain understanding of feedbacks both in the climate cycle (e.g. albedo flip, methane release from permafrost) and carbon cycle, by modelling the temperature response to a given cumulative quantity of CO_2. Over a series of simulations, Allen *et al.* found the increase in temperature associated with an absolute quantity of CO_2 to be much better constrained (i.e. modelled simulations yield a narrower band of possible values) than the increase in temperature

[20] The global mean atmospheric CO_2 concentration was 394 ppmv in April 2012 (Conway and Tans 2012).

[21] Atmospheric residence times extend to hundreds of years for CO_2, millennia for PFCs and SF6 (Forster *et al* 2007).

associated with atmospheric stabilisation scenarios. They sum up the difficulties inherent in trying to derive emissions budgets from temperature targets or vice versa as the ‘stabilisation dilemma’:

> “either we specify a temperature or concentration target and accept substantial uncertainty in the emissions required to achieve it or we specify emissions and accept even more uncertainty in the temperature response”. (Allen *et al* 2009: p.1164)

Allen *et al* calculate that 3.67 trillion tonnes of CO_2 emitted from human activities corresponds to peak warming of 2°C above the pre-industrial, of which roughly half is already spent[22]. Peak warming showed very little sensitivity in their simulations to the timing of additional future emissions, leading them to propose that there is a ‘cumulative warming commitment’ for any given additional quantity of CO_2, assuming a rapid emission reduction pathway thereafter. In support of this approach, Meinshausen *et al* published a ‘2°C check tool’ (*PRIMAP*) to enable ready comparison for any given cumulative emissions budget of the range of probabilities of exceeding 2°C returned by nineteen peer reviewed PDFs for climate sensitivity (Meinshausen *et al* 2009, supplementary data).

When the remaining 50% of Allen *et al*’s 3.67 trillion tonnes CO_2 is compared to the cumulative budgets estimated by other scientists, there appears to be cross-corroboration. Specifically, the IPCC central estimate for the cumulative global carbon budget for the 21st century that they associate with a 450 ppmv CO_2 atmospheric stabilisation target while accounting for carbon-cycle feedbacks is c.490 GtC (range: 375–600 GtC), corresponding to CO_2 emissions of c.1800 $GtCO_2$ (range: 1370–2200 $GtCO_2$[23]) (IPCC 2007b, p.16). Allen *et al’s* 1835 $GtCO_2$ estimate of remaining emissions headroom associated with a cumulative warming *commitment* of 2°C suggests that the lower half of the range of IPCC cumulative emissions budgets only is relevant to 2°C. Indeed the IPCC equates 450ppm CO_2 with at least a 2.8°C increase (IPCC 2007b).

Similarly, Macintosh (2010) notes convergence amongst the recent breadth of independent climate sensitivity modelling studies, which indicates that a 21st century global emissions budget below 430 GtC (1578 $MtCO_2$) is required for a better than 50% chance of not exceeding 2°C. Allowing for the possibility of more rapid and pronounced responses in carbon cycle feedbacks than conventionally expected, Macintosh also

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[22] In a separate commentary, Allen *et a.* note that having taken 250 years to consume the first half of this total, the world is now on track to use up the remaining half in less than 40 years (Allen et al, 2009, Nature Reports)

[23] These IPCC–AR4 figures are for CO_2 *only*, whereas in order to relate emissions to temperature it is necessary to work in CO_2e to budget for the warming potential of non-CO_2 GHGs too. However in this case the amounts are interchangeable, as 1tCO_2 has a CO_2-equivalence of 1t, but it should be noted that non-CO_2 GHGs are not included in these IPCC stabilisation values.

estimates that a 21st century global budget of 360 GtC (1321 $GtCO_2$) would be required for a similar probability of not exceeding 2°C.

Analysing the implications of 'the spirit' of the Copenhagen Accord, Ramanathan and Xu (2010) find that to limit the probability of exceeding 2°C warming by 2050 to 10% or less, and by 2100 to 50% or less a 'full mitigation' budget of c.1375 $GtCO_2$ is required for the remainder of the 21st century.

2.1.3.3 Current and recent historical emissions

The 'global financial crisis'[24] notwithstanding, global emissions have continued to grow at a faster rate than assumed by most analyses (e.g., Smith and Wigley 2006; Clarke *et al* 2007; Clarke *et al* 2009; Wise *et al* 2009). Global CO_2 emissions from fossil fuels and industry increased by 5.9% in 2010, giving the highest annual growth in absolute emissions ever recorded (Peters *et al* 2012). Sheehan (2008) also highlights the use of inappropriately low reference cases in influential climate models, noting that most projections fail to allow for China's anomalous decreased energy consumption between 1979-2001, and that the IEA's and IPPC's emissions growth projections are gross underestimates, failing to capture the observed rapid growth in coal use. Remaining within a given temperature-related cumulative budget, therefore, means taking abatement action immediately and strictly limiting emissions in future.

2.1.4 Apportionment regimes

How the remaining global emissions headroom (i.e. the not-yet-emitted remainder of the cumulative budget for a given stabilisation target (Socolow and Lam 2007) or probability of exceeding a given temperature target) is shared out between countries is really a question of how responsibility for mitigating emissions is shared internationally. Den Elzen and Höhne (2008) summarise the numerous systems that have been proposed by which to allocate a fair share of the remaining global emissions headroom to each nation. Despite decades of negotiations, most recently at UNFCCC Conferences of the Parties in Bali (2007), Copenhagen (2009) and Durban (2011), no agreement has yet been reached on the 'differentiation of future commitments' (den Elzen *et al* 2005) with respect to sharing mitigation obligations between nations. In order to increase their 'standard of living' and attain the welfare benefits of industrialisation, poorer nations inevitably must increase their emissions in the short term. Finding an apportionment regime that respects the development needs of poorer nations, while securing the buy-in of the wealthiest and most CO_2-polluting nations, looks set to be the subject of political horse-trading for some time to come. Without an international agreement in place, industrialised nations have so far proved reluctant to make the stringent cuts in their

[24] The so-called 'global financial crisis' essentially privileges a Western perspective. A more appropriate description is arguably the 'global economic downturn', and in reality this only refers to a reduction in the *rate* of global economic growth.

levels of consumption that would sufficiently reduce their emissions to allow for industrialisation in poor countries while respecting a global budget.

The most broadly acceptable apportionment mechanism is likely to be a form of ‘contraction and convergence’ (C&C), in which all nations reduce per capita emissions to a specified shared global pathway. A refinement to C&C, known as ‘common but differentiated responsibilities’ (Höhne *et al* 2006) allows for delayed convergence for developing countries. This gives poorer, non-Annex 1 countries room to increase their emissions up to a threshold, beyond which point they join Annex 1 countries on the convergence pathway. Other options include the ‘Brazilian Proposal’, taking historical emissions into account in determining the extent of countries’ future commitments (den Elzen *et al* 2005). In setting this out, den Elzen *et al* note that varying the year from which historical emissions are counted (say from 1890 to 1990) considerably alters the ‘level of responsibility’ borne by the earliest industrial nations for the present atmospheric concentration of GHGs.

Focusing on the correlation between per capita wealth and per capita emissions, Chakravarty *et al* (2009) propose that ‘common but differentiated responsibilities’ refer to individuals rather than nations. They derive national emissions budgets by aggregating the responsibilities of individual citizens, based on a combination of current wealth and historical national participation in industrialisation. Intended as a means to broker international buy-in rather than for shifting the burden onto individuals, Chakravarty *et al*’s system accounts for the fact that late-emitting but rapidly industrialising non-Annex 1 countries tend to contain many wealthy individuals who benefit disproportionately from their country’s current and historical emissions, while in even the richest Annex 1 countries there are people who live in relative poverty, consuming little.

2.1.4.1 Annex 1 vs. non-Annex 1 pathways

IPCC–AR4 applies the various approaches to apportionment to the Annex 1[25] and non-Annex 1 groups of countries rather than individual nations, and compares the reductions implied by 2050 against 1990 emissions for given stabilisation scenarios (c.80–95% cuts for Annex 1 countries for a 450 ppmv CO_2e scenario, with non-Annex 1 making a ‘substantial deviation from baseline’) (Gupta *et al* 2007). Anderson and Bows (2011) develop the Annex 1 / non-Annex 1 approach by applying recent historical emissions and current trajectories for both groups to the absolute emissions budgets estimated by Macintosh (2010). With pathways constrained by global budgets, taking deforestation as a ‘global overhead’[26], and allowing for continued non-Annex 1 emissions growth driven

[25] i.e. the forty-one countries plus the European Union which are Annex 1 parties to the United Nations Framework Convention on Climate Change (UNFCCC) – the industrialised countries and ‘countries in transition’. Some writers, for example Peters *et al* (2012), refer to industrialised countries as ‘Annex B’ parties to the Kyoto Protocol – effectively the same group of countries as Annex 1, with the exception of Turkey and Belarus, which are in Annex 1 but not Annex B.

[26] Emissions from deforestation are estimated to account for approximately 8.5% of global emissions in 2010 (Houghton 1999; Global Carbon Project). While the majority of deforestation activity in future years will take

by increasing consumption in the short term[27], Anderson and Bows demonstrate the pivotal importance of non-Annex 1 emissions pathways in defining emissions space for Annex 1 nations, observing:

> "Only if Annex 1 nations reduce emissions immediately at rates far beyond those typically countenanced and only then if non-Annex 1 emissions peak between 2020 and 2025 before reducing at unprecedented rates, do global emissions peak by 2020".

Considering that current emissions trajectories of non-Annex 1 economies show no signs of conforming to a peak before 2025–30 (making a global peak before 2020–25 more or less impossible (Garnaut *et al* 2008)), and reflecting on the dominance of the conventional economic growth paradigm, Anderson and Bows conclude that "there is now little to no chance of maintaining the rise in global mean surface temperature at below 2°C" (Anderson and Bows 2011: p.41). It should be noted that this conclusion is a judgement about widespread institutional unwillingness to accept major changes to the economy, rather than a statement of physical impossibility.

2.1.5 Defining an 'acceptable probability' of exceeding 2°C

Whereas Anderson and Bows (2011) point to the inconsistency between constant economic growth and bringing emissions within the scope of a budget associated with a low probability of exceeding 2°C, the UK Committee on Climate Change's (CCC) argues that it is no longer possible to ensure a low probability of exceeding 2°C due to the quantity of historical emissions and the indeterminate nature of the climatic response (CCC 2008a: p.16). The goal recommended by the CCC is therefore to limit the 'central expectation'[28] of global mean temperature increase to 2°C or as close as possible. Portrayed as pragmatic, this subtle shift from a high to a low probability of *staying at or below* 2°C (alongside the probability of a rise of 4°C being restricted to less than 1%) relaxes the amount of warming that is considered acceptable and, due to intransigence with regard to fundamental economic change (see for example Jackson 2009; Simms *et al* 2010), widely held to be inevitable. Despite the CCC's recommendation, the UK government subsequently signed the Copenhagen Accord, with its express commitment to *"hold the increase in global temperature below 2 degrees Celsius"* (UNFCCC 2009). Given the evidence of likely impacts of the 'cumulative warming commitment' already in train (see §2.1.3.2), let alone from exceeding 2°C, this research does not explore scenarios in which the UK abandons its pledge to limiting warming to 2°C

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place in non-Annex 1 countries, arguably the resulting emissions are a 'global overhead', since Annex 1 countries have already deforested and emitted CO_2 in doing so (Anderson and Bows 2011).

[27] Recognising that development priorities are at the heart of the Copenhagen Accord: "social and economic development and poverty eradication are the first and overriding priorities of developing countries" (UNFCCC 2009).

[28] Elsewhere referred to as the central estimate (e.g., CCC 2010d), i.e. a 50:50 chance.

2.2 **UK emissions scenarios**

2.2.1 UK pathway in relation to global pathway

The UK's carbon budgets (Carbon Budgets Order 2009 and 2011) are ground-breaking in acknowledging the importance of cumulative emissions with respect to climate change and in framing mitigation as *cumulative constraints*. However, it is important to distinguish between the five-yearly statutory budgets and a long term national carbon budget which can be related back to a named probability of exceeding 2°C by a chain of correlation (see Figure 2.1, p.43). The present UK short-term carbon budgets derive from a national emissions pathway (the 'interim pathway') based on the CCC's *2016:3%* global pathway, in turn derived from a global cumulative emissions budget associated with a 63% probability of *exceeding* 2°C warming by the end of the century (CCC 2008a)[29]. In the event that a global agreement on emissions reduction is reached, it is proposed that the UK will adopt the 'intended pathway', based on the CCC's *2016:4% low* global pathway, associated with a 56% probability of exceeding 2°C.

While the language of uncertainty is sometimes open to interpretation, neither a 63% nor a 56% probability of exceeding 2°C warming are, according to the logic and language of estimative probabilities adopted by the IPCC (IPCC 2010), equivalent to a 'good chance' or 'high likelihood' of *avoiding* 'dangerous' interference with the climate system (IPCC 2007b)[30]. Moreover, the global pathways upon which the UK interim and intended pathways are based assume an unrealistic global emissions peak year of 2016 (Figure 2.2, p.53). Consumption emissions growth in non-Annex 1 countries alone (see §2.1.4.1 above) mean that global emissions will continue to grow well past 2016. Hence, without radical reductions above 3%–4% p.a., the CCC's global pathways appear untenably optimistic.

[29] The CCC 2016: 3% low pathway is attributed a 63% probability of exceeding 2°C, based on modelling climatic response to the 2000–2049 global emissions budget using the 'weighted Murphy *et al*' probability density function for climate sensitivity. Meinshausen *et al* (2009), found the range of probabilities of exceeding 2°C returned by nineteen peer reviewed PDFs, including 'weighted Murphy *et al*', for the CCC's 2000–2049 emissions budget is 38%–79%.

[30] Greater than 50% probability of occurrence is described by the IPCC (2007b) as 'more likely than not'; greater than 66% as 'likely'. Subsequent IPCC draft guidance for lead authors on consistent treatment of uncertainties dispenses with the >50% category, referring to 33–66% likelihood as 'about as likely as not', and >66% as 'likely' (IPCC 2010).

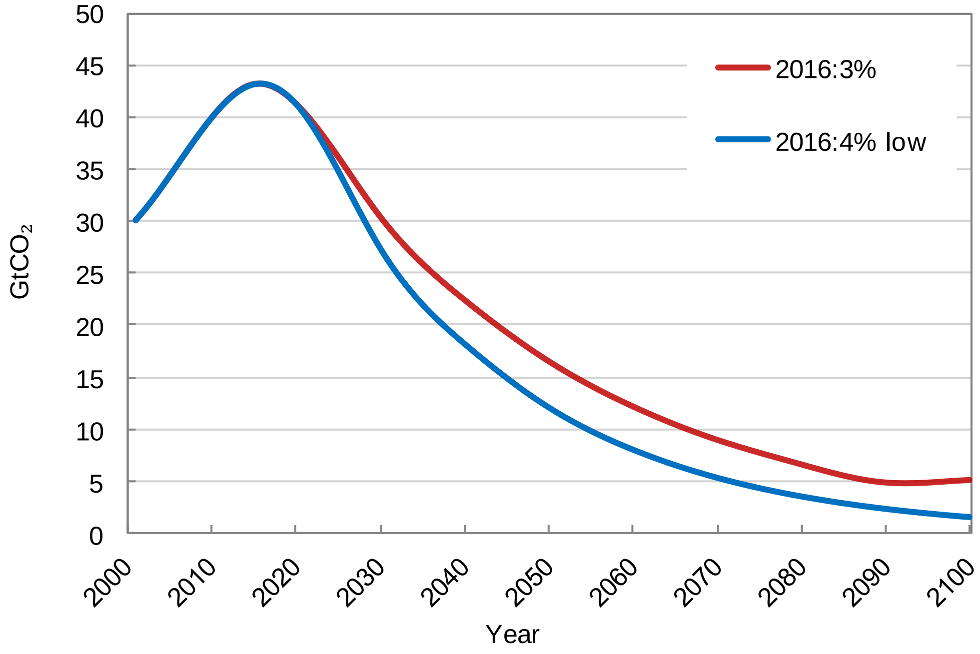

Figure 2.2: The CCC 2016: 3% and 2016:4% low global emissions pathways. The former is associated with a 63% probability of exceeding 2°C, the latter with a 56% probability (CCC 2008b). 2016 refers to the year in which global emissions are assumed to reach their peak. The percentage is the rate of reduction thereafter. 'Low' refers to the pathway's emissions floor[31].

The CCC does not state explicitly the mechanism by which the global *2016:3%* and *2016:4% low* global pathways (Figure 2.2) are translated into the corresponding UK interim and intended budgets and pathways, arguing that it is beyond their (non-political) remit to advise on a particular apportionment mechanism. It notes, however, that it is difficult to imagine a global climate deal that does not require industrialised countries to reduce their emissions to a per capita level which, if applied globally, would be consistent with 2°C (CCC 2008a: p.30). The CCC also recalls that Stern finds scant evidence that any developing country is likely to cease industrialisation at the mean level of global per capita emissions required for 2°C (Stern 2008). Thus, nations emitting 'above the line' must be balanced by other major economies bringing their emissions below the global per capita mean if 2°C is to remain a possible outcome.

The CCC's recommendation, therefore, is that the UK interim and intended pathways are based on a reduction in emissions by 2050 of *at least 80%* below a 1990 baseline (CCC, ibid). Thus, the cumulative emissions total entailed by following the interim pathway out to 2049 is effectively the UK's long-term emissions 'budget' by default – i.e. the cumulative total that bears comparison with a global budget for the first half of the

[31] A quantity of emissions which cannot be avoided, for instance from food production.

21st century, from which a probability of exceeding 2°C can be estimated[32]. Figure 2.3 shows how both the interim and intended short-term statutory carbon budgets (2008–22) fit within the longer term interim and intended emissions pathways. While the interim and intended pathways deliver reductions in annual CO_2 of 29% and 40% respectively by 2020 (cf.1990)[33], note that during this period on the interim pathway an *extra* 506 million tonnes of CO_2 are emitted. Furthermore, while both interim and intended pathway deliver an 80% reduction on 1990 emissions by 2050, an extra 1,015 million tonnes of CO_2 are emitted on the interim pathway between 2000 and 2049. This is accounted for by the interim pathway being based on a global budget associated with a 63% probability of exceeding 2°C, compared to 56% for the intended pathway.

[32] While the CCC pathways describe reductions by 2050 corresponding to the first half of the 21st century (i.e. 2001–2050), the cumulative totals given here are for 2000–2049 to allow later comparison with global budgets whose probability of exceeding 2°C are estimated using the PRIMAP check-tool (Meinshausen *et al* 2009), which uses 2000–49. Note that because emissions are 80% lower in 2050, selecting a later start year significantly reduces the cumulative total for the fifty year period.

[33] Corresponding to reductions in total greenhouse gas emissions of 34% (interim) and 42% (intended) by 2020 – i.e. the middle year of the third statutory carbon budget period.

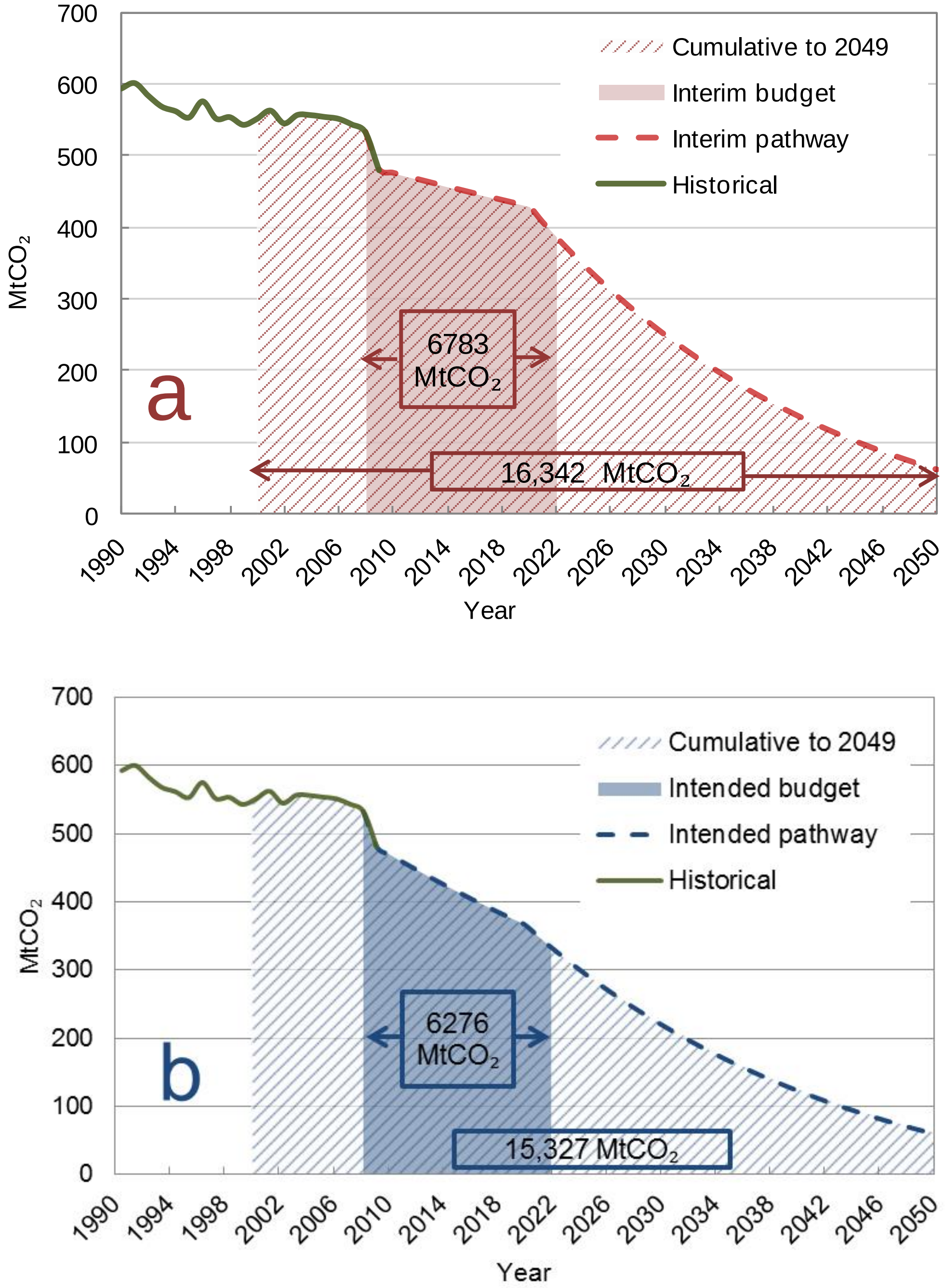

Figure 2.3: (a) UK interim pathway and budget (domestic CO_2 only, does not include international aviation and shipping, see Chapter 5 for analysis of 'total CO_2' budgets) (b) intended pathway and budget (domestic CO_2 only) (CCC 2010b).

2.2.2 Tensions between short term and long term budgets

Huntingford *et al* (2012) examine the compatibility at a global level between short-term emissions trajectories and long-term future end points (such as an 50% reduction in emissions by 2050) for various probabilities of exceeding 2°C. Like Allen *et al* (2009), they find a 'tight link' between cumulative emissions and the probability of exceeding a given temperature threshold. Huntingford *et al*'s study highlights that, once an 'emissions floor' is factored in, there exists a narrow band of 2020 and 2050 emissions levels which are consistent with a given probability of exceeding 2°C. The obvious consequence is that a delay in bringing emissions under control in the short term precludes a low probability of exceeding 2°C – potentially placing 2°C beyond the bounds of possibility.

The tensions between short term and long term budgets highlighted by Huntingford *et al* apply equally at the national level: there is a limited envelope of short term emissions trajectories compatible with a long term pathway associated with a given probability of exceeding 2°C. In essence, for a given probability of exceeding 2°C and assuming a progressive rather than precipitous mitigation curve, the long term budget determines the short term pathway. Consequently, adopting a lower-emitting trajectory in future does not bring a reduced probability of exceeding 2°C, unless sufficient cuts in emissions are made in later years to match the smaller long-term cumulative budget for the lower probability pathway. The presence of an emissions floor may well render such aggressive cuts in later years impossible.

2.2.3 Sectoral balance of effort

Variation in abatement opportunities across the different sectors of the UK economy makes apportioning emissions between sectors arguably more challenging than between nations. Since some sectors may be decarbonised more readily or cheaply than others, so the relative proportion of final energy demand, and hence emissions, from each sector will vary depending on sectoral trade-offs (UKERC 2009). Estimating how these proportions may vary is heavily reliant on assumptions and projections (Helm 2008), but analogous historical data of rapid, economy-wide decarbonisation do not exist. Consequently, econometric modelling of rapid and deep emission reductions is of limited value (Ekins 2004). Thus, rather than offering definitive predictions, econometric models are typically used to generate alternative future energy demand scenarios, which, depending on parameter assumptions and constraints, and the type of supply-side options invoked, will result in significantly different sectoral shares of total emissions (DECC 2009a).

2.2.4 Passenger car sector emissions

Other than dividing the emissions between the traded and non-traded sectors[34], the statutory UK carbon budgets make no further distinction as to where in the economy the necessary ‘emissions savings’ should be made – the expectation is that emissions cuts will be made where they cost least (CCC 2008a). However, expected ‘balance of effort’ of sectoral emissions is set out in the *Low Carbon Transition Plan* (*LCTP*), whereby each UK government department is given responsibility for the portion of total emissions over which it has influence (DECC 2009b). In reality, the level of abatement planned from each sector or departmental area is based on the Department for Energy and Climate

[34] i.e. between those parts of the economy which are included in the EU Emissions Trading Scheme and those that are not. Passenger cars are in the non-traded sector. Around 40% of the UK’s domestic emissions fall within the traded sector, which is a net importer of emissions allowances (DECC 2009a), i.e. has not undertaken sufficient domestic abatement to remain within its quota of allowances.

Change's (DECC) Energy Demand and Emissions Model. This energy system-wide econometric model attributes emissions reduction effort to individual sectors, and hence determines the overall balance of effort, on the basis of the cost effectiveness of 'technically feasible' sectoral measures (DECC 2009a)[35].

2.2.4.1 Planned mitigation and counterfactual baseline

Whereas the overall UK emissions reduction required to meet the first three statutory carbon budgets results in a 29% reduction in annual CO_2 emissions by 2020 (cf.1990), the abatement measures set out in the *Low Carbon Transport* strategy (*LCT*) (DfT 2009b) are expected to reduce annual CO_2 emissions from domestic transport by only 14% (cf. 2008)[36]. This relatively low expectation of abatement of domestic transport emissions reflects the perceived limited availability of applicable 'technically feasible' measures – but also the pervasiveness of the demand growth paradigm and the logic of provision within government (see Chapter 4 on demand-side issues).

Comprising 57% of domestic transport emissions[37], passenger cars are the biggest emitting 'vehicle type', and the biggest emitting domestic *passenger* transport mode by a considerable margin – reflecting the dominance of the automobility regime in personal travel. Figure 2.4 shows the cumulative emissions for the passenger car sector for 2008–22 estimated at 1,013 $MtCO_2$, based on the application of car-specific measures in the *LCT* strategy to a counterfactual baseline level of emissions (DfT 2009a). Note that although intended to produce a 14% reduction in emissions by 2020 (for all domestic transport), at full potential the *LCT* measures for the car sector are expected to deliver *cumulative* savings of 77 $MtCO_2$ against baseline emissions (i.e. 7%).

[35] The same DECC model was used to inform the setting of the UK statutory carbon budgets (Barrs 2008); indeed there is an evident symmetry between the 'abatement opportunities' in the *LCTP* and the scale of the emissions reductions required by the UK carbon budgets.

[36] The *Low Carbon Transport* measures are against 2008 levels, whereas reductions in the Carbon Budgets Orders are against 1990 levels (29% reduction in CO_2, or 34% reduction in total greenhouse gas emissions, by 2020; rising to 40% reduction in CO_2, or 42% reduction in total greenhouse gases – the 'intended budget', to apply in the event of an international agreement on tackling emissions). However, emissions from the car sector were at around the same level in 2008 as in 1990, despite some fluctuation in the interim. This is largely because a gradual but steady increase in traffic volumes (expressed as car kilometres travelled) cancelled out the effects of efficiency gains from improved vehicle and fuel technology during this period. Therefore 14% reduction against 2008 levels is, for the car sector, equivalent to a 14% reduction on 1990 emissions – at least sufficiently so to allow comparison between the targets.

[37] Mean proportion 2008–10 (DECC 2011a).

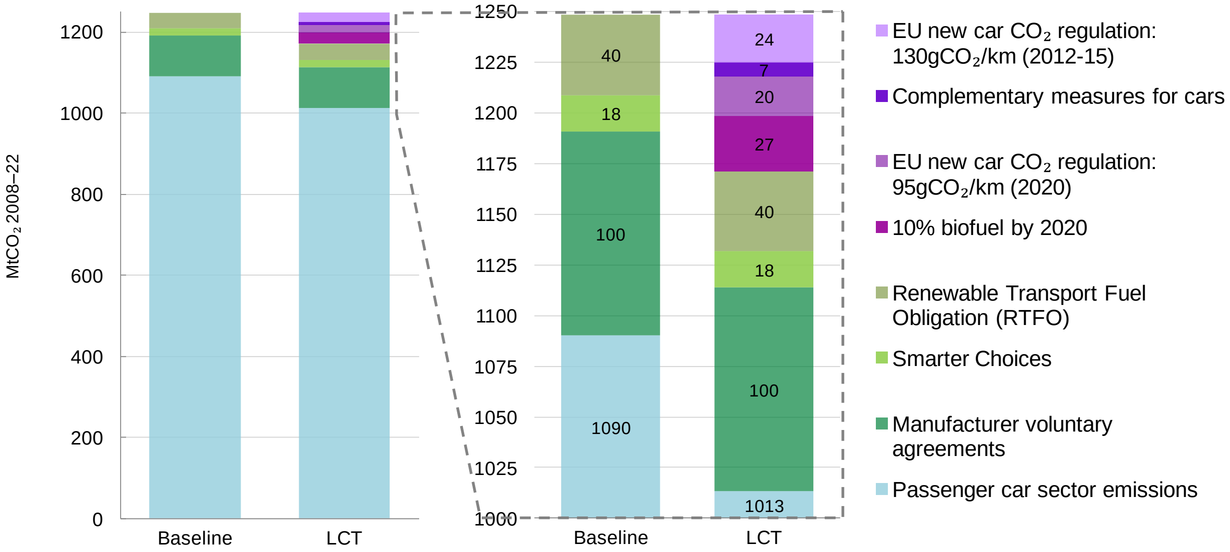

Figure 2.4: Emissions reductions planned for the passenger car sector over the first three statutory budgeting periods (2008–22), with expected cumulative savings in $MtCO_2$ for each measure in the *Low Carbon Transport* strategy (*LCT*). (Source: DfT 2008b; DfT 2009a)

Baselines are notoriously problematic, however. The DfT uses as its baseline a counterfactual level of emissions, which assumes only the measures in place before the publication of the *LCT* strategy (DfT 2009a). This corresponds to the emissions trajectory in the DfT's Road Transport Forecast 2008 (RTF–2008), to which the *LCT* strategy's car sector-specific savings of 77 $MtCO_2$ are applied. It is important to recognise that the counterfactual forecast is based on an assumption that the total distance driven by the UK car fleet each year (VKM_{fleet}) will have increased by 30% in 2025 against 2003 levels – effectively an increase in VKM_{fleet} between 2011 and 2022 of 20%[38].

Table 2.1 shows the DfT's central estimates of changes in road transport CO_2 emissions and 'car traffic volumes' (VKM_{fleet}) predicted in the last three Road Transport Forecasts[39]. It is particularly salient that the *LCT* measures are expected to deliver savings against a backdrop of substantial growth in demand. Hence, the 1,013 $MtCO_2$ residual passenger car sector emissions (Figure 2.4) expected with the *LCT* measures in place are as much the product of this dramatic increase in VKM_{fleet} as they are the result of the mitigation measures themselves.

While the RTF estimates of future emissions apply to Great Britain only, and the VKM_{fleet} estimates to England only, the DfT cumulative emissions baseline used here is

[38] Assuming a steady rate of increase between milestone years for which RTF–2011 provides forecasts, i.e. 2010 (a modelled year in RTF–2011), 2015, 2020 and 2025 (see Table 2.1).

[39] The RTF publications do not disaggregate CO_2 forecasts between types of road transport, thus the changes presented are for 'all road transport', which includes HGVs, LGVs, buses, taxis, motorcycles, etc, as well as cars. However, given the dominance of car emissions in this sector (car emissions are 62% as mean proportion of total *road* transport emissions 2008–10) and the fact that planned savings for non-car modes do not significantly outstrip those planned for the passenger cars, it is assumed here that passenger car sector emissions are effectively forecast to follow the mean rate of change for road transport as a whole.

approximated by assuming that the respective trends for GB and England apply at UK level for emissions and traffic. Thus, by applying the RTF central estimates to historical data on 2003 emissions and VKM_{fleet} for the UK, pathways for both absolute CO_2 emissions and VKM_{fleet} may be derived from the DFT's forecasts (summarised in Table 2.1)[40].

Table 2.1: Predicted changes by 2025† in annual car traffic volumes and road transport $MtCO_2$ in the DfT's last three *Road Transport Forecasts*

	Central estimate in RTF–2008	**Central estimate in RTF–2009**	**Central estimate in RTF–2011**
Change in $MtCO_2$ in 2010, cf. 2003	-8%	~	-9.1%
Change in $MtCO_2$ in 2015, cf. 2003	-3%	-11%	-13.3%
Change in $MtCO_2$ in 2020, cf. 2003	~	~	-18.8%
Change in $MtCO_2$ in 2025, cf. 2003	-3%	-22%	-18.3%
Change in VKM_{fleet} in 2010, cf. 2003	+3%	~	-0.8%
Change in VKM_{fleet} in 2015, cf. 2003	+15%	+4%	+2.5%
Change in VKM_{fleet} in 2020, cf. 2003	~	~	+12.2%
Change in VKM_{fleet} in 2025, cf. 2003	+30%	+21%	+22.8%

† RTF–2009 and RTF–2011 both make predictions out to 2035, beyond the timeframe dealt with in this analysis

The 'with measures' 1,013 $MtCO_2$ residual emissions represent, respectively, approximately 15% or 16% of the interim and intended budgets for UK domestic-only CO_2 2008–22 (Figure 2.3) – a slight increase (of 1% to 1.5%) in the passenger car sector's share. Chapter 5 sets out a method for quantifying sectoral emissions budgets with lower than 63% probability of exceeding 2°C and that take account of assumptions about future emissions from the UK's international aviation and shipping, in addition to assumptions about international responsibility for emissions from global deforestation and the peak emissions year for non-Annex 1 countries.

[40] Following this method, cumulative emissions 2008–22 under the 'with *LCT* measures' RTF–2009 forecast amount to 1,007 $MtCO_2$. However, a value of 1,013 $MtCO_2$ is used here for residual emissions after *LCT* measures are applied, since this is the result of subtracting the 77 $MtCO_2$ car-specific savings in the *LCT* strategy (DfT 2009a) from the 1,090 $MtCO_2$ forecast for 2008–22 in RTF–2008 (i.e. the counterfactual baseline). While RTF–2009 and the most recent version, RTF–2011, both revise the level of demand growth projected, there is little merit in proliferating alternative counterfactual baselines for comparison. Since the RTF–2008 emissions pathway represents the 'without *LCT* measures' baseline in place at the time of publication of the *LCT* white paper itself, it is reasonable to use the cumulative emissions that result in this pathway as the benchmark. Absolute values for annual CO_2 and VKM_{fleet} derived using the method described from the pathways in RTF–2008, 2009 and 2011 are given in Appendix 1, and illustrated in Figures 1.3 and 1.4 in the previous chapter.

The *LCT* strategy's relatively high level of residual emissions is primarily a result of the strong growth in VKM_{fleet} assumed in the counterfactual baseline. Conversely, the relatively *low* level of *absolute* abatement over the period 2008–22 (compared to pre-existing measures) is largely a function of heavy reliance in the *LCT* strategy on technology measures. 65% of *LCT* savings come from EU regulation of new car emissions, including complementary (non-powertrain) measures – which are applied gradually (see Figure 2.5 below). Although the *LCT* white paper makes reference to reducing the need to travel by use of information and communications technology (ICT) and changes to spatial planning policy (DfT 2009b: p.83), it is significant that no additional emissions saving is attributed to demand reduction in the strategy, beyond the 18 $MtCO_2$ for existing 'smarter choices' measures (see §3.1.2). A fleet emissions model allowing quantification of an alternative baseline, which does not assume growth in VKM_{fleet}, is elaborated in Chapter 6, the better to appreciate the contribution to overall sectoral mitigation obtained from the *LCT* strategy's heavy reliance on the EU 2015 and 2020 regulations for new car emissions.

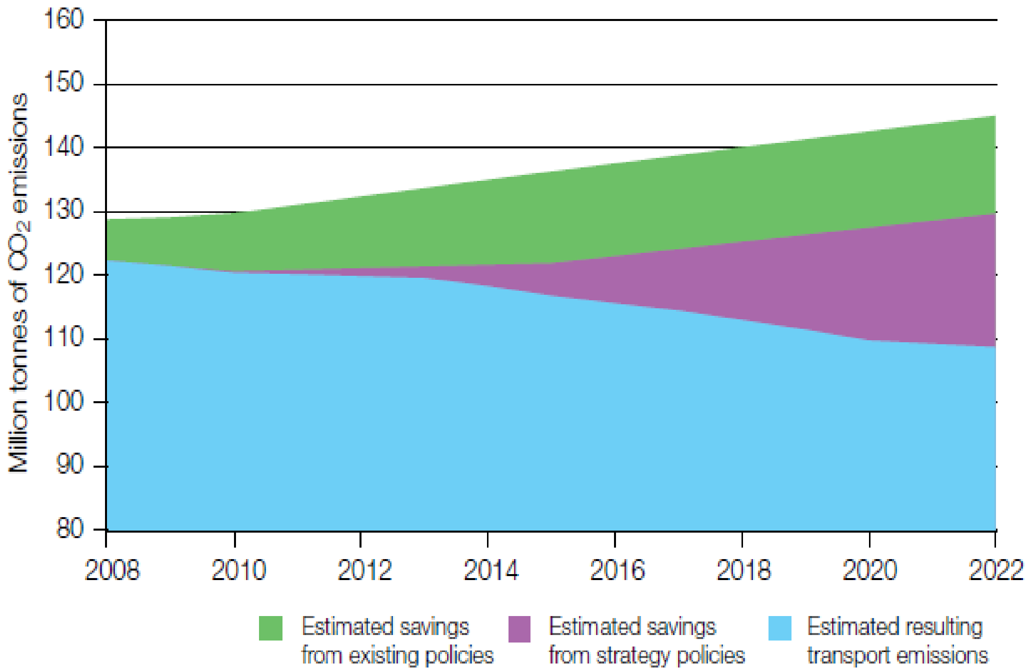

Figure 2.5: Emissions trajectory and emissions savings for domestic transport (2008–22), reproduced from DfT's *Low Carbon Transport* strategy (DfT 2009b). NB: x-axis intersects y-axis at 80 $MtCO_2$.

2.2.5 Passenger car emissions and climate change

While the current UK policy framework claims to prioritise avoidance of 2°C, instrumental policies and regulations fall some way short of offering a good chance of doing so – the interim and intended UK budgets being based on a 63% and 56% chance of *exceeding* 2°C respectively. The passenger car sector, despite its strategic importance with respect to decarbonising the UK arising from its contributing one in eight tonnes of total CO_2, is expected to contribute relatively little to total mitigation effort. However, the reliance on other sectors, principally electricity (see Figure 2.6 below), to make cuts at a greater rate is a high risk strategy, considering both the limited progress to date and in the pipeline (CCC 2011). A discussion of the dominance of technocracy in mitigation planning follows in Chapter 3 on supply-side measures, but suffice to observe here that much greater mitigation would be required from all sectors, should a national pathway be pursued which is consistent with a genuinely low probability of 2°C – or at least lower than the 63% entailed by the current pathway.

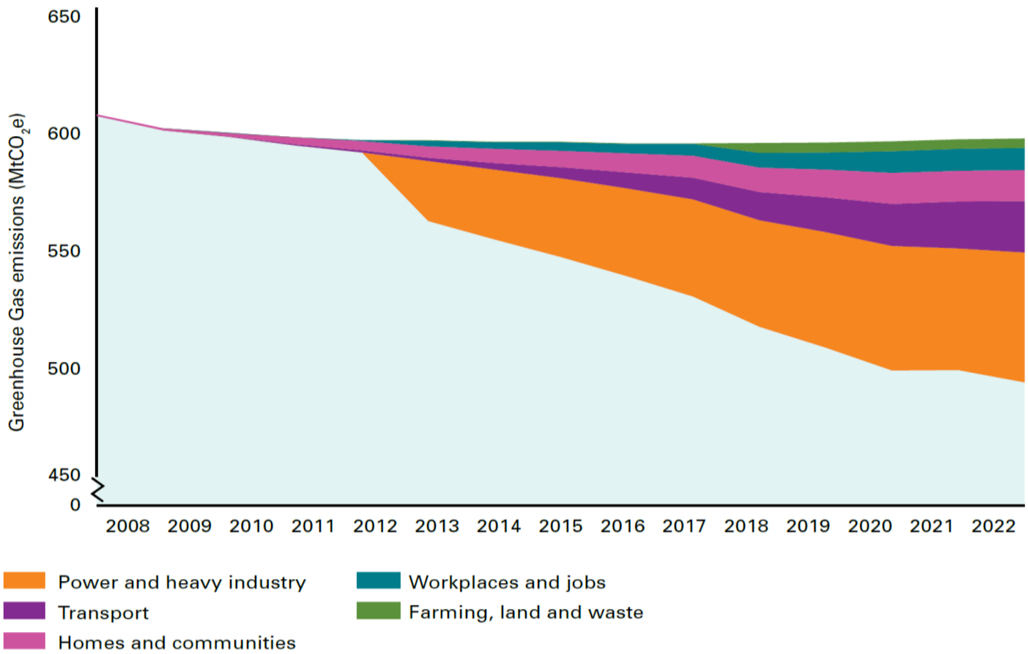

Figure 2.6: The effect of planned mitigation in various areas of the UK economy on total emissions, reproduced from the *Low Carbon Transition Plan* (DECC 2009b)[41]. NB: y-axis is truncated.

2.3 Climate-based scenarios for the UK passenger car sector

The remainder of this chapter looks beyond the *de facto* scenarios which inform and underpin UK mitigation policy to other contemporary emissions scenarios for the passenger car sector, and evaluates their relationship to overarching climate change objectives. A scenario may be defined as “a consistent and plausible picture of a possible future reality that informs the main issues of a policy debate” (EEA 2009b). Scenarios may be classified by several key characteristics: prospective or backcasting, qualitative or quantitative, normative or descriptive, expert input or participatory, whole-system or sector-specific (Mander *et al* 2008a). In envisioning possible outcomes of policy frameworks to address climate change, permutations of these types have emerged, but prospective (forecasts), qualitative (narrative) and descriptive scenarios have tended to dominate. To a large extent the value of forecast scenarios lies in their ability to estimate the likelihood of one outcome over another (Robinson 1982).

[41] The *LCTP* notes that ‘the impact of policies prior to the 2007 Energy White Paper is included in the baseline; without these policies, UK emissions would be higher’.

Backcasting scenarios, on the other hand, which are necessarily normative in that a desired endpoint is specified, are valued for their ability to assess the policy implications of attaining this goal (Robinson, ibid) and their ability to describe feasible pathways to enable transition to that endpoint (McDowall and Eames 2006).

Whether explicitly or implicitly, all scenarios – prospective and backcasting alike – make *assumptions* about society, industry, technology, the economy, natural resources and the environment and their interrelationships. These assumptions directly affect how a given scenario portrays mitigation and adaptation to climate change. This section does not attempt to review the means proposed to achieve particular emissions reduction goals in the studies mentioned – a review of the literature on supply measures and demand-side interventions is provided in Chapters 3 and 4 respectively. Rather this section is a review of the extent to which previous studies have specifically related science-based mitigation objectives to emissions from passenger cars (or emissions from surface transport, domestic transport, road transport or transport more broadly, as and where relevant). In particular, evidence is sought for previous work which has attempted to quantify abatement from the passenger car sector in proportion to its share of total emissions – in other words to quantify what it means for transport to 'pull its weight' (Anable and Boardman 2005). Literature is discussed in chronological order of publication.

2.3.1 Tyndall Centre – Living Within a Carbon Budget (*LWACB*) (2006)

UK energy demand scenarios were devised to remain consistent with atmospheric CO_2 concentration stabilising at 450 ppmv, equating this to a UK CO_2 budget for 2000–2050 of 4.6 GtC (Bows *et al* 2006: p.17), or 16,687 $MtCO_2$, based on assumptions about contraction and convergence as detailed in RCEP (2000) and implied by the 2003 'energy white paper' (DTI 2003). The passenger car sector is treated as a key contributor to economy-wide decarbonisation of 90% emissions cuts against a 2004 baseline, but cumulative constraints for individual sectors are not included in the published work. While there is close agreement between the UK CO_2 budget described in *LWACB* and the '*de facto'* UK cumulative budget under the current interim pathway[42], the *LWACB* value now looks to have a higher probability of exceeding 2°C than originally assumed. This reflects the balance of evidence shifting in the intervening period towards 2°C being associated with concentrations lower than 450 ppmv.

2.3.2 Buchan, Low carbon transport policy for the UK (2007 and 2008)

Following a review of climate science literature, Buchan argues for adoption of cumulative carbon budgets over end point targets, "because the rate of progress

[42] The *de facto* UK interim cumulative budget is given in §2.2.1 above as 16,342 $MtCO_2$ for 2000–49. For the 51 years 2000–50 – the dates used to calculate cumulative budgets in the Tyndall 2006 report – the CCC put the equivalent interim pathway budget at 16,405 $MtCO_2$.

towards the target for 2050 is, in the case of greenhouse gas emissions, just as important as the end date itself" (Buchan 2007). This is illustrated by means of five transport emissions scenarios (e.g. 'slow start', 'straight reduction' etc), which follow different pathways to 2050 but arrive at the same end point reduction. The difference between the scenarios is cashed out as a total carbon deficit against the target budget for the scenario period, although the actual budgets presented are essentially illustrative only. Buchan's phase two report (2008) specifies a series of draft budgets based on "estimates of what should be possible for transport, through a combination of improved vehicle technology and changing behaviour" (Buchan 2008: p.37). Hence, although noteworthy for championing a science-based approach to the *principles* of target setting, Buchan's draft targets are estimated not on the basis of consistency with national or global emissions targets, but rather based on a subjective assessment of feasibility.

2.3.3 Zero Carbon Britain (2007 and 2010)

The Centre for Alternative Technology's *Zero Carbon Britain* (*ZCB*) first report (Helweg-Larsen and Bull 2007) estimates a UK twenty year emissions budget of just 897 MtC (3.3 $GtCO_2e$), based on a twenty-year global budget of 85 GtC (312 $GtCO_2e$), internationally apportioned via contraction and convergence (international convergence to equal per capita emissions from 2014). The second report (*ZCB-2)* appears to shy away from specifying a national cumulative constraint, instead arguing for an equal per capita share of a global total which contracts towards an 72% reduction by 2050 to deliver a 16% probability of exceeding 2°C (citing Meinshausen *et al* 2009) (Kemp and Wexler 2010). In a similar vein as Huntingford (2012), the rationale presented in *ZCB-2* is that as "there are only a limited range of plausible emissions trajectories that can be followed between now and 2050 if we are to stay within any set cumulative budget", therefore "...emissions in 2050 are quite a good indicator of the amount likely to be released in the intervening years". Although the car sector features prominently in the ensuing discussion of mitigation potential, a specific budget or cumulative target is not identified.

2.3.4 Committee on Climate Change (2008 onwards)

The CCC's first report (CCC 2008a) and Fourth Budget Report (CCC 2010d) use a prospective approach to assess the possible contribution of supply and demand-side measures to derive emissions savings opportunities from transport in three scenarios of increasing abatement ambition. No specific target is applied to the transport or car sector, rather effort is shared across the whole economy by selecting amongst options from marginal abatement cost curves (MACC). The CCC estimates cumulative emissions for the passenger car sector under its medium abatement scenario (its recommended pathway, delivering a 60% reduction in UK emissions by 2030) to be 872 $MtCO_2$ between 2008–22 (CCC 2010c) – a reduction of 219 $MtCO_2$ against the DfT baseline (see §2.2.4 above), and almost three times the savings identified in the DfT

Low Carbon Transport strategy[43]. Significantly, the CCC indicate that in the medium abatement scenario, surface transport still occupies around 22% of total emissions in 2030 (CCC 2010d: p.138). However, neither this proportion nor the aforementioned cumulative emissions represent a 'budget' for the car sector *per se*, rather they are a product of the CCC's modelling of abatement potential across the economy. Significantly, the CCC's medium abatement scenario includes a 5% increase in total distance driven by cars on UK roads between 2011 and 2022.

2.3.5 UKERC Energy 2050 (2010)

Using a version of MARKAL (market allocation econometric model) which incorporates demand sensitivity to energy price changes, the UKERC Energy 2050 project (Ekins *et al* 2009) models seven core pathways (plus a counterfactual base case) based on emissions reductions relative to 1990 varying from 15–32% by 2020 and 40–90% by 2050, essentially using a backcasting methodology from the end state target. There is no climate-derived cumulative constraint on emissions, but cumulative totals are calculated for each of the 'carbon ambition' scenarios[44]. Five of the core pathways return at least an 80% reduction by 2050 (i.e. sufficient to meet the obligations of the Climate Change Act), resulting in cumulative emissions outcomes of 1,798 $MtCO_2$ (for the 'super ambition scenario') to 2,039 $MtCO_2$ (for the 'ambition scenario') for the period 2000–50. As such, none would meet the cumulative constraint of the CCC's interim pathway with a 63% probability of exceeding 2°C. Passenger car emissions are dealt with in detail in many of the UKERC scenarios, but are not constrained by a particular sectoral budget – the object of the MARKAL model being to optimise the most cost effective mitigation options across all sectors.

2.3.6 UK Transport Carbon Model (UKTCM)

UKERC Energy 2050's lifestyle scenarios were modelled exogenously in UKTCM, a highly disaggregated, bottom-up transport–energy–emissions model (Anable *et al* 2010). As in the other UKERC core scenarios, the approach taken was to set a constraint of 80% reduction in emissions by 2050. While published work on the UKTCM (e.g. Anable *et al* 2012; Brand *et al* 2012) recognises the importance of cumulative emissions by noting that the *rate* of emissions reductions is critical as well as the end point, model outputs are presented only as emissions (or emissions reductions) in specific end point and interim milestone years.

2.3.7 Other transport studies literature

Within the broader transport research literature there is surprisingly little recognition of the primacy of cumulative emissions with respect to climate change. Notable exceptions

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[43] See further discussion in Chapter 9, §9.3.2.

[44] Some of the UKERC 2050 scenarios use a cumulative constraint for the period 2010–2050 based on the outcome of one of the other scenarios, e.g. 'least cost path' and 'socially optimised least cost' scenarios are constrained by the budget produced by the 'early ambition' scenario (based on 32% reduction in emissions by 2020, 80% by 2050, total emissions: 1,924 $MtCO_2$).

include Anable and Bristow (2007), Anable and Shaw (2007), Whitelegg *et al* (2010), and Kendall and Price (2012), which acknowledge the importance of the rate of emissions reductions as well as the final end point, although actual budgets or cumulative savings are not specified. Beyond the studies mentioned, mitigation is typically framed in terms of emissions cuts achieved by a specified future year, with targets either:

(i) adopted from contemporaneous national end point targets such as 60% or 80% reductions by 2050, e.g. Geurs and Van Wee (2000), Bristow *et al* (2008), Miola (2008), Hickman *et al* (2010), Stanley *et al* (2011), Harwatt *et al* (2011), Leighty *et al* (2012);

(ii) based on notional international end point targets, e.g. Lutsey and Sperling (2009), Uherek *et al* (2010) Sager *et al* (2011);

(iii) based on an estimated equivalence between percentage emission reductions in a given future year and a 'safe' and stable level of atmospheric CO_2, e.g. Tight *et al* (2005), Akerman and Hojer (2006), Hickman and Banister (2007), Girod et al (2012); or

(iv) projected based on past trends, e.g. Kwon (2005).

2.3.8 Comparability between UK transport policy and the transport studies literature

The variety of assumptions (often tacit) about demand and rationale for sectoral burden sharing within the aforementioned studies and policy documents makes cross-comparison between their outcomes highly problematic. For example, while the DfT's target of reducing emissions from all road transport by 14% by 2020 (cf. 2008) can be deconstructed to estimate savings of approximately 77 $MtCO_2$ (§2.2.4.1), this is against a counterfactual baseline which assumes considerable growth in demand for car travel. It also assumes an available level of 'abatement opportunity', rather than working back from the national budget (as does the CCC, although assuming rather more challenging decarbonisation options). Others (such as Tyndall's *LWACB,* CAT's *ZCB* and UKERC) offer national budgets but no detailed account of how individual sectors would share the available emissions space. As such, it is inadvisable to attempt quantitative comparison between policies and studies before a common baseline of future emissions is established, comprising transparent assumptions about demand (see Chapter 6 and subsequent discussion in Chapter 9).

2.4 **Summary**

This chapter has focused on relating climate science to the calculation of mitigation goals for the UK passenger car sector. It has examined the extent to which other studies have observed the correlation trail of evidence by framing mitigation as a cumulative constraint associated with a named probability of exceeding a given temperature target. In the next two chapters the evaluation criteria are relaxed somewhat, to consider what the previous literature reveals about the potential for achieving the long term cumulative carbon budgets implied by the current ‘interim pathway’, proposed ‘intended pathway’, and – more importantly – what potential exists for going further than these mitigation scenarios to deliver a pathway consistent with a lower probability of exceeding 2°C.

CHAPTER THREE – SUPPLY-SIDE ISSUES

3.1 Mitigation priorities

The previous chapter found that for the UK to follow an emissions pathway with a low probability of exceeding 2°C, a tighter cumulative budget will be required than that which underpins current national mitigation policy. Given the narrow band of plausible, non-precipitous emissions trajectories for a given budget, the next ten years are critical in ensuring that a pathway with a low probability of exceeding 2°C is not put permanently beyond reach. Chapter 5 sets out a method for estimating a short-term emissions budget at the sectoral level for a range of probabilities of exceeding 2°C, and Chapter 6 quantifies potential emissions savings from changes to supply side factors. In this chapter, the transport energy research literature is interrogated to assess the availability and scope of supply side measures that can help to address both the *scale* and *urgency* of the mitigation task.

Arguably now a distinct academic field in its own right, transport energy (and environment) research has its roots in traditional disciplines such as engineering, economics, transport and urban planning, in addition to demand-side analysis founded on the social and behavioural sciences. Supply-side measures – application of new technology and infrastructure, and new applications of existing technology and infrastructure – feature strongly in the literature on passenger car sector mitigation. This chapter brings critical judgement to the literature to assess which supply measures could contribute to the rapid (decadal) decarbonisation of the passenger car sector, and to what approximate extent.

3.1.1 Policy selection: efficiency, equity, effectiveness

As noted in Chapter 1, this research applies a basic priority of 'decision criteria' whereby measures are preferred which achieve the necessary emissions cuts:

i. while promoting rather than restricting mobility[45];
ii. at "least" financial cost to the state and to individual car users; and
iii. where possible, minimising disruption to existing patterns of use.

Policies which explicitly address levels of mobility and patterns of use are discussed in the next chapter (on demand-side issues), although where there are mobility implications associated with supply measures (such as rebound effects from improving vehicle fuel efficiency) they are identified here. With respect to the second criterion, while it is not an aim of this thesis to ascribe financial costs to mitigation scenarios, in critically assessing the literature evidence is sought of the approximate costs associated with specific measures and policies. There is a tendency for evaluation of mitigation options to

[45] Mobility is expressed here as passenger-kilometres (PKM).

concentrate on financial costs or 'economic *efficiency*'[46], often estimated using 'non-formalised' cost-benefit analysis (CBA) (Watkiss *et al* 2008). Examples include 'least cost' optimisation in the MARKAL Elastic Demand model (Strachan 2008), or the marginal abatement cost curves used by many government departments and influential consultancy reports (e.g. Hazeldine *et al* 2009; McKinsey & Company 2009). Some would question whether purely economic approaches are able to capture adequately the most important dimensions of policy decisions concerning climate change, in particular inter-regional and intergenerational *equity* (see, for example, Charlesworth and Okereke 2010)[47]. By contrast, Dietz (2008) counters that it is mistaken to claim that non-formalised CBA *cannot* support emissions reduction at the level indicated by precautionary approaches such as those set out in Chapter 2; rather they tend not to. However, even accepting Dietz's contention that CBA can deal with a precautionary approach, fundamentally marginal analysis cannot address *non-marginal changes*.

In conjunction with financial efficiency[48] and equity, a third dimension of evaluation is often taken to be *effectiveness* – the ability of measures or policies to contribute to the delivery of specific ends (Oikonomou and Jepma 2008). In this case the ends are taken to be sufficient reduction in CO_2 emissions to comply with a carbon budget associated with a named probability of 2°C, adopting a similar definition of effectiveness to Sorrell (2003). For present purposes, it is enough to recognise that the dominant mode of policy assessment tends to prioritise economic efficiency over concerns such as equity, especially with respect to welfare (Stiglitz *et al* 2009). In this analysis, to more adequately reflect the scale and urgency of the mitigation challenge, effectiveness is built into the overarching goal of the 'decision criteria' above, whereas the criterion relating to economic efficiency is ranked secondary to the promotion of mobility (and by extension, equality of mobility).

The objective here is not to 'pick winners' in terms of technical mitigation measures, since "there are very few circumstances where a single regulatory instrument is likely to be the most efficient or effective means of addressing a particular environmental problem" (Gunningham and Sinclair 1999). The guiding assumption is that a mix of measures addressing both supply and demand-side factors offers greater flexibility and coverage of a heterogeneous user-base. Moreover, quite different low-carbon transport solutions will probably be needed for rural locations compared with urban areas; and for regular journeys compared with occasional trips (Kohler 2006).

[46] Where efficiency is taken both in its pure economic sense ('Pareto efficiency') and as a broader measure of the achievement of societal objectives (Le Grand 1990).

[47] Nor do such approaches address the health-related impacts and increased risks of death from pollution (e.g. stress from noise pollution, respiratory diseases exacerbated by local air pollution and particulates, contamination of water and food supplies by carcinogenic substances such as VOCs).

[48] The term 'financial' is preferred to 'economic' in cases where cost-benefit 'accountancy' approaches are referred to (market economics), to distinguish from thoroughgoing political and socio-economic approaches (including ecological economics).

3.1.2 Supply-side 'one-sidedness'

As noted in §1.1.1, the current mitigation policy mix for the passenger car sector favours approaches which promote (i) the substitution of lower-carbon energy sources for petroleum; (ii) hastening vehicle efficiency improvements; and (iii) increasing penetration of more efficient vehicles in the fleet. As such, supply-side measures constitute the bulk of the emissions savings for passenger cars in the *Low Carbon Transport* strategy (DfT 2009b), accounting for 92% of total mitigation from the pre-existing measures plus *LCT* measures, and 100% of the itemised car-sector specific savings from *LCT* measures (see Table 3.1 – all measures except 'Smarter Choices' are effectively supply-side).

The quantity of CO_2 emitted per unit distance for a given vehicle is the product of three sets of parameters (King 2007)[49]:

i. carbon intensity of the fuel or energy source – expressed as grammes of CO_2 per joule (gCO_2/J) or per megajoule (gCO_2/MJ);
ii. fuel or energy efficiency of the vehicle itself, i.e. how efficiently an engine or motor converts stored energy into mechanical propulsion – expressed as Joules per kilometre (J/km). This parameter comprises a number of vehicle-specific factors (Boulter *et al* 2009a)[50], including:
    - model-related factors – aerodynamics, rolling resistance and mass;
    - engine size or displacement (in ICEVs), range of optimum load of engine / motor and conversion efficiency (drivetrain configuration: gears, differential);
    - 'technology level', e.g. sophistication of engine and drivetrain management, fuel delivery systems, use of auxiliary hybrid motor, regenerative braking etc;
iii. operational factors, including:
    - driving speed and consistency;
    - frequency of stop-start cycles;
    - braking and acceleration style (progressive or aggressive);
    - use of ancillary equipment such as air conditioning.

Mitigation measures in the *LCT* strategy focus primarily on parameters (i) and (ii) above, respectively through a reduction in fuel-carbon intensity by increasing use of renewable sources, and by making improvements to the vehicle-fuel efficiency of new cars. While there is a small (8%) behavioural component of the savings identified in the *LCT* strategy, interventions to promote efficient driving styles were not the main focus of the Smarter Choices initiative (Sloman *et al* 2010). As such, no savings relating specifically

[49] NB: parameters affecting emissions per unit distance. *Total* distance travelled (expressed as vehicle kilometres, VKM) is at present the single most important determinant of final emissions, and the subject of Chapter 4 on demand-side issues.

[50] Boulter *et al* also list age of vehicle or accumulated mileage as parameters affecting 'emissions', but go on to demonstrate that while age / total mileage to date can affect emissions of 'pollutant emissions' such as NO_x and particulates (due to deterioration in performance of catalytic converters), it does not appear to appreciably affect CO_2 emissions (Boulter *et al* 2009c: p.31).

to parameter (iii) are discernable in the *LCT* strategy. Demand-side issues are explored fully in Chapter 4, but it is important to recognise at the outset the pivotal role played by operational parameters in determining the effectiveness of technological improvements. King's notion of an 'ideal driver' with respect to an 'optimum driving cycle' (see §3.3.2.4 below) will likely prove to be instrumental in achieving the emissions savings potential of the supply-side measures (Schipper 2011)[51].

[51] King does not describe precisely the calculation for the factor relating to 'driving efficiency', simply stating that it reflects "how close is the driver to the "ideal driver" (operating at the vehicle's "design point" or to some optimum driving cycle) and how close are driving conditions to the optimum (for example taking into account congestion levels)" (King 2007: p.21, §2.8)

Table 3.1: *Low Carbon Transport* strategy measures to reduce UK car sector emissions. Savings for existing baseline policies are against a counterfactual emissions level, i.e. had the measures not been in place. Savings for the *LCT* strategy measures are against the baseline and on tank-to-wheels basis only (see §3.2 below). Source for expected emissions savings: (DfT 2009a).

	Policy	Summary of content	Expected emissions saving 2008–22
Pre-existing measures in counterfactual 'baseline'	Manufacturer voluntary agreements (VAs)	Historical undertaking by European (later including Japanese and Korean) car makers to reduce average new vehicle emissions by 25% over ten years 1998/99 to 2009, to 140g CO_2/km. Target was not reached in the event, but VAs nevertheless likely contributed significant emissions savings over counterfactual baseline.	100 $MtCO_2$
	Renewable Transport Fuel Obligations Order 2007 (amended) (RTFO)	First step towards meeting EU Directive on use of renewable energy in transport. Places requirement on fuel suppliers to include biofuel at minimum level: 3.25% by volume of total fuel supplied for 2009/2010, 3.5% for 2010/2011, 4% for 2011/2012, 4.5% for 2012/2013 and 5% for 2013/2014 onwards.	40 $MtCO_2$*
	Smarter Choices package	Measures intended to influence travel behaviour by social marketing to promote travel planning, car share schemes and telepresence.	18 $MtCO_2$
Measures in the *LCT* strategy	EU Renewables Directive (Directive 2009/28/EC) In conjunction with EU Fuel Quality Directive (Directive 2009/30/EC)	Promotes the use of energy from renewable sources. Stipulates 10% *renewable energy* in transport target, to be met by 2020. Expected to be met primarily through the use of biofuels, although the directive is not prescriptive. Biofuels currently supply approximately 4.5% of UK motorised private transport fuel by energy, as a result of the RTFO.	27 $MtCO_2$*
		Sets minimum sustainability criteria and lifecycle GHG savings for energy supplied from biofuels	Potentially limits figure above
	New car emissions standards Regulation EC 443/2009	Sets CO_2 emissions limit of 130g CO_2/km for manufacturers, weighted sales car mass (with exceptions for 'niche' manufacturers, 'super-credits' for ultra-low emissions vehicles, and credit for off-cycle eco-innovations). Phase-in period 2012 to 2015 (65% compliance by 2012, 75% by 2013, 80% by 2014, 100% from 2015). Fines for non compliance. A further 10g CO_2/km to be saved by complementary non-powertrain measures, such as low rolling resistance tyres, efficient air-con etc. Standard to become 95g CO_2/km in 2020.	50 $MtCO_2$

* 62% of the figure given for all road transport, i.e. in proportion to the share of road transport emissions from private cars.

This prevalence of technology-based measures in the current (and historical) policy mix has been criticised for its failure to address the demand-side drivers of growth in traffic volumes (see Figure 1.3), which to date have all but cancelled out emissions savings from efficiency gains (Anable and Shaw 2007). Whilst not wishing to exacerbate this imbalance, the approach taken in this research is to seek additional abatement opportunities according to the order of priorities noted in §3.1.1 above. The implication of the first criterion in particular is that emissions reductions from improvements to vehicle and fuel efficiency (and increased uptake thereof) should be sought before policies which require significant changes in patterns of use. As noted in Chapter 1, this is *not to suggest* that supply and demand issues stand apart, nor that considerable ramping up of demand-side interventions is not likely to be required to deliver pathways with a low probability of exceeding 2°C.

Whilst acknowledging the varying influence of supply-side measures on each of the parameters above, a single common unit of vehicle emissions is nevertheless helpful to enable ready comparison between different vehicles, propulsion types and fuel supply chains. Therefore the composite unit of grammes of CO_2 per vehicle kilometre travelled (gCO_2/km)[52] is cautiously adopted here as the basic unit of mean emissions for a given vehicle–fuel combination. This is done on the explicit understanding that, for a given vehicle or vehicle type, this metric is subject to variation according to 'driving patterns' (Ericsson 2001) or 'cycle dynamics' (Boulter *et al* 2009a)[53], as well as the carbon intensity of the fuel or energy source.

To facilitate more incisive evaluation of potential emissions savings, §3.2 looks at alternative methods of accounting for emissions from passenger cars as a sector by setting 'system boundaries'. This sets the stage for a review in §3.3 of the potential for enhancing the savings attached to the supply-side measures in the current *LCT* strategy, before reviewing evidence on feasibility of additional savings from alternative automotive energy sources (i.e. other than petroleum) in §3.4. Rates of uptake of more efficient vehicles are considered in §3.5.

3.2 **Emissions accounting approaches**

The cumulative savings associated with the *LCT* strategy measures, identified in Table 3.1, are based on assumptions that attribute to the passenger car sector emissions from vehicle use (exhaust) only. Here, the background to these assumptions is briefly reviewed, and alternative methods of attributing emissions to the car sector are considered.

3.2.1 Reporting emissions from passenger cars

Governments report national GHG emissions inventories to the UNFCCC by 'national communication' (NC) source categories; essentially broad sectors of the economy representing where emissions are produced[54]. Thus on a source basis, emissions from

[52] Calculated for a given vehicle by multiplying fuel carbon intensity by vehicle fuel efficiency for an idealised 'mean' driving pattern, i.e. (gCO_2/J) * (J/km) * 1. This aggregated emissions factor is also referred to as a 'bulk emissions factor' (Barlow and Boulter 2009)

[53] Boulter *et al* define cycle dynamics in terms of "the 'aggressiveness' of driving, or the extent of transient operation in a driving pattern", where transient operation refers to changes in speed, i.e. the smoothness or steadiness of driving.

[54] National communication categories are: energy supply, business, transport, public, residential, agriculture, land use land use change and forestry (LULUCF), industrial process and waste management (DECC 2012).

primary energy conversion for electricity generation are attributed to the energy supply sector; emissions from primary energy conversion for transport (i.e. vehicle exhaust, or tailpipe, emissions) are attributed to transport, and so on[55].

In the UK, more detailed emissions data for subsectors of the NC source categories are collected (or in some cases, including road transport, modelled) by AEA Technology for the National Atmospheric Emissions Inventory, under licence to the Department of Energy and Climate Change (DECC). Thus 'transport' is broken down to aviation, road, railways, shipping (plus 'other'); with 'road transport' subsequently disaggregated into passenger cars, light duty vehicles (vans), buses, HGVs, mopeds and motorcycles, LPG emissions (all vehicles) and other road vehicle engines (DECC 2011b).

DECC publishes official emissions statistics on the basis of both source and end-user (or final-user) accounting (Table 3.2). End-user accounting re-apportions source emissions from the production, transformation, transmission and distribution of energy to the final consumer (i.e. where end use occurs). Thus, in end-user accounting, all 'upstream emissions' associated with producing, refining and transporting road fuel are attributed to the various transport sub-categories, including passenger cars. Inevitably, end-user emissions statistics are subject to a number of assumptions, and hence are liable to a wider margin of possible error than source figures (DECC 2012).

Table 3.2: CO_2 emissions from the UK passenger car sector ($MtCO_2$) reported by source and end-user accounting (DECC 2011b)

	2006	**2007**	**2008**	**2009**	**2010**
Source / producer-based (*s*)	74.1	73.7	72.3	69.7	67.4
End-user / final-user consumer-based (*e*)	83.4	82.8	81.0	78.4	75.8
Upstream energy emissions (*e* - *s*)	9.3	9.1	8.7	8.7	8.4
Upstream emissions as % of end-user	*11%*	*11%*	*11%*	*11%*	*11%*

For the purposes of setting abatement targets, the UK government continues to observe the UNFCCC source-based system of accounting (DECC 2011d). Although, as noted in Chapter 2, binding targets are not set for individual sectors (other than traded and non-traded), the *Low Carbon Transition Plan* clearly identifies emissions savings opportunities for each sector, with energy supply as a distinct sector in its own right. The rationale is to task producers (or sources) with reducing the emissions over which they have direct influence. Thus the energy sector is responsible for decarbonising the electricity grid, industry for process and distribution emissions, and road transport for

[55] In this regard, GHG inventories follow the precedent set by reporting of air pollutants (such as sulphur dioxide and particulates), which have pronounced local impacts and are amenable to point source controls (Wood *et al* 2010).

vehicle exhaust emissions. Apportioning upstream emissions to the energy sector, however, arguably detracts from energy conservation since it conceals from end-users the extent of their energy-related emissions. Upstream energy emissions for the car sector (Table 3.2) are not insignificant, amounting to 11% of total emissions for the car sector (i.e. exhaust plus upstream, see §3.2 below). Thus at the sectoral level, the source / end-user accounting distinction has implications not only for who bears responsibility for mitigation, but also affects the amount of mitigation required and types of measures considered appropriate[56].

3.2.2 Comparing emissions from different types of propulsion

The source / end-user distinction becomes especially salient for the passenger car sector when comparing emissions from vehicles with different primary energy sources – for example 'conventional' internal combustion-engined vehicles (ICEVs) with alternative-fuelled vehicles (AFVs – i.e. using a fuel other than petroleum spirit). Whereas for ICEVs primary energy conversion takes place within the vehicle's engine, with CO_2 being emitting from combustion of hydrocarbons, for AFVs such as battery electric vehicles (BEVs) and hydrogen-powered vehicles, primary energy conversion takes place upstream of the vehicle itself. Electricity and hydrogen are 'energy carriers' rather than sources of primary energy in their own right, requiring another source of primary energy for their manufacture. Therefore, while BEVs and hydrogen-powered vehicles release no CO_2 at point of converting energy to mechanical propulsion, emissions associated with the upstream manufacture of electricity or hydrogen are reasonably attributable to final vehicular use. By the same token, emissions associated with the upstream processing and distribution of petroleum can be reasonably attributed to ICEVs.

In order to evaluate the potential for AFVs to reduce car sector emissions by substituting low-carbon or renewable sources for fossil-based primary energy, a means of accounting for the upstream emissions associated with disparate energy supply chains is required. Figure 3.1 summarises the various approaches to emissions accounting, distinguished in terms of what they include and what they exclude. The main accounting approaches in descending order of scope are:

i. full lifecycle analysis (LCA);
ii. lifecycle carbon costs (or lifecycle energy use);
iii. well-to-wheels (WTW), or fuel-chain lifecycle; and
iv. tank-to-wheels (TTW), or vehicle use phase.

[56] At the national or territorial level too, source (or producer-based) accounting tends to conceal the extent of emissions associated with goods and services consumed in the UK but produced overseas. Consumer-based emissions accounting – attributing emissions 'embodied' in exported goods and services to the importing nation – has been proposed as a means to redress this imbalance (Bows and Barrett 2010).

It is worth noting that, while greater inclusivity may be claimed for some methods over others, no practicable method can claim to *comprehensively* represent all carbon emissions associated with passenger cars. This is in part down to system boundary-based exclusions (as illustrated in Figure 3.1), but also because of innumerable interactions with elements outside the system, as well as second order effects of elements within each particular system[57]. For instance, emissions directly associated with vehicle manufacture are indirectly related to personal (and national) economic prosperity, particularly for employees of car manufacturers. This in turn is likely to raise personal consumption, including car use, and hence emissions. Similarly, emissions directly associated with vehicle end-use indirectly facilitate myriad activities incurring additional emissions in other parts of the economy (employment, leisure, retail etc).

The following Sections 3.2.2.1 to 3.2.2.5 briefly review the advantages and limitations of these four accounting approaches, as evidenced in the literature.

[57] Arvesen *et al* (2011) give an incisive account of how considering only first-order effects can lead to 'technology optimism' in climate change mitigation in all sectors.

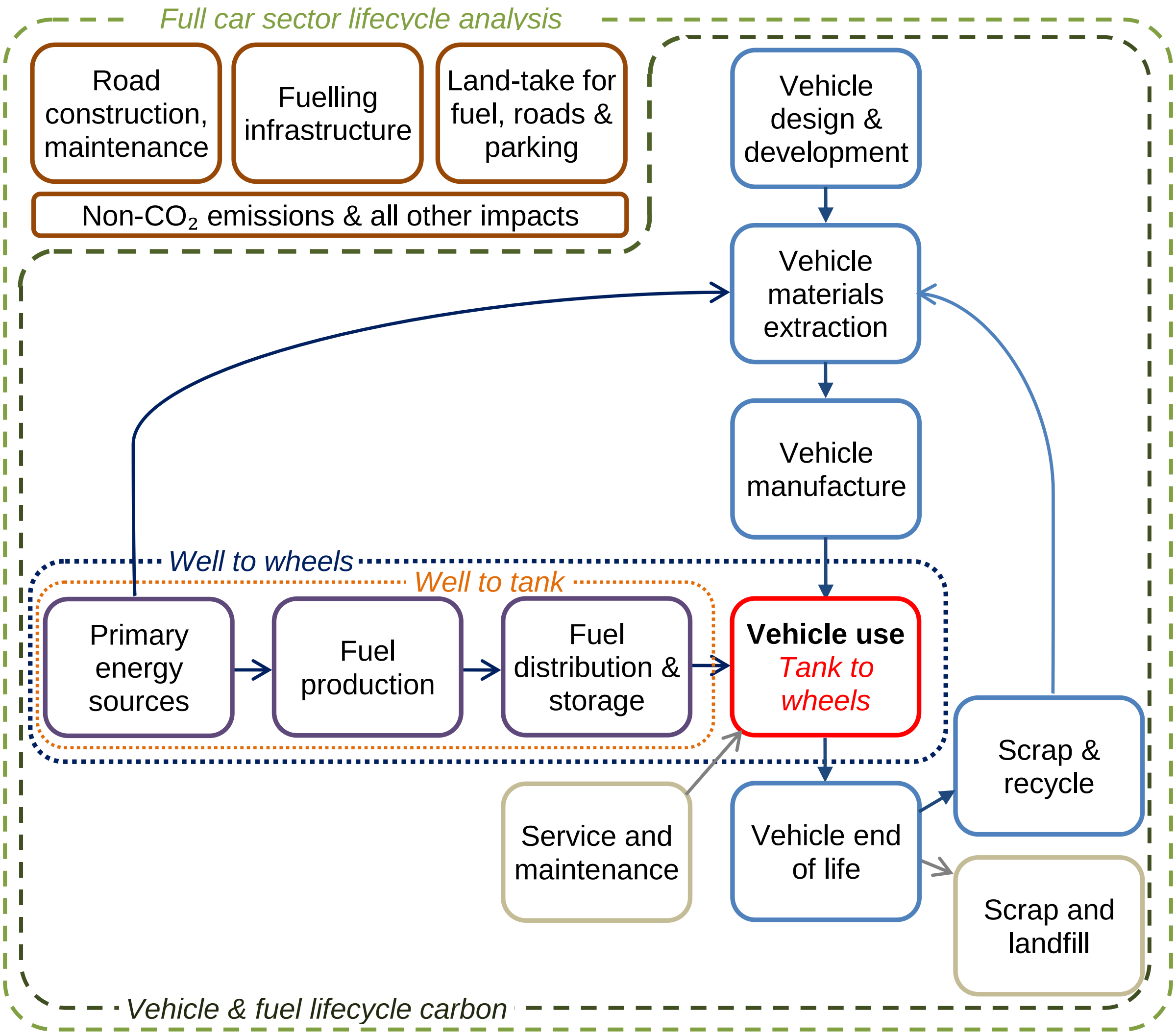

Figure 3.1: Systems boundaries for passenger car sector emissions accounting methods. Emissions sources are grouped by accounting method: full lifecycle analysis (light green dashed boundary), vehicle lifecycle carbon costs (dark green dashed boundary), well to wheels accounting (purple dashed boundary) with subsets well-to-tank (orange dashed boundary) and tank-to-wheels (red box). Box colours relate to different types of emissions sources or producers: fuel supply chain (purple), automotive industry (blue), passenger car use (red), general infrastructure (brown), ancillary industries (grey). Some elements adapted from MacLean and Lave (2003).

3.2.2.1 Lifecycle analysis

Lifecycle analysis (LCA – sometimes referred to as lifecycle assessment) is the most wide-ranging and detailed of the emissions accounting systems commonly applied to the car sector. LCA covers all environmental impacts incurred by each step of the entire vehicle and fuel supply chain, associated infrastructure and end-use. Analysis is complicated by the huge variety of possible permutations, for which the gamut of environmental (and sometimes health) impacts is considered, including GHG emissions but also many other parameters, from ozone depletion to ocean acidification. Such comprehensiveness comes at a price; full LCA is a painstaking process beyond the scope and budget of most studies of passenger car sector emissions (Usón *et al* 2011). While LCA is undoubtedly a valuable tool for estimating the breadth and scope of environmental impacts of energy chains, it is, on balance, probably over-specified for the purposes of selecting CO_2 mitigation strategies. However, LCA impacts are typically identified separately, so the GHG emissions component of full LCA studies such as Leduc *et al* (2010) and Torchio and Santarelli (2010) can usefully be compared with estimates of embodied carbon in other studies using non-LCA methods.

3.2.2.2 Lifecycle carbon costs

Many studies which use the term LCA in fact consider only GHGs or energy use (and by implication global warming potential) (e.g. Eriksson *et al* 1996; Weiss *et al* 2000; Schäfer *et al* 2006; Samaras and Meisterling 2008; Koffler and Rohde-Brandenburger 2010). Typically limited to the vehicle and fuel supply chains (e.g. MacLean and Lave 2003), some varieties of lifecycle carbon cost analyses also include enabling infrastructure (Chester and Horvath 2009; Simonsen and Walnum 2011; Lucas *et al* 2012). By proportionally attributing emissions that occur both upstream and downstream of vehicle use to the passenger car sector, lifecycle carbon analysis better reflects the total emissions embodied in car use than exhaust emissions alone. As such, lifecycle carbon analysis may be regarded as a sector-specific form of consumption-based emissions accounting. While it is a rather less unwieldy toolset than LCA, estimating lifecycle carbon emissions nonetheless involves detailed analysis of embodied emissions in each step of the energy chain, and by necessity relies on a wide range of highly contingent assumptions about energy conservation and conversion efficiencies at each stage, and about equivalence of end-use (Lave *et al* 2000).

3.2.2.3 Well-to-wheels

In addition to direct emissions from vehicle exhausts, the DECC end-user figures in Table 3.2 also include emissions from upstream processes in the fuel supply chain – in other words from (oil) well to (car) wheels. Specifically the DECC end-user figures for the passenger car sector include emissions arising from refineries producing motor fuels (refining, storage, flaring and extraction of raw materials) and from the distribution and supply of road fuel (Brown *et al* 2012). A common methodology for WTW accounting was established by the 2003 Concawe / EC Joint Research Centre report (updated 2007), which reviewed energy use and emissions from conventional and alternative-fuelled vehicles for both vehicle use stage (tank-to-wheels) and all stages of the fuel supply chain (well-to-tank) (Edwards *et al* 2007)[58]. Vehicle lifecycle emissions are excluded in WTW accounting, which Walsh *et al* (2008) refer to as a 'truncation error', arising from difficulties in establishing the boundary between direct and indirect

[58] Electricity is considered 'as a fuel and as a resource' in relation to hydrogen fuel pathways in the original Concawe reports, which did not include electric vehicles. The Concawe / EUJRC team has since published an appendix analysing emissions from the well-to-wheels energy chains for externally charged electric vehicles (Edwards *et al* 2011a).

emissions[59]. Walsh *et al* suggest that 'some' would argue that vehicle construction emissions are fixed overheads, which the end-user is unable to control, although proponents of such an argument have proved elusive. Numerous studies have estimated WTW emissions for possible future configurations of AFVs and ICEVs in scenarios covering pure electric and plug-in hybrid electric vehicles (e.g. Holdway *et al* 2010; Contestabile *et al* 2011; van Vliet *et al* 2011; Ma *et al* 2012; Pasaoglu *et al* 2012; Raykin *et al* 2012), hydrogen-powered vehicles (e.g. Rousseau and Sharer 2004; Van Mierlo *et al* 2006; Campanari *et al* 2009), and alternative liquid-fuelled vehicles (Reijnders 2009; Reijnders and Huijbregts 2009; Shirvani *et al* 2011). Several of these analyses cover several types of alternative propulsion, and many bear comparison with the Concawe methodology. However, as noted above, assumptions about the carbon intensity of the primary energy source are critical in determining overall WTW emissions for electric and hydrogen fuel pathways (Tran *et al* 2012).

3.2.2.4 Tank-to-wheels

The most narrowly-focussed of the accounting approaches considered here, tank to wheels (TTW) accounting is based on fuel consumed during the vehicle use-phase only – i.e. exhaust emissions. This is the method currently used by DECC for annual reporting of sectoral emissions, which are in turn reported and interpreted by the Department for Transport. Historically, the UK car fleet has displayed almost unexceptioned dependence on oil, and, despite increasing commercial availability of AFVs, the fleet remains heavily dominated by petroleum-fuelled ICEVs (DfT 2011f: VEH0253)[60]. TTW represent the bulk of total vehicle lifecycle emissions for modern ICEVs – estimated at c.78% according to Leduc *et al* (2010); or around 84% of WTW emissions according to Concawe (Edwards *et al* 2011b)[61]. Since there is relatively little variation in upstream WTT emissions for ICEVs which share a common energy supply, TTW accounting has hitherto served as a reasonably good indicator by which to compare vehicle emissions. Of course, emissions in the fuel supply chain are not omitted from the national inventory by TTW accounting – they are attributed to the relevant industrial or energy sector where the energy is directly utilised.

Insofar as fuel chain homogeneity has existed within the UK car fleet, using TTW as the basis for like-with-like comparisons has proved relatively unproblematic. However, once alternative, non-petroleum energy sources are brought into play, TTW no longer permits

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[59] It is not necessarily an error to exclude lifecycle processes common to both (or all) vehicle types being compared. Inclusion may actually increase error if common processes have differential *relative* impacts.

[60] Petrol and diesel vehicles made up 98.7% of new cars sold in 2011, down from 99.9% at the turn of the century.

[61] Leduc *et al* use broadly similar values for WTT emissions as Edwards *et al*, but significantly different values for TTW. Edwards *et al* assume a range of mean values for petrol ICEVs of 139–168 gCO_2e/km for TTW, whereas Leduc *et al* uplift their reference case TTW emissions by 14% to reflect observed real world emissions being greater than standard test cycle values as used by Edwards *et al*, plus a further 3% for use of 'off cycle' air conditioning.

meaningful comparisons. Furthermore, TTW accounting cannot capture the important differences in the mitigation approaches applicable to different propulsion types and primary energy sources. These issues represent serious limitations, meaning that emissions savings from AFVs with disparate fuel supply chains cannot be properly assessed by TTW accounting alone. There are other important issues surrounding the manner in which TTW emissions are measured and monitored, in particular relating to the representativeness of standardised vehicle test cycles. This is a problem for the TTW component of all four accounting methods described here, rather than a necessary limitation of TTW accounting in principle, and is discussed separately in §3.3.2.4 below.

3.2.2.5 Regulating emissions: lifecycle carbon, WTW or TTW?

A recent study by Bishop *et al* (2012) makes the case for basing vehicle emissions regulatory targets on WTW assessment of the fuel supply chain, in order “to assess accurately” which future vehicle—fuel combinations offer the greatest potential mitigation. Based on assumptions about worst-case current TTW emissions for a petrol ICEV and best case upstream WTT emissions, Bishop *et al* estimate that the WTW equivalent of the 120 gCO_2/km EU 2015 emissions target is 141 gCO_2/km. Note that vehicle lifecycle emissions are not included in this figure, which Bishop *et al* justify weakly on the grounds that around 85% of a new vehicle’s lifecycle emissions “originate during its use”[62]. Kendall and Price (2012), however, note the potential for future AFVs to *increase* the proportion of emissions associated with the vehicle construction phase (for energy intensive battery and fuel cell manufacturing, for example). Similarly, Ma *et al* (2012) observe that most traditional WTW analyses of EVs do not include construction lifecycle emissions. Kendall and Price conclude that regulating only TTW emissions risks inviting perverse outcomes whereby vehicles with higher overall lifecycle emissions are favoured, and argue for inclusion of vehicle lifecycle emissions within the regulatory calculation. By extension, the same danger applies to WTW assessments that do not include construction lifecycle emissions.

Comparison of mature technologies such as ICEVs with niche technologies like BEVs and FCVs must also take account of possible future improvements in lifecycle energy use from *learning processes* at various levels (organisational, industrial processes, social, etc) (Kemp *et al* 1998). Manufacturing and recycling efficiencies may improve markedly as niche technologies undergo learning-by-doing processes and start to benefit from positive feedbacks (Struben and Sterman 2008). Hence a fair comparison of lifecycle emissions warrants the application of technological learning curves to energy

[62] Bishop *et al* do not specify whether by “use” they mean TTW or WTW emissions, and unfortunately their supporting reference for this assertion, a car industry FAQ document (SMMT 2011b) is similarly non-specific, distinguishing only between ‘production’, ‘recycling’ and ‘use’ as comprising ‘manufacturing process lifecycle CO_2’. Other more rigorous and transparent analysis suggests that vehicle use phase (TTW) emissions are responsible for around 80% of lifecycle carbon, whereas WTW may be around 92% (Leduc *et al* 2010).

use at relevant stages (e.g. manufacture and vehicle end-of-life) for niche technology platforms (Ahman 2003; Schwoon 2008).

The need to assess emissions savings across disparate fuel-chains forms a compelling rationale for replacing the current system of TTW accounting with a lifecycle carbon accounting approach. Under such a system, it is sometimes argued that a more appropriate unit of emissions or energy carbon intensity should also be adopted, for example gCO_2/MJ consumed (e.g. Schäfer *et al* 2006). This has certain advantages in terms of representing more accurately the upstream emissions associated with alternative fuel and vehicle supply chains. However, using energy–carbon intensity as the main metric has the distinct disadvantage of still requiring further data on vehicle–energy efficiency to calculate CO_2 *per vehicle kilometre*, which is the 'functional unit' of real interest. It is accepted that to compare between ICEV and AFV energy chains a more refined analysis is warranted. However, it is clear from the measures identified in the *LCT* policy mix that the bulk of emissions savings are expected to come from improvements to ICEV technology, with no savings explicitly attributed to AFVs in the period to 2022.

The next section (§3.3) considers evidence from the literature on the potential for increasing the ambition of the measures in the *LCT*. The following section (§3.4) considers the potential for additional savings from non-petroleum-based fuel chains and vehicles, by reviewing evidence for potential UK fleet penetration by AFVs over the critical timeframe to 2022.

3.3 **Increasing abatement through amplification of existing measures**

Whereas the *LCT* strategy identifies 'savings opportunities', here the literature is surveyed for evidence that the potential extent of these 'opportunities' may be greater than suggested by the emissions savings currently ascribed to them.

3.3.1 Increasing renewable energy content of road fuel

While the EU Renewables Directive is not prescriptive about the form of renewable energy to make up the 10% contribution to road transport energy by 2020, it is widely expected that member states will deliver on their obligations by increasing the use of biofuels (CEU 2011). However, biofuel expansion is problematic. The UK government limited the rate of increase of biofuels set by the pre-existing Renewable Transport Fuels Obligation (RTFO) based on guidance from the Gallagher Review of the indirect effects of biofuels production (RFA 2008). A review of the National Renewable Energy Action Plans (NREAPs) of the 27 EU members reveals widespread heavy reliance on imported liquid biofuels to meet the 2020 target; it is estimated that the associated land use change in biofuel exporting regions would lead to an increase in overall emissions of between 81% and 167% compared to conventional petroleum (Bowyer 2011). Full implementation of the UK's NREAP would make it the biggest volume importer of biofuels in the EU, creating *additional* emissions of up to 13.3 $MtCO_2$ per annum from indirect land use change associated with the production of biofuels for the UK's road transport needs (Bowyer 2011).

Other concerns regarding biofuels centre on the potentially severe penalties to scarce water, land and food resources in already stressed world regions. While the EU Fuel Quality Directive is intended to ensure minimum lifecycle carbon savings and set sustainability criteria, there is evidence to suggest that the rate of UK biofuel consumption is already close to the maximum limit of sustainable global production (Thornley *et al* 2009).

Given these serious issues of increasing overall emissions through land use change and the conflict with food and water security priorities, increasing the volume of biofuel blended into road fuels above the current 5% level of the RTFO is not considered a feasible emissions mitigation option within the ten year timeframe of this analysis.

3.3.2 Tightening existing emissions standards for manufacturers

Almost two-thirds of the cumulative emissions savings proposed by the *LCT* strategy are expected to come from vehicle manufacturers complying with European Union regulations. Regulation EC 443/2009 requires vehicle manufacturers to reduce mean new car emissions to a specified target level, phased in from 2012, reaching full compliance by 2015, with a lower target telegraphed for 2020. Targets are set specifically for each manufacturer, based on the mean mass[63] of their new vehicle sales in each year. For a manufacturer whose new vehicles sold are of average mass – currently 1372 kg (EEA 2010) – the target is 130 gCO_2/km by 2015, with a further 10 gCO_2/km to be delivered from non-powertrain measures (including but not limited to: low-rolling resistance tyres, aerodynamic profiling, use of biofuels). The target is set to reduce to 95 gCO_2/km in 2020. The EU standards are mandatory insofar as manufacturers will pay a financial penalty – an 'excess emissions premium' – for each gram of CO_2 per kilometre above their specific emissions target reflected in their annual EU sales.

3.3.2.1 Closing the loopholes

The EU regulation contains a number of provisions – arguably 'loopholes' in the emissions standard. First, there are derogations for small volume and niche manufacturers, enabling them to negotiate their own targets[64]. Second, manufacturers have the option of joining together with other manufacturers to form a pool, so that their combined sales fleet is treated as a single entity with a single emissions standard. Subsidiary companies with higher mean emissions per vehicle than a parent manufacturing company can thus benefit from a less demanding emissions target than

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[63] Mean 'kerb weight', i.e. mass of unladen vehicle (no passengers) with a full tank of fuel.

[64] Small volume manufacturers are those with fewer than 10,000 new registrations per annum; niche manufacturers 10,000–300,000.

they would otherwise receive. Third, all manufacturers may exceed their sales- and mass-weighted emissions targets without penalty by earning 'super credits', allowing them to sell multiple inefficient vehicles for each 'ultra-low emissions' vehicle sold[65] (EEA 2010). Ultra-low emissions vehicles are deemed to have *exhaust* (TTW) emissions less than 50 gCO_2/km. Therefore electric vehicles earn super-credits, since all their emissions occur upstream (see §3.2.2 above). Fourth, phase-in of the EU emissions standards allows car makers to select their lowest emissions vehicles for inclusion in the regulated portion of their sales, giving manufacturers still more leeway around the 130 gCO_2/km mean target during the phase in period[66]. Fifth, manufacturers can obtain a further emissions credit of 7 gCO_2/km for verifiable 'eco-innovations' – emissions-reducing technologies which are not recognised under the current testing procedure (EEA 2010)[67].

The result of protracted and adversarial negotiations between manufacturers and the council of the EU, these 'loopholes' were ostensibly created to level the playing field for small volume manufacturers and create an incentive for electric vehicle production (ten Brink 2010). However, each of these 'loopholes' effectively weakens the overall impact of the EU regulation on emissions. It has been suggested that once their combined abatement-lessening effect is taken into account, the fleet mean target of 130 gCO_2/km is in reality closer to 140 gCO_2/km (T&E 2011).

3.3.2.2 More stringent emission targets

With over twenty different conventionally-fuelled vehicle models available for purchase in the UK in 2011 with claimed emissions less than 100 gCO_2/km (VCA 2011), and with many of the major manufacturers already offering vehicles to the UK market with claimed emissions less than the 2020 target, the emissions targets are evidently well within the technical capabilities of car makers[68]. Several major manufacturers are already close to full compliance with their 2015 targets – over three years ahead of schedule Toyota, Peugeot, Citroen and Fiat are all within 6 gCO_2/km of their respective 2015 targets (EEA 2010).

Concerns that to achieve the targets would entail prohibitive financial costs (ACEA 2007), or that the efficiency improvements required would not be possible without a new breakthrough technology (Fontaras and Samaras 2010) turned out to be unfounded

[65] The super-credit allowance is 3.5 inefficient vehicles per ultra-low emissions vehicle in 2012–13, reducing to 2.5 inefficient vehicles in 2014, 1.5 in 2015, then 1 inefficient vehicle from 2015 onwards. In this context ultra-low emissions is defined as below 50 gCO_2/km on a TTW basis, whereas to qualify for UK government initial purchase subsidy ultra-low vehicles are defined as below 75 gCO_2/km on a TTW basis.

[66] 65% of vehicles sold by each manufacturer in 2012 must meet their mass-weighted mean emissions target (based on a limit–value curve set at 130 gCO_2/km), increasing to 75% of new registrations in 2013, 80% in 2014, and reaching full compliance in 2015.

[67] Additional credits are also available for vehicles capable of running on 85% biofuels ('E85'), in countries where at least 30% of fuelling stations offer E85 fuel. This does not apply in the UK, where only a handful of filling stations provide E85.

[68] 'Claimed emissions' refers to manufacturer stated emissions, based on measurements over the official legislative drive cycle using a chassis dynamometer.

(T&E 2011; Varma *et al* 2011). Moreover, there appears to be considerable untapped potential in internal combustion vehicle efficiency gains; Berggren and Magnusson (2012) report engineering rules of thumb which suggest practical efficiency gains by a factor of two for petrol spark ignition engines, with a further factor of two available from propulsion efficiency gains. Thus there is little evidence that any engineering barrier exists to prevent manufacturers from achieving more demanding standards. As Berggren and Magnusson note, "[the] critical issue is not technology. The critical issue is a long-term oriented, technology-neutral, innovation and competition driving policy, built around stepwise tightening of emissions and incentive levels" (2012: p.642).

Other studies have estimated savings potential of increasing the mean TTW efficiency of a European fleet dominated by ICEVs in the short term. Wells *et al* (2010) detail four scenarios for achieving mean emissions of 80 gCO_2/km for new cars in Europe in 2020, each of which reflects the likelihood of continued prevalence of ICEVs. Notably, two of their scenarios do not invoke any new technology at all, rather they achieve the target emissions level by vehicle lightweighting and 'retuning' of performance characteristics towards more modest driving styles, and by realigning the fleet profile to smaller vehicles.

Arguments against the feasibility or cost-effectiveness of technical efficiency improvements are frequently made about the U.S. car fleet, where mean new car (type approval-equivalent) emissions in 2011 were around 210 gCO_2/km (EPA 2012). Reading the U.S.-based mitigation literature, it is important to keep in sight the considerable difference in baseline emissions between the typical U.S. car and typical European car (or Japanese, or Korean car, etc). The U.S. automotive sector's resistance to regulatory pressure to reduce vehicle emissions, even to the level of the current average European car in use, speaks of the culture of conservatism in automotive manufacturing[69]. Perhaps even greater concern arises where this conservatism permeates into the scientific literature: for example the potential for mitigating U.S. passenger car emissions is repeatedly and grossly underestimated in U.S.-based analysis. For example, Colella *et al* (2005) speculate that the ICEV is approaching the end of its product development cycle and is now into diminishing returns with respect to efficiency gains. They go on to suggest that only marginal improvements are to be expected in efficiency over the U.S. 1999 fleet mean fuel consumption, which they estimate at around 17 mpg (7l /100km, equating to around 385 gCO_2/km for petrol ICEVs) – reflecting the much greater mass, engine size and power of U.S. 'light duty vehicles'[70]. Recognising the gulf between U.S.

[69] US regulations set standards for (sales weighted) mean new car 'fuel economy' of 35.5 mpg (US) from 2016 onwards, equivalent to approximately 156 gCO_2/km (Schipper 2011).

[70] Note that the U.S. passenger car sector is commonly aggregated into the 'light duty vehicle' sector. This indicative of a high proportion of sports utility vehicles and pick-up trucks (light trucks) for use as primary household vehicles, effectively functioning as private cars. There is evidence of a trend towards similar consumer preferences in the UK, but at present emissions from vans used for private or domestic trips are

vehicle emissions and the reduction potential currently available, Cheah *et al* (2009) posit a compromise in vehicle performance and size as a means to achieve a reduction in U.S. mean new car emissions by a factor of two by the 2030s. U.S. estimates of technical mitigation potential should therefore be regarded as emerging from a socio-economic context, including a car culture and consumer-preferences quite different from those in Europe and the UK.

In contrast to the unambitious incrementalism evident in some studies of U.S. fleet mitigation, others have indicated that low-cost and low-complexity measures (idle shut-off, stop start, lightweighting) can deliver quick wins in terms of emissions reductions in the EU car fleet, finding that a reduction to mean new car emissions of 125 gCO_2/km is readily available by deployment of such simple expedients (Silva *et al* 2009). Lytton (2010) summarises recent evidence on the emissions savings potential of ‘optimising conventional cars’, citing estimates of a conceivable 40% improvement in ICE efficiency through engine downsizing (E4tech 2007), and up to 30% reduction against current mean new car emissions through a combination of engine and non-powertrain measures by 2020 (King 2007).

In this context, Davies and Harms (2007) observe that significantly tighter vehicle emission targets are likely to be necessary if European climate objectives are to be achieved, and propose investigation into the feasibility of a mean new car emissions limit of 70 gCO_2/km by 2025.

3.3.2.3 Discarding vehicle mass weighting of targets

Although intended to ensure competition and reflect the varying utility of different types of vehicle, the mean mass-based targets do not provide an incentive for manufacturers to reduce average vehicle weight, a key determinant of fuel efficiency and hence emissions (T&E 2011). In response to this, some argue that vehicle footprint (approximately the area between the wheel centres) is a better utility parameter, since some large cars have lower mass than some small cars. Moreover, by basing emissions targets on footprint size rather than mass or pan area (total area beneath the chassis), there is less opportunity for manufacturers to ‘game’ the system by increasing the mass or pan area to bump vehicles into the next, less stringent, emissions category (Kågeson 2012). Significantly, Fiat’s current new car mean emissions are at present the lowest of any manufacturer (126 gCO_2/km), yet it still has further to go to reach its full compliance target (120 gCO_2/km) than its nearest low emissions rival, Toyota, because Fiat’s cars are on average 15% lighter than those of Toyota (EEA 2010). Fiat’s situation is a case in point: the EU regulation provides no obvious incentive for its heavier competitors to reduce the average weight of their vehicles, even though this would reduce total emissions in absolute terms.

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not counted within the private car sector statistics, but are reported under ‘light goods vehicles’ (DfT 2011f: VEH0102).

Weighting vehicle emissions standards for individual manufacturers based on any of the utility parameters mentioned – mass, footprint or pan area – effectively prioritises the diversity of the automotive industry over absolute emissions reduction. This important question about which is more important notwithstanding, the notion that manufacturers whose existing product portfolio is skewed towards larger, higher emitting vehicles would be unfairly penalised by an absolute emissions standard is no longer self-evidently true. Wells *et al* (2010) suggest the possible application of advanced materials in reducing the mass of larger vehicles, albeit at a price premium. Wells *et al* identify the Mercedes-Benz F700 as an example of a luxury high-performance saloon with emissions of 127 gCO_2/km (well below category-mean) achieved by use of hybrid powertrain. It is an indication of how fast the low-emissions vehicle market is evolving that this has been considerably surpassed through recent advances in diesel engine efficiency. Furthermore, since Wells *et al*'s report, several makers of large executive saloons, such as BMW and Volvo, have brought to market large, high performance cars with claimed emissions comparable to compact cars. For example, the BMW 320d combines 0–62 mph in 8.2 seconds performance with emissions of 109 gCO_2/km; while the Volvo V50 DRIVe (with a 2.6 m wheelbase) uses idle shut-off technology to achieve 99 gCO_2/km over the NEDC standardised test-cycle.

Analysis of the expected manufacturing responses to the EU new car CO_2 regulations leads Cuenot (2009) to conclude that the EU targets will not be met in time without a departure from current trends in vehicle mass, observing:

> "Linking CO_2 emissions allowance to the average vehicle's weight is a risky strategy for the EU, as it is likely that heavier fuel-saving technologies will be the most popular amongst the OEMs, lowering their average CO_2 emissions, and giving them easier targets to be reached".

3.3.2.4 Real-world emissions accounting and monitoring

In addition to the issues relating to the provisions of the EU new car regulations, there is also an important question about whether the current type approval (TA) system of measuring emissions from new cars is a reliable indicator of emissions under real-world, on-the-road driving conditions. There is a growing body of evidence that real-world driving conditions are in fact more fuel-consuming, and hence produce more emissions, than the conditions assumed by the new European driving cycle test (NEDC). Mellios *et al* (2011) compare the NEDC type approval test with a set of driving cycles representative of more naturalistic conditions ('ARTEMIS'[71]), and estimate CO_2 emissions under real world driving conditions to be 11–17% higher than NEDC type approval results. Weiss *et al* (2011) also found that on-road CO_2 emissions exceeded type approval results by 21 ± 9%, averaged over four real-world journey types. Andre *et al* (2006) suggest that in order to capture the typically different usage patterns of larger

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[71] ARTEMIS: Assessment and reliability of transport emission models and inventory systems, project funded by the European Commission within the Fifth Framework Research Programme, DG TREN.

high-powered cars and smaller low-powered cars, separate, more appropriate, sets of test cycles should be adopted. By monitoring real world usage of 77 vehicles over 10,300 trips, Andre *et al* found that for cars with a higher power to mass ratio (those they refer to as 'high-motorized' vehicles; typically due to significantly greater engine size, rather than low vehicle weight), motorway driving accounts for around 31% of use; whereas for smaller cars motorway driving was only 20% of total use. Taking into account more naturalistic driving styles, Howey *et al* (2011) found that nine out of fourteen ICEVs with claimed TA emissions of 110 gCO_2/km (or below) significantly exceeded that threshold when driven by ordinary drivers over a real-world journey (some by as much as 50%)[72].

While the experiences of ordinary drivers mean that the divergence between claimed and real fuel consumption (and, for ICEVs, by extension emissions) has been an 'open secret' for many years, interrogation of substantial user-populated fuel consumption databases, such as www.spritmonitor.de and www.honestjohn.co.uk, confirms that the discrepancies are endemic and increasing in divergence (Mock *et al* 2012).

Discrepancies arise from a combination of driving style factors (optimal timing of gear changes, aggressiveness of acceleration and braking), speed (NEDC models a top speed of 140 kmh and mean speed of 52 kmh; real-world top and mean speeds are often higher and lower than these values respectively), terrain (NEDC does not include inclines), use of off-cycle equipment such as mobile air-conditioning, and ambient air temperature (NEDC tests are carried out in the range 20–30°C, whereas ICEVs lose efficiency at lower, more typical Northern European temperatures).

The possibility of 'cycle-beating' with respect to 'pollutant' emissions such as NOx and CO (as described by, for example, Kageson 1998), also applies to CO_2. A single set of standardised test cycles allows manufacturers to design cars to meet desired emissions criteria during the observed test cycles. As noted above, the NEDC test cycles do not represent typical usage patterns and hence typical engine loading under real world conditions, leading to Mellios *et al*'s sobering conclusion that, "there are possible ways to meet the regulation requirements...while [cars] greatly deviate in real-world CO_2 emissions...a situation where the letter of the regulation is met but the target (actual CO_2 reduction) is not" (Mellios *et al* 2011, p.28).

The observed variation has led several emissions modelling studies to apply an uplift factor to stated NEDC-based TA emissions (referred to elsewhere as 'claimed' emissions) (Nemry *et al* 2008; Leduc *et al* 2010). Defra's methodology for company

[72] In a separate report of the same 'experimental' event, Lytton (2011) points out that a smaller number of ICEVs actually outperformed their expected type approval based emissions, with a single petrol ICEV averaging 67 gCO_2/km over the 92 km test run. Data are not presented in either account (Howey or Lytton) on the type approval emissions of specific vehicles used in the test, so it is not possible to calculate the mean deviation from type approval.

reporting of their transport related GHG emissions prescribes an uplift factor of 15% over TA mean emissions values (AEA 2011).

3.3.3 Petrol vs. diesel efficiency

Several studies have commented on the limited contribution to absolute emissions reductions from 'dieselisation' of the European car fleet (Bonilla 2009; Schipper and Fulton 2009; Tovar 2011; Hivert 2012). However, this is essentially a circumstantial outcome, reflecting a combination of demand-based factors (diesel vehicles are typically driven further than are petrol vehicles) and vehicle design and consumer preference factors (diesels typically have larger engine capacities in order to deliver petrol-like performance, and tend to be larger vehicles overall). Slight differences in the upstream energy involved in refining diesel versus petrol spirit aside, Schipper and Fulton conclude that "otherwise diesel is basically a fuel economy technology" (2009: p.8, §7). Approximately 98% of the UK car fleet comprises 'conventional' ICEVs[73], with the share of diesel engines growing rapidly over the last decade. While several commentators suggest that in the event 'dieselisation' may not have brought absolute reductions in fleet emissions, they concede (like Schipper) that this is because of increased use or selection of proportionally larger diesel cars (Bonilla 2009; Tovar 2011; Hivert 2012). Contrary to this, whilst considering the effects of the manufacturer voluntary agreements, Fontaras and Samaras (2007) venture that the EU trend of reducing emissions from new cars is largely attributable to an increase in the market share of diesels, and suggest that scope for continuing this trend is finite once the diesel market reaches saturation.

3.3.4 'Persuasive' technology

Modern automobiles feature an array of devices and controls which effectively automate procedures conventionally dependent on driver input, from automatic activation of ancillary systems such headlights, wipers and air-conditioning, to more integrated functions such as ABS braking, cruise control, speed limit recognition and alerts. Cousins (2006) estimates emissions savings per VKM of 10–20% are possible from more informative instrumentation such as gear shift indicators to optimise driving style. Introduction of on-board regulators such as continuously variable transmission (CVT) in some cars (e.g. Peugeot 2008 diesel hybrid) already limits the immediate effect of engine revving, effectively overruling aggressive driving behaviour. It is interesting to observe that in Meschtscherjakov *et al*'s (2009) trial of five feedback-based persuasive

[73] In technical terms, conventional ICEVs are homogeneous charge spark ignition stoichiometric combustion-engined vehicles. In the UK fleet petrol ICEVs (comprising older port injection spark ignition – PISI; and modern direct injection spark ignition – DISI) still dominate, at 71% of all cars in use (DfT 2011d: VEH0203), but are steadily losing new car market share to diesels (direct injection compression ignition – DICI), which reached 46% of new registrations in 2010 (DfT 2011d: VEH0253). New car sales penetration by diesels exceeds 50% sales in several major EU markets, including France, Austria, Spain (Zervas 2010). Overall, around 30% (and rising) of the total EU car fleet is diesel-powered (Nemry *et al* 2008).

interfaces, participants were least receptive to the one mechanism that actually presented physical resistance to inefficient driving[74].

Anable *et al* (2006) suggest the possibility of capping top speeds by automatic vehicle systems, and the further option of rationalising vehicle design to respect the 'system boundaries' set by national speed limits, rather than the sub-optimal efficiency which results from current performance tuning for speeds far in excess of national legal and safe limits. Options for ceding speed control to intelligent road management systems, or car-following systems using pulse-and-glide and constant speed operation may also considerably enhance the fuel efficiency compared to fully autonomous driver control (Li and Peng 2012).

3.3.5 Hybrid technology

The EU new car emissions regulations, upon which the bulk of the UK's passenger car mitigation is based, are not prescriptive about which technology types manufacturers may employ to deliver the target of 130 gCO_2/km by 2015. Reviewing powertrain-only options to improve internal combustion efficiency, Taylor (2008) estimates a potential improvement in basic engine fuel efficiency of up to 15% in the ten years to 2018 with conventional ICE technology alone, rising to 21–28% for non-conventional ICEVs – i.e. using an electric motor recharged from the vehicle alternator. Smokers *et al* (2006) conclude that reaching the powertrain-specific EU 2015 emissions target of 120 gCO_2/km will require hybridisation to penetrate all segments of the car fleet (small, medium, luxury etc). However, as noted by Cuenot (§3.3.2.3), the linking of EU emissions targets to vehicle mass invites the continued production and sale of heavy, 'luxury' cars that can be brought within the relevant mass-based emissions limit with hybrid technology. Such a scenario returns scant benefit in terms of absolute emissions savings.

3.4 Additional supply-side emissions savings beyond the *LCT* measures

This section briefly considers additional car sector mitigation options, over and above those in the *Low Carbon Transport* strategy, and assesses their potential for emissions reduction in the next ten years.

3.4.1 Electric vehicles

The UK government currently provides financial support for electric vehicles (EVs), intended to create incentives for early adopters of EVs and facilitate roll out of charging infrastructure, as a means to reduce car sector emissions in the medium to long term (DfT 2011a). In the short term (10-year time horizon), emissions savings from plug in electric vehicles are expected to be minimal, in the region of 1% to 4% reductions (cf.

[74] The 'eco-pedal', which returns pressure to the sole of the driver's foot in increasing proportion to the level of 'wasteful acceleration' detected by the system. All other measures gave advisory information visually or audibly. The eco-pedal did not overrule driver input.

1990), with more significant reductions of between 4% and 16% envisaged in the medium term (20-year timeframe) (Arup / Cenex 2008).

Actual emissions saving from EVs (including both battery electric and plug in hybrid electric vehicles) will depend on both the carbon intensity of the electricity grid and the penetration of EVs into the UK car fleet. Several studies note the importance of distinguishing between the average (mean) emissions factor (or intensity) of the electricity grid, and the marginal emissions factor (Howey *et al* 2011; Ma *et al* 2012), where marginal electricity is the additional burden placed on the grid by increasing demand. Ma *et al*'s analysis of UK hourly generation data indicate that the marginal emissions factor is typically 60% higher than the mean, and is likely to remain high until sufficient low-carbon and renewable generation capacity is able to cover the already growing minimum baseload demand. Over shorter trips, at slower urban driving speeds and driver-only loads, Ma *et al* find that battery electric vehicles (BEVs) can be emissions-competitive with size-matched ICEVs and hybrids under the current UK marginal emissions factor. Over longer, higher speed trips, under the UK marginal emissions factor, Ma *et al* find that BEVs are likely to result in a net increase in lifecycle GHG emissions against a comparable modern ICEV. Smith (2010) reaches a similar conclusion, whilst noting that the trade off between battery energy density (Wh/kg) and power density (W/kg) imposes a range limit on EVs, which puts 50–75% of CO_2 emissions from passenger car use beyond the reach of EV penetration.

While the *potential* emissions savings from EVs under idealised low-carbon electricity generation mixes are commonly invoked in the literature, many studies also note electricity system decarbonisation as a prerequisite of achieving mitigation with EVs. Holdway *et al* suggest "that EVs should be...promoted where electricity generation is the least carbon-intensive" [75], and that "decarbonisation of electricity production should go hand-in-hand with the introduction of EVs" (Holdway *et al* 2010: p.1830).

3.4.1.1 Decarbonisation of the electricity generating sector

The current state-of-play in the UK's electricity supply is such that grid decarbonisation is obstructed by a lack of investment capital during the recession, and a planning process not conducive to expediting large scale renewables projects, as evidenced by 'below-trajectory' additions of wind and marine generation (CCC 2011). The recent cancellation of the UK's sole carbon capture and storage demonstration plant (Richards 2012), and the absence of planning applications for new nuclear capacity also impede the decarbonisation of the UK's electricity grid. Furthermore, emissions savings from electrification of transport will require a decarbonised grid with significantly greater capacity than at present, to accommodate additional loading not only from EVs, but also

[75] The full quotation's inclusion of the modifier 'particularly' before the word 'promoted' rather weakens Holdway *et al*'s recommendation. Their comparison of emissions from EVs under various fuel sources for electricity production with current fleet average ICEV emissions (rather than best available ICEV technology) further undermines the force of the analysis.

more extensive use of electricity in industry and domestic heating (CCC 2008a). Given that the mean emissions intensity of the electricity grid actually increased in 2010 (CCC 2011), and with low-carbon generation additions behind schedule, it is fair to say that the higher end of the aforementioned Arup / Cenex medium-term emissions savings is optimistic[76]. On the consumer demand side, early uptake of EVs has been disappointingly slow, thought to be down to a combination of factors including high initial purchase prices for EVs compared to conventional internal combustion vehicles, foundering consumer confidence in the range and reliability of EVs, together with generally stagnant new car sales during the recent economic downturn (ENDS 2011; SMMT 2011b).

Mellios *et al* (2011) reach similar conclusions to Ma *et al* regarding the emissions benefits of BEVs and plug-in hybrids over short, low speed journeys. Considering the extra credit given to car manufacturers under the EU provisions for vehicles with exhaust emissions below 50 gCO_2/km and the current use of TTW accounting, Mellios *et al* highlight the unfortunate consequence of promoting the use of BEVs over ICEVs is that they simply allow inefficient ICEVs to persist. The corollary of this conclusion is that the promotion of EVs as a direct all-purpose replacement for ICEVs may in fact jeopardise achievement of the longer-term EU mitigation goal in absolute terms.

Notwithstanding these issues of low-carbon electricity supply and fleet penetration by EVs, the expected emissions savings from EVs are to be delivered in the twenty-year time horizon, whereas a 2°C constrained national pathway requires emission cuts with immediate effect (see §5.3.4).

3.4.2 Alternative fuels – Fischer-Tropsch fuels

Synthetic ‘drop-in’ liquid fuels have been suggested as a more immediate option for reducing the carbon content of energy consumed by cars. However, although synthesis of liquid hydrocarbons from biomass feedstock using the Fischer-Tropsch process[77] has the potential to reduce overall emissions, supply is subject to the same sustainability constraints as conventional biofuels (see §3.3.1); whereas natural gas and coal feedstocks (in the absence of CCS) are counterproductive in terms of emissions reductions (van Vliet *et al* 2009).

3.4.3 Hydrogen

Interest in hydrogen as a transport fuel is as old as the motor car itself (Das 1990). Since US R&D investment during the manned space missions of the 1960s, development of

[76] The emissions savings mentioned from EVs assume the Defra long-term marginal factor for the National Grid of 0.43 $kgCO_2$/kWh. For comparison, Howey *et al* (2011) estimate the present day marginal emissions factor to be 0.69 $kgCO_2$/kWh, whereas the five year ‘rolling average’ in 2009 (the most recent data published by Defra) emissions factor for electricity consumed (generation plus transmission and distribution losses) was 0.52 $kgCO_2$/kWh (AEA 2011)

[77] The Fischer-Tropsch process is a series of chemical reactions in which a syngas (mixture of hydrogen and carbon monoxide) obtained from a primary energy source such as coal, natural gas or biomass is converted into liquid hydrocarbons – most commonly synthetic or ‘FT’-diesel (Dry 2002).

hydrogen-fuelled vehicles for the mass market has appeared tantalisingly close – a breakthrough is often said to be imminent, within the next five to twenty years (Jones 1971; Winsche *et al* 1973; De Boer *et al* 1976; Schlapbach 2009). Others, even more optimistically, claim the paradigm shift to the hydrogen economy is already well underway (Clark 2008). A review of the literature on hydrogen in transport reveals a curious intensity of debate – the development of a 'hydrogen-economy' is undoubtedly a technical challenge to be relished. There is a body of research claiming that hydrogen's current potential is not being realised, as well as making much of its future potential contribution to world energy needs and climate-related emissions reductions (for example Balat 2008; Mazloomi and Gomes 2012). Yet despite intensive industry and government-funded research programmes, there remain a number of technical barriers to the application of hydrogen at a commercial scale in the passenger car sector, and more pertinently to achieving actual emissions reductions in the passenger car sector.

Hydrogen fuel cell vehicles (FCVs) are essentially EVs powered by electricity generated on board through an electrochemical reaction using hydrogen fuel and oxygen. The most common fuel cell system set up is the polymer-electrolyte fuel cell (PE-FC, also known as a proton exchange membrane fuel cell) (Larminie and Dicks 2003). In both test bench and on-road prototypes, PE-FCVs have been found to be significantly more efficient than petroleum internal combustion – fuel cells currently return around 40%–45% of the energy in the fuel, compared to 25–30% for the petroleum powered internal combustion engine (Ball and Wietschel 2009; Corbo *et al* 2009). Hydrogen may also be used in internal combustion, although evidence suggests that once 'parasitic' losses in the transmission, distribution and storage of hydrogen are taken into account, it is more efficient to use electricity directly, rather than to produce hydrogen for fuel cells or internal combustion (Hammerschlag and Mazza 2005; Bossel 2006; Page and Krumdieck 2009).

3.4.3.1 Hydrogen as an energy carrier

While it is often pointed out in the transport and engineering literature that hydrogen is the most abundant element in the universe (e.g. Oman 2002; Chapman 2007; Inderwildi *et al* 2009), it does not exist in elemental form on earth and must be obtained by processes involving a primary energy source – common methods being steam reformation of natural gas and electrolysis of water. As mentioned in §3.2.2, the carbon intensity of the primary energy source governs to a large extent the ultimate emissions savings potential of storing energy as hydrogen.

Of the studies which present the most optimistic estimates of hydrogen's contribution to CO_2 mitigation, many are premised on ill-founded assumptions about the emissions intensity of the requisite electricity used for 'manufacturing', distributing, storing, and potentially reforming hydrogen for vehicular use (Clark and Rifkin 2006). Some take a more measured view (e.g. Inderwildi *et al* 2009), but remain nonetheless optimistic about the scale and pace of decarbonisation currently in train in the electricity generation sector, with carbon capture and storage (CCS) often posited as a surrogate for actually decarbonising the electricity supply (Marbán and Valdés-Solís 2007). Looking at the potential for generating hydrogen from fossil fuels while sequestering CO_2, Abbasi and Abbasi (2011) point to the current R&D trends in syngas and hydrogen production, which are heavily focused on coal gasification. They observe that to derive any worthwhile emissions reduction from hydrogen produced in this manner would require a functional means of sequestering billions of tonnes of CO_2 from coal fired power stations and gasification plant – a facility that will not be available within the next decade.

Reporting on the EU-funded MATISSE project, which modelled economic aspects of a transition to hydrogen power in the passenger car sector, Köhler *et al* (2010) found that the cost of subsidising the set up of the requisite network of infrastructure for hydrogen-fuelled passenger cars is likely to be less than the subsidy required to bring vehicles to market readiness. They argue that: "hydrogen offers effective solutions to both emission problems and concerns about security of energy supply, since hydrogen is an energy carrier that is emission-free at final use; and can be obtained from a variety of different primary sources and readily stored" (Köhler *et al* 2010: p.1238). The supposition that hydrogen offers an accessible solution to mitigation is often repeated throughout the socio-technical 'scenarios and visions' literature (Winter 2005; Clark and Rifkin 2006), but is at odds with the technical literature on the energy penalties currently associated with both manufacturing and storing hydrogen (Shinnar 2003; Ball and Wietschel 2009).

Given the technical problems posed by storing volumes of hydrogen on board cars and the scarcity of materials required for building fuel cells, major market penetration by hydrogen fuel cells before 2035 is considered unlikely (Frenette and Forthoffer 2009). These concerns notwithstanding, hydrogen offers emissions reduction potential in the car sector only in so far as the electricity used to produce the hydrogen is itself low-carbon. As discussed in §3.4.1.1, the UK electricity grid does not appear likely to offer this potential within the near-term period of interest for this analysis.

3.5 Increasing uptake of lower emissions vehicles

3.5.1 National differences

Considering the existing availability of vehicles with claimed type approval emissions well below the 2015 and 2020 EU targets, it follows that achieving these targets does not require any major technical or engineering innovation that manufacturers have not already made – at least on the basis of type approval emissions. Rather, achievement of the emissions targets will require a significant increase in the penetration of low-emissions vehicles into the car fleet, by increasing the proportion of sales of low-emission new cars. New cars emitting less than 130 gCO_2/km made up 38% of UK sales in 2010, compared to 65% of new vehicles registered in EU27 countries in 2009 (CEU 2010). The sub-130 gCO_2/km share of new vehicles registered in the UK rose to 47% in

2011[78] (DfT 2012d, VEH0256). Although UK sales of sub-100 gCO_2/km cars doubled in 2010, they still made up only around 2% of new car sales (SMMT 2011a). Thus it may turn out that collectively manufacturers meet their 2015 targets even while UK mean new car emissions remain greater than 130 gCO_2/km, if sales of low emissions vehicles in other EU countries compensate for poor sales in the UK. Although the UK is amongst the four most significant national markets in the EU, representing around 15% of total new car sales in 2010 (Table 3.3), the current discrepancy between UK sales of low emissions vehicles and the EU trend reveals a distinct possibility that the UK may still be behind the curve in uptake of cleaner cars in 2015. This would seriously undermine UK car sector mitigation, since 65% of planned abatement opportunities in the *LCT* strategy (over and above those already in effect) derive from meeting the EU 130 gCO_2/km target and complementary measures (see Table 3.1).

This divergence reflects the lower proportion of diesel ICEVs in the UK fleet compared to the rest of Europe (§3.3.3), itself attributed to diesel prices being higher in the UK than any other EU27 country (AA 2012), and one of only four EU countries where diesel prices per litre are higher than for petrol. The divergence between the EU27 mean new car emissions level and the UK's is also a function of the UK passenger car market being skewed towards higher powered vehicles, with the mean engine displacement (in cubic centimetres), top speed (mph) and power (measured in kW) of UK new cars being higher than all other member states bar Germany – although conversely UK mean new car weight is the lowest in Europe (Campestrini and Mock 2011).

[78] At time of writing, EU data for 2011 are not yet available.

Table 3.3: Mean CO_2 of new cars and national new car sales figures for selected EU member states in 2010, and percentage change since previous year. Data source: T&E 2011.

Member state	New registrations	Share of EU27 total sales	New car mean gCO_2/km in 2010	Emission ranking 2010	New car mean gCO_2/km in 2009	Emission ranking 2009	Change 2009–2010
Germany	2,873,269	22%	151	22	154	17	-1.80%
France	2,250,395	17%	131	3	134	1	-2.60%
UK	2,026,120	15%	144	12	150	11	-3.80%
Italy	1,954,123	15%	133	5	136	4	-2.40%
Spain	975,933	7.4%	138	9	142	7	-2.80%
Belgium	551,385	4.2%	133	7	142	6	-6.00%
Netherlands	479,515	3.6%	136	8	147	10	-7.60%
Austria	328,261	2.5%	144	11	150	12	-4.00%
Sweden	277,203	2.1%	151	23	165	23	-8.20%
Portugal	222,780	1.7%	127	2	134	2	-5.00%
Poland	219,120	1.7%	146	15	152	13	-3.70%
Denmark	133,309	1.0%	127	1	139	5	-8.9%
All others	869,921	6.6%	149		157		-5.3%
EU-27	13,161,334	100%	140.3		145.7		-3.70%

While the *rate* of improvement in new car emissions in the UK 2009–10 was slightly better than the EU27 mean, Table 3.3 also shows the UK's actual mean new car emissions to be some 17 gCO_2/km worse than Denmark, and 13 gCO_2/km worse than France. Only Germany has new car registrations and emissions comparable to the UK, leading some industry commentators to suggest that these large car markets are holding back achievement of EU-wide emissions targets (T&E 2011).

3.6 Summary

Based on the preceding survey of supply-side mitigation in the short term, four broad categories of supply-side measures can be discerned in the literature:

(i) vehicle and fuel technology already available at the commercial scale, or which could rapidly be made available:

- TTW vehicle–fuel efficiency improvement of conventional ICEVs through powertrain refinements (e.g. stop-start technology, idle shut-off, engine downsizing-plus-turbocharging, performance-limiting technology);
- TTW vehicle–fuel efficiency improvement in conventional ICEVs through switching to small diesel (DICI) engines in preference to petrol (PISI/ DISI);
- TTW vehicle–fuel efficiency improvement of conventional ICEVs through non-powertrain measures, principally lightweighting, control of ancillary equipment such as mobile air-conditioning and gear-shift optimisation;

- TTW vehicle–fuel efficiency improvement of vehicles by increasing use of non-conventional ICEV technology, in particular auxiliary hybrid motors;
- use of small pure electric vehicles (BEVs and PHEVs) for short distance, low-average-speed and light-load urban trips;

(ii) infrastructure projects at both national and local scales:

- WTW fuel–carbon efficiency improvement to the electricity grid through addition of low-carbon and renewable generating capacity;
- Deployment of EV supply, charging and maintenance networks – in step with the rate of improvement in WTW efficiency in the electricity grid;

(iii) research and development projects not yet commercially viable:

- lifecycle vehicle–fuel efficiency improvements in EVs through development of high energy-density batteries with low mass and volume;
- lifecycle vehicle–fuel efficiency improvements in hydrogen-powered vehicles through development of high energy-density on-board storage (and /or reformation) technology, with low mass and volume;
- lifecycle fuel–carbon efficiency improvements to biomass-based liquid fuels, subject to lifecycle analysis of environmental and equity impacts of indirect land-use change;
- lifecycle fuel–carbon efficiency improvements in solid to liquids and gas to liquids synthetic fuels (subject to lifecycle analysis of environmental and equity impacts of indirect land-use change if using biomass feedstock);

(iv) regulatory and standard-based measures:

- accounting and monitoring principles used to estimate emissions from specific vehicle types, and the passenger car sector as a whole; and
- measures to increase penetration of low-carbon vehicles into the fleet.

The next chapter considers demand-side issues, including vehicle interventions to affect driver-based vehicle operational parameters, traffic volumes (total vehicle kilometres, or VKM_{fleet}) and end-user preferences in relation to selection of low-carbon vehicles.

CHAPTER FOUR – DEMAND-SIDE ISSUES

4.1 End user demand

This chapter sets out the key issues and background literature relating to passenger car end-use. Demand is broadly taken to refer to the *amount* that people use cars (vehicle kilometres, VKM), although there are a number of other dimensions relating to issues more helpfully thought of as 'demand-side' than supply-side, including car purchasing, driving style and contextual policies such as land-use planning, which affect the need to travel. All aspects of demand are identified in this chapter, with emphasis on the potential for constraining total vehicle kilometres while preserving current levels of mobility (expressed as passenger kilometres, PKM). Car choice and driving style are treated in relation to their contribution to delivering the full potential of emissions savings from supply-side measures, as described in the previous chapter.

The following sections §4.1.1 – 4.1.4 examine the background assumptions which underpin the alternative paradigms of demand management and growth. Sections §4.2 – 4.5 then follow a similar structure to the previous chapter, setting out the key metrics of demand, assessing expected mitigation under current policies, before looking at the potential for current policies to be extended in ambition, and for additional interventions that could contribute to reduction in demand.

4.1.1 The demand management / reduction paradigm

The passenger car sector, in its foreseeable short-term socio-technical configuration, cannot be adequately decarbonised without an effective constraint on car-kilometres. The reasons for this are at least fourfold:

i. The current oil-dependence of the fleet means that incremental improvements in vehicle–fuel carbon intensity reduce car fuel consumption, which, *ceteris paribus*, reduces the cost per kilometre, inviting rebound effects (Sorrell *et al* 2009). Even without rebounds, if demand for car-kilometres reverts to pre-recession growth trends, expected growth in the driving population alone will cancel out emissions savings from vehicle–fuel carbon improvements, as has been the case over recent decades (see Chapter 1, Figures 1.2–1.4).

ii. The existing fleet is renewed on a rolling basis, taking approximately 20 years to replace 95% of the current stock under historically observed rates of vehicle retirement and replacement, with 50% replaced by between 12 years (Spencer 2008)[79] and 14 years (Leibling 2008)[80]. With improvements to vehicle technology taking well over a decade to penetrate fully into the fleet, supply-side emissions savings build gradually, allowing existing inefficient vehicles to continue using up the remaining cumulative emissions budget. As noted in Chapter 2, conforming to a

[79] Based on data from AEA Technology for National Atmospheric Emissions Inventory.

[80] Based on data from SMMT (Society of Motor Manufacturers and Traders).

pathway and budget associated with a low probability of exceeding 2°C will require much greater cuts in total cumulative emissions in the short term than are currently planned from vehicle–fuel carbon intensity reductions. Relying on 'natural' rates of attrition and renewal in the car fleet will not bring about the level of mitigation required.

iii. Evidence points to economic and population growth being the major drivers of growth in total car-kilometres. As incomes rise, so does demand for faster, more convenient modes of transport: an 'irresistible force' (Lave 1992) almost invariably towards the private car[81]. With more drivers entering the population, aggregate demand increases. UK mean real disposable income has almost doubled since 1970, whereas the real total cost of driving has declined (Headicar 2012a). With economic growth as top political priority, *ceteris paribus,* increasing demand for private car-kilometres is the likely consequence.

iv. As demand for car-kilometres has grown, so too has the concomitant culture of 'car dependence', which now permeates 'developed' nations (Jones 2011). Most tangibly manifest as the omnipresence of car-based infrastructure (roads, street furniture, demarcated space, parking, bridges, flyovers, tunnels, etc), it is also in evidence as the ubiquity of the car in nearly every aspect of everyday life (employment, leisure, education and household), and in the promotion of the aspirational and positional aspects of automobility. Non-car modes come to appear variously more difficult and dangerous (e.g. unpowered modes), time consuming (unpowered modes and public transport) or expensive (public transport) than car travel. Where such perceptions occur, they further reinforce the modal dominance of cars (Van Exel and Rietveld 2009). Car dependence has so far proved to be a one-way street in terms of influencing people's expectations and aspirations about convenience and other qualitative aspects of travel (comfort, safety, privacy, spontaneity, etc) (Stradling 2011). Once people start to drive, they rarely revert to non-car modes as their main conveyance unless compelled to do so (by financial or health difficulties or license restrictions, for example)[82] (Møller and Thøgersen 2008). Thus, in the absence of intervention, non-car modes struggle to gain modal share in a culture where the car is the incumbent first preference.

4.1.1.1 Assumed accepted necessity of demand management

Within the vast literature on travel demand management (Goodwin (2008) estimates 5,000 written studies relevant to the UK), it is noticeable that the 'necessity of demand management' has become something of a mantra. So pervasive is the presumption that

[81] The notion of 'peak car', or network saturation, is discussed later in this chapter.

[82] A notable exception to this propensity to 'stick with the car' is when moving home from sub-urban or rural area to a densely urban area, where public transport provision is more concentrated (reducing the need to drive) and congestion and parking charges increase driving costs.

the need for demand management is widely accepted that it is tempting to take as read a political impetus to at least *restrict growth* in demand for private vehicle kilometres. For example, observing the danger to public health posed by air pollution from motorised transport rather than specifically dealing with carbon emissions and climate change, Fujii *et al* (2001: p.797) state that,

> "[this] threat is most likely to become more acute in the future unless private car use for daily travel is substantially reduced. … Although everyone probably would agree that reducing private car use is highly desirable, sacrificing the convenience, individual freedom, and time savings a private car offers may at the same time appear to be arduous. Like many environmental problems, this conflict of self-interest and public interest has the character of a *social dilemma* or *social trap*".

The arduousness, perceived or otherwise, of forgoing car-based convenience is in no doubt; the ensuing review of demand-side policy interventions demonstrates a very limited track record of success to date. However, Fujii *et al*'s confidence appears misplaced in suggesting universal endorsement for the sentiment that "reducing private car use is highly desirable". Nonetheless, Fujii et al render explicit an important assumption that often remains tacit and which is virtually endemic throughout the transport energy literature – namely the *accepted* necessity of demand reduction. Before commencing a review of the potential for amplifying emissions savings through demand management, it is worth reflecting on the alternative, equally influential, paradigm of positive demand growth. This provides a vantage point from which the difficulties involved in implementing demand management policies are more clearly apprehended.

4.1.2 The growth paradigm – transport and economic prosperity

The groundswell of political opinion and research which militates against general acceptance of the necessity of demand management is formidable. Arguing in favour of reinvigorating the UK's road-building programme on the grounds of economic benefits to society, Banks *et al* (2007) take the view that sufficient emissions reduction can be achieved through technical improvements to cars – even to the extent of suggesting that a 90% reduction in emissions could be achieved 'by 2050' in conjunction with a doubling of UK road use. While Banks *et al* posit that a greater increase in road traffic could be reconciled with a reduction in emissions than the DfT, they share the same basic supposition that growing traffic volumes and declining emissions are compatible.

In principle this argument has some appeal; if emissions per kilometre reduce more steeply than total vehicle kilometres (VKM) rise, then theoretically traffic volumes could grow while emissions shrink. Furthermore, since it is conventionally argued that mobility is a key driver of national economic prosperity (Eddington 2006a), growth in vehicle kilometres becomes an end worthy of promotion, insofar as it is treated as a proxy for mobility. All too often mobility is implicitly equated with private transport, due to the *de facto* dominance of the car. This influential position essentially contradicts the presumption of the accepted necessity of demand reduction. Eddington argues that the causal connection runs both ways, with private transport creating economic opportunities, facilitating productivity and promoting welfare and consumption-based 'quality of life', all of which in turn create either the means or the need for further travel.

4.1.2.1 Varieties of decoupling

Banister & Berechman (2001) observe that mutual reinforcement and positive feedbacks have historically existed between growth in private transport and the economy, but go on to argue that this is not a *necessary* relationship. Banister and Berechman suggest that the connection may be severed, 'decoupling' economic growth from reliance on polluting forms of transport by a combination of more efficient transport technology, modal shift and demand reduction. They note the difficulty of envisaging demand reduction under conditions of increasing affluence and leisure time, and point out that efficiency improvement can itself lead to an increase in demand. Thus decoupling conceived simply in terms of reducing 'transport intensity'[83] (Stead 2001; Banister and Stead 2002), usually referred to as 'relative' or 'weak' decoupling (Tapio 2005), will not necessarily deliver any reduction in absolute emissions. This has in fact turned out to be the case historically in industrialised countries, where demand growth has outstripped transport efficiency gains (or carbon intensity reductions), leading to a continued increase in emissions, albeit at a slower rate than may otherwise have occurred (Tapio *et al* 2007).

Evidently, weak decoupling, or reducing transport intensity is inadequate with respect to observing a cumulative emissions budget which requires urgent and deep cuts in absolute emissions. Weak decoupling is contrasted with absolute or strong decoupling, whereby GDP grows while (in this case, transport) emissions decline. A recent review of national GDP and transport CO_2 emissions statistics found evidence of strong decoupling between 2000–2005 in a diverse group of countries, which significantly included EU27 member states and other wealthy countries (France, Germany, Denmark, Japan, Switzerland) (Finel and Tapio 2012). It is not possible to ascertain from Finel and Tapio's published results what the extent of emissions reduction was for any individual country, nor which forms of transport were responsible for the decrease in absolute emissions – the study included freight and passenger transport by road, rail, air and water. However, their findings lend credence to the logical coherent assertion that economic growth need not be frustrated by a reduction in transport emissions.

With respect to climate change, the more important question is whether *absolute, aggregate emissions* from passenger cars may be brought down rapidly and to the extent required to meet emissions budgets consistent with a low probability of exceeding

[83] Where 'transport intensity' is defined as "an aggregate measure of the resource importance of transport in the national economy, transport intensity is therefore the ratio of gross mass movement to Gross Domestic Product (GDP)" (Gray *et al* 2006, citing Peak 1994). Gray *et al* go on to distinguish between *traffic* intensity (ratio of GDP to aggregate VKM travelled), *energy* intensity (ratio of amount of energy used to move a given number of passengers a certain distance), and *carbon* intensity of transport (amount of carbon emitted for a given number of transport movements).

2°C. Whether this can be achieved in tandem with short term GDP growth remains moot. Possible rebound effects (improved efficiency giving rise to increased vehicle use and potentially increasing emissions overall) notwithstanding, there is good reason to believe that economic growth may not be compatible with the necessary rates of emission reduction. Anderson and Bows note that the only comparable historical analogue for the requisite rates of emissions reduction comes from the dismantling of the former Soviet Union, when emissions decreased at approximately 5% p.a. for ten years in conjunction with economic contraction (Anderson and Bows 2008). The Stern Review considered the possibility of continued economy-wide growth in parallel with emissions reductions, asserting that “tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries” (Stern 2006: p.ii). This has been taken in some quarters as supporting implementation of soft behavioural interventions such as travel plans, ostensibly over direct regulation or interventions which curtail demand (e.g., Enoch and Ison 2008). However, notwithstanding that several of the Stern Review’s assumptions about necessary rates of emission reduction are highly optimistic (for example, based on global emissions peaking by 2015), it should be noted that its emphasis is on *longer* term economic growth. Moreover, the Stern Review actively calls for a pronounced reduction in demand for emissions-intensive goods and services driven by an effective carbon price.

Accepting that since 2009 passenger car sector emissions have declined in the UK for the first time ever, it is salient that this has occurred during a period of economic recession. Banister & Berechman (2000) list four economic trends affecting demand for passenger car VKM:

i. changes in work patterns and increased leisure time;
ii. socio-technical changes exerting a transformative force on the economy;
iii. shift from a resource-based to an information-based economy; and
iv. continuing urbanisation and the rise of ‘global cities’.

The combined effect of these pressures, they argue, suggests the potential for ‘exponential growth [in mobility] over the next ten to twenty years’; the implication being that economic growth itself is likely to be a key driver of demand for passenger car VKM.

This analysis does not attempt to settle the question of the possibility of absolute, strong decoupling of passenger car emissions and economic growth. It is important to note, however, that the guiding assumption in UK transport mitigation policy appears to be not only that strong decoupling of emissions and GDP is possible, but that this can be achieved without reduction in car-kilometres. In fact, the DfT’s annual *Road Transport Forecasts* clearly presuppose that growth in car kilometres (as well as GDP) can be decoupled from transport emissions, through huge reductions in transport carbon intensity[84]. This position, rather than an acceptance of the necessity of demand reduction, more accurately characterises the mindset of UK transport policy-making. This is despite repeated exhortations to the contrary from transport energy researchers, who caution that reducing transport intensity alone will not be sufficient to deliver the desired pathway. That is to say, not by reducing intensity at rates that may be realistically expected in the short- to medium-term, given the current oil-dependence of the fleet and limited progress towards decarbonisation of electricity. A reduction in aggregate car-kilometres (VKM_{fleet}) is therefore seen by the transport energy *research* community as a necessity if climate change objectives are to be met. With this divergence in mind, Marsden *et al* observe that “serious gaps exist between the research and practitioner community” (Marsden *et al* 2009: p.2). Such gaps result from differences in decision-making priorities and processes in research and policy, leading to a ‘clash of cultures’ (Brownson *et al* 2006).

4.1.3 Cognitive dissonance in transport mitigation policy?

On the one hand then, the political rhetoric is clear on the need to address emissions from the passenger car sector, and even acknowledges the need for ‘behavioural shifts’ in order to achieve this (DfT / GSR 2011). Famously one former secretary of state for transport, John Prescott, was moved even to promise to reduce the number of journeys made by car in the five years from 1997 (Hansard 1998)[85]. Despite acknowledging the difficulty of such a task at the time, policies which might actually deliver such a reduction in demand for private car use have not been forthcoming.

On the other hand, it is notoriously difficult to obtain in advance public approval for policies which actually constrain private car use, hence governments have traditionally shied away from actively intervening coercively – or indeed effectively. The only recent domestic policy with any reported suppressant effect on national traffic volumes, the Fuel Duty Escalator, was scrapped in 1999, with duty rates further reduced the following year in response to protests over fuel prices (Salmons 2011). Johnson et al (2012b) note:

> "the difficulty of...further [fuel] duty rises has already been demonstrated by the consistency with which both this government and its predecessor have announced, and then failed to implement, duty increases. From their peak in March 1999, real (inflation adjusted) fuel duty rates were 16% lower by December 2010".

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[84] The most recent edition of the DfT’s annual *Road Transport Forecasts* predicts a return to pre-recession growth resulting in an increase on 2010 car traffic volumes of 37% by 2035 accompanied by 9% reduction in CO_2 from road transport (DfT 2012c).

[85] Note that this bold promise was not framed as a reduction in total car-kilometres, although when asked for reassurance on this promise ‘to reduce traffic levels overall’, the secretary of state assented.

According to Begg and Gray, the abolition of the duty escalator means that "the government has no control over traffic growth or CO_2 emissions" (Begg and Gray 2004: p.162).

Tensions between competing perspectives have existed in UK transport policy for years – reducing demand, often for ends such as congestion management (see for example May 1986), versus supporting popular aspirations and the 'freedom' of the car (Jones *et al* 2005). This manifests in the concern, as reported in Lucas *et al*'s feedback from an expert stakeholder seminar, that "the government is trying to solve the problems that are associated with car use, *not* car use itself" (2009: p.14). A case in point is the recent announcement of intent by the coalition government on increasing the national speed limit, argued for by the former secretary of state for transport on the grounds that: "increasing the motorway speed limit to 80 mph would generate economic benefits of hundreds of millions of pounds through shorter journey times" (BBC 2011).

Ostensibly, the primary concern of transport policy since the 1990s has been alleviating network congestion rather than managing demand *per se*. While Headicar (2008) sees evidence that the need for some form of demand management is acknowledged in policy circles, it is significant that it is envisaged as being delivered through 'improved opportunities' for non-car travel. This can be seen for example in the Road Traffic Reduction Act 1997, which, while making provisions for local authorities to report on traffic volumes and set strategies for dealing with congestion, does not compel them to do so. Gilliard (2009) also notes that the 1998 government white paper on transport "aimed at behaviour change, mode shift and tackling car use", but supported car ownership. Incidentally, the white paper adopted an argument advanced by the RAC Foundation's 1995 Car Dependence Report, that many short trips made by car may easily be substituted by other modes, arguing that this shows the potential for people to use cars less without great sacrifice. However, dealing only with short trips is inadequate from an emissions reduction point of view – as Figure 4.6 (p.109) shows, car journeys of ten to twenty-five miles collectively generate a greater share of total emissions than any other distance category.

From expert stakeholder interviews with policy-makers, Gilliard found:

> "Ambitions such as traffic reduction, constraining or reversing car use and significant mode shift for personal and freight movement were identified as firm policies *without any examples anywhere in the world of how this might be achieved without road pricing*, *for which no powers yet existed in the UK*. The same applied to the wider goals for transport such as promoting economic growth, enhancing the vitality of town and city centres, and tackling social exclusion: *it was more a statement of faith than a matter of evidence that transport could deliver these results*". (Gilliard 2009: p.15. Emphasis added)

Gilliard goes on to note that:

> "Certainly, the Department [for Transport]'s own road traffic forecasts showed no expectation of success in these stated policies and the National Road Traffic Forecasts of the time anticipated there would be a steady growth in road traffic, albeit at a lower rate than previous estimates". (ibid.)

4.1.4 Implications for this study

The previous sections demonstrate the conflicting priorities within transport policy-making. Furthermore, with an economic recession now stretching into its fourth year, there is no immediate prospect of policies that restrict mobility or otherwise ostensibly jeopardise economic growth. Whereas in many cases throughout the policy literature mobility is equated with car driving, clearly this is not a *necessary* relationship. Public and unpowered modes also provide mobility, albeit sometimes involving longer overall journey times. In areas where public transport is more concentrated, the mobility advantages of public over private travel can be exploited – "there is nothing...inevitable about growing automobile dependence in cities" (Cameron *et al* 2004: p.297). Insofar as demand for travel is derived demand (i.e. used to derive some other additional benefit), increasing incomes create new opportunities to consume in ways that prompt additional travel to obtain or partake (Echenique 2007). However, several authors, notably Schafer and Victor (2000) and Metz (2002) argue that even as national wealth and individual incomes rise, people's daily travel time budgets are relatively invariant – in the UK the mean time spent travelling has remained fairly static around 1.1 hours per person per day (385 hours per person/year) since the 1970s (Metz 2008). This apparent ceiling on *mean* travel time budgets leads to increasing demand for faster modes, hence the ascendancy of the private car.

The decision priorities described in Chapter 1 indicate that effective mitigation measures will be sought that, first and foremost, promote rather than restrict mobility. In setting out the key dimensions and metrics of demand, the next section elaborates the connection between private car-kilometres and mobility. It highlights car occupancy as an important variable in determining the extent to which reductions in total vehicle kilometres may be achieved while preserving not only present levels of mobility *per se*, but also present levels of 'car-based mobility'

4.2 Metrics of demand – 'choice areas'

Gross *et al* (2009) set out a typology of choice areas relevant to demand (Figure 4.1).

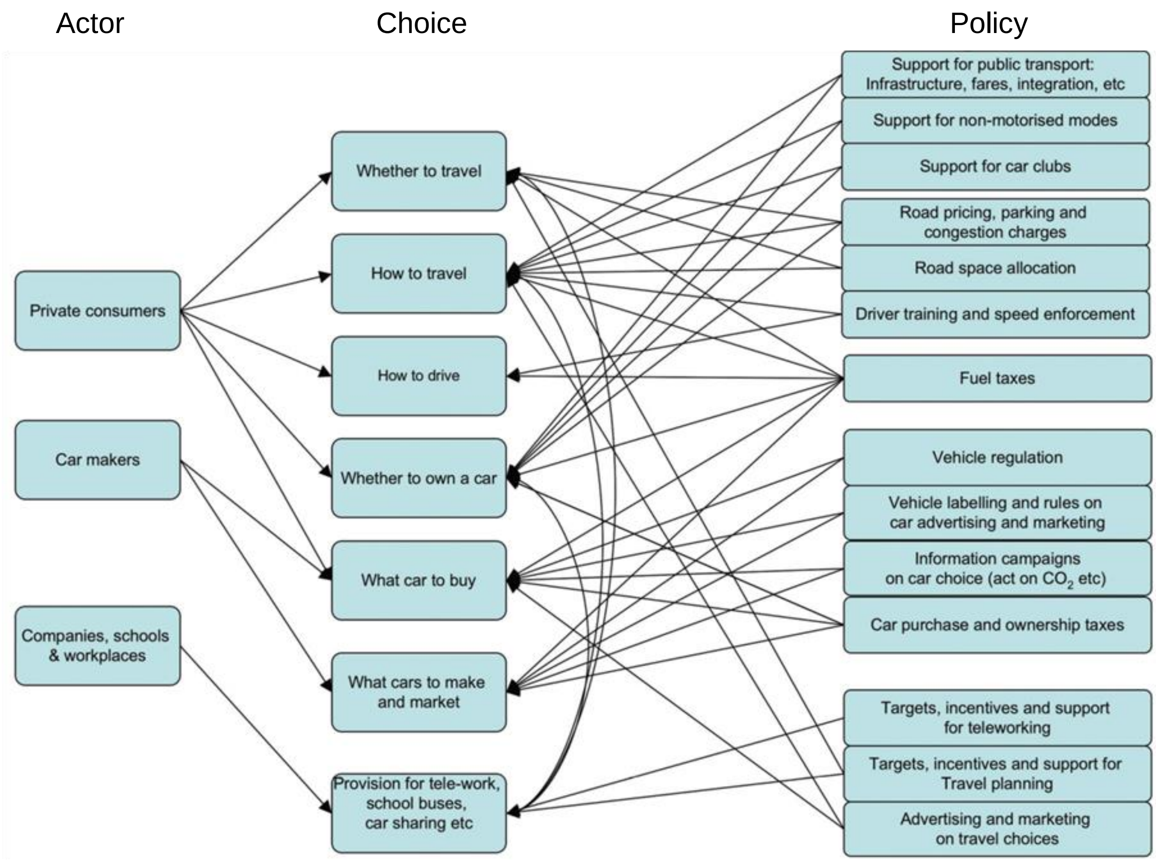

Figure 4.1: Typology of actors, choices and policies in personal transport (reproduced from Gross *et al* 2009)

Choices made by car makers are dealt with in the previous chapter on supply-side issues. Choice made by companies, schools and employers affect the travel options available to car drivers, and are dealt with in §4.4.5.3 on infrastructure and enabling measures. With respect to choices directly relating to passenger car use, the remaining elements in Figure 4.1 may be distilled down to the following dimensions:

i. vehicle use: driving distance (whether to travel or not, whether to drive alone or car-share, mode choice, linking of trips);
ii. vehicle or technology choice (which, if any, car to drive); and
iii. vehicle use: driving style (how to drive, as mentioned in the previous chapter).

The defining characteristics of each of these dimensions of demand are briefly set out below, before the background literature on policies intended to affect them is reviewed.

4.2.1 Vehicle use and mobility

The first category or dimension of demand, vehicle use, is the one most often thought of as representing 'passenger car demand'. It is important to distinguish between demand for vehicle kilometres (VKM, or more accurately car-kilometres) and passenger kilometres (PKM). With respect to *emissions* and mitigation, VKM is the more revealing and hence useful metric. As noted in Chapter 1, demand is taken elsewhere throughout this analysis to refer to *vehicle kilometres,* unless explicitly stated otherwise in the text.

Using only vehicle kilometres, however, would not fully reflect the personal mobility dimensions of car use. Most cars are capable of carrying more than just a driver alone – one vehicle kilometre typically facilitates more than one passenger kilometre. Passenger kilometres also provides a common metric which allows comparison with other modes of transport, private, public and unpowered. Previous chapters noted that in evaluating mitigation measures this analysis prioritises promotion of mobility above other criteria. The distinction between car driving and mobility is crucial in allowing this priority to be met whilst simultaneously reducing demand for car-kilometres. Passenger kilometres may increase whilst car-kilometres fall, either by increasing the mean number of passengers carried per car-kilometre driven, or by transferring car-kilometres to another mode. Moreover, other modes may grow independently of car-traffic volumes, with additional trips made by non-car modes, over and above those that would otherwise be made by car. In this analysis mobility is identified with passenger kilometres only.

For the purposes of estimating emissions from the whole UK passenger car sector, vehicle kilometres are treated as an aggregate value (see Chapter 1, Figure 1.3). However, exclusive focus on the aggregate value hides the socio-economic and demographic variation and trends that underlie the total traffic volume, which are highlighted in the next section.

4.2.1.1 Trends in vehicle use and mobility

There is a growing body of literature on the possibility of 'peak car', referring to per capita demand for vehicle kilometres reaching an upper limit, set either by individuals 'travelling as much as they wish' or externally imposed by network congestion and capacity limits (or both). Headicar (2008) observes that National Travel Survey data show annual per capita driving distances have declined slightly between 2001 and 2010 following a steady rate of year on year increase from 1980 (Figure 4.2). The implication is that the increase in total vehicle kilometres travelled on UK roads between 2001 and its peak in 2007 was driven wholly by growth in UK population – i.e. by additional car drivers entering the system (see Figure 4.9 on p.113). This presents a different set of issues with respect to demand management than growth driven by rising per capita demand. In particular, given that mean driving distances have already declined in the last decade, from the perspective of the individual end-user, demand restraint interventions may appear unnecessary. To curb rising aggregate demand, however, there is little option but to further reduce per capita driving, since the alternative – limiting the availability of driving licences – would result in social and economic exclusion. Headicar (2008) suggests that rather than interfering with people's *right* to own (and drive) a car, policies which promote alternatives to car ownership may be able to start to reverse the upward trend in population growth-related aggregate VKM.

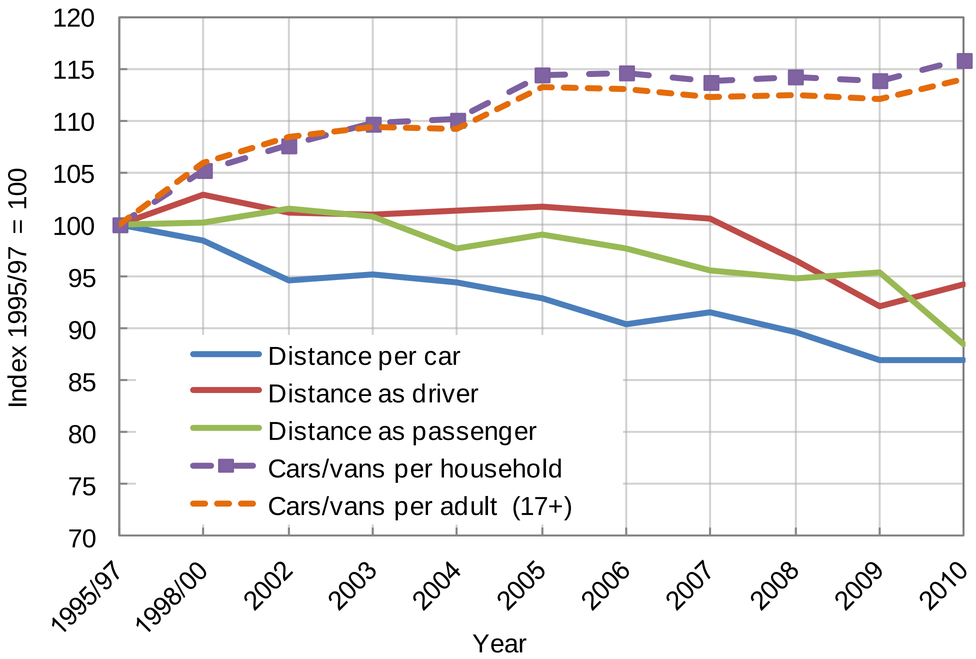

Figure 4.2: Changes in UK car use and ownership 1995-2010. Data source: (DfT 2011b)

Without access to detailed data on historical fleet composition and use pre-1994, it is difficult to ascertain accurately longer term trends in annual distances per vehicle (VKM_{veh}). Estimated by dividing total licensed vehicles by total VKM_{fleet}, Figure 4.3 shows that mean VKM_{veh} – perhaps surprisingly – has varied relatively little over the six decades of the post-war period. Notwithstanding the decline in mean VKM_{veh} since the peak that lasted from the late 1980s to 2000, mean annual VKM_{veh} in 2010 (14,283 km per vehicle) was little more than in 1951 (13,986 km per vehicle).

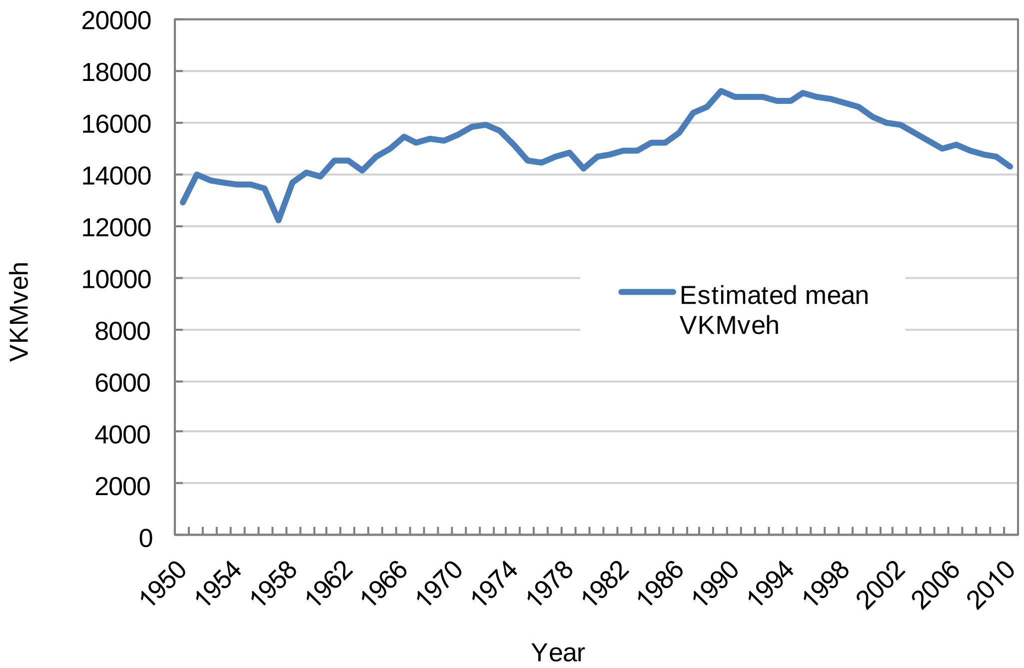

Figure 4.3: Historical mean annual VKM_{veh} based on historical total annual VKM_{fleet} divided by total fleet size. Data sources: (DfT 2011f, VEH0103; DfT 2011e, TRA0201)

4.2.1.2 Car ownership and population growth

Le Vine et al suggest that the assumptions underpinning traditional traffic growth models, such as the DfT's, do not appear to accurately reflect the now much weaker relationship between car ownership and average travel per capita (Le Vine *et al* 2009). Like Headicar, they also speculate that car driving distances may have reached their per capita maximum level, either as result of people's desire to travel being satisfied, or due to the restrictive effects of network congestion and saturation. They note that the 17% increase in UK citizen population between 2006 and 2031 projected by the Office for National Statistics is likely to degrade network performance substantially thus leading to 'downward pressure' on per capita driving distance.

As above, Le Vine *et al* reflect that even if per person driving distances remain stable, total demand for car-kilometres will continue to grow in line with citizen population. Headicar concurs: "future increases in population mean that...traffic levels will rise even if car use per individual continues to flat-line" (Headicar 2008: p.10). Metz adds that the scale of the ensuing demand growth will be to a large extent determined by *where* the additional population live and work (Metz 2012).

For the purposes of framing demand management policies, therefore, in addition to aggregate vehicle kilometres and passenger kilometres, levels of car ownership (measured as number of cars per capita), population growth and per capita driving distance are also important and revealing metrics. Figure 4.4 illustrates the 0.6% p.a. mean growth in total UK population since 2001, with 2009–10 showing a 0.8% increase, the highest since the start of the 'baby boom' in 1962 (ONS 2011c). Another important demographic factor to consider is that, although the uptick in birth rate since the low of 2002 is yet to add new drivers to the population of UK license holders, the lower death rate and longer life expectancy means that older drivers are remaining active for longer, whilst the trend for an increasing proportion of women to hold a driving licence is likely to further increase the potential demand for car use, especially amongst older people.

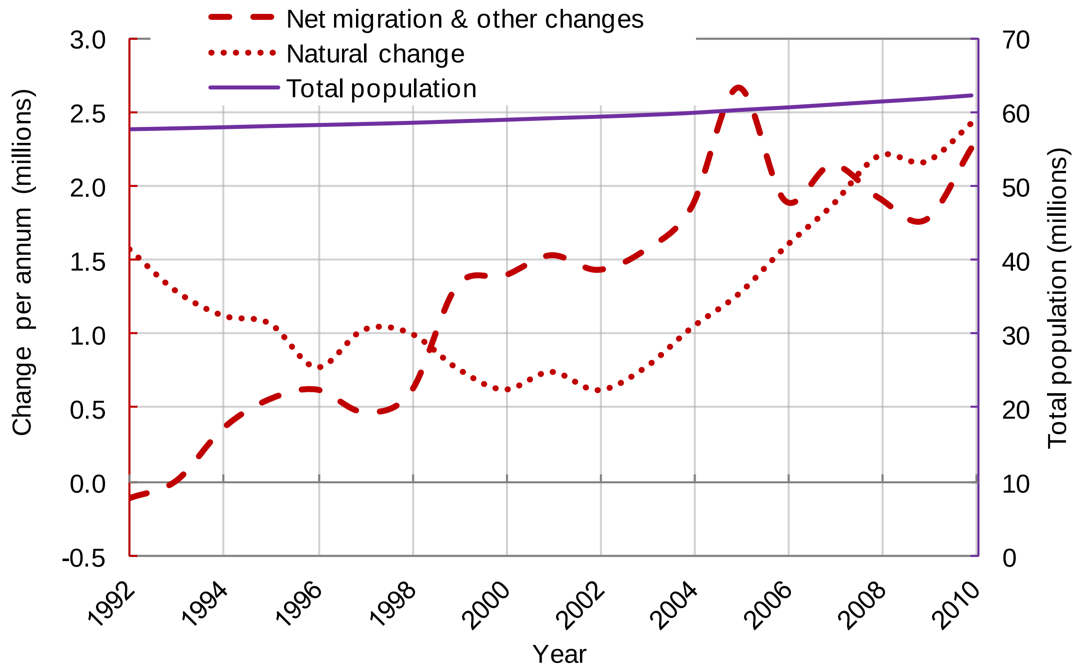

Figure 4.4: Total UK citizen population since 1992 and principal components of change. Natural change is the difference between births and deaths, net migration the difference between emigration and immigration. Data source (ONS 2011b).

Figure 4.5 illustrates the long term trend of car ownership expanding dramatically, the proportion of all British households with one or more cars increasing from 14% in 1951 to 75% in 2010, and in later years the proportion of households having two or more cars surpassing that with no car.

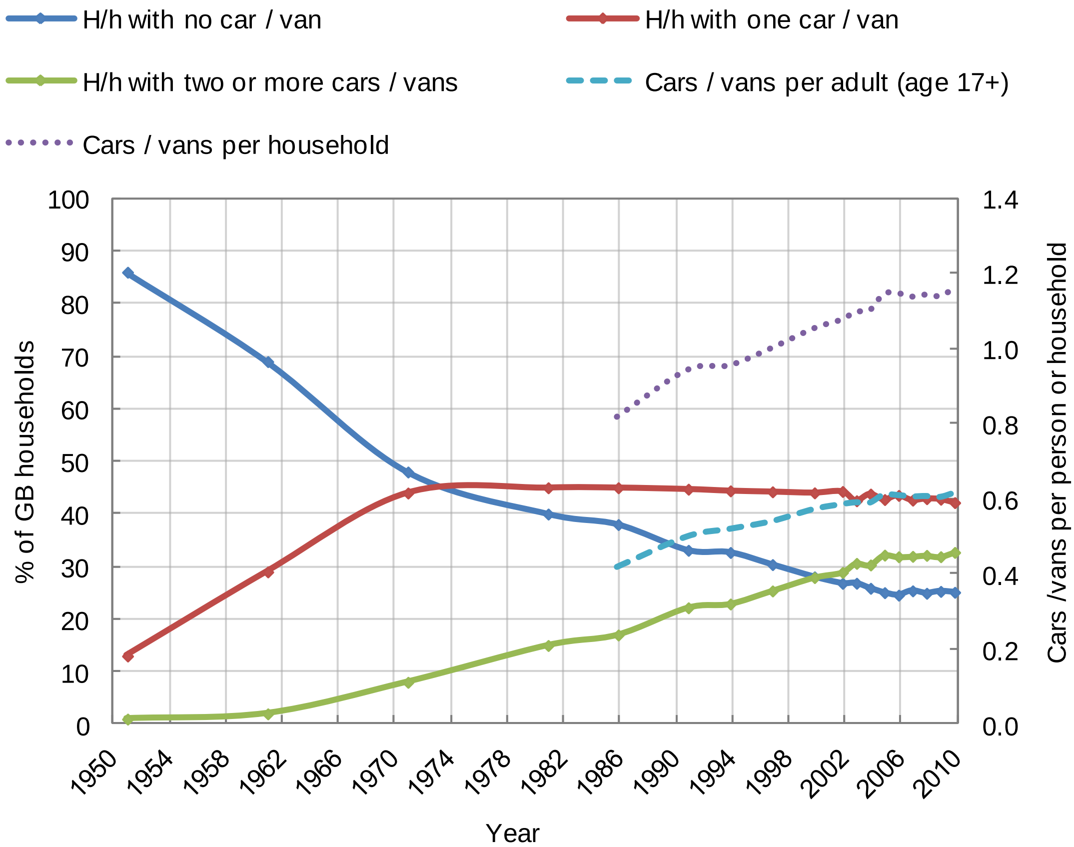

Figure 4.5: Trends in household and per person car availability (Great Britain). Data source (DfT 2011b, NTS0205). Data for mean cars /vans per adult and household (h/h) available only from 1985–6.

4.2.1.3 Variations in per capita VKM

Going deeper still, analysis of NTS data shows that the historical growth in per capita driving distances during the 1980s and 1990s was the result of longer mean journey distance, rather than increased trip frequency, which Headicar (2012a) attributes to increasing affluence giving people greater access to cars and broadening the field of home, work and leisure locations.

Aggregate vehicle kilometres also disguise variation in distances driven and emissions generated according to differences in personal and household income (Brand and Boardman 2008), region, location (urban, suburban, rural) and settlement size (Headicar 2012a). Each of these variations has bearing on the targeting and implementation of demand management policies.

Other key determinants and parameters of demand include real incomes, total cost of motoring, mean car trip distance and car trip frequency (by journey purpose). Emissions from passenger cars are shown by distance and journey purpose in Figure 4.6. The distance category 10 to 25 miles is responsible for over a quarter of all emissions from passenger cars.

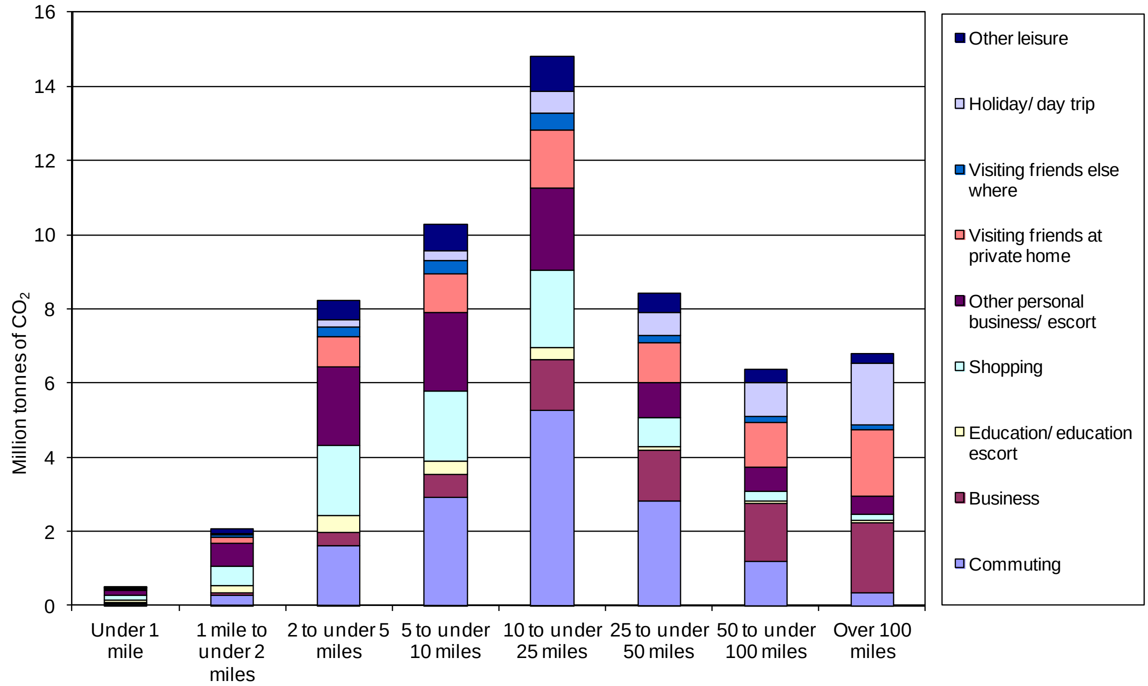

Figure 4.6: Estimated CO_2 emissions from household cars by journey purpose and journey length, GB, 2002–2006 average. Source: (DfT 2008a).

4.2.1.4 Falling 'real costs' of driving

As shown in Figure 4.7, despite the gradual upward trend and several spikes in the price of fuel, the 'total cost of motoring', comprising cost of vehicle, purchase and circulation taxes, maintenance and insurance, has declined in real terms since the start of the 1980s (i.e. prices adjusted for incomes and inflation). This is largely due to the lower initial costs of buying a car (Potter and Parkhurst 2005), and the improvement in mechanical reliability and longevity in modern vehicles. The real cost of petrol has increased by 20% since 1980 (DfT 2009c). In contrast to the decline in 'all motoring' costs, mean disposable income has risen markedly against 1980 levels, almost doubling over the intervening 30 years. Against this backdrop, public transport fares have risen by over 50% during the same period, increasing the cost differential between private and public transport.

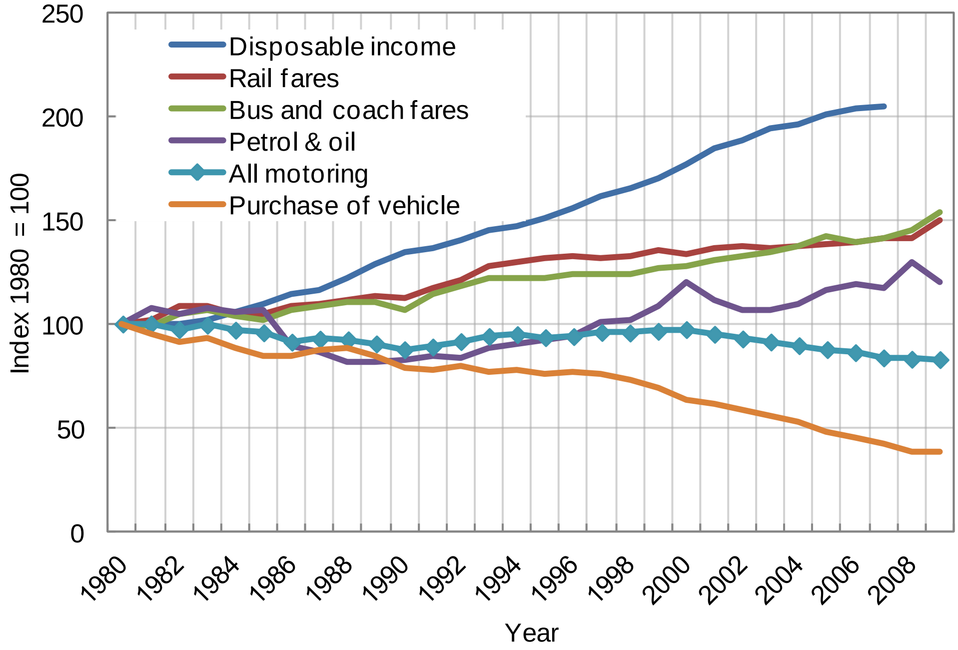

Figure 4.7: Real disposable income and transport costs 1980-2010. Data source: (DfT 2009c, Trend 2.6b)

4.2.1.5 Vehicle use – occupancy

In conjunction with aggregate and per capita VKM and PKM (and associated aforementioned variables), car occupancy, expressed as a ratio of passenger kilometres to vehicle kilometres, is also an important basic unit of demand in this analysis. Headicar refers to occupancy as affecting the 'conversion between travel and traffic' (2009: p.46). Data are collected in the NTS on car journey purposes, stage distances and the number of passengers present. From these data and national road traffic statistics, the DfT estimates total passenger kilometres travelled by car in Great Britain, using a mean occupancy factor for all journey purposes. Occupancy figures published by the DfT from the NTS are expressed as mean rates per trip, disaggregated to seven different trip purposes (see Table 4.1). This is useful for comparing between typical vehicle loadings for typical trip purpose categories, but it is not a reliable guide to mean occupancy of all vehicle kilometres travelled on UK roads. Mean occupancy per vehicle kilometre (regardless of trip purpose) is not published by the DfT, but can be estimated from the raw NTS data by distance-weighting trip stage occupancy rates. Estimated distance-weighted mean occupancy per vehicle kilometre (referred to hereafter as 'bulk occupancy') for the UK is likely to be lower than the DfT-published mean occupancy for all trip types (unweighted by share of total UK car-kilometres, referred to hereafter as 'trip occupancy' – Figure 4.8) since low occupancy journey purposes dominate total VKM_{fleet} – Figure 4.6. A third unit relating to occupancy common in the interventions literature is the single occupancy rate, a percentage of all trips of a particular type or purpose which are made by lone drivers. While useful for monitoring the effects of interventions such as travel plans (see §4.4.5.1 below) to reduce the number of drive-alone trips, single occupancy rates are insensitive to vehicle occupancies greater than one, hence are not used in this analysis.

Given the difficulty in obtaining a reliable estimate of bulk occupancy, and the emphasis placed on the DfT published figures as being an 'average for all trips', it is fair to say that where occupancy is specifically dealt with in the literature, it is almost without exception trip occupancy[86]. This need not in itself be problematic, so long as there is no suggestion that the values referred to are the mean for all distance travelled on UK roads, and are not interpreted as such. It is an unfortunate consequence of the difficulty of obtaining bulk occupancy values that trip occupancy is often treated in the literature as the only occupancy rate of interest, and indeed is seldom if ever referred to in a way to actually distinguish it as trip rather than bulk occupancy. An example of potentially misinterpreting the data in this way can be seen in Cairns (2011: p. 26), where trip occupancy is treated as bulk occupancy without discrimination.

4.2.1.6 Trends in occupancy

Cairns *et al* note that "there is a very long tradition of observations that the average occupancy of cars is rather low" (2004: p.221). Surprisingly little research has focused specifically on the *reasons for the decline* in mean occupancy in the UK over the last half century, but several commentators have ventured suggestions as to the underlying causes. Table 4.1 shows the mean occupancy per trip for a range of journey purposes.

[86] Terminology is further complicated by occupancy being variously referred to in the literature as 'load factor', 'occupation (factor)', 'vehicle loading', 'vehicle utilisation', and (especially in the U.S. literature) 'ridership'. Others simply refer to passengers (or persons) per trip or per vehicle. This makes a comprehensive keyword search of the literature difficult.

Table 4.1: Mean vehicle trip occupancy of GB cars and vans. Source: (DfT 2011b: NTS0906)

Purpose[87]	Mean trip occupancy	Single occupancy rate[88]
Commuting	1.18	*86*
Business	1.17	*86*
Education	2.03	*36*
Shopping	1.67	*50*
Personal business	1.42	*68*
Leisure[89]	1.72	*53*
Holiday/day trip	2.05	*40*
Other including just walk	1.98	*35*
Total (mean for all trips)	1.56	*61*

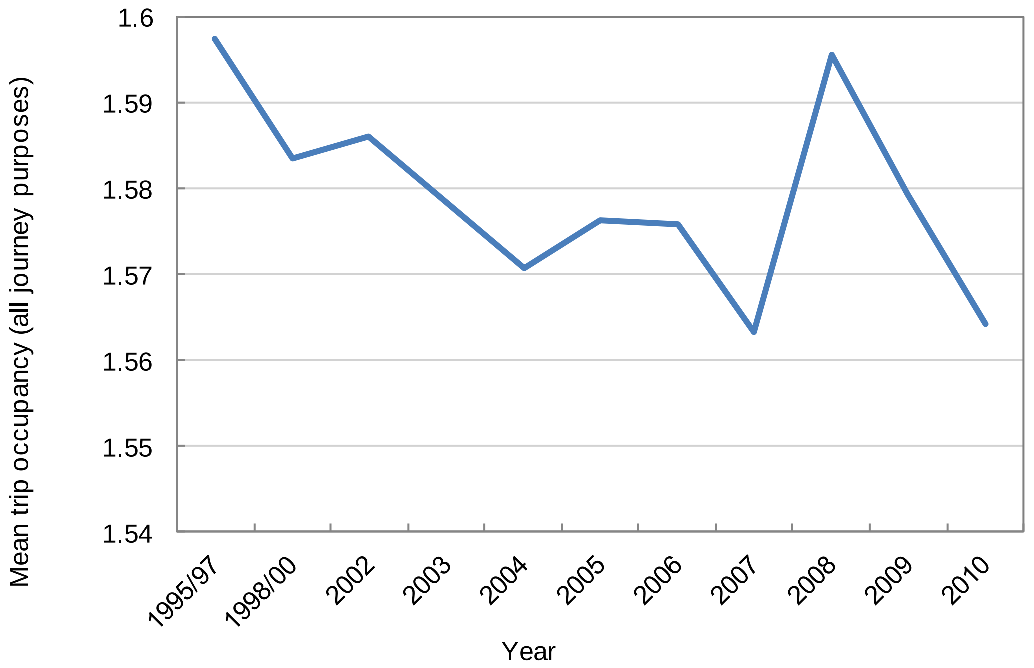

Figure 4.8: Historical mean trip occupancy rate for GB cars and vans (all journey purposes). Source: (DfT 2011b: NTS0905)

Figure 4.8 shows a reducing trend in trip occupancy over the last two decades – the apparent spike in 2008 is attributed to an underreporting of higher occupancy journeys such as shopping and personal business in 2007, and an underreporting of lower occupancy journeys in 2008 (DfT 2012a)[90].

Kwon and Preston (2005) suggest possible reasons for the decline include reducing mean household size, which they note has dropped from 2.91 persons per household in

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[87] Each purpose includes the appropriate escort purpose. For example, education includes escort education.

[88] Single occupancy rate refers to the percentage of trips for each journey purpose that are driver-only.

[89] Visit friends at home and elsewhere, entertainment and sport.

[90] Difficulties in obtaining accurate estimates of vehicle occupancy arising from monitoring inconsistencies are also recognised by Levine and Wachs (1998).

1971 to 2.33 in 2001[91], and the increase in households with more than one car, which increases individual access to cars. Headicar (2009: p.27) also identifies a declining trend in household size as a key contributor to a corresponding downward trend in car occupancy, arguing that households with two or fewer people undertake fewer journeys 'as a household', and also that lower household size increases car availability per adult. Headicar's reasoning is similar to Kwon and Preston's – that mean trip occupancy (for all trips) has declined because of a decline in occupancy rates for longer distance holiday and day trips (partly driven by decreasing mean household size). However, longer distance holiday and leisure trips, while having typically much higher occupancy rates (>2.0 persons per trip) than daily commute or business trips (~1.2 persons per trip), make up a smaller proportion of total distance driven.

Kwon and Preston further speculate that the increase in the proportion of women obtaining a driving licence over recent decades (Figure 4.9) may also influence mean occupancy.

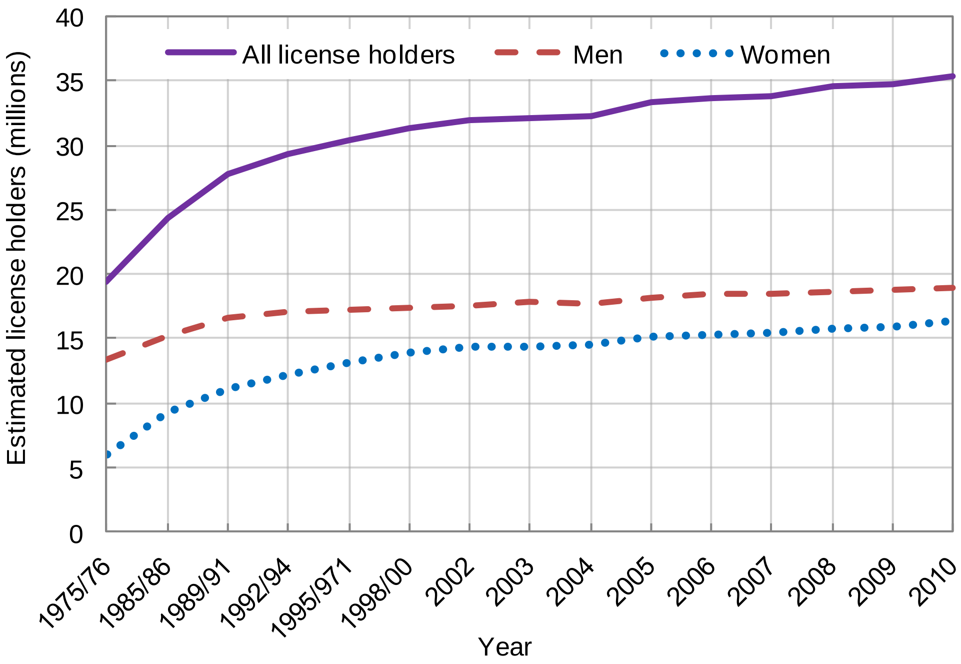

Figure 4.9: Changes in total number of driving license holders in UK, and number of men and women with driving licenses, 1975 to 2010. Data source: (DfT 2011b: NTS0201)

Probably as significant a contributory factor is the changing profile of the workforce over the last fifty years, including the greater proportion of women in paid employment. In particular, the proportion of mothers working full-time increased from 23% in 1996 to 29% in 2010; the proportion of mothers working part-time remaining fairly constant at around 37% (ONS 2011a). In households with children, it tends to be women more often

[91] 2011 UK census data show 2001 mean household size to be 2.38 persons, having further declined to 2.35 in 2011 (ONS 2012)

than men who take children to and from school and childcare (Jain *et al* 2011). This is evident in the greater distance travelled for 'escort education' purposes by women than men shown in Figure 4.10, but clearly school runs represent only a small portion of total mileage.

Use of a car makes possible multi-stage, multi-purpose journeys, allowing childcare responsibilities to fit around full- or part-time paid employment (or vice versa). Increased daily time pressures, especially early in the morning, arising from more demanding household and work routines, may therefore contribute to the increase in drive-alone commuting stages (Lyons and Chatterjee 2008). The much greater commuting distances travelled by men in the NTS survey (Figure 4.10) illustrates the possibility of mileage increasing further as more women enter the workforce.

Figure 4.10 Mean per capita distance travelled (all modes) by gender and journey purpose in Great Britain in 2010. Data source NTS0612 (DfT 2011b).

Figure 4.11 shows total distance driven by men has declined steadily since the 1990s, whereas distance driven by women increased to 2006. Despite this increase, on average the mean distance driven by women is still only around half that driven by men[92].

[92] NTS statistics represent mean values for all surveyed respondents – including those who do not drive or make journeys for particular purposes. Hence, Figure 4.11, for example, does not represent mean or median distances for all men or women *who drive*, but rather average values for all those surveyed, including non-drivers. The lower rate of license holding amongst women (Figure 4.9) may be responsible for skewing the mean driving distance for women, making it lower than the mean for all women who do regularly drive.

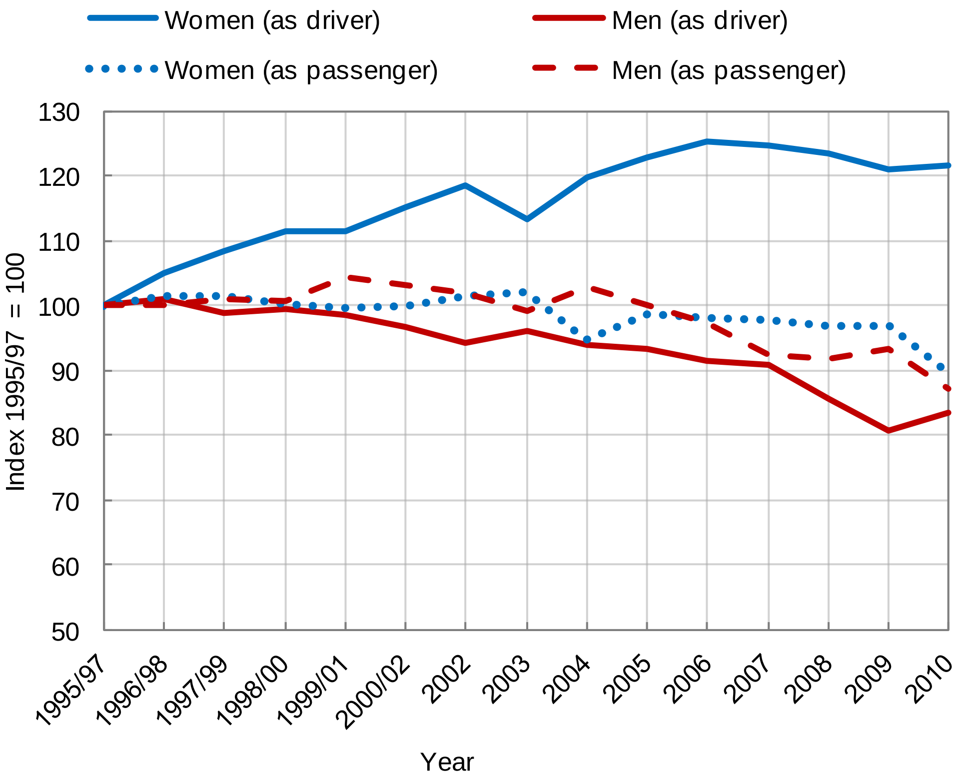

Figure 4.11: Annual per capita driving distance by gender since 1995. Data source: NTS0103 / 0305 / 0605 / 0606 (DfT 2011b)

Other variables which might help to explain the steady decline in bulk occupancy coincide with those thought to have driven the increase in vehicle kilometres over recent decades, in combination with an increase in the number of households with access to more than one vehicle. Prime amongst these is the relative cost of driving, which has fallen in real terms over the last fifty years (Headicar 2008), as shown in Figure 4.7. Giuliano and Dargay find that household car ownership rises in line with incomes, as do typical household driving distances (Giuliano and Dargay 2006). They attribute the UK's lower typical driving distances compared to the USA principally to the higher cost of fuel in the UK; predicting that falling real term costs will continue to be matched by traffic growth.

In summary, Headicar (2012b) suggests that the observed decline in car occupancy may be as straightforward as:

a) more cars per adult means more adults able to drive themselves (single person occupancy) and not needing to be given lifts (dual occupancy);
b) proportionately fewer children, hence fewer 'automatic' passengers in car owning households; and
c) proportionately more single person households, hence fewer instances of multi-person households travelling together, for instance on social trips.

4.2.2 Metrics of demand – vehicle choice

Chapter 3 showed that the use-phase is responsible for around 80–90% of total lifecycle carbon emissions from ICEVs. Since the key determinant of emissions from a given ICEV is the distance driven (VKM_{veh}), the initial choice of vehicle, while infrequently exercised, clearly has long-term emissions consequences. Car purchasing behaviour and ways to influence it are therefore crucial considerations in delivering the full potential of technical improvements. Put simply, technology improvements can only reduce emissions insofar as they penetrate the fleet. Consumer attitudes and car preferences are well studied; there is good consensus within the literature that overtly environmental considerations are seldom in the top tier of consumers' purchasing criteria (Choo and Mokhtarian 2004), tending instead to rank as a low priority (Lane and Potter 2007). Factors relating to affect[93], status and relative position have traditionally exerted a much stronger influence on purchasing behaviours (e.g. Johansson-Stenman and Martinsson 2006). More troublingly, from a mitigation perspective, careful analysis of revealed as opposed to stated preferences for new vehicle purchases indicates that while consumers often report fuel consumption as a high priority consideration, it does not typically translate into selection of efficient vehicles – referred to by Anable *et al* (2009) as the 'mpg paradox'. Anable *et al* go on to note that it is the relative and largely subjective experience of fuel cost rather than 'fuel efficiency' per se that has led to consumers responding to increasing fuel prices by shifting to smaller cars. The same research team also suggests that miles per gallon is probably too complex a metric for most consumers to meaningfully compare total vehicle running costs over time (Anable *et al* 2008). In a study of U.S. car driving households, Turrentine and Kurani (2007) also found that consumers are ill-equipped to systematically monitor fuel consumption and expenditure; although as always, caution must be exercised when drawing comparisons with the USA. U.S. petrol costs are around 40% of the UK price per litre – although mean fuel consumption for new U.S. cars is approximately 54% higher (76% higher for cars and light trucks combined) than in the UK, which evens out the price difference to a large extent[94].

At a more basic level, factors affecting selection between vehicles by 'market segment' is of particular interest given the shift in consumer preferences towards larger vehicles in recent years. It would be hard to argue that the growth of, for example, the sports-utility

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[93] Affect (and its adjective, affective) is used here in the psychological sense, meaning relating to emotional response or 'feeling': "what a person feels about the attitude object, how favourably or unfavourably it is evaluated, reflecting its place in the person's scale of values" (Gross 1992: p.514).

[94] US gallon (4.404 litres) in May 2012 = $3.73 (US EIA 2012); UK petrol July 2012 average £1.32 litre (Fubra 2012). July 2012 exchange rate 1 USD = 0.648 GBP. Mean fuel consumption U.S. cars and 'light trucks' (essentially pick-ups, SUVs and other LDVs used as household cars) in model year 2011 = 22.8 mpg, equivalent to emissions of 243 gCO_2/km (EPA 2012). UK mean new car emissions in 2011 = 138 gCO_2/km (SMMT 2012). Comparison on the basis of purchasing power parity or GDP per capita may yield different results.

vehicle (SUV) and multi-purpose vehicle (MPV) market has come about by car makers responding to previously latent consumer preference for much larger and more highly specified vehicles. A more plausible interpretation might be that through advertising and promotion manufacturers have actively created (or opened up) a market for these products. Ostensibly countering this hypothesis, Wallis (2011) observed a shift towards low emissions vehicles in car manufacturers' advertising spending in the UK national press 2008–09 (based on vehicle excise duty band). However, Wallis does not report what proportion of auto-makers' total advertising budgets is spent on print advertising as opposed to other media (in particular, a comparison with television advertising spend would be helpful), nor how advertising spend on other media breaks down by car market segment. Reviewing the policy measures currently deployed to inform and promote low-emissions vehicle choices (which at present consist of eco-labelling of new vehicles, advertising and marketing standards guidance for manufacturers, and web-based information provision for consumers), Wallis concludes that increasing environmental awareness appears to have had little effect on car purchasing habits, suggesting that labelling has so far failed to engage people.

Evidence reviewed in Chapter 3 highlighted the wide commercial availability of vehicles with official type approval emissions well within the EU 2015 new car emissions target (130 gCO_2/km), and several that are claimed to be within the 2020 target (95 gCO_2/km), along with the relatively small UK new car market share of such vehicles. Clearly, for such vehicles to have an impact on aggregate absolute emissions they need to penetrate the car fleet extensively. The EU regulations send a signal to manufacturers, who are fined for every gCO_2/km above their sales-weighted mean target reflected in their annual sales. However, the studies above suggest that the message is not getting through to consumers as well as might be hoped. Awareness of emissions differences between vehicles is helped by differentiated vehicle excise duty bands – especially by exemption from London congestion charges for vehicles in 'band A', with claimed (type approval-based) emissions below 100 gCO_2/km. Nevertheless, at present rates of uptake of low emissions vehicles, 'leaving it to the market' does not look likely to deliver sufficient mitigation to meet the challenging emissions budgets outlined in Chapter 2.

Examination of the DfT's vehicle licensing statistical tables reveals that while sales of new cars with emissions less than 130 gCO_2/km are building year on year (Figure 4.12), they still account for less than 12% of the total fleet (Figure 4.13 and Figure 4.14). The most popular band in terms of new car sales is 131–140 gCO_2/km (18%), followed by 111–120 gCO_2/km (17%) and 121–130 gCO_2/km (16%).

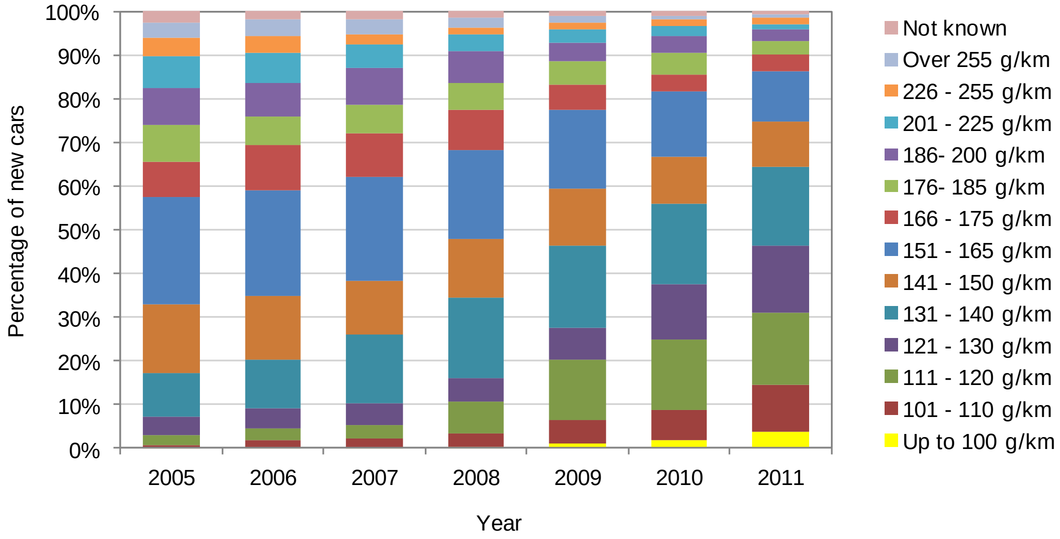


Figure 4.12: Percentage of UK new car sales by CO_2 emissions band. Data source: (DfT 2012d VEH0256)

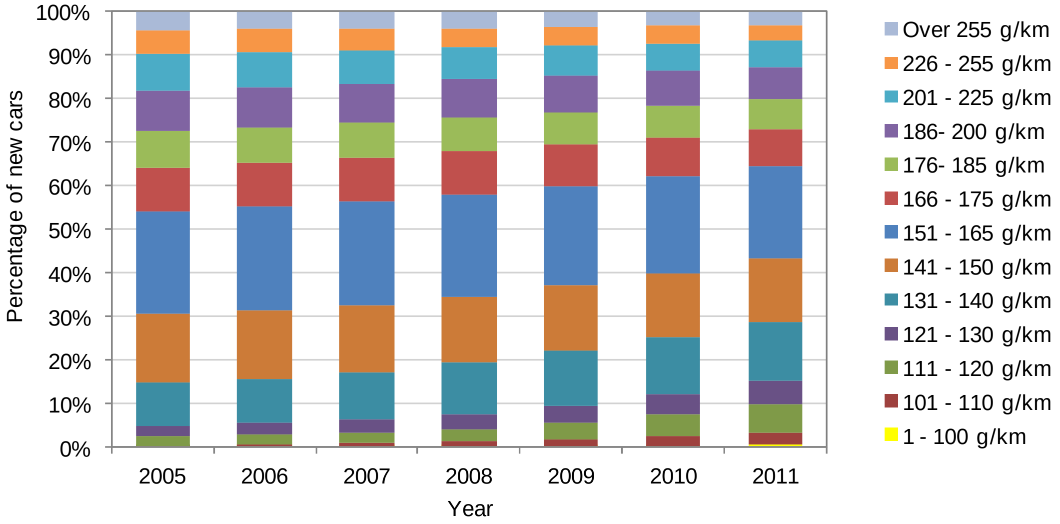


Figure 4.13: Percentage of all UK cars by emissions band. Data source: (DfT 2012d VEH0206)

4.2.3 Scrappage

As a means to increase the rate of penetration into the fleet of new, low-emissions vehicles, vehicle scrappage incentive schemes are often suggested to have theoretical potential to reduce sectoral emissions so long as an emissions stipulation is set as a condition of participation in the scheme (Dill 2004; Aldred and Tepe 2011). However, the theoretical potential is far from certain once lifecycle emissions from vehicle production are taken into account. A recent study by Kagawa *et al* (2011) argues that *extending* rather than shortening vehicle operational lifetimes reduces lifecycle CO_2. This controversy notwithstanding, the UK's scrappage incentive scheme (2009–2010) did not include an environmental stipulation on the incoming vehicle, and as a consequence beneficiaries of the scheme were at liberty to select potentially *more* polluting vehicles than the outgoing vehicle being replaced (Lane 2009). Other schemes (U.S. ‘cash for clunkers’ (Tyrrell and Dernbach 2011), French and German schemes (ITF 2011)) have had varying degrees of success in increasing the uptake of lower-emissions vehicles. However, schemes do exist which place a maximum threshold on emissions of replacement (incoming) vehicles, the UK’s electric vehicle subsidy offers £5000 towards the initial purchase price of any vehicle with exhaust emissions less than 75 gCO_2/km – a standard currently met only by EVs.

Scrappage incentive schemes notwithstanding, the UK car fleet has shown a significant variation in both the rate of penetration of new car additions to the fleet, and in the rate of retirement (or conversely, of survival) for vehicles of older vintages. Chapter 6 (fleet emissions model method) defines this historical variation in more detail and describes a method for estimating the potential emissions consequences of alternative rates of penetration and turnover.

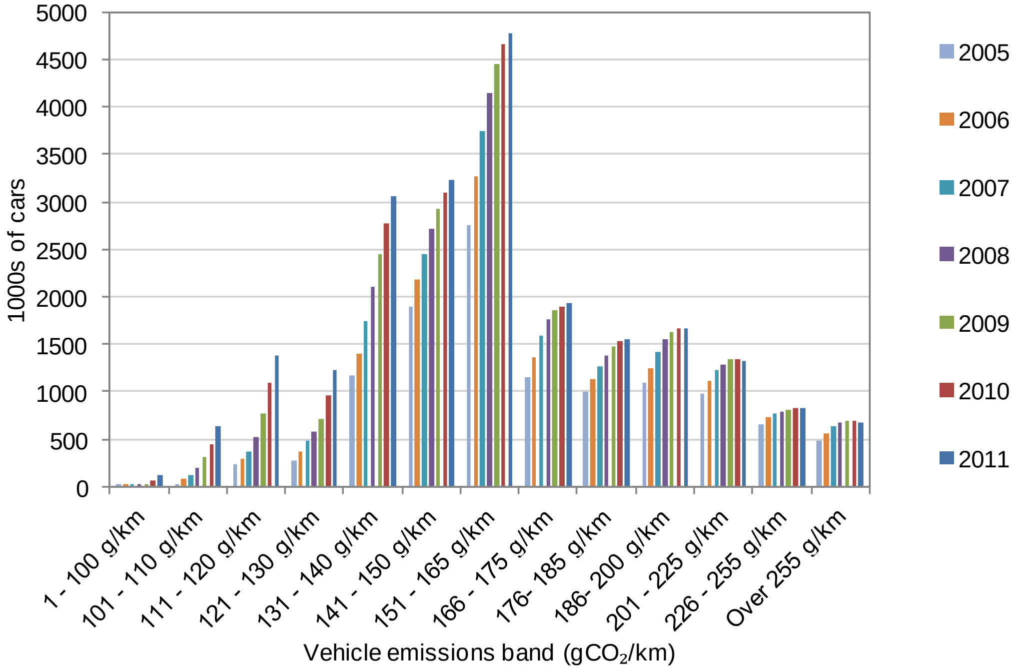


Figure 4.14: UK car fleet profile (all cars) by emissions band. Data source: (DfT 2012d VEH0206)

4.2.4 Metrics of demand – driving style

The current fleet comprises mainly petroleum-fuelled internal combustion engined vehicles, emitting CO_2 directly in proportion to fuel used (subject to the accounting boundaries highlighted in Chapter 3). The rate at which a given ICEV consumes fuel is itself directly related to vehicle distance travelled, but strongly influenced by speed and other driving-style or operational parameters (§3.1.2). Averaging these operational factors for a given vehicle, a 'bulk emissions factor' gives a broad estimate of the mean amount of CO_2 emitted per vehicle-kilometre travelled (Ntziachristos and Samaras 2012). As noted in the previous chapter, this analysis proceeds from cautiously adopting gCO_2/km as its working metric of vehicle–fuel carbon intensity and assumes that driving style closely matches the optimum for the vehicle and road conditions. Acknowledging that real world driving styles and conditions seldom replicate test conditions, Chapter 3 assembled arguments for uplifting official type approval values for vehicle emissions to better reflect typical real world conditions. Principal determinants of how closely driving style matches the optimum are how aggressively or progressively acceleration and braking are executed, as well as speed, stop-start cycle frequency and gear shifting. Of these, speed has been most extensively modelled, notably in the work of the Transport Research Laboratory (Barlow and Boulter 2009). It is beyond the scope of this analysis to judge how incremental changes in driver behaviour might affect the ICEV speed-scaled emissions functions developed by TRL. Nevertheless, there are clear implications for policies which create pressure to adopt driving styles which more closely match the optimum – especially with respect to optimum speed. While optimum engine loading (as it relates to speed) clearly varies from vehicle to vehicle depending on engine size, fuel consumption and hence emissions increase substantially over 50–60 mph for the majority of passenger cars that make up the current fleet (Anable *et al* 2006). Therefore policies which address the current discrepancy between real world driving styles (and conditions) and manufacturer-claimed or type approval emissions will be crucial in ensuring that supply-side measures hit their mark.

4.3 Existing demand-side interventions

This section outlines the extent of expected mitigation from existing demand-side policies; §4.4 looks at the evidence of the potential for increasing the ambition of existing measures, §4.5 looks at additional interventions in the literature. UK passenger car sector demand-side policies and measures in effect in July 2012 are summarised in Table 4.2

Table 4.2: Summary of demand-side emissions reduction policies and interventions for the passenger car sector, based on and adapted from Whitmarsh and Kohler (2010) – *measures in italics not included in Whitmarsh and Kohler*.

Type	Interventions already implemented
EU measures	• Car labelling (energy GHG emissions efficiency) from automobiles
Complementary to European Climate Change Programme	• Fuel taxes • Annual vehicle registration taxes differentiated by exhaust CO_2 (vehicle excise duty, VED) • Car purchase tax (VAT)
Technology promotion measures	• Tax reductions on biofuels and LNG • Consumer / retailers' information campaign • *'Ultra-low emissions' vehicle subsidy*
Measures for vehicle components—tyres, lubricants and air conditioning systems	• Labelling • Subsidies
Infrastructure measures	• Subsidies for new control, monitoring technologies • Public expenditure on infrastructure for GHG policies and measures • Road pricing †
Soft measures	• *Smarter Choices and Sustainable Travel Towns initiatives* • *Driver emissions awareness campaigns (e.g. 'ACTon CO_2'* • *Eco-driving: new driver training and test*
Regulations affecting patterns of car use and driving style	• *Speed limits* • *Minimum occupancy vehicle lanes* • *Parking charges and restrictions* • *Urban congestion charging schemes*
	Now defunct interventions
Consumer measures	• Subsidies for early retirement (scrappage)*

† Whitmarsh and Kohler include road pricing as an infrastructure measure, however apart from a limited number of stretches of privately managed roads, road pricing has not been implemented in the UK.

* The Department for Business Innovation and Skills offered a scrappage incentive between May 2009 and March 2010. There is currently no plan on the table to reintroduce the scheme.

4.3.1 Emissions savings from current demand-side policies

As noted in Chapter 3 estimated emissions savings from the current policy mix includes 18 $MtCO_2$ emissions savings delivered by the Smarter Choices policy package (against a counterfactual baseline of emissions that would otherwise have occurred).

Emissions savings expected from the other policies listed in Table 4.2 are assumed to be either:

- already included in the baseline measures in place before introduction of the *Low Carbon Transport* strategy (*LCT*) – for instance the effects of pre-existing policies such as fuel taxation (and duty), vehicle purchase and circulation taxes, speed limits;
- aggregated with other measures already inventoried separately – for instance, savings from car labelling would be difficult to separate from overall savings achieved by the introduction of the EU new car emissions regulations;
- assumed to be negligible – for instance component labelling and subsidies are unlikely to contribute savings in the order of millions of tonnes of CO_2 in the short term, since they reduce construction and maintenance related emissions which as a whole constitute less than 15% of total ICEV lifecycle emissions, with marginal differences for any individual component being a fraction of this; or
- subject to such uncertainties that quantification would be spurious.

4.3.2 Types of demand-side policy

Observing that the long-list of available 'land use and transport policy instruments' numbered over seventy separate types, Matthews *et al* (2002) propose a six-fold taxonomy of demand-side interventions: (i) land use policies; (ii) infrastructure provision; (iii) management and regulation; (iv) information provision; (v) attitudinal and behavioural measures; and (vi) pricing. Each type is further subdivided by mode. The Online Transport Demand Management Encyclopedia (http://www.vtpi.org) uses five categories: (i) improved transport options; (ii) incentives to use alternative modes and reduce driving; (iii) parking and land use management; (iv) policy and institutional reforms; and (v) TDM and support programmes (Litman 2003).

Both Matthews *et al*'s and Litman's categorisations reflect a range of salient features of the interventions listed, with Matthews *et al*'s aiming for exclusive sets, to avoid certain instruments appearing in more that one category (May *et al* 2003). While any taxonomic system is to an extent arbitrary, there is value in selecting one that discriminates between interventions according to the features of particular interest. Given the scale and urgency of the emissions reductions required of passenger car use, the element of interest in this analysis is the potential for rapid and *effective* delivery of mitigation through a reduction in total car-kilometres travelled.

Loukopoulos (2007) considers effectiveness one of three essential outcome variables of TDM measures (Figure 4.15), alongside political feasibility and public acceptability. Loukopoulos notes that the primary determinant of policy effectiveness tends to be its level of coerciveness, whereas public attitudes tend to be less favourable towards coercive market-based measures. He goes on to suggest that political feasibility (essentially a measure of political acceptability) is lower for expensive interventions than low-cost measures. Loukopoulos, citing Taylor and Ampt (2003), also observes that more coercive measures tend not to find favour with elected politicians since “protagonists of restrictive TDM measures may be dismissed through the democratic process and, as such, less-restrictive TDM measures are a safer option”. The three outcome variables are also inter-related and affect each other. Thus, Loukopoulos suggests that effectiveness is dependent both on public acceptability and political feasibility.

This analysis therefore uses five categories to differentiate between interventions according to the manner in which they either compel, coerce, encourage or facilitate a change in the level of vehicle end-use (car-kilometres). The categories are presented below in descending order of coerciveness, with the existing policies and measures from Table 4.2 attributed accordingly. This categorisation is similar to that presented in Gärling and Loukopoulos (2007), itself a refinement of Steg (2003), but with economic measures separated out into two categories to reflect the differing coercive properties of charges and incentives.

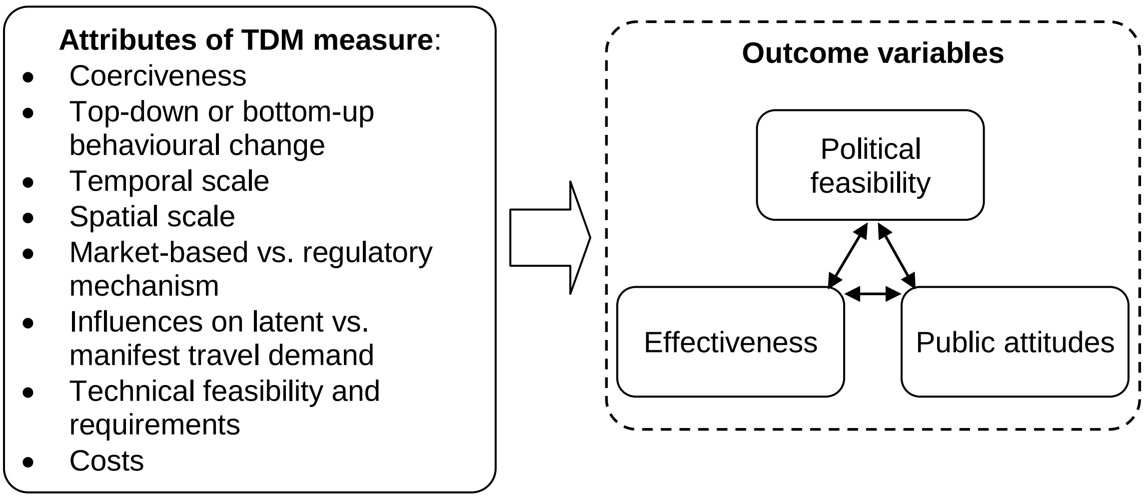


Figure 4.15: Effects of intervention attributes “on key outcome variables and the interrelationships between these outcome variables”, reproduced from Loukopoulos (2007).

i. Command and control policies (CAC)

Command and control measures take the form of direct legislation: laws, regulations and legal standards with which affected parties are legally obliged to comply. In Table 4.2 speed limits, minimum occupancy vehicle lanes and parking restrictions are command-and-control.

ii. Economic instruments – taxes and charges

Traditional economic instruments include taxes, levies and charges. They coerce rather than strictly compel, since they do not prohibit or legally oblige specific behaviours – although the distinction is moot for those without sufficient income to pay the fees. Hence such instruments are also referred to as ‘quantity constraints’, in that they restrict access to particular goods and services. In the case of passenger cars, fuel tax (and duty), initial car purchase tax, annual VED (also known as circulation tax (Potter 2008)), road user charging and parking charges are examples of economic instruments.

iii. Economic incentives

The ‘carrot’ to the ‘stick’ of charges and taxes (or ‘pull’ to the ‘push’), incentives such as preferential rates of taxation on particular types of fuel fall into this category. Likewise, the current subsidies for cars with exhaust emissions less than 75 gCO_2/km, and the gradation of VED bands to favour lower-emissions vehicles. The scrappage incentive scheme that ceased in 2010 was also a good example of this class of measure.

iv. Soft measures

Policies which encourage or incentivise rather than coerce or compel are referred to as ‘soft’ policies (in contrast with ‘hard’ regulation). These interventions often use targeted information provision in conjunction with enabling measures to create new opportunities for people to try different behaviours. Insofar as the behaviours they promote are entirely voluntary, soft measures depend on their ability to engage members of the public in a way that more coercive measures such as regulation and market-based economic instruments do not. The Smarter Choices package (Cairns *et al* 2004) includes a number of soft measures such as travel planning advice on combining trips, car sharing etc. Other instances are vehicle and component labelling (although manufacturers may be regulated with respect to producing the labels themselves) and driver training.

v. Enabling and infrastructure measures

Whereas i–iv apply directly to either car makers or car drivers, there are a range of policies which facilitate particular demand-side changes – either by design or by default. Smarter Choices and Sustainable Travel Towns initiatives for instance include provision for car clubs and car sharing schemes to be established. Not included in Table 4.2, but closely related to reducing demand for car-kilometres are policies relating to provision of public transport and facilities for unpowered modes (walking and cycling). Finally, policies on land use, planning and development all exert a strong influence on long term demand for car-kilometres.

4.3.2.1 Existing policies by 'choice area'

Policies listed in Table 4.2 refer to the choice areas as set out in §4.2 above as follows.

- Vehicle use: driving distance – demand for car-kilometres
  Fuel taxes, road pricing, Smarter Choices, parking charges, minimum occupancy lanes, congestion charging schemes
- Vehicle or technology choice
  Fuel taxes, car labelling, vehicle registration and purchase taxes, ultra-low emission vehicle subsidies, congestion charging schemes (which exempt vehicles with exhaust emissions below a certain threshold, e.g. 100 gCO_2/km in the London congestion charging zone.
- Vehicle use: driving style
  Fuel taxes, driver awareness campaigns and new driver training, speed limits

Aligning policies by choice area in this way shows that fuel taxes and charges have the broadest potential application across all three choice areas, since constraining fuel use by increasing its cost not only affects distance driven, but also encourages selection of less fuel-consuming (thus lower-emissions) vehicles and promotes more fuel-efficient driving styles.

4.4 **Intensifying existing demand management policies**

4.4.1 Public and political acceptability of coercive policies

As alluded to earlier, successive UK governments have stopped short of decisively intervening in levels of demand for car-kilometres by regulatory and coercive means. Whether historically influenced by the economic arguments rehearsed above, or inhibited by fear of negative public reaction, the end result has been much the same. However, the economic downturn that started in 2008 and now entering its fifth year makes it even harder to find popular support for policies which restrict driving by increasing the price of fuel or road use. Recognising the deep unpopularity of fiscal measures which cause fuel prices to increase, in June 2012 the coalition government was persuaded to back-track on its pre-announced budget statement and abolish a planned fuel duty rise of 3p per litre for fear of a repetition of the fuel protests of 2000 (Wright 2012). Road user charging, discussed and recommended by government select committees for decades has yet to see the light of day in any programmatic national form. Hensher and Puckett (2007) recall then transport secretary Alistair Darling's announced intention in 2005 to set in motion a process of replacing VED and fuel taxation with pay-per-mile road user charging over the course of a decade. Within a month of the announcement the pilot scheme was cancelled. Instead, the national government made implementation of road charging a condition of transport innovation funding (TIF) packages available to local and city authorities, effectively passing on the almost impossible task of squaring road charging with the public. Despite the solid approval ratings for the London congestion charge amongst residents of the capital, no comparable scheme has been passed elsewhere in the UK. This is thought largely due to the different approaches taken to introducing the London scheme and other proposed charging schemes. Whereas London's congestion charging zone was 'pushed through' from the top-down by an elected mayor, others (notably Edinburgh and Manchester) failed to gain sufficient support at local council level, forcing public referenda on charging. Both popular votes bear out the strong public antipathy to charging before schemes are introduced. Given the public dislike for taxes and charges it is little wonder that there is a lack of political appetite for actively constraining demand for car-kilometres through coercive interventions.

The knotty issue of how to reconcile effective mitigation of passenger car sector emissions with the conflicting priorities of elected officials, economic growth and the aspirations of the wider driving public will likely endure. Debates about the possibility of sustainable economic growth and the ability of democratic referenda to deliver solutions which call for individual restraint are beyond the scope of this work, other than to note the consequences for sectoral and national emissions. Hence, intensification of measures is invoked here to *highlight the implications* for passenger car sector emissions *of not exercising demand restraint*, and to allow honest assessment of the mitigation burden this implies for supply-side measures.

4.4.2 Command and control policies

4.4.2.1 Minimum (high) occupancy vehicle lanes

Creating and enforcing minimum occupancy vehicle lanes on key arterial and commuting routes has the potential to affect vehicle use (car-km) directly. Usually referred to as high occupancy vehicle lanes (HOVLs, although a driver plus one passenger travelling together in a car capable of carrying five or more people cannot truly be said to constitute high occupancy), evidence on the potential for increasing mean trip occupancy from existing UK schemes is encouraging. Cairns (2011) lists six existing HOVLs in place in the UK in 2010, for which evidence of impacts is summarised below.

- *A647 Stanningley Road, Leeds (1.5km, peak hour operation only)*

  Average vehicle occupancy (AVO) before scheme (1998) 1.35, increased to 1.51 after three years of scheme operation (2002) – a 12% increase in AVO (KBR 2004). Increase in bus patronage also reported

- *A4174 Avon Ring Road, Hambrook, north Bristol (1.5km, morning peak only)*

Reduction in peak hour single occupancy from 80% before implementation, to 70% five years later (Dixon and Alexander 2005) – or a 7% increase in AVO (KBR 2004)

• *A370, Long Ashton bypass, North Somerset (2km section)*

Cairns (2011) reports highest recorded volume of people carried one year after scheme implemented

• *A47 in Birmingham*

No specific data available, but Birmingham City Council report increased AVO (Cairns 2011)

• *hard shoulder of the M606 and M62 near Bradford (opened 2008, 1.7km, full-time operation) and A63 in Leeds (opened in 2009)* Data not yet available

While mean bulk occupancy rates were found to increase in all cases where data are available, total traffic volumes (car-kilometres) cannot be guaranteed to decline as a result, since additional demand may be generated by improved journey times and improved flow (essentially a form of rebound effect). KBR's feasibility study for the Highways Agency assumes a 'base case' of 10% reduction in total traffic on any given corridor where HOVLs are implemented – assuming that the *same number of people travel on the route* (KBR 2004). Strongly caveated by noting the confounding effects of local conditions, KBR states that the range of 5–15% reduction in vehicle kilometres is supported by evidence from schemes in other countries where HOVLs are more widely implemented. This range of values is corroborated by Noland *et al* (2006).

Gross *et al* (2009) list several limitations of HOVLs, noting in particular that peak hour restrictions have no traffic reducing effect at other times of day, and that trips to collect passengers may add to total driving distances. Examining data on California's extensive network of HOVLs, Kwon and Varaiya (2008) suggest that the evidence for any HOVLs incentivising increased occupancy is overstated. Nonetheless, Kwon and Varaiya use an average vehicle occupancy value of 2.1 for HOVLs, but claim that many of those sharing cars would do so in general purpose road lanes anyway, being family members. This is a relatively high occupancy factor for a car-dependent country – significantly greater than the national mean car occupancy of 1.59 (US Department of Energy 2010)[95]. Millard-Ball and Schipper (2010) suggest that the decline in US national mean occupancy, from 2.1 in 1970, is largely attributable to the decline in carpooling on both commuting and non-commuting trips. Therefore Kwon and Varaiya's logic for claiming that HOVLs do not incentivise increased occupancy is not self-evidently correct;

[95] NB: it is not possible to ascertain with certainty from the publication whether this is bulk occupancy for all VKM or trip occupancy. Since it is based on household travel survey data, it is assumed to be trip occupancy, and therefore compares directly with the trip occupancy values given by Kwon and Varaiya.

although their principal interest is in alleviation of network congestion, and they do not explicitly consider the value of an absolute reduction in vehicle kilometres.

4.4.2.2 Speed limits

Noland *et al* (2006) observe that the best vehicle efficiencies are typically achieved in the range 30–60 miles per hour, hence measures to reduce and enforce the national speed limits on motorways, dual-carriageways and A-roads from 70 mph to a speed within this range could be an effective policy to reduce fuel consumption (and by extension, emissions). Noland *et al* estimate that reducing motorway speed limits to 90 kmh (approximately 57 mph) could produce a 2.9% reduction in total fuel consumed.

Anable *et al* (2006) estimate that proper (i.e. effective) enforcement of the current 70 mph limit would reduce total car sector emissions by 1 $MtCO_2$ p.a.; a reduction in motorway speed limits to 60 mph they estimate would return annual emissions savings of approximately 1.9 $MtCO_2$. Anable *et al* note that limiting speed also exerts restraint on distance travelled:

> "speed enforcement and reduction is the only fuel efficiency measure with a built-in restraint mechanism. Whereas fuel efficient engines have reduced the cost of travel, speed limiting effectively increases the cost of a journey through time penalties and the discouragement of longer journeys". (Anable *et al* 2006: p.26)

Carsten *et al* (2008) estimated the impact of in-vehicle intelligent speed adaptation (ISA) technology, with both voluntary and mandatory speed override. Used on typical A-roads they estimated limited fuel consumption and emissions savings from either form, but on 70 mph roads a 3.4% reduction in CO_2 emissions is predicted for voluntary ISA, and a 5.8% reduction for mandatory (non-overridable) ISA. Such technologies could be extremely valuable in ensuring that the emissions savings from the technical improvements identified in Chapter 3 are realised, remembering the growing divergence between official type approval gCO_2/km and real world emissions (see also section on 'persuasive technology', §3.3.4).

It is worth noting that, contrary to the aforementioned evidence, the balance of government opinion in 2011–12 is swinging away from speed restraint towards *increasing* the national speed limit to 80 mph – expected to result in additional emissions of 1.3 $MtCO_2$ p.a. from cars (Anable 2011; UKERC 2011).

4.4.3 Economic instruments

4.4.3.1 Fuel taxation – effect on driving distance

In a review of short and long term price elasticities, Goodwin *et al* (2004) estimate that a 10% increase in the real price of fuel brings a reduction in traffic volumes of 1.5% in the first year, building to a cut of 3% within around five years; with fuel consumption falling by 2.5% in the first year, building to a reduction of around 6% within five years (differences between reductions in VKM and fuel consumed arise from the price increase leading to more efficient driving styles). Varying the detailed assumptions about elasticities changes the outcome for emissions and vehicle kilometres, and indeed there is a wide literature which describes alternative iterations of Goodwin *et al*'s calculations (e.g. Potter 2008; Salmons 2011; Johnson *et al* 2012b).

4.4.3.2 National road user charging

As noted above, national road user charging has been on the policy agenda for well over a decade, but antipathy towards charging amongst car drivers appears to have sapped political will to implement it. Consequently, the privately managed M6 toll road in the Midlands remains the only sizeable stretch of charged roadway in the UK.

It has been claimed that road charging on a time and place varied pay-per-mile basis has the potential to more evenly and accurately apply a price signal to vehicle end-users than the current fuel taxation system (Johnson *et al* 2012a), since fuel taxes do not capture differences in congestion and utility from driving at different times of day and parts of the country. De Palma and Lindsey (2011) suggest that the principal advantages of road pricing over other transport demand management interventions lies in forcing would-be drivers to consider “all aspects of their behaviour: number of trips, destination, mode of transport, time of day, route, and so on, as well as their long-run decisions on where to live, work and set up business” (ibid, p.1378). Of the wide variety of possible configurations of road user charging reviewed by De Palma and Lindsey, the most relevant to this analysis are distance based schemes and high occupancy toll (HOT) schemes, the latter being a toll-waiver for vehicles with occupancy of two persons or more. Such a system has the potential to create further incentive to share car journeys (over and above possible travel time savings in HOVLs), thus reducing overall car-kilometres.

4.4.3.3 Congestion charging

Evidence from existing congestion charging schemes indicates that they are highly effective in reducing both traffic flow across perimeter cordons and within charging zones. Four years after its introduction, the Central London congestion charging zone effected a 30% reduction in chargeable vehicles entering the zone and 28% reduction in chargeable vehicle kilometres circulating within the zone (TfL 2007). Reviewing the effects of a pilot scheme for congestion charging in Stockholm, Eliasson *et al* (2009) reported -22% vehicles entering the zone and -15% VKM within the zone, noting that the charge applied in the Stockholm pilot was half the price of that in London. May *et al* (2010) corroborate this range of reductions, and go on to note that public opposition to charging schemes is dynamic, with evidence of levels of acceptability increasing post-implementation for charging schemes in London, Bergen, Trondheim and Stockholm. As May *et al* observe: “this helps explain why referenda held immediately before implementation are particularly unsuccessful” (ibid, p.58). They suggest that critical success factors include the provision of alternative transport modes and judicious application of discounts and exceptions through complementary policy instruments funded by charging revenues.

4.4.3.4 Limitations on delivering mitigation objectives through market-based instruments

Strategies based on taxation or road user charging are inflexible in the extent to which people comply with the policy at the point of purchase – in obtaining the good or service in question, there is no lawful option but to pay the tax or charge. However, such measures do not *compel* any change in consumption behaviour, since those individuals who can afford to do so may simply pay the tax and continue to use high-carbon transport goods and services unabated. There is close correspondence between personal transport emissions and income (see for example Brand 2008), suggesting that taxes or charges would have to be set at a relatively high threshold to effect a change in behaviour from those who emit most.

4.4.4 Economic incentives

4.4.4.1 Cost differentiation of vehicle taxation – effect on vehicle purchasing

Brand *et al* (2011) estimate that car purchase 'feebates' administered carefully can yield considerable reductions in vehicle cumulative lifecycle emissions by incentivising consumer selection of low-emissions vehicles. Their 'extreme ambition' policy scenario involves a subtle system of purchase tax rebates, waivers and fees depending on vehicle exhaust emissions (fees of £8000 for cars over 200 gCO_2/km), with emissions band thresholds progressively reducing year by year from 2015. Cumulative lifecycle car sector emissions savings 2010–2020 under this extreme 'feebate' scenario are estimated at approximately 43 $MtCO_2e$ against baseline (8% p.a. reduction in 2020 on 2010 levels). The same study also estimated the emissions savings potential of more steeply banded vehicle excise duty (circulation tax), the most extreme scenario assuming VED rates at double the current duty for each of the thirteen emissions bands, with progressively tightened CO_2 limits on the threshold of each band every five years. This scenario Brand *et al* estimate to return 3% emissions savings by 2020, compared to baseline. Ryan *et al* (2009) corroborate the thrust of Brand *et al*'s findings, suggesting that vehicle circulation taxes exert a strong influence on consumer purchasing behaviour, with the potential to reduce mean new car emissions beyond the then current manufacturer voluntary agreements (EU regulations have now superseded the VAs).

4.4.5 Soft measures

4.4.5.1 Workplace travel plans

Cairns *et al* (2010) found that well-designed workplace travel plans achieved a mean reduction in employee commuting journeys of 18%. Gross *et al* (2009) note that workplace travel plans have traditionally focussed on increasing occupancy through car sharing schemes and increasing public transport use, although tend to have less of an effect on total travel demand unless teleworking and teleconferencing are included in the package of measures. Further obliging or incentivising employers to adopt best practice in workplace travel planning has the potential to make appreciable contributions to emissions savings.

4.4.5.2 Nationwide implementation of Smarter Choices measures

A number of recent meta-analyses have reviewed the research evidence base on the potential effects of soft transport interventions on car use. Cairns *et al* (2008) estimate based on a review of literature that full implementation of the Smarter Choices package of measures could reduce national traffic levels by 11% in the course of a decade (range of estimates 5% to 25%). In a comprehensive meta-analysis of 141 studies of the impact of workplace, school and personalised travel plans, Möser and Bamberg (2008) find the mean reduction in car trips per study is 11% (NB this is a reduction in car *trips*, whereas Cairns *et al*, included in Moser and Bamberg's study, report reduction in vehicle-kilometres). Richter *et al* (2010) conducted a similar meta-analysis by country, finding reductions of a similar scale reported by studies in Australia (7–14% reduction in car trips, with one study recording a 14% reduction in car-kilometres travelled), Japan (mean reduction in car-kilometres of 12%), Germany (12% reduction in trips as driver) and Sweden (14% reduction in driver trips). Graham-Rowe *et al* (2011) reviewed 77 TDM studies, categorising them by methodological rigour, finding that 62% were relatively weak methodologically (i.e. without control groups), and were therefore unwilling to generalise conclusions from the majority of studies. Of the 12 studies they identified as methodologically strong (with control group and post-intervention follow-up) only half reported on reductions in vehicle-kilometres, at a mean reduction of 6.3 km per person per day. Although the authors do not comment further on this finding, it seems an incredibly high saving, given that the UK mean driving distance for commuting trips is 10.2 km (DfT 2011b). Of studies considered methodologically strong in Graham-Rowe *et al*'s typology, some had very small sample sizes (e.g. n=8) and only two were conducted in the last decade (in 2002). Findings from the 'medium-quality' investigations tended towards the range of driving distance reductions mentioned above, being in many cases the same studies as reviewed in the aforementioned meta-analyses.

4.4.5.3 Land use and planning policies

Proost and Van Dender (2011) review empirical evidence from the USA of the putative causal connection between residential density and travel distance (lower densities are associated with significantly higher annual driving distances). They find that a change in residential density of 1000 units per square mile (40% of their sample mean density) leads to a reduction in annual VKM of approximately 5%. Proost and Van Dender observe that while a 5% reduction is non-negligible, a 40% increase in population density is not an option for the majority of established population centres. While geographical distances and fuel prices both differ greatly between the USA and the UK, the principal policy lesson still applies: to contain private transport energy use for new and re- developments, low density urban sprawl is to be avoided.

Banister and Anable (2009) argue that the effects of land use characteristics on travel behaviour are cumulative and mutually reinforcing, and identify three key spatial influences on demand for travel: (i) density of development; (ii) proximity and quality of local facilities, mixed use development; and (iii) local neighbourhood and design (road layout, parking charges etc). Relative location of home and work (for all household members) is a case in point, being amongst the strongest determinants of household passenger car kilometres (Maat and Timmermans 2009). These influences underpin a range of structural constraints on travel choices, which are explored in more depth in this research through qualitative interviews with drivers (see Chapters 7–9).

It is worth noting that the decadal timescales involved in addressing such fundamental 'landscape' factors is not commensurate with the immediate timeframe of mitigating 'dangerous climate change'. Reflecting on tensions between short-term mitigation needs and reliance on long-term technical solutions, Anable and Shaw (2007) suggest that even the period to 2030 is a challenging timeframe in which to address the structural issues pertaining to the incumbent socio-technical regime[96].

4.5 Additional demand-side interventions

Looking beyond the measures already deployed, the possibility of additional mitigation through novel demand-side measures is sought. Three sets of interventions are considered: (i) regulation of new car sales in the UK by a maximum emissions standard; (ii) inclusion of passenger car emissions in the 'upstream' EU Emissions Trading Scheme; and (iii) a 'downstream' cap-and-trade system of personal carbon emissions quotas.

4.5.1 Regulation of new car sales and 'choice editing'

Building on the analysis of the mitigation potential of 'optimising conventional cars' in §3.3.2.2, it is evident that direct regulation of the UK new car market could deliver large emissions savings fairly rapidly. Brand *et al* (2011: p.953) recall that the King Review estimates that "choosing the lowest emitter (rather than the average) in any market segment will tend to make a difference of about 25% to fuel efficiency and CO_2 emissions". Thus even within vehicle market segments, introduction of a Japanese-style system of 'top runner regulation' is a potentially high-return mitigation strategy[97]. However, greater emissions reductions still are available by selecting the best available technology of all classes. By discarding vehicle mass and other 'utility parameters' as the basis for differentiating amongst car market segments and for setting manufacturer new car emissions standards (see §3.3.2.3), regulators could require that *all* new cars comply with a maximum emissions threshold. Directly regulating the availability of new cars by emissions would require courageous and resolute leadership, given the political

[96] Citing Foresight report subsequently published as Kohler (2006).

[97] Top-runner regulation in Japan iteratively sets mandatory compliance thresholds in consultation with industry stakeholders, based on best available technology with a specific product category (Nordqvist 2006).

lobbying capacity of the car industry. It is nevertheless considered here as a serious policy proposition, given the scale and urgency of mitigating emissions from the passenger car sector, and the uncertainties and timescales attached to other options.

Recently popular in government circles, behavioural economics, or ‘nudges’ (Thaler and Sunstein 2008), describes a loose collection of soft, non-coercive interventions which could potentially affect car-buying choices. In the case of vehicle choice, at present there is commonly too great a price differential between standard models and low-emissions versions to be amenable to gentle nudging towards the latter. However, a liberal interpretation of the nudge toolset includes choice editing, which has been successfully applied to change purchasing habits in other areas of consumption – most notably in the removal from sale of incandescent lightbulbs in the UK. Whether or not this strictly counts as soft paternalism[98] is debatable, since in the case of incandescent bulbs their sale is regulated, ostensibly in an attempt to ‘force’ technological development of more efficient forms of lighting.

4.5.2 EU ETS

Bringing road transport (including passenger cars) into the European Union Emissions Trading System has been tabled as a possibility by, amongst others, the European Commission, the UK Committee on Climate Change and IPPR (Grayling *et al* 2006). However, as argued by Bows *et al* (2009), the scheme’s use of Clean Development Mechanism credits to effectively offset emissions within participating domestic European sectors, allied to the lock-in effects of not addressing domestic emissions in the short term, mean that emissions trading is not able to ensure the necessary cuts in absolute emissions. These fundamental problems notwithstanding, the EU ETS is not designed to deliver a pathway premised on avoiding a 2°C rise, and hence is not considered in this analysis.

4.5.3 Personal carbon trading (PCT)

Raux (2010) weighs the pros and cons of applying a quantity constraint on CO_2 from private transport by taxation compared to upstream (e.g. EU ETS) and downstream tradable permits (PCT). Raux argues that a downstream market for trading carbon emissions permits – variously referred to as personal carbon allowances, domestic tradable quotas, tradable emissions quotas – could potentially be more effective in mitigating emissions in the passenger car sector, since end-users “are more sensitive to quantitative signals than price signals in this area” (ibid, p.147). The optimum boundaries, allocation and rules of such a system vary in the literature, but the cornerstone is direct allocation to individuals of a strictly capped national emissions budget in the form of emissions credits, which must be surrendered when purchasing

[98] There is some academic debate as to precisely what constitutes a ‘nudge’ – some commentators, for instance attendees at a June 2010 conference on ‘Green Nudges’ at Manchester Business School, suggesting that choice editing is too strong an intervention to strictly count as a nudge.

energy goods and services (in addition to the usual financial payment). Unused credits can be sold via a centrally administered carbon market. Total credits within the system are tightly controlled and would be reduced annually in line with national emissions objectives.

Wadud (2011) considers the merits of PCT for passenger cars along the traditional dimensions of cost efficiency, effectiveness and equity. Wadud notes potentially high effectiveness, with PCT being able to deliver better assurance of respecting a national emissions limit than other market-based alternatives such as fuel or carbon taxes – especially where growth in emissions is driven by rising driver population or vehicle ownership, rather than per capita distances. Wadud also finds PCT potentially advantageous in terms of progressiveness, but with efficiency drawbacks arising from relatively high start-up and monitoring costs. Indeed cost-effectiveness per tonne of carbon saved was the primary reason for rejecting PCT as a mitigation instrument by the last Labour government (House of Commons 2008).

However, as shown in Chapter 2, for the UK to meet its political objectives of mitigating dangerous climate change, much greater reductions than currently planned are needed within the next decade from all sectors, and passenger cars in particular. Therefore, there is good reason to re-evaluate PCT in light of the scale and rate of mitigation demanded by national emissions pathways based on clearly acknowledged probabilities of exceeding 2°C. Re-evaluation should take account not only of cost-effectiveness, but also the ‘assurance of delivery’ that can be derived from market-based instruments.

4.6 Synthesis

The rich literature on travel behaviour and practices suggests that concerted programmatic application of measures in combination could deliver a sizeable reduction in total VKM. Given the multiplicative nature of emissions savings from disparate measures, it is inadvisable to assume that measures taken together can simply be added up. However, amongst the more sober estimates of the cumulative contribution of demand-side interventions, Goodwin finds that “the evidence available is rich concerning reductions in car use up to about 20%-30%, but very sparse, at the present time, for changes greater than that” (Goodwin 2008: p.32). Goodwin’s estimate is notably not time-specific, but it may reasonably be supposed that the scale of demand reductions to which he refers could be achieved within the next decade through the concerted application of the full range of TDM measures. It remains to be seen whether greater reductions in demand could be achieved through more fundamental infrastructural changes to the fabric of the UK (through changes to spatial planning policy for residential, commercial, industrial sites) – and over what time horizon. Finally, the evidence on individual (per capita) annual driving distances are in gradual decline at present, so whether certain sections of the driving public may be amenable to greater reductions in demand than the 30% suggested by Goodwin is an area that warrants further enquiry. What is clear is that there is strong public aversion to plainly coercive policies and measures, which makes the realising the full potential of TDM highly contentious. Whether a comprehensive and transparently equitable system of energy or emissions rationing such as personal carbon trading could more rapidly deliver reductions at a greater scale than conventional piecemeal TDM interventions is another open question – but one that merits serious consideration in further research.

4.7 Summary

This chapter has attempted to review and synthesise the diverse literature on the demand-side issues most salient to rapidly mitigating emissions from the passenger car sector. The current policy mix contains a range of soft measures to encourage more efficient patterns of use, as well as relatively weak incentives to select low-emissions vehicles and adopt energy-efficient driving styles. Conflicts of priorities are identified both within government and in the ability of democratic referenda to approve restraint-based mitigation policies. The chapter breaks car sector demand down into a number of constituent elements, most significantly vehicle kilometres, passenger kilometres and car occupancy. The historical decline in mean occupancy suggests potential for containing total VKM by stopping or reversing this trend. Finally, the considerable literature on transport demand management (TDM) interventions is surveyed and is found to comprise a mix of methodologically variable experimental studies and empirical findings from real-world application of measures at sub-national level in the UK, or at subnational or national level in other countries.

CHAPTER FIVE – EMISSIONS BUDGETS

5.1 Overview of methodology

The review of climate science and mitigation literature in Chapter 2 highlighted that the current UK policy framing of sectoral mitigation with reference only to end point targets is fundamentally out of step with a scientific framing of the relationship between global warming and cumulative emissions. It also demonstrated that the relatively modest rate of emissions reduction planned for the passenger car sector in the *Low Carbon Transport* strategy (DfT 2009b), expressed as a 14% reduction in domestic transport CO_2 emissions by 2020 (cf. 2008), is far-removed from a national emissions pathway associated with a low probability of exceeding 2°C. More to the point, without reference to a cumulative constraint, reduction targets for end-point targets are dangerously misleading, having no basis in climate science – an important point overlooked by virtually all existing literature on transport mitigation.

Chapter 3 identified a heavy reliance in current UK passenger car sector mitigation policy on technology measures which, taken alone, are insufficiently ambitious to deliver abatement of the scale required for a low-probability of 2°C pathway. Chapter 4 found additional mitigation potential in amplifying the currently planned abatement from ‘soft policy’ interventions (such as driver education, information provision and incentives), and broadened the field of options to include direct regulation of new car emissions at the national level. However, the evidence suggests that an outright reduction in vehicle kilometres would require introduction of a quantity constraint such as fuel duty, carbon allowance or road user charging. There is also good reason to believe that without such a price signal, emissions savings from regulating new car sales, or from reducing and enforcing speed limits, are likely to be negated by rebound effects, whereby more efficient vehicles and driving styles allow greater distances for the same financial cost.

The next three chapters set out an analytical methodology (Figure 5.1) for:

a) estimating emissions pathways and cumulative budgets for the passenger car sector consistent with a range of named probabilities of exceeding 2°C;
b) estimating the fleet-wide emissions reduction potential of a range of standards for hard regulation of new car emissions; and
c) estimating the potential mitigation contribution from demand reduction interventions.

5.1.1 Quantitative framing

As noted in Chapter 2, whereas many previous transport scenario studies have focused primarily on the *scope* for delivering *given* mitigation targets (Schwanen *et al* 2011), this chapter specifically addresses the disconnect that persists between climate science and the quantification of sectoral mitigation. In this section, four arguments (or reasons) are advanced for increasing the currently low expectations of short-term transport mitigation. A methodology for deriving an emissions budget at the national level is then provided in §5.2. §5.3 describes what such a cumulative constraint would mean for the UK's passenger car sector in terms of absolute emissions reductions in the short to medium term, followed by summary conclusions of the mitigation implications of the budgets.

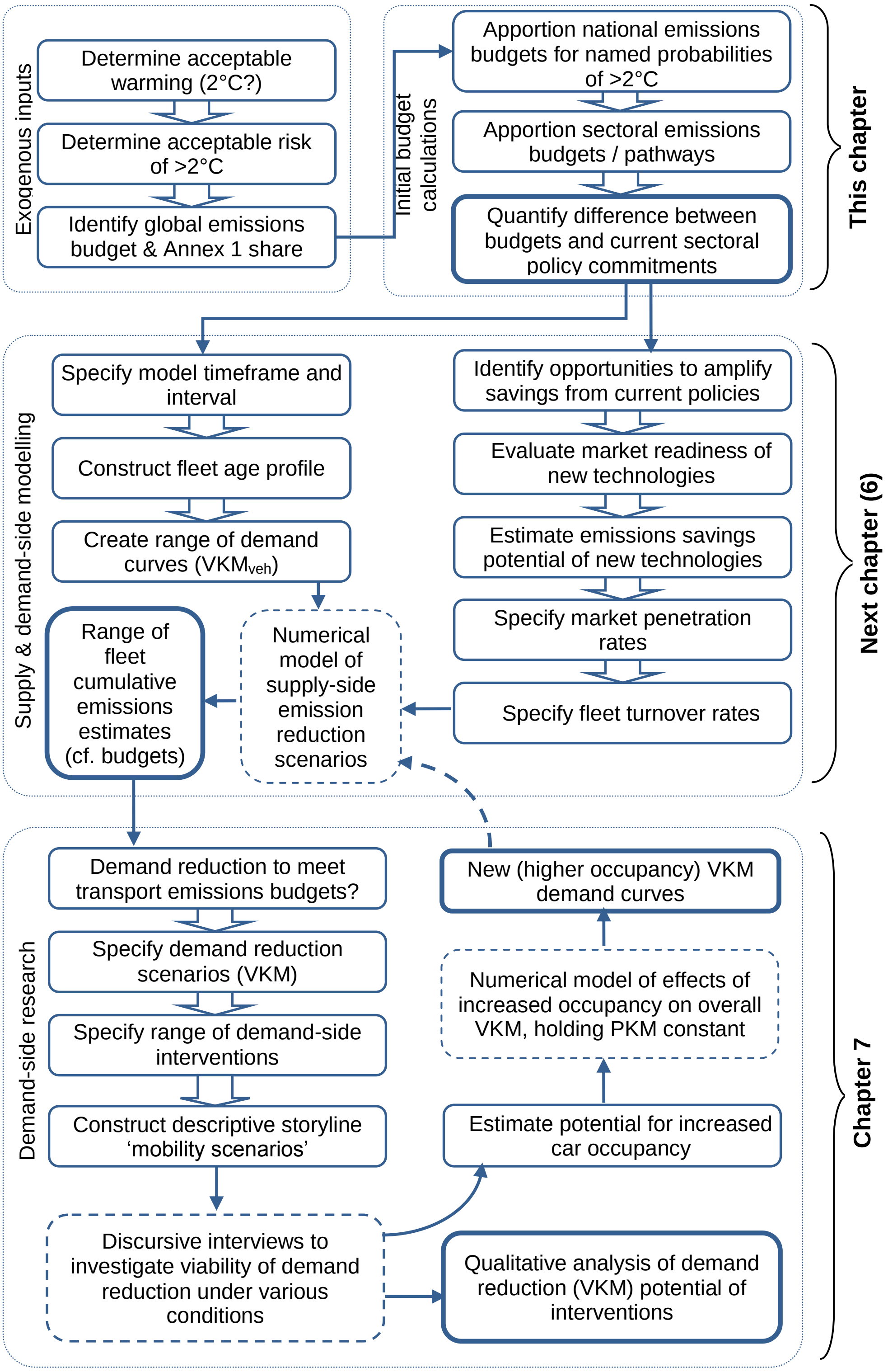


Figure 5.1: Schematic of analytical methodology (bold boxes show key outputs)

5.1.2 Four reasons to increase the ambition of car sector mitigation

5.1.2.1 Reason 1: Long term targets are misleading, only cumulative emissions matter

As shown in Chapter 3, many of the most significant emissions cuts typically envisaged for the car sector are expected to come from technologies that will not reach maturity until well into the 2020s or beyond (e.g. battery electric vehicles, hydrogen vehicles) (CCC 2010d). However, as Chapter 2 noted, to delay reductions from this key sector risks sacrificing all possibility of respecting a UK *cumulative* emissions budget and accompanying commitments on 2°C (Anderson *et al* 2008).

5.1.2.2 Reason 2: Be clear about the entailed probability of exceeding 2°C

The UK's carbon budgets are premised on a pathway (the CCC's *2016:3%*) derived from a global cumulative emissions budget associated with a 63% probability of *exceeding* 2°C warming by the end of the century (CCC 2008a). Much more ambitious emissions abatement than that entailed by current UK legislation is necessary to reconcile the high level political goal of avoiding 'dangerous' climate change with the national and sector-level mitigation interventions planned to achieve it.

5.1.2.3 Reason 3: Realistically assess emissions growth in industrialising nations and account for deforestation

The UK's statutory carbon budgets do not explicitly take account of the widely differing circumstances of industrialised and industrialising nations. Deriving a national from a global emissions budget is subject to several crucial assumptions, foremost among which are questions of:

a. how much 'headroom' remains in the global budget for Annex 1 to emit once allowance is made for non-Annex 1 to increase their emissions (Bows and Barrett 2010; Anderson and Bows 2011) (see §2.1.4);
b. how global emissions from deforestation are treated (discussed in §5.2.2.2);
c. when global emissions will reach their peak; and
d. the necessary extent of an 'emissions floor' to allow for irreducible non-CO_2 emissions from agriculture, reducing the scope for energy emissions.

With 82% of the world's 7 billion people (PRB 2011), non-Annex 1 production-based emissions exceeded those of Annex 1 only in 2006 (den Elzen and Höhne 2008; IEA 2011); their consumption-based emissions[99] overtaking those of Annex 1 in 2009 (Peters *et al* 2012). Despite the recent predominance of non-Annex 1 emissions overall, their per capita emissions are around one fifth or one sixth of those from Annex 1 nations when calculated on a producer or consumer basis respectively (Davis and Caldeira 2010, supporting information). While the analysis underpinning the UK's carbon budgets (CCC 2008a; CCC 2010a) assumes that global emissions will peak in 2016, the balance of evidence strongly suggests that this is unduly optimistic, (e.g. Meinshausen and Hare

[99] Production-based emissions plus the emissions associated with imports, but removing those from exports.

2008; Sheehan 2008), if not impossible without an almost immediate decoupling of GDP and emissions (Le Quéré *et al* 2009). As noted in §2.1.3.3 (p.49) global CO_2 emissions from fossil fuels and industry increased by 5.9% in 2010, giving the highest annual growth in absolute emissions ever recorded (Peters *et al* 2012). The emissions trajectories of emerging and industrialising economies show no signs of conforming to a peak much before 2025–30 (Garnaut *et al* 2008), rendering a global emissions peak earlier than 2020–25 more or less impossible. If 2°C is to remain in prospect, it is vitally important to be realistic about the implications of continued non-Annex 1 emissions growth driven by increasing consumption, particularly given "social and economic development and poverty eradication are the first and overriding priorities of developing countries" (Copenhagen Accord, UNFCCC 2009).

5.1.2.4 Reason 4: Avoid 'passing the buck' between sectors

As described in Chapter 2, other than dividing the UK carbon budgets between the traded and non-traded sectors, the UK government and the CCC make no further distinction as to where in the UK economy the 'emissions savings' necessary to achieving the emissions budgets should be made – the expectation is that emissions cuts will be made where they cost least (CCC 2008a). However, for any individual sector to reduce its emissions by less than the national rate of decarbonisation, equivalent additional savings from another sector must be made or the national pathway becomes unobtainable. The scale of the challenge is significantly greater when abating for lower probabilities of exceeding 2°C, particularly when accounting for realistic emissions growth from non-Annex 1 countries. Under such constraints, there would be little to no latitude for any high emitting sector to reduce its emissions by less than the national mean rate, since additional mitigation opportunities from other sectors would be minimal (the privileged treatment currently afforded aviation and shipping is discussed in §5.3.3).

Table 5.1: Summary of reasons for increasing UK abatement ambition

Reason 1	Early and ambitious abatement is essential for a pathway with a low probability of exceeding 2°C (once reasons 2 and 3 are taken into account).
Reason 2	A pathway that delivers a low probability of exceeding 2°C necessarily entails significantly greater emissions cuts from all major emitting sectors than one intended to deliver a 63% probability of exceeding 2°C.
Reason 3	National emissions budgets in Annex 1 countries will need to respect the remaining headroom in a 2°C-derived global budget, once non-Annex 1 emissions are accounted for.
Reason 4	Significant asymmetry in the division of abatement effort between major emitting sectors is not an option when mitigating for lower probabilities of exceeding 2°C.

Reasons 1, 2 and 3 are applied in the following section. A set of national emissions budgets is derived from global emissions pathways which reflect the UK's 2°C commitments, but associated with probabilities of exceeding 2°C lower than the 63% which underpins current UK mitigation policy. These budgets explicitly account for emissions growth within non-Annex 1 nations. Reason 4 is applied to the car sector in §5.3, which develops a methodology for specifying quantified sectoral emissions budgets, in which each sector makes its appropriate contribution to a temperature-derived emissions budget.

5.2 Deriving national budgets from global 2°C pathways

This section outlines a set of emissions budgets for the UK, derived from global budgets associated with progressively lower likelihoods of *exceeding* 2°C than is entailed by the UK's present carbon budgets.

5.2.1 Viable global pathways

Three global emissions scenarios, which are explicitly associated with lower probabilities of exceeding 2°C than the CCC's *2016:3% low,* are proposed as a basis for deriving UK-scale emissions pathways. The first assumes a 56% probability of exceeding 2°C and is premised on the CCC's most stringent pathway (*2016: 4% low*) (CCC 2008b). The second and third global scenarios are taken from Anderson and Bows (2011), one with a 52% chance of exceeding 2°C (*'C+5'*) and, the most demanding (due to a smaller budget), with a 36% chance ('*C+1*') (Figure 5.2). Both *C+5* and *C+1* have explicit and very different assumptions about non-Annex 1 and Annex 1 emissions to those implied in the CCC's global budgets – namely, *C+5* and *C+1* assume that if 'international development' goals are to be given equal priority with climate goals, then allowance must be made in the Annex 1 pathway and budget for non-Annex 1 nations to continue to *increase* their emissions in the short term.

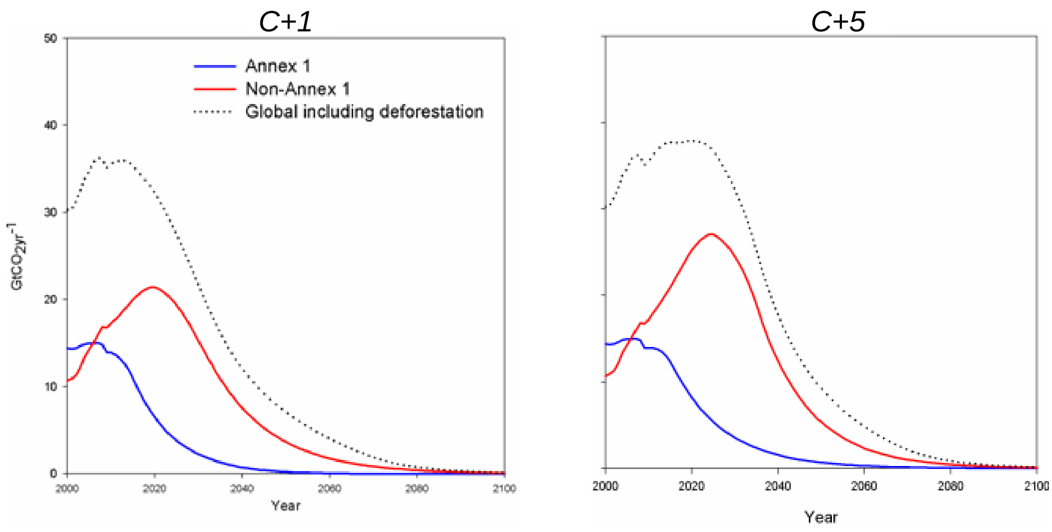


Figure 5.2: Global CO_2 scenarios for a 36% and 52% chance of exceeding 2°C respectively. *C+1* has a cumulative twenty-first century CO_2 budget of 1321 $GtCO_2$, *C+5* has a budget of 1578 $GtCO_2$ (reproduced from Anderson and Bows, 2011).

5.2.2 Apportionment to the national level

As alluded to in §2.1.4, the highly contentious nature of international negotiations on apportionment regimes makes it more or less impossible to predict with any degree of assurance the outcome of this on-going and glacially slow political process (the CCC itself demurs to recommend a particular method). Rather than attempt to recreate the outcome of politically negotiated apportionment, this analysis takes a more 'teleological' approach – working back from global budgets with named probabilities of exceeding 2°C to national budgets based on a number of simple and transparent assumptions.

Three global scenarios (*2016:4% low*, *C+5* and *C+1*) are taken as the bases for five UK CO_2 emissions pathways (Figure 5.3). The two foremost assumptions in translating the global to national pathways are:

(a) the split between Annex 1 and non-Annex 1 nations, and

(b) the treatment of emissions from deforestation and land use change (hereafter deforestation).

5.2.2.1 Sharing the global emissions budget between Annex1 and no-Annex 1

Although the CCC does not explicitly state the mechanism by which the 2016:4% low global pathway is translated into the corresponding UK 'intended budget', it is evidently a form of contraction and convergence (CCC 2008a). The first of five UK national CO_2 pathways used here, *UK1*, is based on data published by the CCC as the UK 'intended path' (CCC 2009).

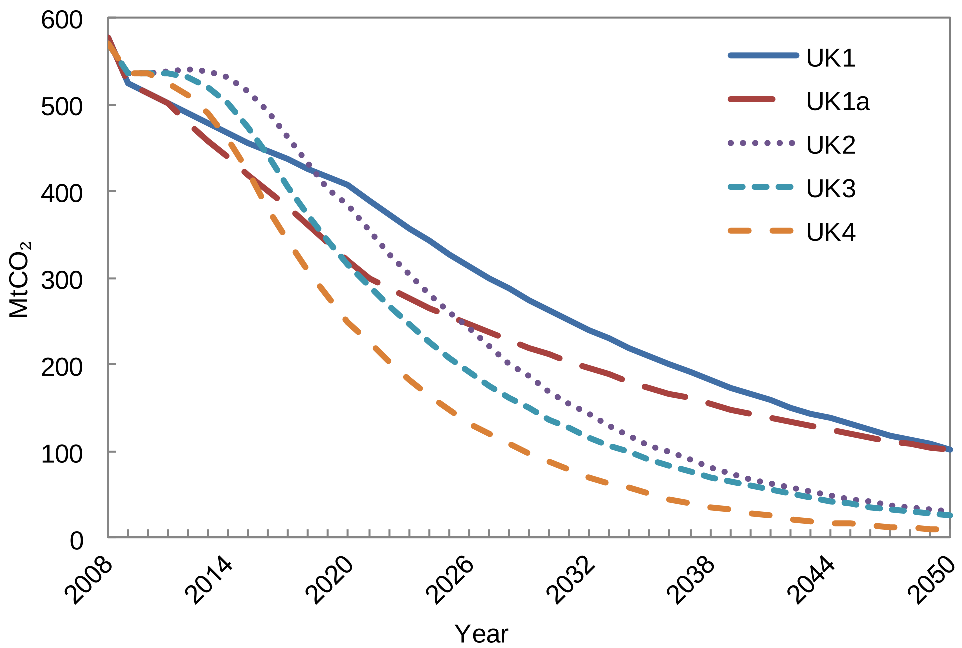


Figure 5.3: UK total CO_2 emission pathways based on various probabilities of exceeding 2°C (in brackets): *UK1* is the CCC's 2016:4% low intended path (56%); *UK1a* is the CCC intended path with modification to account for global deforestation (see §5.2.2.2); *UK3* and *UK4* are based on Anderson and Bows' (Anderson and Bows 2011) Annex 1 C+5 (52%) and C+1 (36%) pathways respectively; *UK2* is a hybrid pathway based on CCC global emission budget (56% probability of >2°C) and assumptions about non-Annex 1 emissions growth based on Anderson and Bows (2011).

Sidestepping the imponderable politics of international apportionment negotiations, in the absence of compelling arguments for an alternative allocation amongst Annex 1 nations, this analysis apportions the *C+5* and *C+1* Annex 1 emissions to the forty-one separate Annex 1 nations based on their mean share for the years 2008–2010 (i.e. the most recent available data). UK emissions (domestic CO_2 plus international aviation and shipping) were 3.85% (one twenty-sixth) of combined Annex 1 CO_2 for this period (DECC 2011a). Hence Annex 1 emissions pathways from the *C+5* and *C+1* scenarios are translated into two corresponding national pathways, *UK3* and *UK4*, based on this fraction and following the same rate of decarbonisation as the overall Annex 1 group in the respective global scenario. It should be noted that this is an essentially apolitical assumption, and not intended in any way to suggest the likely outcome of UNFCCC negotiations.

National pathway *UK2* is based on the CCC's global scenario *2016:4% low*, which is disaggregated to non-Annex 1 and Annex 1 using Anderson and Bows' (2011) approach, then allocated to the UK at its historical one twenty-sixth share of Annex 1 emissions. This illustrates how explicit assumptions about non-Annex 1 emissions would affect the UK national emissions pathway if applied to the CCC's global scenario. Annex 1 emissions in this case are estimated from the *C+5* Annex 1 pathway – the difference between global emissions over the remainder of the twenty-first century in *2016:4% low* and *C+5* being distributed between the Annex 1 and non-Annex 1 groups on a per capita basis (i.e. 82% to non-Annex 1, 18% to Annex 1 (PRB 2011)). This additional emissions headroom is ascribed to the Annex 1 emissions pathway over the period 2013–2035, to reflect the lead time needed to decarbonise the electricity supply, and the currently below-trajectory additions of new nuclear and renewable generation capacity to the UK grid (CCC 2011). As a result, the *UK2* pathway has a higher cumulative emissions budget in the medium term than the other *2016:4% low*–derived pathways, although over the period to 2050 the *UK2* budget is lower than for *UK1* (Table 5.2).

5.2.2.2 Deforestation as a 'global overhead'

Emissions from deforestation are estimated to account for approximately 8.5% of global emissions in 2010 (Houghton 1999; Global Carbon Project). While the majority of deforestation activity in future years will take place in non-Annex 1 countries, arguably the resulting emissions are a 'global overhead', since Annex 1 countries have already deforested and emitted CO_2 in doing so (Anderson and Bows 2011). Thus, for pathways *UK2*, *UK3* and *UK4*, a highly optimistic estimate of deforestation emissions (266 $GtCO_2$ for the twenty-first century) is subtracted from the global pathways *before* estimating the emissions headroom available for Annex 1 nations in light of assumptions about non-Annex 1 growth.

Conversely, the assumption implicit in translating the CCC's *2016:4% low* global scenario into the UK intended pathway is that emissions from deforestation are the responsibility of the individual deforesting nation. To highlight the considerable difference that this assumption makes to the emissions space for an already deforested nation such as the UK, a fifth national pathway, *UK1a*, is derived by adjusting the intended pathway (*UK1*) in proportion to the share of the *2016:4% low* global budget consumed by the 266 $GtCO_2$ deforestation estimate. This pathway, *UK1a,* reflects a 14% reduction in total UK emissions for the period 2011–2050 to allow for proportionate worldwide emissions from deforestation.

Table 5.2: Summary of derived UK total CO_2 emissions pathways and budgets.

	UK1	*UK1a*	*UK2*	*UK3*	*UK4*
'Parent' global budget and probability of >2°C	*2016:4% low* 56%	*2016:4% low* 56%	*2016:4% low* 56%	*C+5* 52%	*C+1* 36%
Deforestation treated as a global overhead?	No	Yes	Yes	Yes	Yes
non-Annex 1 emissions peak year	N/A	N/A	2025	2025	2020
Annual reduction rate	2.3% to 2020, up to 4.8% to 2050	Up to 6% to 2020, ~3.7% to 2050	Up to7% to 2020, ~8% to 2050	Up to 7.5% to 2016, 8% to 2050	Up to 8.7% to 2016, 10% to 2034 11% to 2050
Reduction on 1990 emissions by 2022	39%	53%	47%	56%	67%
UK total CO_2 budget 2008–2022 ($MtCO_2$)	6,908	6,307	7,166	6,650	6,042
Reduction on 1990 emissions by 2050	83%	84%	95%	96%	99%
UK total CO_2 budget 2008–2050 ($MtCO_2$)	12,730	11,144	10,542	9,431	7,742

5.3 Sectoral pathways

This section disaggregates the national pathways from §5.2 to give emission budgets for individual sectors of the UK economy. These then form the basis for inter-comparison of the levels of sectoral abatement required to deliver a greater or lesser probability of achieving the top-level policy objective of restricting warming to 2°C.

5.3.1 Determining the sectoral balance of effort

Whilst the Energy Demand and Emissions Model used by DECC to identify least cost savings strategies may be appropriate for relatively incremental reductions in emissions (e.g., ~2–4% p.a.), it is arguably unsuitable for addressing the non-marginal rates of reductions accompanying the national pathways described earlier. Emissions from all sectors must, on aggregate, not exceed the national budget. Consequently, for any one sector to decarbonise at less than the mean national rate, another sector must decarbonise at a proportionally greater rate than the mean – all the more important for major emitting sectors, such as passenger cars. With such a challenging mean rate in the first place (typically over 8% p.a.), it is difficult to envisage how a quantified case for special treatment of one sector, at the expense of yet more challenging reductions from other sectors, could be justified[100].

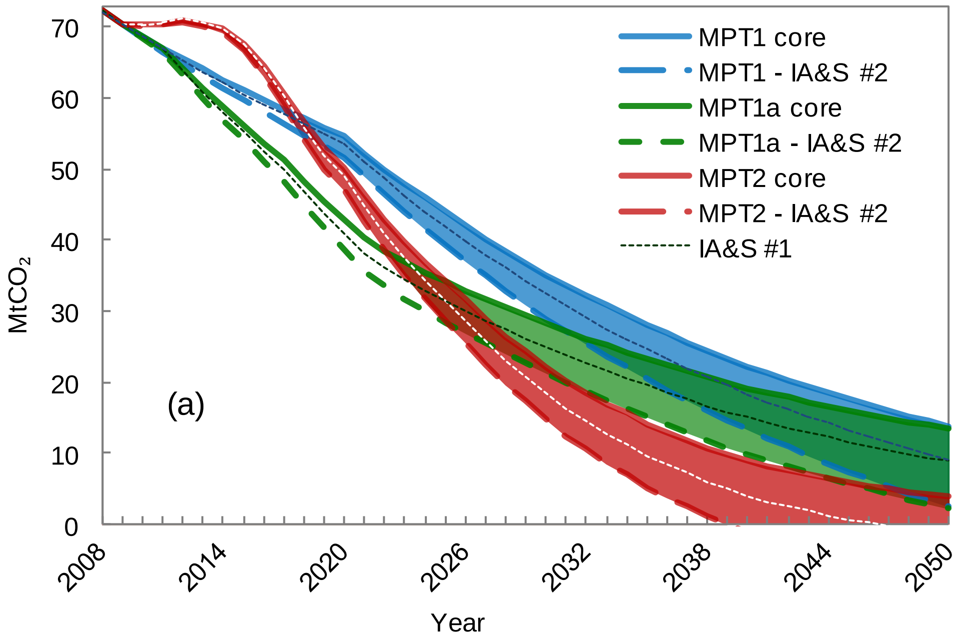
5.3.2 Car sector core pathways and budgets

Building on the above rationale, this analysis apportions the 2°C-derived national emissions budgets (Table 5.2) to the sectoral level based on the principle that sectors

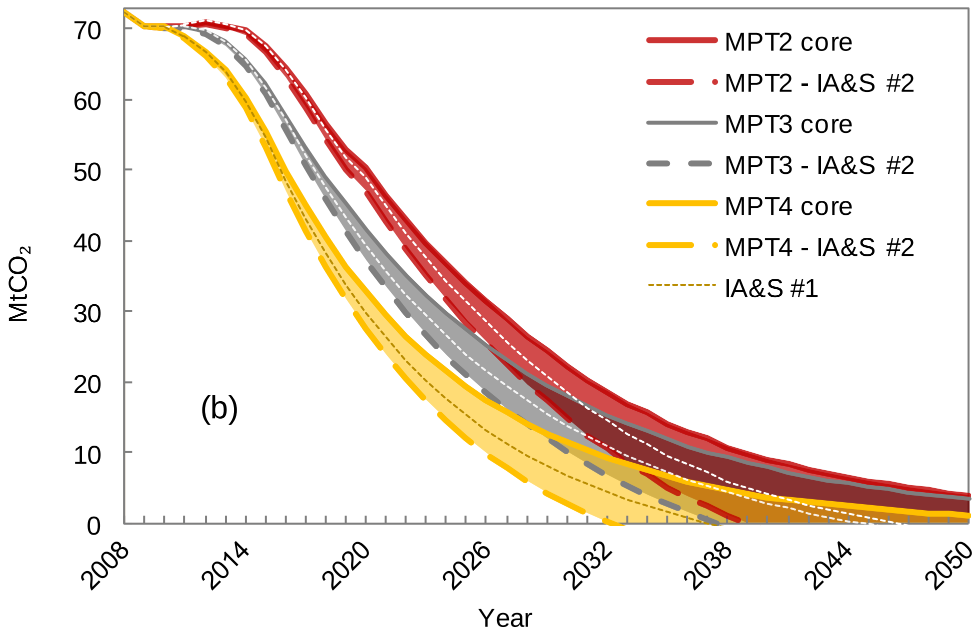
[100] For practical reasons an exception to this relates to emissions from international aviation and shipping – see §5.3.3.

must reduce their emissions *at least* at the national mean rate of decarbonisation[101]. Hence, the rates of annual emissions reduction in the national CO_2 pathways (*UK1 to UK4*) are applied to the car sector to produce corresponding *core* pathways for motorised private transport (*MPT1* to *MPT4* in Figure 5.4), along with corresponding cumulative budgets (Table 5.3). These pathways mirror directly the UK pathways, which, in turn, were derived from global pathways with associated probabilities of exceeding 2°C. The core pathways assume *all* sectors decarbonise at the national mean rate.

[101] Experience suggests emissions targets are seldom fully realised, so this simple principle is premised on a more candid interpretation of reality whereby it is unlikely any sector will over-deliver on already stringent reductions



a) Car sector emissions pathways derived from UK pathways based on a global budget with 56% probability of exceeding 2°C (the CCC 2016:*4% low*).



(b) Car sector emissions pathways derived from UK pathways based on global budgets with decreasing probabilities of exceeding 2°C (56%, 52% and 36% respectively – *the 56% MPT2 pathway is also show in (a) for comparison*

Figure 5.4 (a & b): car sector (motorised private transport, MPT) emissions pathways are shown on two separate plots for visual clarity. Shaded areas represent the *variation* in cumulative 'emissions space' (the total area under each curve) available for the car sector under different international aviation and shipping (IA&S) growth trajectories (see §5.3.3). 'Core' pathways assume no special treatment for the IA&S sectors. Thin dotted lines show car sector emissions assuming IA&S emissions decline then plateau at the level of 2005 bunker fuels-based estimate from 2020 onwards (scenario *IA&S #1*). Thicker dashed lines show car sector emissions assuming 1.2% p.a. growth in IA&S emissions (scenario *IA&S #2*).

5.3.3 Assumptions about international aviation and shipping (IA&S) emissions

Whereas emissions from other UK sectors have declined over the last decade (on a producer basis), CO_2 from the UK's international aviation and shipping has continued to increase (CCC 2011), driven by a steady growth in demand. Technical decarbonisation, of aviation in particular, is hampered by the short to medium term absence of suitable low-carbon fuel substitutes (Bows 2010). Moreover, allocating emissions from international shipping to the national level is fraught with political and practical challenges, with no definitive accounting methodology yet agreed internationally[102] (Gilbert *et al* 2010).

For mitigation relating to 2°C to be robust, it must take account of uncertainties in the baseline emissions and trajectories associated with international aviation and shipping. To this end two alternative IA&S scenarios are applied to the *UK1* to *UK4* pathways, as follows.

IA&S #1 adopts the arguably optimistic assumptions used by the CCC in developing their intended path for domestic CO_2. Emissions from aviation and shipping are estimated from international bunker fuel sales, and assumed to revert to their 2005 levels by 2020 (CCC 2009).

IA&S #2 builds on the work of Bows *et al* (2009), relating shipping emissions to UK GDP as a proportion of global GDP[103]. Emissions from UK international aviation are taken from UNFCCC memo submissions (UNFCCC 2010). Looking forward, scenario *IA&S #2* assumes conservative growth in combined international aviation and shipping emissions of 1.2% p.a., equivalent to the historical mean rate of change over the decade to 2009.

From the resulting domestic-only CO_2 pathways (i.e. once IA&S emissions are removed from the respective national budgets), two further sets of car sector pathways and budgets are then derived using the approach outlined in §5.3.2 (i.e. according to the principle of decarbonisation at the mean rate for all remaining sectors). These additional pathways highlight the sensitivity of other sectors to assumptions about emissions from international aviation and shipping (dashed / dotted lines in Figure 5.4). Figure 5.4(b) and Table 5.3 demonstrate how, for lower probabilities of exceeding 2°C, even a historically conservative growth trajectory for international aviation and shipping

[102] While aviation is included in the EU Emissions Trading Scheme (EU ETS) from 2012 onwards, the EU ETS is not based on restricting warming to 2°C. Many major emitting countries, for example China and the USA, contest the inclusion of aviation and shipping within any sub-global emissions scheme.

[103] Although UK aviation bunker fuel sales correlate well with UK aviation emissions, UK marine bunker fuel sales underestimate the UK's international shipping emissions, since vessels often refuel outside of national waters (Wood *et al* 2010; Gilbert and Bows)

emissions consumes the UK's entire CO_2 emissions budget as early as 2032, effectively making those pathways non-viable.

5.3.4 Car sector cumulative budgets

The *Low Carbon Transport* (*LCT*) white paper expresses mitigation in terms of a 2020 emissions target. Such end point targets can be misleading unless based on an explicit cumulative constraint. Nevertheless 2020 is an appropriate timeframe for short-term mitigation, particularly given 2°C budgets demand early (and deep) reductions in emissions[104]. To facilitate comparison with the CCC's UK carbon budgets and the national pathways and budgets described in §5.2, the car sector budgets underpinning this analysis are summarised for the period 2008–22 in Table 5.3.

Table 5.3: CO_2 cumulative budgets for the car sector (motorised private transport, MPT).

	Counter-factual†	*LCT**	*MPT1*	*MPT1a*	*MPT2*	*MPT3*	*MPT4*
'Parent' national pathway and probability of >2°C in 'grandparent' global budget	~	*'Interim'* *63%*	*UK1* *56%*	*UK1a* *56%*	*UK2* *56%*	*UK3* *52%*	*UK4* *36%*
MPT $MtCO_2$ 2008–22: core pathway no special treatment for IA&S (*2022 reduction on 1990*)	**1,088**	**1,011** (*15%*)	**920** (*31%*)	**840** (*47%*)	**937** (*40%*)	**869** (*51%*)	**789** (*63%*)
MPT $MtCO_2$ 2008–22 core pathway reduction against counterfactual *baseline*	~	77	168	248	152	219	299
MPT $MtCO_2$ 2008–50: core pathway	~	~	1,701	1,488	1,379	1,234	1,012
% of UK total CO_2 budget consumed by IA&S in 2050 on core pathway	~	~	*10%*	*10%*	*10%*	*10%*	*10%*
MPT $MtCO_2$ 2008–22: *IA&S #1* bunkers estimate, plateau by 2020 (*2022 reduction on 1990*)	~	~	912 (*33%*)	824 (*50%*)	930 (*43%*)	857 (*55%*)	770 (*68%*)
MPT $MtCO_2$ 2008–50: *IA&S #1*	~	~	1,599	1,367	1,255	1,099	890
% of UK total CO_2 budget consumed by IA&S in 2050 in IA&S scenario 1	~	~	*39%*	*40%*	*136%*	*156%*	*455%*
MPT $MtCO_2$ 2008–22: *IA&S #2* hybrid estimate, low growth (*2022 reduction on 1990*)	~	~	896 (*36%*)	807 (*53%*)	915 (*46%*)	840 (*59%*)	751 (*72%*)
MPT $MtCO_2$ 2008–50: *IA&S #2*	~	~	1,456	1,219	1,160	1,010	828
% of UK total CO_2 budget consumed by IA&S in 2050 in IA&S scenario 2	~	~	*84%*	*85%*	*290%*	*332%*	*972%*

† This represents a counterfactual level of emissions, had the policies in the *Low Carbon Transport* (*LCT*) white paper not been in place (DfT 2009a), and included demand growth – see §2.2.4.1
* Based on emissions savings measures proposed for passenger cars in the 2009 *Low Carbon Transport* white paper (DfT 2009a)

[104] The UK government adopted the CCC's Fourth Carbon Budget in June 2011, setting emission limits for the period 2023–2027. While this later budgetary period is essential for medium term mitigation planning, the principal concern of this analysis is that a lower probability of exceeding 2°C demands early action.

Table 5.3 integrates the implications of Table 5.1's four reasons for increasing the ambition of car sector abatement, showing that:

- cumulative budgets for 2°C-related pathways make clear the manyfold increase in abatement effort required (Reason 1), with an increase of 388% required for a 36% probability of exceeding 2°C, compared to the currently planned mitigation;
- reducing probabilities of exceeding 2°C place progressively greater mitigation obligations on the car sector (Reason 2);
- accounting for growth in non-Annex 1 emissions (*MPT2* to *MPT4*), and for global deforestation (*MPT1a* to *MPT4*), reduces UK car sector emissions space still further in the period to 2050 (Reason 3); and
- growth in emissions in 'privileged' sectors such as aviation and shipping leaves much less space for other sectors, and may make lower probability pathways untenable by using up the entire budget (Reason 4).

Table 5.3 further illustrates how, assuming equal treatment of domestic sectors, reducing the probability of exceeding 2°C from *UK1*'s 56% (the CCC 'intended budget') to *UK4*'s 36% would shrink the car sector's emissions space for the decade to 2022 by 14%. Over the period to 2050, the corresponding emissions space reduces by 40%. Once international aviation and shipping are accounted for (on a low-growth emissions trajectory, i.e. not decarbonising at the mean rate), the emissions space for cars shrinks by up to 51% over the period 2008–50 (to 828 $MtCO_2$) for a 36% compared to 56% probability of exceeding 2°C; emissions space 2008–22 reducing by up to 18% (to 751 $MtCO_2$). On pathways *MPT2*, *MPT3* and *MPT4,* IA&S emissions exceed the total UK CO_2 emissions space by as early as 2032 – see Figure 5.4(b). Hence, privileging IA&S emissions is not viable while respecting a low probability of 2°C and accounting for non-Annex 1 emissions growth.

The lower car sector emissions associated with a 36% compared with a 63% chance (the interim pathway) of exceeding 2°C suggests that following the interim path to 2022 locks out any prospect of respecting a low probability of exceeding 2°C. Even without special treatment for international aviation and shipping, the 2008–2022 budget on the 63% probability pathway is equivalent to the *entire* 2008–2050 car sector budget on the 36% probability pathway.

The next chapter sets out a method for estimating the level of technology improvement that would be required to meet such challenging sectoral budgets.

CHAPTER SIX – FLEET EMISSIONS MODEL

6.1 Introduction

This chapter describes a method for using the emissions budgets from the previous chapter to inform construction of UK passenger car sector mitigation scenarios. A model of the UK car fleet is specified, which allows possible configurations of supply-side technology and end-user demand to be backcast from a given emissions budget. Budgets are then applied as a cumulative constraint on sectoral emissions over the decade to 2022. The model also allows prospective exploration of the cumulative emissions outcomes of various technology and end-user demand combinations, by varying the parameters that determine profiles of fleet age and use.

§6.2 gives an overview of the approach taken in this analysis, highlighting the main objectives and research questions to be addressed in this stage of the research. A detailed account of the various parameters, data source and relevance is given in §6.3. The configuration and interaction of these elements in model assumptions is then presented in §6.4, along with methodological limitations of the approach taken. §6.5 sets out the parameter assumptions used to construct a range of quantitative fleet emission scenarios.

6.2 Model rationale and principal objectives

The objectives of this chapter are to establish a working methodology to answer research questions 2, 3 and 4, as outlined in the introductory chapter:

- How much of the necessary mitigation could be achieved through new and existing technology?
- What, if any, shortfall remains between existing sectoral mitigation goals and potential technology savings over the next decade?
- What are the emissions implications of assumptions about future demand?

6.2.1 Emissions accounting method

Chapter 2 reviewed the literature on supply-side technology, and identified a range of vehicle and fuel technologies which could be applied within the short timeframe that Chapter 2 noted as critical for UK emissions budgets. Here, the applicable technologies are aggregated and bulk emissions factors estimated for new cars entering the fleet in any given future year. As noted in Chapter 3, within the timespan of interest, dominance of the fleet by internal combustion-engined vehicles (ICEVs) is unlikely to change. Therefore, while recognising the need for a systematic shift to targets and monitoring that takes into account vehicle lifecycle carbon emissions, this analysis refers to the tank to wheels (TTW) component of the energy chain, for the reasons explained in Chapter 3, §3.2.2. For present purposes, the primary advantage of using TTW emissions accounting is that it allows ready comparison with the current statutory emissions budgets and planned sectoral abatement measures (both based on source accounting) as well as the current regulatory monitoring and target setting procedures (based on TTW accounting).

6.2.2 Model overview

The main elements and steps undertaken in this stage of the analysis are represented in Figure 6.1.

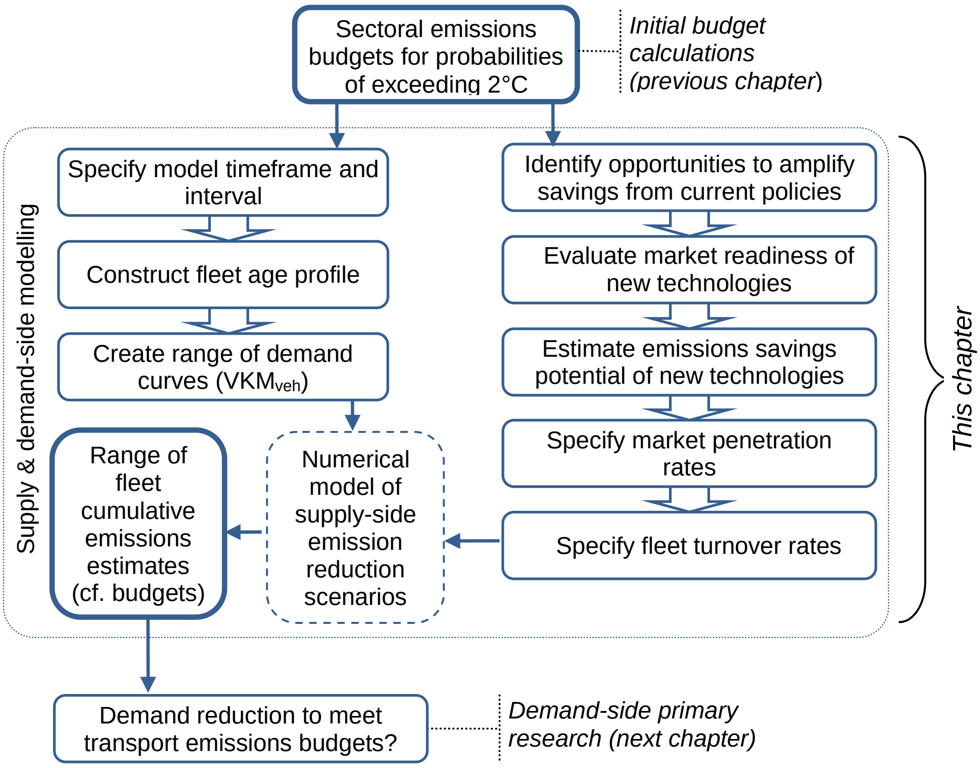


Figure 6.1: Overview of fleet model design

6.2.2.1 Timeframe

As observed in Chapters 2 and 5, understanding the quantity of cumulative emissions likely to be released in the next ten years is critical for determining whether the UK's longer-term emissions pathway fits with a lower than 50% probability of exceeding 2°C. While many analyses of passenger car mitigation focus on the longer term potential of technology innovations, this analysis is concerned with the possibility of rapid mitigation over the period from the present, 2012, to 2022. To allow comparison with other contemporary emissions scenarios and the UK's statutory carbon budgets, the model period is set for the fifteen years 2008 to 2022, using the most recent empirical data available from authoritative sources for the period 2008 to present (2012). Principal data sets are published at varying delays after the close of the previous year (in some cases over twelve months later), for example source category-specific emissions, vehicle licensing statistics, vehicle kilometreage road count data and so on. The lack of availability of one or more of these for 2011 effectively brings 2011 into the model period, since empirical data are absent. At time of finalising the model build, emissions statistics have not been published at sectoral level for 2011.

National statistics are published annually for key datasets, and data are available on fleet composition disaggregated to one-year vehicle age categories (by number of years since first registration). Therefore the year is the natural unit of time for this analysis, being both short enough to allow changes in fleet composition to be observed and long enough to permit meaningful changes to have occurred between one model time interval and the next. Annual decomposition also allows vehicle age to be matched directly with year of first registration, giving a clear picture of progression of vehicles of different emissions intensities working their way through the fleet.

6.2.3 Model emissions identity and basic structure

Potter (2007) relates the simple emissions identity posited by Ehrlich and Ehrlich and later Ekins *et al*:

Emissions = Population x Consumption x Technology

Adapting this for personal transport, Potter offers:

Total Emissions	=	Population	x	Car journeys per person	x	Journey length	x	Emissions per VKM

Which can be effectively reduced to:

Total Emissions	=	Population	x	Per capita driving distance	x	Emissions per VKM

As highlighted in Chapter 4, citizen, and hence driver, population growth rather than per capita driving distance is expected to be the principal driver of growth in total vehicle kilometres, if indeed a return to pre-recession growth occurs in the near future. Per capita driving distance has been in decline in the UK since 2001, while total vehicle-kilometres has continued to increase, in line with growth in the total number of vehicles in the fleet (i.e. the *vehicle* population, or fleet). While fleet growth is itself partly a product of growth in the UK licence holding population, it has in recent decades also been strongly driven by the increase in second car ownership and the downward trend in mean household size. The array of complex and highly uncertain relationships between the many socio-economic and demographic influences on car ownership and use may or may not continue to hold in future. To circumvent this uncertainty, this analysis therefore expresses the relationship between the *vehicle* numbers (fleet) and emissions directly (while acknowledging, and later discussing, the central importance of driver population, population growth and per capita driving distance):

Total Emissions	=	Total number of vehicles in fleet	x	Per vehicle driving distance (VKM_{veh})	x	Emissions per VKM

However, this fleet level identity effectively aggregates variations between vehicle age categories. Vehicle age (or 'vintage') is closely correlated with vehicle–fuel carbon efficiency and annual usage. Therefore, more detail may be derived by decomposition of emissions by vehicle age:

Total annual emissions = Sum:

Number of cars <1 year old	x	Mean annual distance by cars <1 year old	x	Mean emissions per km of cars <1 year old
Number of cars 1–2 years old	x	Mean annual distance by cars 1–2 years old	x	Mean emissions per km of cars 1–2 years old
Number of cars *n to n+1* years old	x	Mean annual distance by cars *n to n+1* years years old	x	Mean emissions per km of cars *n* to *n+1* years old
Number of cars 16 years and older	x	Mean annual distance by cars 16 years and older	x	Mean emissions per km of cars 16 years and older

At its simplest level, this is the essential structure of the MS Excel-based fleet emissions model constructed and specified for this research. The principal advantages of this approach are:

i. the mitigation potential of improving technology can be estimated by varying the rate at which new cars (<1 year old) penetrate the fleet; and
ii. the mitigation potential of changes to all key parameters can be tested separately, holding others constant, or in combination.

This identity captures the varying effects of the principal determinants of emissions from the UK car fleet in any given year, namely:

i. total vehicle kilometres travelled (VKM). In this model, mean annual distance driven per vehicle (VKM_{veh}) can be varied independently; total distance driven by the whole fleet (VKM_{fleet}), is a product of both fleet size and typical usage. This allows the effects of changing usage levels to be viewed, which affect vehicles of different ages (and therefore emissions intensity) proportionally.

ii. vehicle age profile of the stock of vehicles already in use. Cars are typically driven significantly greater distances in their first few years of registration than in later years.
iii. mean vehicle–fuel carbon intensity of cars in use by age, expressed as grams CO_2 per kilometre (gCO_2/km). Cars in newer age categories have lower mean emissions per kilometre than older vehicles first registered under less demanding emissions control standards.
iv. number of new additions to fleet. This gives the maximum rate at which new technology can penetrate into the fleet in a given year.
v. number of vehicles retired from the fleet from each age category. In combination with new additions, this determines both the rate of growth (or contraction) of the fleet, as well as the rate of turnover.
vi. mean vehicle–fuel carbon intensity of new vehicle registrations.

Several of these factors are themselves the product of a number of other more complex determinants. For example, total vehicle kilometres travelled is affected by fuel prices, national economic prosperity and household disposable income levels, congestion, weather, relative prices of public transport modes, amongst other things. Mean vehicle–fuel carbon intensity from cars in use is an approximation of the highly variable and usage-dependent efficiency and emissions of millions of individual vehicles. For any given vehicle, fuel efficiency and emissions values are dynamic, changing according to speed, steadiness of speed, stop rate, road conditions, driving style, occupancy (and other loading factors), use of auxiliary systems (such as heating and aircon) and condition of key components (especially engine and transmission (powertrain) and tyres). The number of new additions to the fleet will be affected by national economic prosperity, interest rates, scrappage schemes and other financial inducements, company car taxation structure and number of new drivers and household car ownership trends.

The complex interplay of the underlying contributory factors above was the subject of the review of literature on supply-side and demand-side issues in Chapters 3 and 4. Qualitative assessment in those chapters of available measures and interventions that could feasibly be applied within the next decade are synthesised and brought to bear in constituting quantitative model ‘scenario runs’ in this stage of the research. As such, scenarios include varying rates of vehicle emissions factors consistent with the scientific literature on potential vehicle–fuel efficiency improvements over the next decade. Particular technology types are not specified within the model. Rather, scientifically robust values for mean new car emissions for each future year are selected by user input and the mitigation potential quantified, either holding all else equal or in combination with alterations to other fleet parameters. In this sense the model is what is sometimes referred to as ‘technology neutral’, in that it does not depend on or specify a particular course of technological development to deliver the emissions values used (Sanden and Azar 2005).

Similarly, levels of demand, expressed as per vehicle annual driving distance, are varied in the modelled scenarios (presented in Chapter 8, results). The importance of the many socio-technical, political and economic factors that influence the introduction of lower-emissions vehicles to the fleet, and the socio–economic, geographical, cultural and other structural aspects of demand for car travel are recognised. However, attempting to precisely quantify their complex influence is beyond the scope of the emissions modelling exercise undertaken here. Baseline values for the core fleet emissions parameters listed above are selected to accurately reflect appropriate real world data, without attempting to model the individual drivers of each element. This is a pragmatic approach – quantification of contributory factors is in many cases subject to large potential error, making predictions vague at best, dangerously misleading at worst. In preference to highly problematic predictions or attempts at futile precision, the approach taken here is to adopt a transparent set of assumptions, which can be readily evaluated and alternatives tested. Moreover, as raised in §3.1.1, under a mitigation schedule of unprecedented rates of change, the types of econometric model commonly deployed to estimate the contributory effects of underlying variables are without basis in historical data or evidence for the rates of non-marginal change sought here.

6.3 Main parameters – data sources and uncertainties

6.3.1 Fleet size and composition

The DfT's annual Transport Statistics Great Britain (TSGB) table VEH0211 includes a detailed breakdown of numbers of vehicles registered by year of first registration (DfT 2011f). The most recent version available at time of final preparation of this thesis in February 2012 was last updated by the DfT in June 2011. Numbers of cars on the road in each year 1994–2010 are given by year of their first registration, going back to 1970 (with two further categories, 'pre-1970' and 'unknown'), based on data collected by the DVLA.

During analysis of these data it became apparent that in several cases the number of vehicles given as first registered in a particular year appeared to have increased by the following year (i.e. more cars first registered in year *x* at the end of year *x*+1 than at the end of year *x*). This was queried with the DfT's vehicle licensing statisticians, who after undertaking further investigation subsequently offered the following by way of explanation:

> "Dealers often have end of calendar year targets to hit in terms of car sales from their manufacturers. In order to hit these (or exceed them), it is not unusual for dealers to pre-register cars towards the end of the year. In practice, this means that they buy new cars from the manufacturers, put them on SORN [statutory off road notice] immediately, and then sell them as “nearly new” at a discounted price. ...They cannot resell them for a minimum of... 3 months, so it is likely that they

> stagger the purchase of the vehicles over the last few months of the year so they can then let them trickle out between January and March (ahead of the new registration plates in April)". (DfT 2012b)

The largest of these discrepancies occurs in 2008, when a total of 68,000 vehicles that were not registered in 2007 'appear' in the fleet. However, since this represents less than a quarter of one percent of total vehicles registered in that year, it was decided that these discrepancies were of no practical consequence in terms of skewing the age profile of the fleet and no further action was considered necessary to correct them.

Similar data on vehicles by year of first registration for the Northern Ireland car fleet were obtained from the Department for Regional Development Northern Ireland's (DRDNI) annual Northern Ireland Transport Statistics publications. Data for cars on the road in Northern Ireland in 1995–1999, 2000–2004, 2005–2007 and for 2007–2010 were obtained from DRDNI (2000; 2005; 2008; 2012) respectively. The DRDNI data are for the vehicle tax group 'private and light goods' (PLG) rather than cars only, thus include light goods vehicles registered before March 2001 (those registered after this time fall into a separate tax class). The DRDNI reports also present tables of vehicles currently licensed by body type, e.g. Table 1.7 in DRDNI (2012). Using these values for total licensed cars, the mean percentage 2006–2010 of PLG vehicles in Northern Ireland made up by cars is thus estimated at 98.7%. This share was then applied to the rolling cumulative PLG totals for each year since first registration, which were then separated out into discrete one-year age-bins, comparable to those in the statistical releases for Great Britain, by subtracting total registrations for each age category from registrations up to and including the previous year. The Northern Ireland data were then transposed into a matrix of similar structure to TSGB VEH211, covering licensing years 1995–2010 (Appendix 2), allowing values from both matrices to be summed to give the total number of cars by year of first registration for the whole of the UK for 1995–2010 (Appendix 3).

6.3.2 Vehicle retirement rate

The retirement rate, sometimes expressed as its inverse, the survival rate, represents the removal of vehicles from use between one vehicle age category and the next. Retirement occurs in all age categories, visible from second year of registration onwards, although in younger age categories (second and third year of registration) the rate is typically less than 1%, largely attributed to accidents and thefts. As vehicles age, increasingly they are scrapped once no longer mechanically sound or cost-effective for their owners to repair, giving retirement rates of 5–7% for cars in their tenth year of registration, rising steeply thereafter to 25–32% for cars of fifteen years and older (see Figure 6.2). These rates, derived from the vehicle licensing data compiled by the DfT and DRDNI, show some variation over the last decade. 2006 shows the highest rate of retirement for the majority of vehicle age categories, while 2010 had the lowest rates across nearly all age categories; recession conditions apparently discouraging new car purchases and prolonging the working life of vehicles already in use.

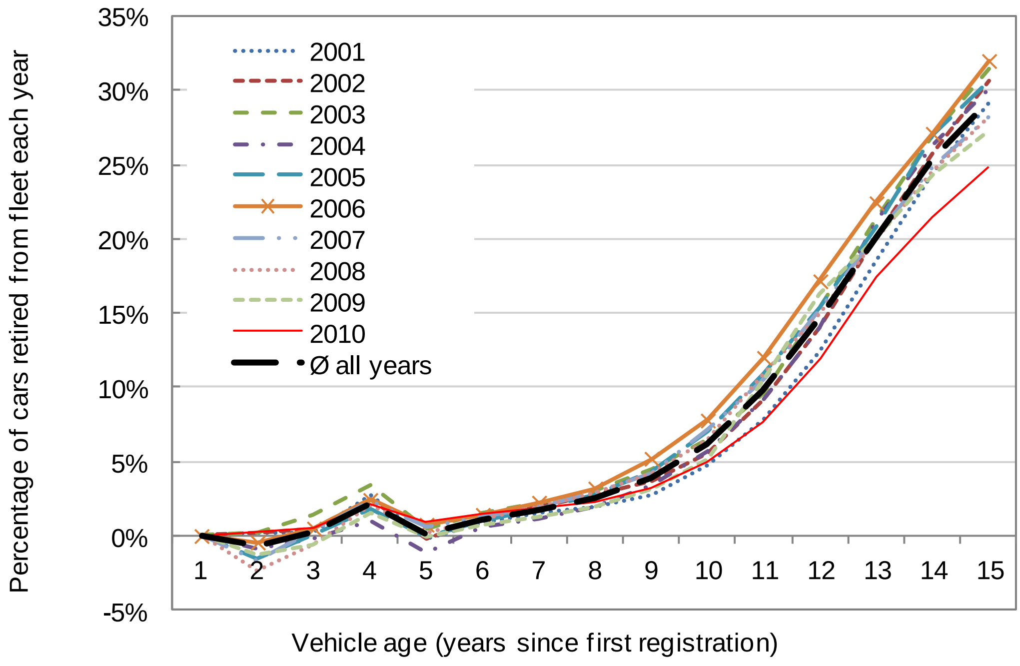


Figure 6.2: Annual retirement rates for the UK car fleet 2001–2010 (source DfT vehicle licensing statistics and DRDNI transport statistics).

Cases where negative rates of retirement are displayed in Figure 6.2 (i.e. where the curve drops below the x-axis) are believed to be where vehicles have been bought and immediately declared off road by dealers who have withheld them for later release into the market (see §6.3.1 above). Raw data of all retirement rates for each vehicle age category in each year from 2001 to 2010 are available in Appendix 4.

For the purposes of selecting appropriate retirement curves to use prospectively in the fleet emissions model, it was assumed that negative rates of retirement do not occur in future years. Four alternative rates of retirement were sought from the historical data for use in the fleet model for future years, to serve as base rates that could then be proportionally increased or decreased to observe the influence of this model parameter on rates of penetration of new vehicles. To accomplish this, the 2006 and 2010 curves were smoothed to remove discrepant values and produce a progressively increasing rate of retirement during the first seven years of registration, after which point the actual historical values were used directly. A third hypothetical curve was also created to represent a high rate of fleet turnover, with similar low rates of retirement as 2006 and 2010 curves for the first six years of registration, progressively diverging thereafter towards a 50% rate of retirement for vehicles fifteen years and older. The fourth curve represents an intermediate rate of retirement, based on the smoothed 2006 and 2010 curves for years 1–5, then the mean of historical values (2000–2010) thereafter. The four modelled alternative retirement rate curves are show in Figure 6.3 below.

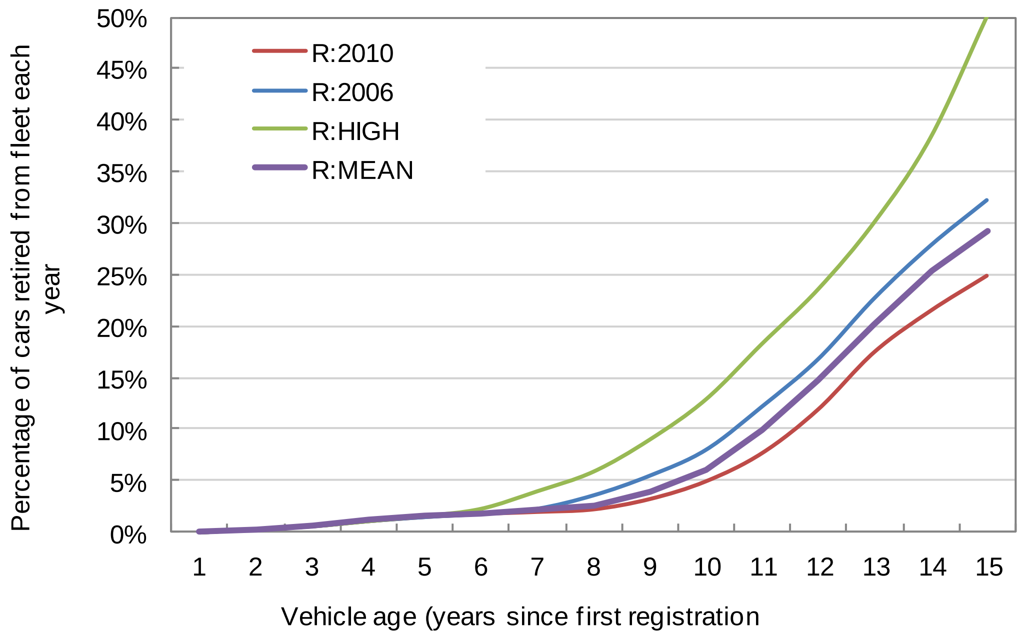


Figure 6.3: Alternative retirement rate curves for prospective use in fleet emissions model, based on 2006 and 2010 historical curves, a hypothetical enhanced (high) rate of turnover, and an intermediate based on 2005/2010 smoothed curve for ages categories 1–5 (then the arithmetic mean of historical values 2000–2010).

6.3.3 Fleet profile and penetration rate

Taken together, fleet composition in any given year (with implied retirement rate) can be construed as a 'fleet profile', a snapshot or 'cross-section' of the numbers and proportional share of vehicles already in use along with the number of cars registered for the first time that year (new car purchases, also referred to as new additions to the fleet). New additions represent the rate at which new technology penetrates into the fleet, and have shown consistent growth until 2002, although remaining high through the middle of the last decade. Higher rates of new additions were driven by rising household disposable incomes (with a corresponding steady increase the proportion of households owning more than one car) and increasing capacity of the road network. Peaking at almost 2.6 million in 2002, new additions have since declined to around 1.95 million in 2010. Figure 6.4 shows the historical trend of new additions (vehicle age one year since first registration in the chart) alongside trends within each vehicle age category.

Figure 6.5 (page 162) shows the same data as a line plot, which gives a different perspective on the dynamic profile of the fleet, as well as trends in the varying proportions and effect of the vehicle population in one age category on that of the next. More than simple commentary on fleet composition, this has implications for modelling the future fleet. Most significantly, it highlights the likely effects of the recent economic downturn on new additions to the fleet; that is, a decline in total fleet size is likely unless new additions make an unprecedentedly strong recovery with almost immediate effect. Even should the rate of vehicle retirement decline still further than its current low, without an uptick in car purchasing, inevitable attrition due to wear and tear, mechanical failure and accidents means that the fleet will contract. This suggests that the current fleet size is unsustainable, being the result of previously much higher rates of new additions, which were in step with higher rates of retirement. The recent low rates of new additions and retirement are consistent with an equilibrium fleet size which is smaller than at present.

Fleet size, growth vs. equilibrium, along with other key assumptions underpinning the scenarios constructed in the model are described in §6.4.2 below.

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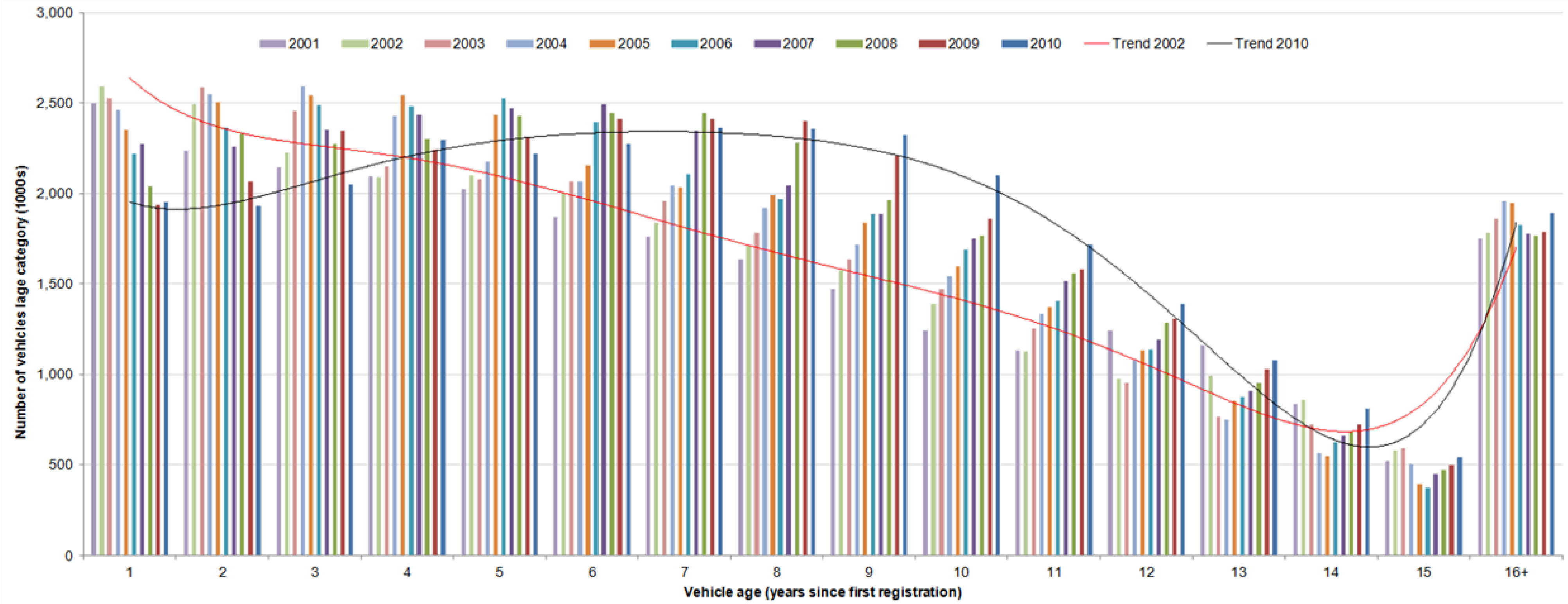

Figure 6.4: Historical trends in UK car fleet by vehicle age category. Source DfT vehicle licensing statistics and DRDNI transport statistics). Trendlines shown for illustrative purposes only – the convex shape of the 2010 curve (in black) denotes:

a. a much reduced rate of vehicle retirement across intermediate and older vehicle age categories in 2010 compared to previous years;

b. the influence of previously much higher rates of new additions during the mid-2000s gradually 'trickling down' through the fleet profile, as intermediate-aged vehicles come to the fore in terms of proportion of the total fleet.

Also of note:

- pronounced drop off in new additions year by year
- remarkably little variation in numbers in the unbounded age category (sixteen years and older) in comparison to all other age categories.

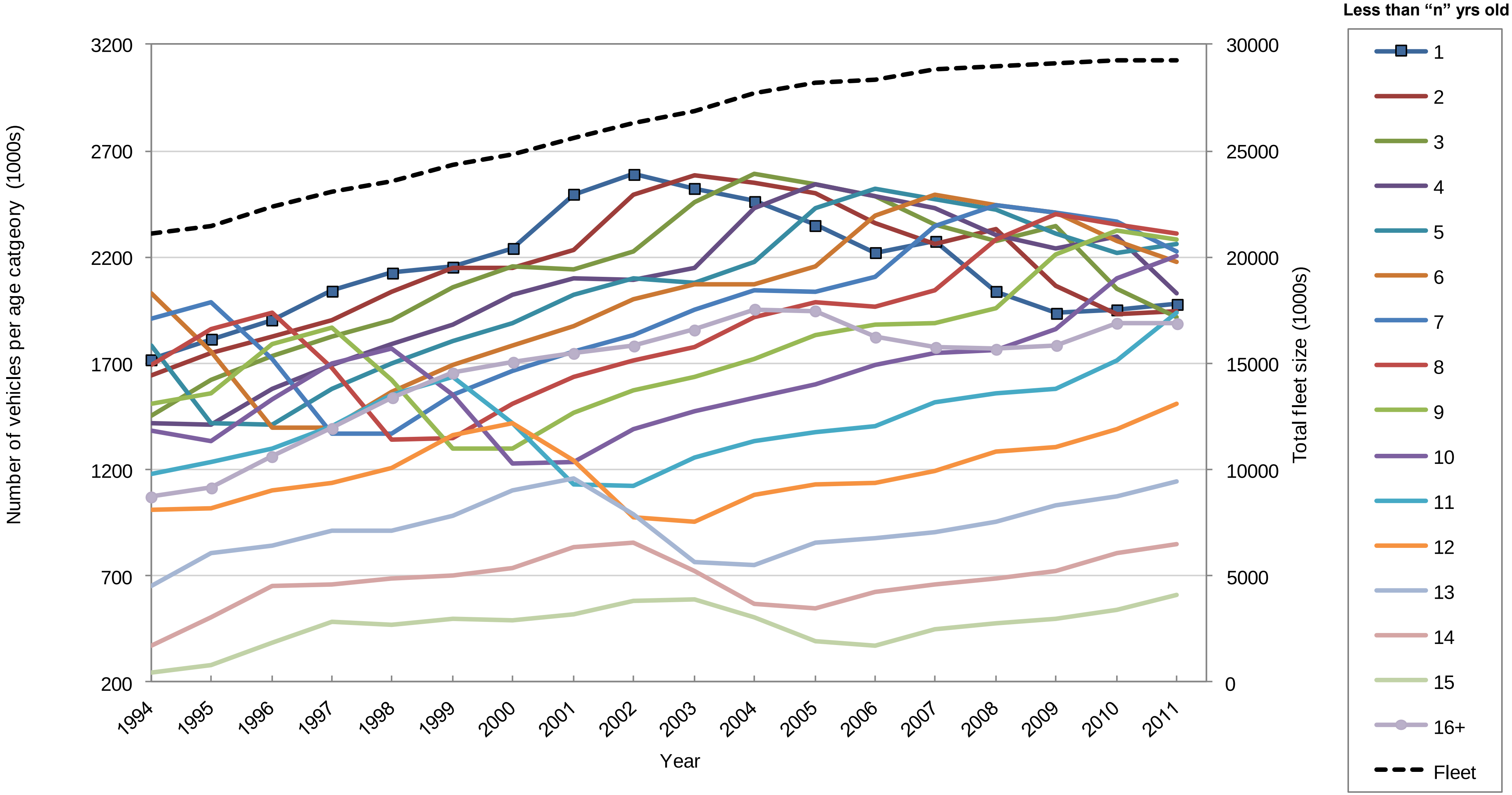

Figure 6.5: Changes in fleet profile by age of vehicle (less than 1 year to 16+) since 1994. Note the peak in new additions (cars less than one year old) in 2002, and the slowdown in growth of overall fleet size from 2004. (Data source: as Figure 6.4).

6.3.4 Typical kilometres travelled per vehicle each year

Cars are not used uniformly throughout their lifespan, with annual driving distances tending to be higher during the early years of a car's use. Although widely observed anecdotally, reliable and consistent data applicable to the UK could not be identified amongst published datasets. 'Age proportionate' per vehicle mean annual driving distance values were provided on request by the DfT, who derived estimates from traffic count and vehicle licensing data sets averaged over several years to produce sufficient sample sizes and reliable estimates. Age proportionate VKM values were thus obtained for four separate periods to reflect the range of demand observed over the last decade (Figure 6.6).

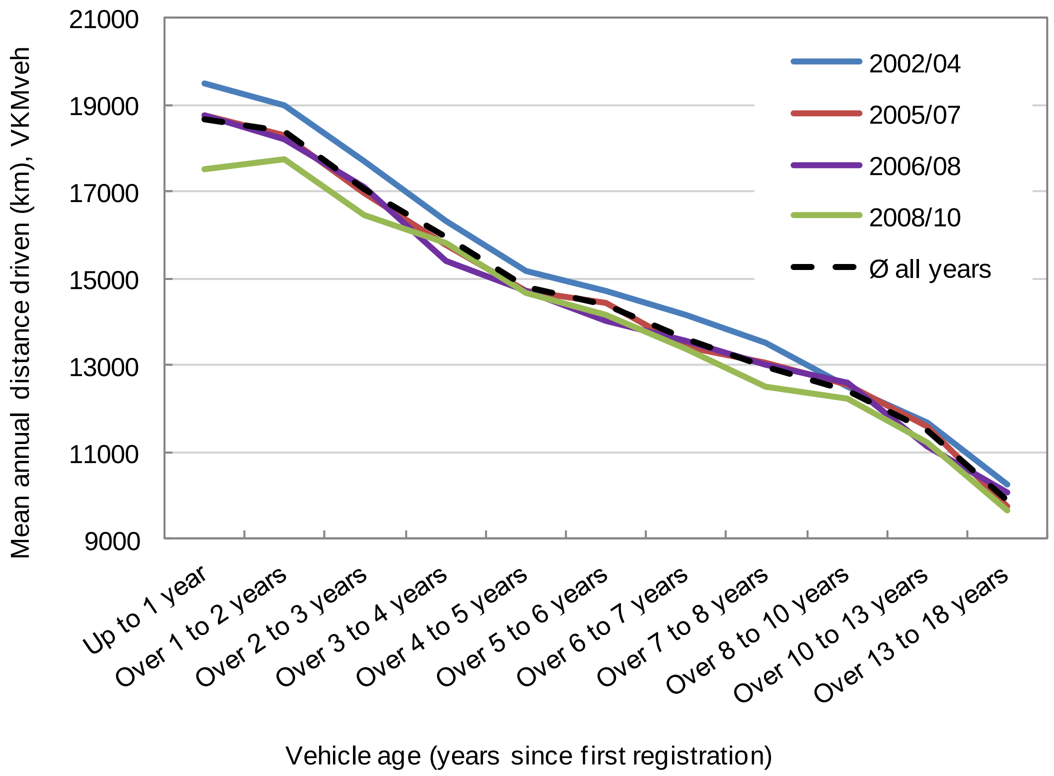

Figure 6.6: Age proportionate mean annual vehicle kilometres travelled (VKM_{veh}). Data source DfT vehicle licensing statistics department. Ø is mean of all years.

First, pre-recession conditions corresponding with historically high per capita driving distances were calculated from 2002–2004 data (representing a relatively high per vehicle annual distance). Second, declining per capita driving distances reflected in the mid-decade period 2005–2007 and then immediately pre-recession 2006–2008 were obtained. Third, the most recent data available were obtained for recession conditions, based on 2008–2010 traffic counts. The latter represents a relatively low per vehicle mileage, corresponding with significantly reduced per capita driving distances compared to those observed at the turn of the century. Mean values for age proportionate per vehicle driving distances for all years 2000–2010 were also obtained, which represent an intermediate medium per vehicle mileage (mean values for all years in fact turned out to be very close to the 2005–2007 and 2006–08 values, see Figure 6.6).

In order to produce adequate sample sizes, older vehicle age categories are grouped, so whereas typical mileages are available for discrete one-year age categories (or bins) up to and including 10 years old, older vehicles are grouped into increasingly broader categories. To estimate a proportionate driving distance for discrete one-year bins in the older vintages, a second-order polynomial regression curve[105] was fitted to each data set (2002–2004, 2005–2007, 2006–2008, 2008–2010 and the mean of all years, noted as Ø in charts and tables), and the respective equations used to interpolate values for intermediate age categories. Raw VKM_{veh} data, interpolated values and regression curve plots are available in Appendix 5. Figure 6.7 shows the interpolated values used as the base curves for age proportionate annual vehicle driving distance in the fleet emissions model.

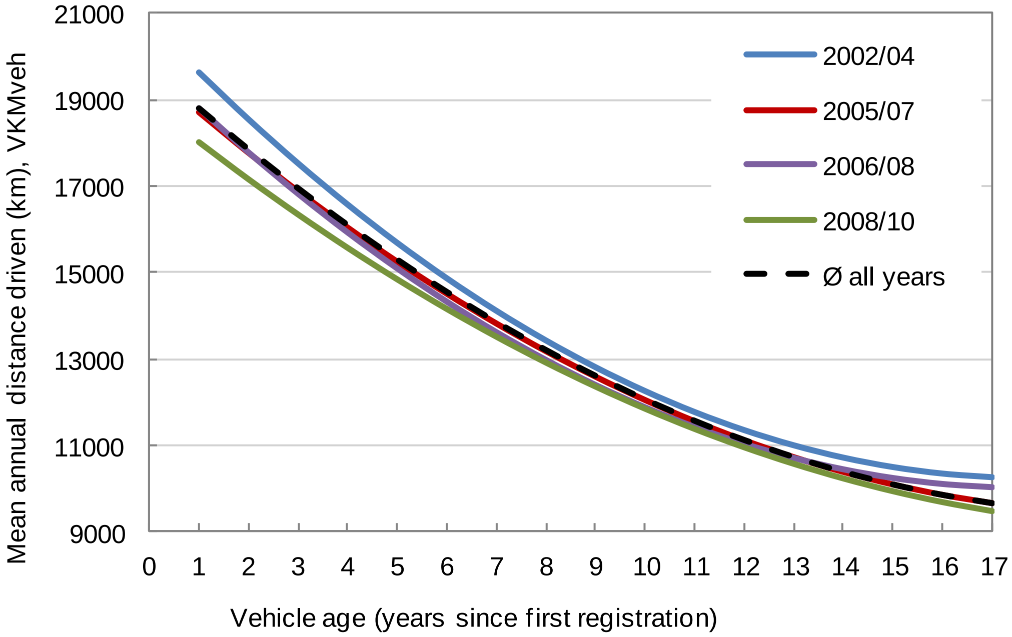

Figure 6.7: Interpolated values for age proportionate mean annual driving distance for five separate historical datasets. Data source: (DfT 2011c).

A preliminary observation about the raw data plotted in Figure 6.6: the most recent mean distance curve (2008–2010) shows lower annual VKM_{veh} for cars less than one year old than for two year old cars (difference of 234 km p.a.). Since no such pattern is evident in any other time period sampled, this is treated as an anomaly thought likely to be the result of suppressant effects on driving distance during the economic downturn from 2007–8 onwards. Hence the interpolated values assume VKM_{veh} declines with age from the year of first registration, as appears to be the case from data collected for all recent periods except 2008–2010.

[105] A second order polynomial curve fit the data better than linear or other curves, returning an appreciably higher R^2 value.

Note also that the final age category is open-ended, including cars of sixteen years and older. Since available data do not capture further variation within this unbounded age group, for practical purposes all vehicles of sixteen years and older are assumed to be driven the same distance annually (age proportionate mean for all years is 9,644 km or just under 6,000 miles).

6.3.5 Total vehicle kilometres travelled in the UK

As noted above, the total quantity of vehicle kilometres travelled in the UK (VKM_{fleet}) is a product of per vehicle driving distance and number of vehicles in the fleet. Historical data on estimated total kilometres driven in Great Britain are available from the DfT's annual road traffic statistics series. As with the vehicle licensing statistics, these data do not include Northern Ireland (N.I.), so in this analysis GB values are scaled to UK level to account for the Northern Irish citizen population as a share of GB citizen population (2.98% of GB in 2009). Other analyses (e.g. the Committee on Climate Change, 2011) use a similar approach, but use a slightly higher estimate of N.I. population share (4% (CCC 2012)). As such, the approach here uses a comparatively conservative estimate of VKM travelled in Northern Ireland[106]. However, the outcome of the small difference between these N.I. scaling factors is likely to be negligible, since N.I. represents such a small proportion of total UK citizen population. Figure 6.8 shows the historical trend in total fleet distance travelled, which has declined during the recession from a peak of 410 billion vehicle kilometres in 2007 to 397 billion VKM in 2010.

[106] It seems unlikely that per vehicle distances in N.I. would be greater than in GB, since levels of car ownership are similar, at 1.16 per household in N.I (DRDNI 2009) compared to 1.14 per household in GB (DfT 2011b: NTS9902). It is arguably more likely that distance per vehicle is less in N.I. than in GB, since the national territory is geographically smaller; emissions from trans-boundary journeys into the Republic of Ireland are not at present attributable to the UK's inventory. Northern Ireland transport statistics are presently being collated and integrated with the DfT's GB data to give whole UK coverage, but were not available at time of writing. Requests made directly to DRDNI for assistance with actual road counts or official estimates of VKM in N.I. went unanswered.

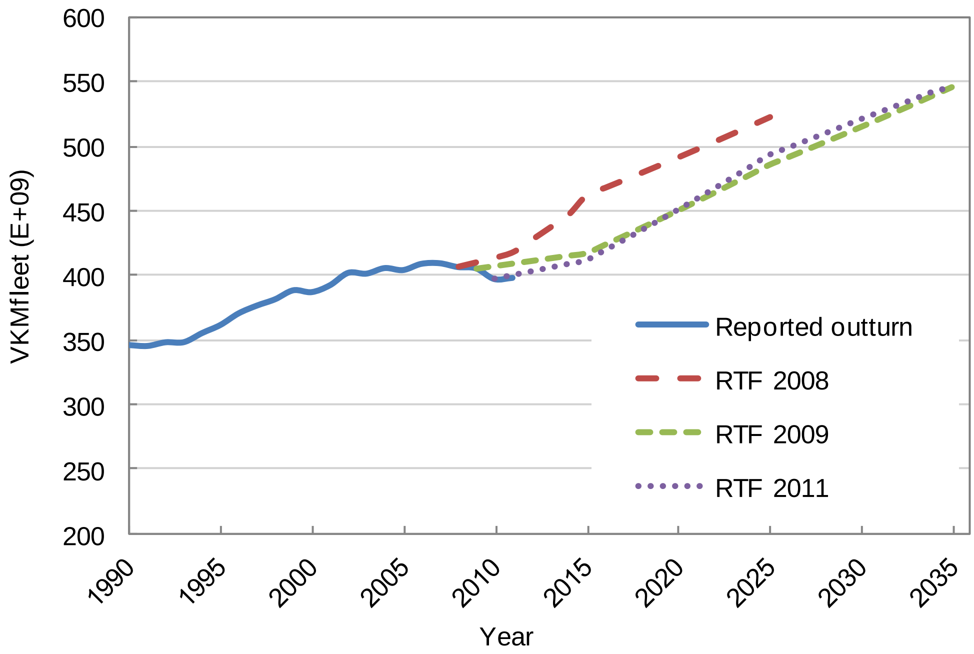

Figure 6.8: Total distance travelled by UK cars by year. RTF series are the DfT's Road Transport Forecasts released each year. Source: DfT traffic statistics and RTF reports.

The three years of falling total demand for passenger car travel 2008–10 are without precedent in the history of popular motoring. 2011 shows a very similar albeit minutely higher volume of traffic than 2010. However, as can be seen from the DfT's Road Transport Forecasts also shown on Figure 6.8, the expectation is for future growth in total traffic volumes, driven predominantly by growth in the UK driver population. §6.5 sets out the selection of model input values for demand growth.

6.3.6 CO_2 emissions per vehicle kilometre

Central to estimates of future sectoral emissions is the extent to which a reduction is assumed in the mean emissions per kilometre of new cars entering the fleet. 'Official' mean emissions values for gCO_2/km values for new cars are based on the NEDC test cycle during the type approval of manufacturers' new models, not on real world driving styles or conditions. It is widely accepted that type approval CO_2 data are not a reliable guide of ultimate exhaust emissions from on-road use (see Chapter 3) – Defra's guidance on estimating company CO_2 emissions recommend an uplift of +15% over the manufacturer-claimed type approval (TA) emissions values of cars in use (Defra 2011). In constructing the fleet model for this analysis, historical mean emissions data for new vehicles for each year 1994–2007 are taken from the Transport Research Laboratory (Boulter *et al* 2009c). The TRL series closely resembles that published by the Society of Motor Manufacturers and Traders in their annual new car CO_2 report (SMMT 2011a), from where mean new car emissions values for 2008–2010 are taken. The complete historical series of mean new car CO_2 emissions is shown in Figure 6.9.

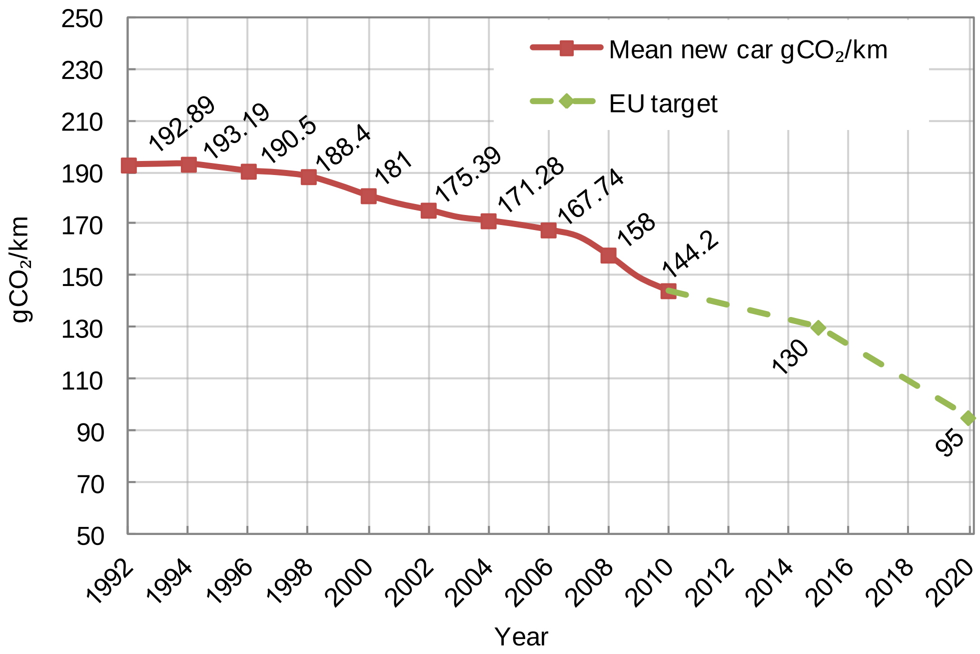

Figure 6.9: ‘Official’ historical mean new car CO_2 emissions per kilometre, based on type approval data (values for even years only shown as data points). Source: TRL and SMMT.

§6.4 on model calibration and validation describes how these values were treated, and gives details of assumptions about future compliance with type approval.

6.3.7 Total annual emissions from the passenger car sector

The product of all foregoing parameters, total annual passenger car sector emissions are estimated by a fleet model on behalf of the UK Department of Energy and Climate Change by AEA Technology, published (as the National Atmospheric Emissions Inventory) by source category as described in Chapter 4. The AEA methodology makes a bottom-up estimate of fuel use by cars (and all other road transport) which is then normalised with total fuel sales data recorded in the DECC's Digest of UK Energy Statistics (DUKES)[107]. Fuel sales do not discriminate between the various types of vehicle for which emissions must be estimated – although petrol sales are predominantly attributable to cars[108], diesel vehicles include cars, LGVs, HGVs, buses, etc. Therefore fuel consumption estimates for each vehicle type are adjusted to ensure they sum to total road fuel sales. Bottom-up fuel use estimates for cars are based on average speed related fuel consumption factors, along with data on fleet composition and total distance travelled on roads of different typical driving speeds. In 2008 AEA updated the inventory method making a number of methodological changes as well as new emissions factors (gCO_2/km), noting:

[107] As per UNFCCC stipulation that reported CO_2 for national communication categories is based on fuel sales.

[108] Motorcycles consume <2% of total petrol. Taxis are included as cars.

> "For CO_2, these changes have only affected the distribution of fuel consumption and hence CO_2 emissions between vehicle types, but the total CO_2 emissions from road transport in all years remains unchanged, because these are based on the total fuel consumption figures reported in DUKES" (NAEI 2012: p.404).

A summary of the key aspects of the normalisation process as stated by AEA is quoted in Box 6.1 below. In the same report, AEA describe how, "The important equations relating fuel consumption to average speed were updated and are based on the new fuel consumption-speed relationships for detailed categories of vehicles compiled by TRL on behalf of DfT" (NAEI 2012: p.405), stating further that, "The TRL equations were derived from their large database of emission measurements compiled from different sources covering different vehicle types and drive cycles. The measurements were made on dynamometer test facilities under simulated real-world drive cycles" (NAEI 2012: p.406). However, the detailed TRL reports on the revisions made to speed-scaled average fuel consumption and emissions factors make clear that for new vehicles they were instructed to use standardised NEDC, type approval based emissions factors, which are based on drive cycles which poorly reflect real world conditions, and consequent emissions.

Reporting on TRL's work on generating emissions factors, Boulter *et al* state: "For most categories of petrol and diesel car the CO_2 emission functions which were derived ... showed little or no difference between all Euro categories" (2009b: p.42), indicating that no reduction in CO_2 was detectable during the period from the implementation of the first European standard for pollutant emissions in the mid-1990s to the then most recent standard (Euro 4: this came into force in 2006). The same TRL report states that, in spite of this finding,

> "However, type approval data for new cars, and publications by the European Commission and car manufacturers, indicate that new car CO_2 emissions are decreasing with time. Consequently, and again at the request of the DfT, an alternative approach to generating CO_2 emission functions was used, which took into account the reduction in emissions from new cars. The validity of this approach should be tested once more emission data for Euro 5 and Euro 6 technologies become available."(Boulter *et al* 2009b: ibid)

The alternative approach used was wholesale adoption of the type approval CO_2 values (as shown in Figure 6.9) for new cars from 2008 onwards, as requested by DfT economists (TRL 2012). In a subsequent report Boulter *et al* (2009c) suggest that:

> "The principal reason for basing the CO_2 functions primarily on the type approval data was that the sample size was much larger than in the database of measurements over real-world driving cycles. Whilst at one level this is clearly not consistent with the approach used for other pollutants, whereby type approval data are rejected, it could be argued with some justification that CO_2 is less susceptible to differences between real-world cycles and the NEDC than other pollutants".

However, the idea that CO_2 is less susceptible to differences between the type approval test cycle and real world driving is repeatedly and directly contradicted throughout the series of TRL emissions factors reports, for example:

> “It should be noted that the CO_2 data which form the basis of these [NEDC] calculations do not fully reflect real-world vehicle operation. For example, real-world CO_2 emissions are affected by a number of factors, including the use of auxiliaries (headlights, radios, air conditioning, etc.), the prevalence of ‘eco-driving’ and level of maintenance. In fact, for cars a combined ‘uplift’ factor of +15% on NEDC-based CO_2 emission factors has been agreed between DfT and DEFRA to take into account the various real-world effects (DEFRA, 2007)[109]. Otherwise, models are available to allow factors such as air conditioning to be taken into account." (Boulter *et al* 2009c: p.40).

[109] Since superseded by (Defra 2011)

Box 6.1: Top-down normalisation of road fuel consumption estimates (NAEI 2012: pp.409-410)

The normalisation process introduces uncertainties into the fuel consumption and hence CO_2 emission estimates for individual vehicle classes even though the totals for road transport are known with high accuracy.

For petrol, the fuel consumption calculated for each vehicle type consuming petrol is scaled up or down by the same proportion to make the total petrol consumption align with DUKES. So for example, the fuel consumption estimated for petrol cars, LGVs and motorcycles are all increased by 5% to align with fuel sales in 2008. Cars consume the vast majority of this fuel, so the DUKES figures provide a relatively accurate description of the trends in fuel consumption and CO_2 emissions by petrol cars. A small residual is consumed by petrol LGVs and motorcycles, so their estimates are susceptible to fairly high levels of uncertainty introduced by the normalisation process.

For diesel, a number of different vehicle classes (cars, LGVs, HGVs and buses) all consume similar amounts of fuel. Either the fuel consumption for all diesel vehicles can be scaled to align with DUKES, as carried out for petrol normalisation, or that for specific vehicle types can be adjusted to bring the total in line with DUKES.

Because all vehicle types make a similar contribution to diesel consumption, adjusting the calculated figures for all vehicle types by scaling can lead to distorted trends in the figures for specific vehicle types over a time-series. After discussions with officials at DfT, it was decided to retain the consumption for cars, LGVs and buses at the values calculated by the bottom-up approach and use HGVs to “carry the burden” of bringing the total diesel consumption in line with DUKES

6.3.7.1 Treatment of historical emissions data

There is an evident lack of clarity with respect to the most appropriate emissions factors upon which to base estimates of passenger car sector emissions. There is also clearly a certain leeway in attributing emissions based on road fuel sales to individual vehicle categories. As such, it must be recognised that the historical emissions data published for the passenger car sector are ‘best estimates’; estimates which are revised over time as methodologies are updated and benchmarks redefined. With this in mind, the starting position of this approach is to cautiously adopt the values for historical car sector emissions, with an eye on where such estimates may deviate from real world conditions.

6.4 Model calibration and validation

Figure 6.10 gives an illustrative overview of the basic model elements and structure.

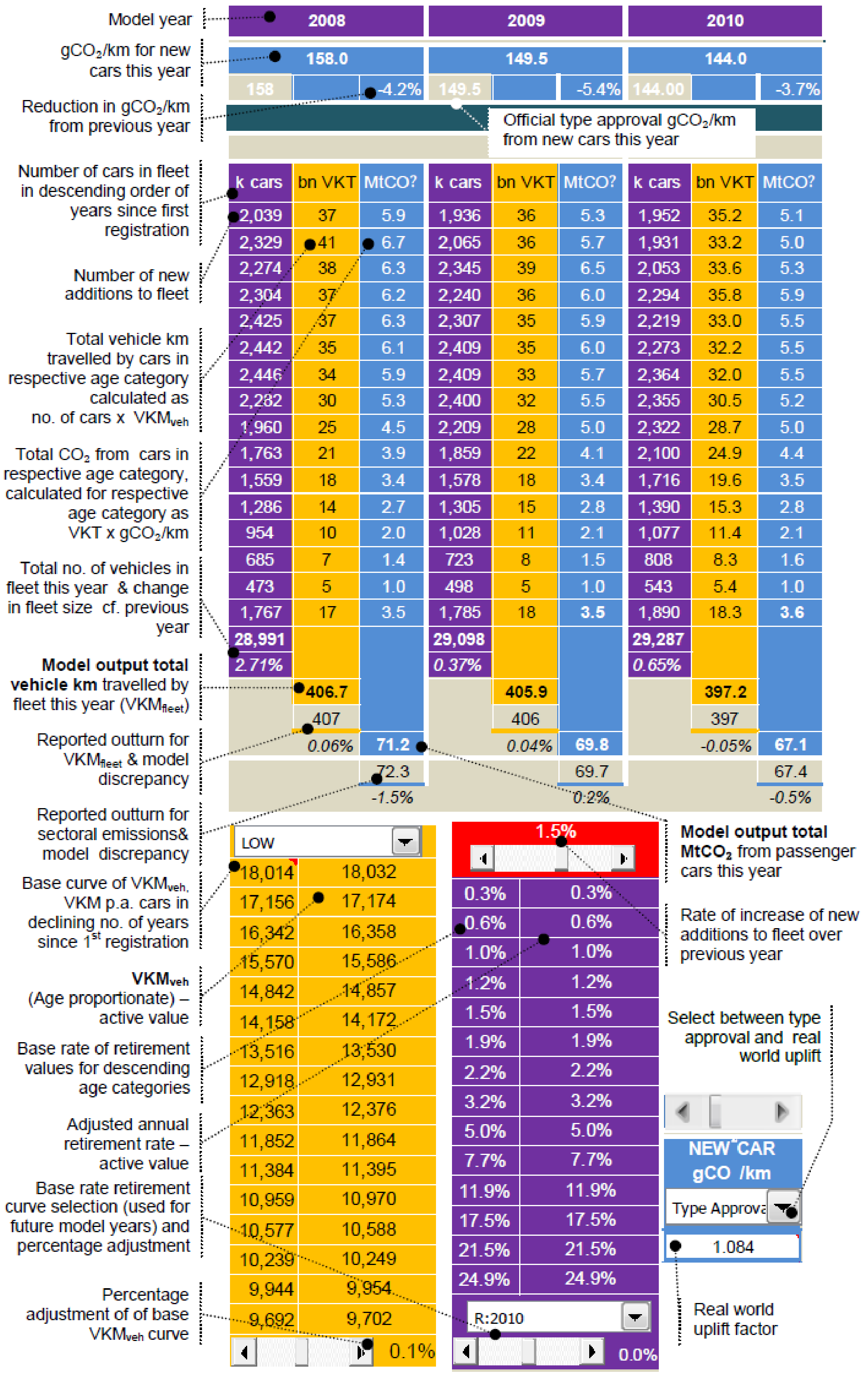

Figure 6.10: Principal model elements (illustration only)

6.4.1 Model calibration

In order to ascertain how well the constructed model represents reported historical values for annual fleet vehicle kilometres travelled and fleet CO_2 emissions, default values for gCO_2/km of new cars entering the fleet were set in the model using type approval values for the most recent three years of available data, as published by the DfT (DfT 2011g) and SMMT (SMMT 2011a). Using observed historical data on fleet composition, retirement and the age proportionate VKM_{veh} (mean 2008–2010), model outcomes closely matched reported historical values once total fleet vehicle kilometres travelled were matched by minor percentage adjustment of the age proportionate VKM_{veh}. Discrepancies between model outcomes were an underestimate of 1.7% for 2008, a 0.1% overestimate for 2009 and a 0.5% underestimate for 2010 (see Table 6.1).

The same structure, procedure and type approval gCO_2/km data series were then applied to years 2000–2008. For this time period, however, the model returned a mean 7.8% underestimate of sectoral emissions compared to the reported historical values published by DECC.

Table 6.1: Model outputs compared to reported historical values for passenger car sector emissions using type approval gCO_2/km data.

	$MtCO_2$		
Year	**Reported historical**	**Model estimate**	**Discrepancy**
2000	76.29	69.90	-8.38%
2001	76.10	70.17	-7.79%
2002	77.35	71.21	-7.93%
2003	76.01	70.22	-7.62%
2004	76.44	70.26	-8.08%
2005	75.59	69.37	-8.22%
2006	75.09	69.68	-7.20%
2007	74.53	69.12	-7.26%
2008	72.27	71.05	-1.69%
2009	69.71	69.76	0.08%
2010	67.40	67.06	-0.50%

Mean bulk emission factors for new cars in each year 1994 to present were then uplifted by 8.4% to reflect underestimate produced by applying type approval values to pre-2008 data. This brought the model estimate of annual sectoral CO_2 emissions into very close correspondence with reported emissions values, with an R^2 relationship of 0.87 (see Figure 6.11 and Figure 6.12). With an uplift of 8.4%, 2008–2010 model outputs for total CO_2 track reported emissions by an overestimate of 6.6%–8.5%, albeit also displaying a strong correlation with R^2 of 0.95 (Table 6.2 and Figure 6.12)[110].

[110] Although there is the possibility of producing a false positive correlation based on only three data, 2008–2010 (by necessity).

Table 6.2: Model outputs compared to reported historical values for passenger car sector emissions using 'real world' uplift factor of +8.4%

	$MtCO_2$		
Year	**Reported historical**	**Model estimate**	**Discrepancy**
1994	72.82	71.76	-1.45%
1995	72.03	72.93	1.24%
1996	74.86	74.34	-0.69%
1997	75.49	75.19	-0.40%
1998	74.95	75.65	0.93%
1999	76.46	76.53	0.09%
2000	76.29	75.77	-0.68%
2001	76.10	76.07	-0.04%
2002	77.35	77.19	-0.20%
2003	76.01	76.12	0.14%
2004	76.44	76.16	-0.36%
2005	75.59	75.20	-0.51%
2006	75.09	75.54	0.59%
2007	74.53	74.93	0.53%
2008	72.27	77.01	6.57%
2009	69.71	75.62	8.48%
2010	67.40	72.70	7.85%

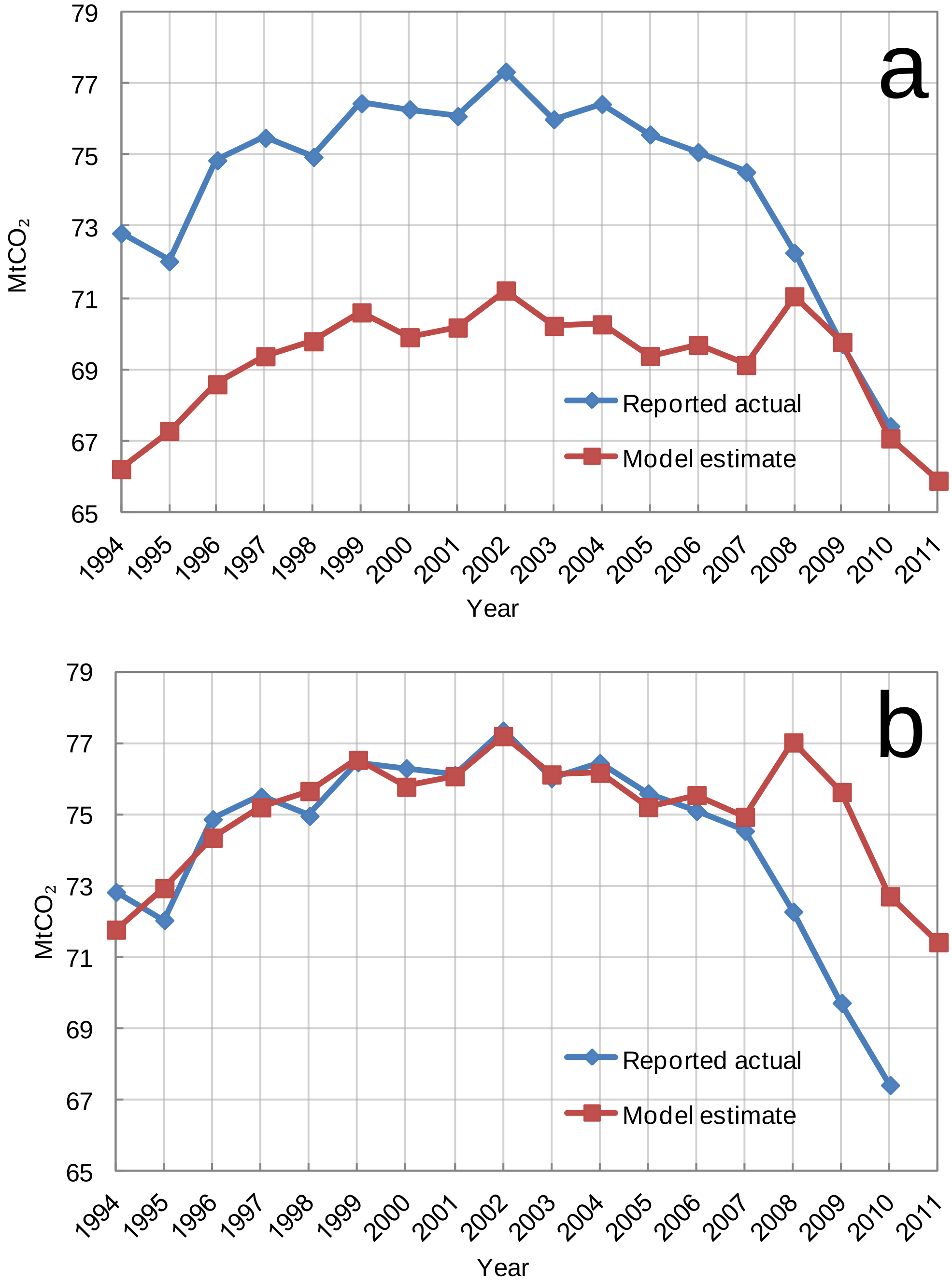

Figure 6.11: Comparison of reported historical passenger car sector CO_2 emissions against model estimates using (a) type approval values for new car bulk emissions per kilometre (gCO_2/km), and (b) type approval values uplifted by 8.4%.

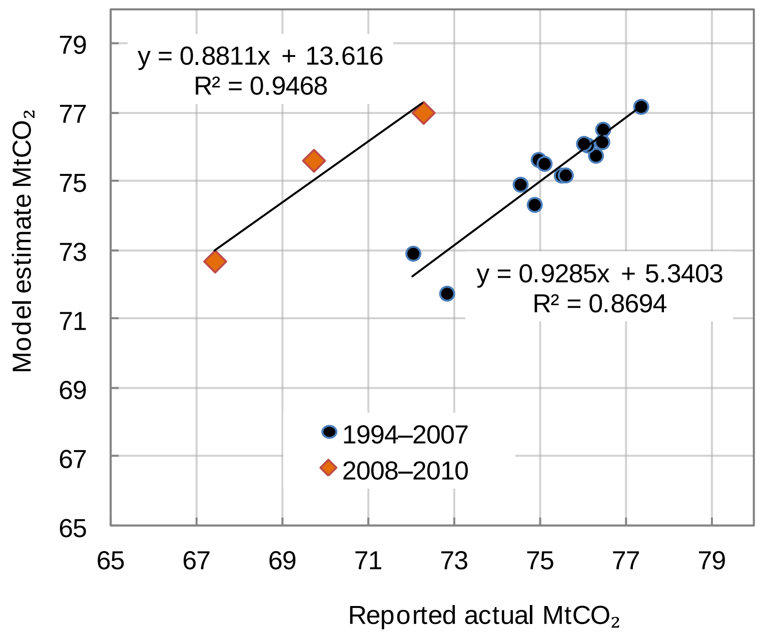

Figure 6.12: Correlation between model estimates of sectoral CO_2 and reported historical values with uplift of 8.4% over type approval bulk emissions (gCO_2/km) for new cars. Data are separated into two series to reflect the prominent divergence from 2008 onwards.

6.4.2 Parameter checking and model validation

The pronounced inflection in the trendline of modelled emissions (compared to reported historical emissions) in 2008, clearly visible in Figure 6.11, prompted much reflection, checking and rechecking of all model parameters, consultation with custodians of the original data sources and with other transport research professionals. A number of possible explanations for the sudden change in the degree of fit at 2008 were considered, including the ever-present possibility of factors outside the modelled parameters exerting an unseen influence. One such off-model parameter may be that the onset of the economic recession in 2007–8 brought about a marked change in driving styles amongst the general populace seeking to achieve greater fuel efficiency (also known as 'fuel economy'), to the extent that type approval emissions factors were effectively delivered in real world driving. While this hypothesis has a ring of plausibility to it, there is as yet no sound evidence confirming a widespread (in fact, virtually universal) adoption of eco-driving habits. Nor is there evidence that such driving techniques, even if widely adopted, could produce emissions reductions in the real world (with its congested roads, hills, overtaking etc), which so closely match expected savings under stylised legislative test cycles.

A second possible explanation is that the estimates of total vehicle kilometres travelled on UK roads is inaccurate. As noted in §6.3.5 above, the values for total UK VKM_{fleet} in the model are *derived* from *estimates* published by the DfT for Great Britain, scaled up to UK level to account for the Northern Irish population, using a scaling factor based on Northern Ireland citizen population as a percentage share of GB citizen population.

Other analyses (e.g. the CCC, 2011) use a similar approach, but use a slightly higher estimate of N.I. population share (§6.3.5). As such, the approach uses a conservative estimate of VKM travelled in Northern Ireland, but given the small percentage shares involved, the difference is incapable of explaining the discrepancy in emissions estimates. Using type approval values for new car gCO_2/km, a considerable underestimate in VKM_{fleet} would be required to explain the corresponding historical underestimate of sectoral CO_2 up to 2007. There is nothing to suggest that such an underestimate in VKM_{fleet} has occurred[111].

As well as the possibility of off-model factors exerting an unseen influence, there is also the possibility that model assumptions are mistaken or inappropriately applied. For instance, the model estimates total vehicle kilometres in a bottom-up fashion, by multiplying the number of vehicles in each one-year age-bin by the mean driving distance for vehicles of the relevant age category. The grouping of older vehicles into age categories covering several vintage years inevitably means that some of the vehicle one-year age categories in the model are multiplied by mileages which may not be precisely representative of their real use[112]. However, since this source of error occurs only for older age categories, which tend to have much lower annual mileages, the effect is unlikely to be significant. While these older categories also have higher bulk emissions factors per kilometre of travel, their considerably lower driving distance again means the effect of any slight overestimation is unlikely to make a noticeable impact on the overall emissions for the model year in question. A possible exception is the oldest age category, vehicles of 16 years and over, which is a consistently populous group at between 1.7 and 1.9 million cars (approximately 5–7% of the fleet), but since this varies very little from year to year it does not appear responsible for the divergence between modelled emissions and reported outturn from 2008.

Model year 2008, in addition to marking the start of the divergence between modelled and reported sectoral CO_2 estimates, also shows a break with the broadly consistent downward trend in sectoral emissions. This in itself would be cause to question the model results for this year. However there are a number of unusual features of the fleet profile in and immediately prior to 2008 that help to make sense of this unexpected result.

i. With the recession starting to take hold in 2007–8, the harshest effects were yet to trickle down to the level of per vehicle driving distances; reported total VKM_{fleet} in 2008 was the third greatest total volume of traffic on record, surpassed only by 2006 and 2007.

[111] Following a 'minor roads benchmarking exercise' changes were made to the DfT's road count methodology in early 2012. In February 2012 the DfT published revised total VKM for Great Britain for years 2000 onwards. The revised road count VKM_{fleet} data were incorporated into the final build of the model.

[112] As noted above, vintages were grouped by DfT statisticians to obtain workable sample sizes and hence more reliable estimates.

ii. Immediately prior to 2008, in 2007 the unbroken eight year decline in the rate of new additions to the fleet was halted temporarily, with new additions showing an increase on 2006 – swelling the ranks of higher mileage vehicles in 2008. Even so, given that aggregate demand (VKM_{fleet}) declined minutely from 2007 to 2008, this still leaves the modelled rise in total emissions unexplained.

iii. Analysis of the recorded number of vehicles in each age category in 2008 reveals a noticeable reduction in the rate of retirements across (almost) all categories, but especially for older, higher emitting vehicles.

iv. 2008 shows the largest instance on record (+2.4%) of vehicles that had been held back from registration the previous year being released into the fleet. 2007 showed the second greatest magnitude of this ‘phenomenon’, with the 1–2 year age-bin growing by 1.7% (as opposed to contracting by a fraction of a percent as in other years due to 'natural attrition'). Furthermore, the 2–3 year age-bin in 2008 also anomalously shows a small increase (0.6%) on the previous year. Whilst, as noted in §6.3.1, in general these ‘out of step’ influxes are thought too minor to make an appreciable difference on fleet profile, it is significant that in 2008 it is the highest-mileage vehicle age categories that are expanded uncharacteristically.

It is important to be aware of the limitations and assumptions governing the dynamic interactions between all fleet profile elements, but their consistent application across all years within the model validation timeframe (1994 to 2010) indicates that they alone are not capable of explaining the sudden divergence of modelled emissions with reported outturn emissions from 2008 onwards.

Given the strong correlation between model estimates and reported historical sectoral CO_2 until 2007, attention therefore turns to other significant changes or features which may help to understand the sudden departure. Foremost amongst the changes known to occur from 2008 onwards is the adoption by AEA / NAEI of type approval data for use in bottom up estimation of passenger car sector emissions. Prior to this, average speed-scaled bulk emissions factors for cars of each age category were based on the Transport Research Laboratory’s collated results from a variety of test cycles in multiple databases. As described in §6.3.7 above, from 2008 onwards, type approval, NEDC based values were substituted for TRL’s Light Duty Vehicle database values, despite TRL rejecting the use of NEDC values for all other types of (non-CO_2) emissions, and their strongly-worded advice regarding the inadequacy of type approval values in reflecting real-world road conditions and driving styles. With this in mind – along with the accepted inevitability of having to adjust the CO_2 emissions of other users of road fuel (notably HGVs, see box 6.1 above) to reconcile bottom-up emissions estimates with

DUKES fuel sales figures – there is good cause to treat post-2008 reported car sector CO_2 emissions with caution.

Given the widely acknowledged need to increase type approval gCO_2/km values to reflect real-world conditions when estimating emissions from car use (Defra 2011), this analysis proceeds by applying an 8.4% uplift to type approval vehicle emissions factors across all years past and future.

6.5 **Quantitative scenario construction**

6.5.1 ‘No growth’ baseline

In order isolate the effects of particular fleet parameters on total emissions, the majority (eight of fifteen) of the fleet scenario runs presented in Chapter 8 (results) assume that the total number of cars in the UK car fleet quickly equilibrates and remains static for the remainder of the model timeframe. The purpose of the baseline fleet profile is to estimate the effects of changes to other parameters on a relatively stable fleet – fleet size growth or shrinkage would mask the effects of changes to technology and mileage. Also, given the variety of factors that have bearing on fleet composition and rates of change, it is not possible to predict or prescribe with assurance the complexion of the fleet in future. Hence, a baseline or reference fleet profile is constructed to hold fleet growth and composition static, or as close to static as possible given the inevitable dynamic attrition arising from annually variable rates of new additions and retirement. This is achieved by building up the rate of new additions to the fleet to precisely balance the rate of vehicle retirement, which is held constant at its present (relatively low) rate. Fleet stabilisation is achieved with immediate effect (model year 2012), but the rate of new additions does not peak until 2017 (at approximately the same level as that seen in 2004), before declining again gradually.

A ‘no growth baseline’ is constructed subject to the following caveats.

i. It is fair to say that, owing to the complex interplay of elements and influences, the fleet does not naturally tend towards equilibrium (as noted in §6.3.3 above). While this is in no way intended as a prediction of a likely future outcome, picking one fleet composition profile over another is a necessarily judgemental process, and the approach taken here is to create a baseline against which changes in vehicle-fuel emissions factors and driving distances can be evaluated without being counteracted by absolute fleet growth. The fleet size adopted for the baseline takes the 'all else remaining equal' (*ceteris paribus*) approach.
ii. In order to place the current fleet (broadly) into equilibrium, the alternative to ramping up the rate of new car additions to the fleet is to suppress the rate of retirement. Without a major injection of new stock, the sharp drop off in new car sales since 2007 that is already percolating through the fleet, means that as vehicles are retired in the older age categories there are fewer vehicles coming

through to replace them in future years. However, suppression of the rate of retirement below its current all time low is both harder to engender in reality (vehicles will continue to be subject to mechanical failures and accidents), and counterproductive in terms of reducing emissions (by prolonging the life of higher emitting vehicles).

iii. Several demographic and consumer factors suggest a reversal of the recent short-term trend in new additions to the fleet is significantly more likely than a protracted decline. Foremost among these is that fleet growth has been and will likely continue to be driven primarily by a combination of license holder population growth and reducing mean household size (§4.2.1). More importantly for the short term, over half of annual new car purchases are by companies rather than by private individuals. While new cars registered to private individuals remains in decline, purchases by companies have grown strongly in the last two years, both in absolute terms and, consequently, as a proportion of total new registrations – now accounting for almost 60% of new cars (DfT 2011f: VEH0252). This suggests that a recovery in the rate of new additions to the fleet is already in process.

6.5.1.1 Baseline fleet profile construction

Step 1	• Set the fleet retirement rate. For baseline fleet profile, this is the 2009–2010, a low rate of retirement.
2	• Total fleet size is brought into equilibrium by making minor adjustments to the rate of change of new additions to fleet (Δ new).
3	• Set annual mileage of each vehicle age category (a.k.a. age-proportionate VKM_{veh}) for each future year. Default VKM_{veh} for baseline model runs is set to LOW (i.e. the mean interpolated values for 2008–2010 from the datasets provided by the DfT, shown in Figure 6.7 above).
4	• With baseline fleet parameters set, the mean bulk emissions (gCO_2/km) factors for each model year are set to produce an estimate of total fleet emissions for each year and a cumulative total over the model period. • Bulk emissions factor trajectories may be 'backcast' by either: i. specifying the desired mean bulk emissions factor for a future year (or the desired rate of change in mean bulk emissions factors). The model then applies a per annum rate of change (Δ gCO_2/km) from the current value (2011) uniformly across future years. ii. specifying a sectoral cumulative emissions budget. The model then displays the level of annual emissions consistent with the corresponding pathway, which can then be matched by making adjustments to Δ gCO_2/km, or by adjusting VKM_{veh} or VKM_{fleet} (see step 6).
5	• Set real-world uplift factor. For all RW model runs this is +8.4% (see §6.4.2 above). One baseline runs uses type approval (TA) values with zero uplift to illustrate the disparity between sectoral emissions estimated from mean bulk emissions factors based on real world driving and estimates based on the idealised legislative type approval test cycles.
6	• Set VKM_{veh} as desired, either to simulate reductions in per vehicle use directly, or to respect a constraint on total distance travelled by the fleet in any given

year (VKM_{fleet}), or to complement and balance the effects of supply-side savings achieved by Δ gCO_2/km.

- Annual changes to per vehicle driving distances (Δ VKM_{veh}) implied by different combinations of $VKM_{fleet,}$ bulk emissions factors and fleet profile may backcast in the model by specifying an end point reduction in VKM_{fleet} for 2022.
- For each year 2011 to 2022, the model then calculates an even annual rate of change in total distance driven (Δ VKM_{fleet}), and applies the resulting constrained VKM_{fleet} to the active VKM_{veh} curve to give new modelled values for VKM_{veh}. VKMveh can be manually adjusted to make fine alterations or non-linear / non-progressive changes.
- Note that the changes in VKMveh given for each year are particular to the year in question, given the dynamic nature of the fleet profile from one year to the next as new additions are made and older vehicles are retired.

6.5.2 Model runs assuming fleet growth

Several scenarios are presented in Chapter 8 (results) which feature growth in the total fleet size. This reflects the observed trend of increasing fleet size over time, driven by a combination of license holder population growth and second car ownership. Notably total fleet growth is not attributable in any significant part to variation in historical retirement rates. Although there is recent evidence of increasing rates of survival of older vehicles during recession years, this corresponds to years in which overall fleet growth has been relatively low. Retirement rates have declined since their peak in 2005–06, coinciding with a slow down in the overall rate of fleet growth. Therefore, as in the 'no growth' scenarios, in the fleet growth scenarios the current low rate of retirement is held constant and growth is driven by an increase in the rate of new car additions to the fleet in future years, to produce growth in total fleet size at the rate of 0.6% per annum. This rate of growth is based on:

i. Analysis of the historical trends in fleet size. As shown in Figure 6.5 above, total fleet size increased at a mean rate of 1.7% per annum between 2001 and 2010 (albeit with considerable variation from year to year). Since 2007 growth has slowed to a mean rate of 0.6% per annum, due to a 10% fall in new car sales from 2007 to 2008, and further 5% fall in sales in 2009. In these years a corresponding decline in vehicle retirement resulted in net fleet growth despite the falling intake of new vehicle stock.
ii. Projected growth in the UK citizen population over the next decade and beyond. A net increase in the UK citizen population of 4.9 million people is expected by 2020, equivalent to a mean annual rate of growth of 0.8% (ONS 2011b).

Fleet growth or contraction is undoubtedly influenced by a range of factors in addition to population, including the price of new cars, the price of fuel (in absolute terms and relative to other modes of transport), personal and household incomes, and levels of congestion both locally and across the road network (degree of saturation). Thus it is not considered appropriate to simply apply historical growth rates or projected population growth out into future years uncritically, since there exist constraints to fleet growth that may alter patterns of car ownership in future. However, given the issues raised in Chapter 4 in relation to the persistent centrality of the private car to UK transport policy, it also seems entirely feasible that 'business as usual' growth in total fleet size may be resumed within the foreseeable future. Indeed, this is amongst the key assumptions that underpin the strong growth in total car travel in the DfT's Road Transport Forecasts 2011.

Therefore, taking account of both the historical rate of annual increase in fleet size, the projected increase in national population, and the possibility that network saturation (amongst other factors) may exert a downward pressure on fleet expansion in coming years, critical judgement is exercised and a mean annual increase in total UK car fleet size of 0.6% is adopted for use in a moderate growth fleet profile. This rate is applied in seven of the fifteen fleet emissions scenarios presented in Chapter 8. All other fleet scenario runs assume that fleet size is quickly brought into ‘no growth’ equilibrium, as described earlier. It must be emphasised that 0.6% represents a considerably lower rate of growth than the mean over the decade to 2012, but equally, as a sustained rate of growth for the next decade, it also represents a reversal of the trajectory of fleet size set by declining new car sales in recent years. However, should new car sales and fleet retention return to their long-term historical trend in coming years, then overall fleet growth is liable to be increased considerably. The chief purpose of this analysis is to estimate the emissions consequences of changes to technology and end-use rather than produce detailed and potentially spurious projections of all possible fleet-size outcomes.

6.5.3 Reduction in VKM_{fleet} through increasing car occupancy

Several of the scenario runs include a constraint placed on total VKM_{fleet} based on assumptions about increased car occupancy. As noted in Chapter 4, the car occupancy values published as national statistics by the DfT refer to mean occupancy per trip for cars, vans and taxis by journey purpose. These values are not scaled in any way for total distance travelled (DfT 2012a). Based on other DfT datasets, which break down the typical annual distance travelled as a driver of a car by journey purpose, the DfT haselsewhere published estimates of the proportions of total VKM_{fleet} by journey purpose (see Figure 4.6 on p.109). By weighting trip mean trip occupancy values for each journey purpose in proportion to the share of total VKM_{fleet} for that journey purpose, a bulk average vehicle occupancy factor per car kilometre travelled can be estimated (see Table 6.3).

Table 6.3: Published trip occupancy values and share of total VKM_{fleet} by journey purpose, used to calculate mean bulk occupancy per vehicle kilometre

Journey purpose	**Trip occupancy (cars only) ✳ A**	**% of total VKM_{fleet} † B**	**Weighted share of occupancy per VKM C (=A*B)**
Commuting	1.18	26%	0.30
Business	1.17	13%	0.15
Education and education escort	2.03	2%	0.05
Shopping	1.67	13%	0.21
Personal business inc. other escort	1.42	15%	0.22
Visiting friends at home	1.78	14%	0.25
Visiting friends elsewhere	1.63	3%	0.05
Holiday and day trips	2.06	8%	0.16
Other leisure: entertainment, sport & other	1.99	6%	0.12
	Mean occupancy per VKM SUM:C		**1.512**

✳ These values differ slightly from those published in NTS0906, which are for car, taxis and vans used for non-commercial journeys. These values are for *cars only*. Source: (DfT 2012a).

† Values are taken from the underlying data behind chart 3.14 *'Estimated CO_2 emissions from household cars by journey purpose and journey length, GB, 2002/2006 average',* in the DfT Carbon Pathways Analysis 2008: (DfT 2008a).

With this framework in place it is possible to estimate the difference made to bulk occupancy for all VKM_{fleet} by varying the trip occupancy rate for specific journey purposes. Of particular interest are those journey purposes with the lowest typical rates of car occupancy, namely commuting and business. Of the two lowest occupancy journey purposes, commuting represents by far the largest share of total VKM – in fact it represents the largest share of total VKM of any single purpose. Commuting trips are more amenable to regular journey sharing than many other trip types, being generally more routinised than business trips for example, with fixed origin and destination and time of day. Therefore, the approach in this analysis is to consider the possibility of increasing the trip occupancy factor of commuting trips, and estimate the effect on overall bulk occupancy per vehicle kilometre.

Table 6.4: Effects on bulk occupancy of increasing mean trip occupancy for commuting

Change in commuting trip occupancy rate	New commuting trip occupancy	New bulk occupancy VKM_{fleet}
0%	1.18	1.512
+20%	1.41	1.572
+33%	1.57	1.611
+50%	1.77	1.662

Increasing bulk occupancy holds the potential to reduce the number of vehicle kilometres travelled to deliver the same number of passenger kilometres. Therefore, this analysis considers the mitigation potential of reducing total VKM_{fleet} while holding passenger kilometres constant by means of increased bulk occupancy per kilometre, derived from increased trip occupancy for commuting.

The published average occupancy for all trips (trip occupancy) for cars, taxis and vans is 1.564, the mean for cars only being 1.571 (DfT 2012a). The difference between these trip occupancy values and the per kilometre bulk occupancy in Table 6.3 has a considerable effect on the estimation of passenger kilometres travelled. The passenger kilometre data published in the DfT's National Travel Survey series are estimates based on a weighted occupancy factor of around 1.62 (DfT 2012a), but how such an occupancy figure is arrived at remains opaque. Indeed there is a considerable lack of clarity about how trip occupancy values are weighted by distance and treated in general. It is noteworthy that the passenger kilometre statistics in TSGB0101 are based on this weighted occupancy, which is not consistent with the shares of total VKM_{fleet} by journey purpose. This opens the possibility that the TSGB passenger kilometre data series overestimates total distance travelled by car passengers in Great Britain, an area ripe for further research.

Given the considerable discrepancy between calculated bulk occupancy per VKM and that used to estimate passenger kilometres in the TSGB series, for present purposes it is necessary to estimate present car passenger kilometres based on the values in Table 6.3 and 6.4. Although the total passenger kilometres for 2010 estimated by applying the calculated bulk VKM occupancy of 1.512 are 6.8% less than using the official TSGB0101 value, the absolute value is less important than ensuring that the change in total VKM_{fleet} is made in proportion to the change in bulk occupancy per VKM. Since changes to the commuting trip occupancy rate are expressed here as changes to the calculated bulk occupancy per VKM, it is necessary to hold constant the total passenger kilometres estimated from the bulk occupancy per VKM, in order to estimate a new quantity of VKM_{fleet} consistent with this level of occupancy and passenger kilometres[113]. This new value for VKM_{fleet} is then fed back into the fleet emissions model as a constraint on total VKM_{fleet} in 2022. The model then applies an even annual decrement in VKM_{fleet} back from the constrained 2022 total VKM_{fleet} to the present (2011) total VKM_{fleet}. This allows

[113] The value for VKM_{fleet} must be scaled up from GB to UK level to account for Northern Ireland, as noted in §6.5 above.

the additional mitigation potential of increased occupancy to be estimated, over and above mitigation delivered by the supply-side parameters.

For scenario runs which include growth in total fleet size and a commensurate increase in VKM_{fleet}, a counterfactual level of future passenger kilometres is estimated based on the current bulk occupancy rate per VKM and the model-output value for VKM_{fleet} in 2022. The increased rate of occupancy is then applied to this counterfactual estimate of passenger kilometres to estimate an equivalent level of VKM_{fleet} for 2022 under fleet growth conditions.

An example of the application of the increased bulk occupancy factor calculated from a 33% increase in trip occupancy for commuting journeys is shown in Table 6.5, resulting in a reduction in VKM_{fleet} of 6.2% by 2022 (compared to 2010). The final value for VKM_{fleet} is scaled up to UK level before being input back into the fleet emissions model as a constraint on 2022 VKM.

Table 6.5: Worked example of relationship between increased bulk occupancy and VKM_{fleet}, holding passenger kilometres constant.

Year	Bulk occupancy per VKM	Estimated passenger kilometres (PKM) (bn)	Equivalent VKM_{fleet} (GB only)
2010	1.512	583	386
2011	1.520	583	384
2012	1.528	583	382
2013	1.536	583	380
2014	1.544	583	378
2015	1.553	583	376
2016	1.561	583	374
2017	1.569	583	372
2018	1.577	583	370
2019	1.586	583	368
2020	1.594	583	366
2021	1.603	583	364
2022	**1.611**	583	362
Annual % change in PKM		0.33%	
Reduction in VKM_{fleet} by 2022 cf. 2010			6.2%

6.5.4 Summary of modelled scenario runs

Table 6.6 below gives an overview of key model assumptions and scenario parameters along with recognition of possible alternative assumptions that could be made or would have different implications.

The fleet model is a necessary simplification of the UK car fleet in use. While it is important to recognise the limitations imposed by adoption of certain values for key parameters such as those listed in Table A.A, the addition of further refinements and alternative values significantly increases the range of possible outcomes, without necessarily offering strikingly different model outcomes. For each additional variable, a further suite of model runs is required to demonstrate the combinatorial effects of that parameter with all other parameters – with diminishing returns. Nonetheless, certain refinements – such as incorporating license holder trips per year per purpose – would undoubtedly increase the sophistication of the model method, and allow the sensitivity of model outcomes to be tested against changes in each constituent element.

Table 6.6 Summary of fleet model assumptions and scenario parameters

Assumption	Model default	Comment and alternatives
Annual per vehicle driving distance (VKM_{veh})	Annual distance per vehicle is not dependent on other factors such as car journeys per person and journey length.	A further dimension could be added to the model, to represent the license holding population, with trips per person per journey purpose and distance per trip treated as separate variables. in order to understand the flexibility of each parameter
Car age related mileages	For future model years it is assumed that annual car distance travelled (VKM_{veh}) will deteriorate with vehicle age at the same rate as has been observed in recent years (mean 2008–10).	Alternative vehicle usage age profiles could be adopted (the model already allows for this), to simulate a return to lower fuel prices, higher economic growth etc.
License holders as proportion of UK population (no. of citizens)	For all scenarios (including those where increase in total UK citizen population is assumed) the current proportion of driving licence holders is assumed to remain constant in future.	There is emerging evidence that driving license holdership amongst younger age groups is in decline in recent years. Reducing the rate of increase in no. of vehicles licensed in proportion to total citizen population could add another nuance to the citizen population and fleet growth assumptions.
Bulk car occupancy	In estimating the changes to bulk occupancy that might be attained by changing trip occupancy rates for different journey purposes (commuting, business, etc) it is assumed in all cases that the proportions of annual aggregate VKM represented by each journey purpose remains constant.	Variations could be made to the composition of aggregate VKM_{fleet} by journey purpose, i.e. altering the proportion of VKM_{fleet} represented by commuting from its present share. This may have interesting consequences for bulk occupancy.

Table 6.7 gives a summary of selected model runs, detailed results from which are presented in Chapter 8 (results). The following elements are common to all scenario runs:

- Main driver of fleet size is new additions, retirement held constant at 2008–2010 mean rate (except scenario 7.1 which uses 2000–2010 mean rate of retirement).
- Age proportionate VKM_{veh} is LOW (2008–2010 mean) from 2010 onwards.
- Real world uplift is 8.4%.

Scenario runs in Table 6.7 are colour coded according to five possible new car emissions target-setting and monitoring approaches, each of which differently affects the burden placed on demand reduction:

- (purple) NEDC / type approval (TA) test is not replaced, EU target values are not altered. Represents claimed TA-based emissions.
- (red) NEDC / TA test is not replaced, and EU targets are not altered. Real world uplift (+RW) scenarios reflect real world outcome of corresponding TA scenarios.
- (orange) NEDC / TA test is not replaced, but EU targets are tightened. Real world uplift applied to resultant emissions (+RW)
- (green) NEDC / TA test is replaced with one more closely matching real world emissions. EU target values are retained, but applied at face value to real world emissions.
- (blue) NEDC / TA test is replaced with one more closely matching real world emissions, and even more stringent values are pushed to constrain sectoral emissions.

Scenario runs featuring fleet growth *and* increased average vehicle occupancy (AVO) rates for commuting trips (scenarios 5.2, 5.3 and 6.1) do not assume any other constraint on VKM_{veh} – i.e. fleet growth leads to an increase in VKM_{fleet} which is partly offset by the increase in AVO.

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Table 6.7: Summary of model scenario runs and main input parameters

No.	**Scenario run family and descriptive title** *(RW= real world; TA= type approval; AVO = average vehicle occupancy factor, or trip occupancy)*	**'Real world' gCO_2/km in 2020**	**Type approval gCO_2/km in 2020**	**% change p.a. in gCO_2/km**	**Change in VKM_{fleet} by 2022 (cf 2011)**	**Change in fleet size by 2022 (cf 2011)**	**Per annum rate of change in fleet size**
	Scenario family: Baseline fleet profile						
1.1	Type approval baseline: EU 2015 & 2020 targets	102	95	-4.1%	0%	0%	static from 2011
1.2	Real world baseline: EU targets +RW uplift	102	95	-4.1%	0%	0%	static from 2011
1.3	'Intentional baseline', EU targets realised as RW values	95	88	-4.8%	0%	0%	static from 2011
	Scenario family: technology push from 2015						
2.1	90gkm -3% p.a. +RW uplift	84	77	-3% from 90g in 2015	0%	0%	static from 2011
2.2	90gkm TA targets as RW emissions	77	71	-3% from 90g in 2015	0%	0%	static from 2011
	Scenario family: 'per vehicle' demand reduction						
3.1	Baseline +RW -25% VKM_{veh}	102	95	-4.1%	-25%	0%	static from 2011
3.2	Baseline +RW -50% VKM_{veh}	102	95	-4.1%	-50%	0%	static from 2011
	Scenario family: fleet growth from 2013						
4.1	EU +RW, fleet growth, no VKT cap	102	95	-4.1%	8.4%	6.2%	+0.6% from 2013
4.2	EU targets TA as RW,fleet growth, no VKT cap	95	88	-4.8%	8.4%	6.2%	+0.6% from 2013
4.3	EU targets, fleet growth, total VKT cap	102	95	-4.1%	0%	6.2%	+0.6% from 2013
	Scenario family: increased occupancy						
5.1	Baseline +RW uplift, +33% commuting AVO	102	95	-4.1%	-5.7%	0%	static from 2011
5.2	Fleet growth, +RW uplift, +33% commuting AVO	102	95	-4.1%	-0.5%	6.2%	+0.6% from 2013
5.3	EU tgts TA as RW, fleet growth, +33% comm. AVO	95	88	-4.8%	-0.5%	6.2%	+0.6% from 2013
	Scenario family: technology push, fleet growth, demand reduction						
6.1	90gkm -3% p.a. +RW, fleet growth, +50% comm. AVO	83	77	-3% from 90g in 2015	-2.6%	6.2%	+0.6% from 2013
6.2	90gkm -3% p.a. +RW, fleet growth, -25% VKM_{veh}	83	77	-3% from 90g in 2015	-20%	6.2%	+0.6% from 2014
	Scenario family: alternative retirement						
7.1	Scenario 1.3, at 10-year historical mean retirement rate	95	88	-4.8%	0%	0%	static from 2011
7.2	Scenario 1.3, holding 2010 retirement & new additions	95	88	-4.8%	-10%	-10.5%	-0.4% to -1.6%

CHAPTER SEVEN – QUALITATIVE INTERVIEWS

7.1 Overview

This chapter sets out the methods used to explore in depth the potential for achieving the levels of demand reduction indicated by the various supply side scenarios (produced by the method described in the previous chapter), summarised in Figure 7.1 below.

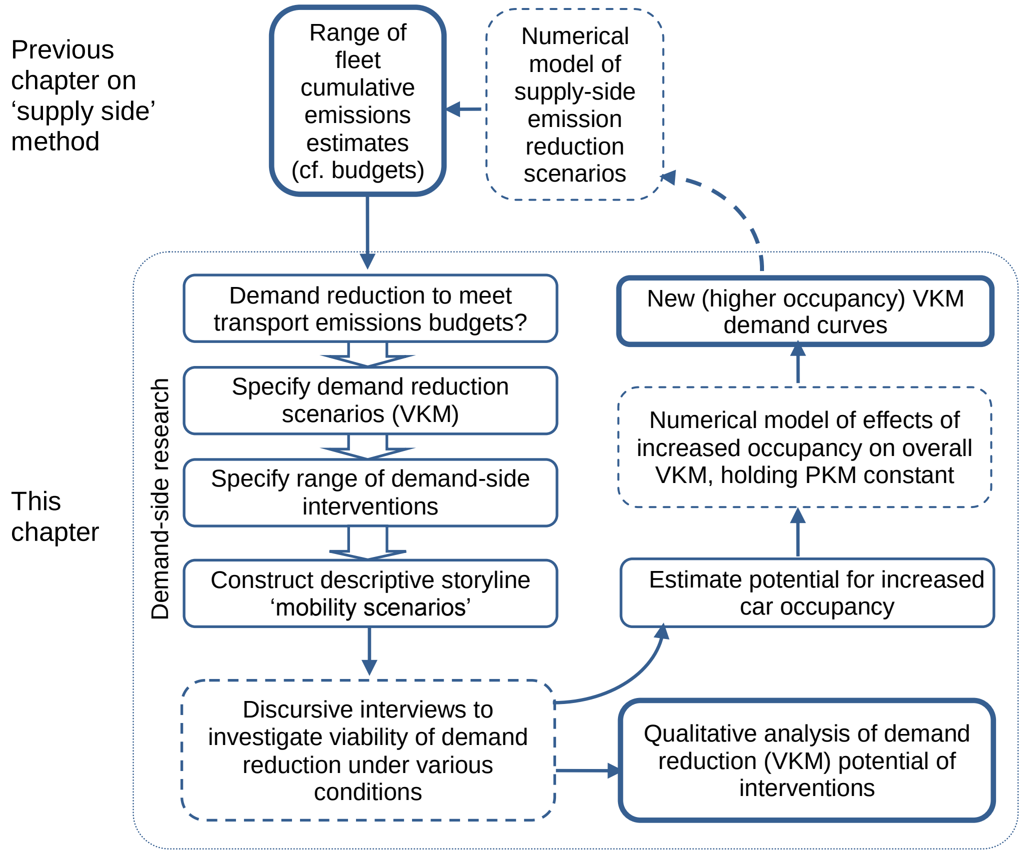

Figure 7.1: Demand-side analytical methodology (bold boxes show key outputs)

§7.2 sets out the rationale for using a qualitative approach to analysing demand-side mitigation potential, based on the need to understand the real-life structural and habitual determinants of car use, and describes a framework for exploring the obstacles to rapid and large-scale reductions in car use at the level of individual drivers. §7.3 gives an overview of the procedures used to design, recruit, conduct and analyse a series of interviews with members of the driving public. Section 7.4 explains the principles which inform the methodological design and analysis of the data.

7.2 Where does qualitative research fit into the overall structure?

Travel behaviour and practices are well-researched fields. As noted in the review of demand-side issues and relevant literature in Chapter 4, there is a considerable amount of published work seeking to ascertain the potential of a wide variety of policy instruments and interventions to produce reductions in per capita levels of car use. While many of these studies are relevant to this work in terms of informing the range of interventions considered and their potential for delivering incremental reductions, few if any have approached the challenge of addressing rapid and large-scale mitigation in the short term (decadal timeframe). The previous chapter described the fleet emissions scenario model constructed to estimate the effects on passenger car sectoral emissions over the next decade of a range of possible rates of improvement to vehicle–fuel efficiency. The fleet emissions scenarios themselves are presented in the next chapter (results), but it is plain from the outset that even under the most ambitious supply-side ‘technology trajectory’, the level of demand factored into the scenarios is pivotal in determining the emissions outcome. To ensure that possible rebound effects are accounted for, demand management should be considered *in parallel* with supply-side mitigation to lock in emissions savings from vehicle–fuel efficiency gains. Moreover, mitigation by (most) supply-side measures is limited by the rate of penetration of new vehicles into the fleet. Demand-side interventions have the potential to cut across the fleet, affecting end-use of new, older and more polluting vehicles alike, in addition to affecting the use of other modes. With respect to rapidity of mitigation then, demand-reduction has a theoretical advantage over supply measures.

Several of the quantitative scenario runs generated using the model described in the previous chapter and presented in the next posit dramatic shifts in the level of total demand for car transport. Specifically, a number of model runs estimate sectoral emissions for scenarios in which total fleet vehicle kilometres (VKM_{fleet}) reduces by up to 50% by 2022. Such ‘extreme’ levels of demand reduction are beyond the range typically considered achievable, feasible or desirable (see conclusions to Chapter 4). Nevertheless, based on the emissions budgets specified in Chapter 5, it is clear that far greater rates of reduction than previously countenanced will be necessary to deliver a lower probability of exceeding 2°C than currently entailed by measures and policies in place. As shown in Chapters 2 and 5, to move from a 63% probability of exceeding 2°C to 36% would require an almost fourfold increase in planned car sector mitigation for the next decade. It is with these mitigation needs in mind that this chapter explores the possibility of substantial, non-marginal shifts in demand for car kilometres.

Using the quantitative model in the previous chapter, emissions savings were estimated for two fleet trajectories: one ‘no growth’ and one assuming that the number of vehicles in the fleet will increase at 0.6% per year from 2013 to 2022 (increasing total fleet size from c.29 million UK cars in 2011 to c.31 million in 2022). Where such fleet growth is driven by citizen and license holder population growth from net inward migration rather than second car ownership, per capita demand reduction may be the only way to allow enough ‘breathing space’ within the confines of an emissions budget for supply-side measures to sufficiently penetrate the fleet and significantly contribute to mitigation (see §4.2.1.1). Fleet growth driven by net inward migration most likely relates to new and first vehicles for what are effectively new households, thus more heavily utilised than vehicles bought as a second or third car for an existing household. Positive 'natural change' in population size (difference between birth rate and death rate) may also lead to an increase in fleet size in the long run (§4.2.1.2).

7.2.1 Non-marginal change

Are reductions in per capita or total fleet vehicle kilometres of, say, ten, twenty-five or fifty per cent realistic? As described in Chapter 4, in the current political climate in the UK, given the present level of provision of public transport and considering the strong basis of cultural and economic support for the private car, reductions in car use at the top end of this range are hard to imagine – certainly there is little evidence to suggest such large changes would be embraced by policymakers or public (see §4.1.3)[114]. The question remains: to what extent could demand reduction be expected to contribute to meeting the scale of emissions reductions indicated by the budgets in Chapter 5, given the stated political objectives of limiting the probability of exceeding 2°C? Whereas other studies have investigated the *potential* demand reduction from single interventions or packages thereof, this work directly tackles the question of *whether* packages of demand measures, coercive and non-coercive, could *deliver the reductions required* to meet cumulative budgets associated with named probabilities of 2°C (§5.3.4), once available supply-side measures have been implemented.

The primary research in this work addresses the question by exploring the level of endorsement or rejection of large-scale reductions in 'per capita' VKM[115], through detailed discursive interviews with drivers who currently consider car use a necessity. This aspect of the research asked respondents to consider how a range of near-term policies, if introduced within the next eight years, would affect their lives. Respondents were invited to discuss their reaction to such policies, and to describe what factors currently constrain reductions in their current level of car use and what changes would need to occur to overcome them. By adopting a candid approach to the rationale for asking these questions (namely the inability to deliver a low probability of exceeding 2°C through technology measures alone) interviews were premised on a straightforward framing of the issue at hand. This allowed the dialogue to home in on where respondents located responsibility for mitigating emissions from car use, and the extent to which they believed available demand-side policies were (a) supportable and (b) likely to produce the desired effect.

7.2.2 Selection of method

Several methods for exploring these issues with car drivers were considered, including more quantitative social research such as stated choice experiments. Such methods

[114] However the implicit corollary of this is acceptance of the impacts that accompany unmitigated climate change. Furthermore, the constituencies tacitly 'accepting' these impacts are not the same as the constituencies who will live with them.

[115] To the extent that individuals interviewed represent a single vehicle in the fleet. See §7.3.3.1 and §9.4.1.

were ultimately rejected on the basis that few if any respondents are likely to be familiar with the scale and rate of changes under consideration, nor with many of the interventions proposed to deliver them (précised at the end of Chapter 4). Stated choice experiments were considered not to allow sufficient interaction (between researcher and respondent) or deliberation (allowing respondents to discuss, elaborate and even change their opinions during the course of the interview). In recognition of the lack of a common basis in experience for changes in demand at the rate and scale proposed, and of the more novel demand management tools, key concepts and premises were summarised in a narrative description of 'life in 2020', i.e. once the interventions had been applied. These narrative, storyline scenarios formed the basis for each interview and allowed respondents to envisage how such policies might affect them, and set the scene for a discussion about what other provisions may need to be put in place in order for their current level of mobility to remain viable.

Whereas more quantitative approaches such as questionnaires, structured interviews or discrete choice models produce narrowly categorised, homogenous data that can be cross-compared between participants and experiments, the semi-structured interview technique adopted here produces much richer, heterogeneous data in the form of detailed deliberative responses to the narrative scenarios presented. Again, this approach is justified by the unconventional nature of the subject matter up for discussion, which does not lend itself to quantification by pre-determined, pre-calibrated preference ranking or response categories. Indeed, rather than second-guess likely responses in advance, a 'grounded' approach was adopted in order to allow the pertinent issues to emerge from the data during analysis (see §7.4 below). This involves approaching the research task without preconceptions about outcomes and allowing respondents to identify the issues and concepts they think are most salient (Pidgeon *et al* 1991). The role of the researcher / interviewer is to attempt to categorise and codify response data according to recurring themes[116], reiteratively returning to the sample and testing new hypotheses about the most pertinent themes as the interview series progresses (Robson 2002). Given the scale of the reductions in car use implied by the emissions budgets and quantitative scenarios, narrative scenarios are a particularly useful tool for exploring non-marginal changes in complex systems.

7.3 Interview design and qualitative scenario construction

To address the question of how changes in travel behaviour could contribute to delivering the necessary mitigation to achieve the short-term budgets identified for the passenger car sector in Chapter 5, a series of 42 in-depth interviews were conducted with members of the driving public.

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[116] Examples of such themes might be the need for flexibility in personal travel arrangements, or a distrust of government policy.

7.3.1 Sample targeting

As Chapter 4 alluded, per capita driving distance varies considerably throughout the population with several socio-economic and demographic factors influencing car use. For example Brand and Boardman (2008), Le Vine and Polak (2009), Susilo and Stead (2009) all attest to a relatively small percentage of the driving population (10–20%) being responsible for a disproportionately large share of total travel related CO_2 emissions (50–60% in the UK). Both Brand and Boardman and Susilo and Stead looked at total CO_2 from all personal travel modes, including aviation, which makes up a large share of personal travel emissions from the highest emitters. However, Le Vine and Polak show that the relationship remains true at the level of passenger cars only – noting that not only do higher mileage drivers contribute a greater share of emissions simply by their greater total vehicle kilometres travelled, but they also tend to accumulate more mileage for commuting and business purposes than low mileage drivers – in both percentage and, critically, absolute terms. Commuting and business trips have the lowest trip occupancy rates of all journey purposes, suggesting that higher mileage drivers are also amongst the lowest occupancy car drivers.

In recognition of the uneven distribution of total VKM_{fleet} and emissions from car use, interviews were sought with people with higher than average annual driving distances. This was done on the basis that interventions which are successful in reducing demand from high-mileage drivers will deliver greater mitigation potential than those which affect only lower mileage drivers.

7.3.2 Recruitment, pre-screening, preparation

The primary research interviews were scheduled in the summer immediately following a five-year update of the University of Manchester's staff travel survey, which the researcher was fortunate to be involved in designing and implementing. A request for contact details of respondents who would be willing to participate in further research about personal travel was inserted at the end of the staff travel survey, sent to approximately 11,300 staff across the university and higher education precinct in Manchester, including the NHS teaching hospitals, music college and other associated public sector organisations. The staff travel survey had a response rate of 33%, of which a similar percentage provided their contact details and registered interest in participating in further research (i.e. approximately 1,200 contact details). Staff travel survey results remain strictly confidential, therefore the contact details provided were done so anonymously of answers to initial survey questions.

Once university ethics committee approval for the present research was granted, an email was sent to the long list of travel survey contacts thanking them for expressing interest in further participation and inviting them to supply the following basic pieces of information:

- respondent's main commuting mode and daily distance travelled to work[117];
- respondent's job area within the university (academic, support, estates, etc);
- gender; and
- availability over the coming month for a face to face interview.

This initial email was accompanied by a research information sheet that provided detailed background information about the purpose and proposed content of the interview (sample email and information sheet are available in Appendix 6). Response rate to this initial email was 16%, i.e. 177 separate replies indicating willingness to participate in an interview, of whom approximately 50% either did not regularly drive to work or did not provide sufficient information to determine suitability for inclusion in the sample and were immediately declined. The remaining respondents to the initial contact email were screened to select for interview those respondents with the highest daily mileages (used as a rough proxy for annual mileage), while including as broadly a cross-section of the university and higher education precinct's driving population as possible, with respect to job role (and, by proxy, income level), age and gender. In many cases further email dialogue was necessary to establish the respondent's true level of car drivership. Hard and fast criteria for selection were not applied, however, with selection being primarily on the basis of regular driving to work of more than five miles each way, but with several respondents included who provided information that indicated they would add valuable variety to the sample by virtue of journey distance, complexity, or their travel history. For instance several respondents were selected who commented that while they do not drive regularly to work at present, they drive extensively for leisure or other purposes, or until recently had driven long distances to work. Selection was a dynamic process, partly subject to availability of respondents during a four week window (which happened to coincide with the summer vacation period between university terms), and partly to preserve a balance of gender and job-types amongst the sample.

Forty-two interviews were arranged on the University of Manchester campus, predominantly at respondents' places of work or nearby, the remainder at Tyndall Manchester offices. At time of arranging the interview, formal consent to use the resulting data was obtained, and a pre-interview questionnaire (Appendix 7) was sent to gather more detailed information about respondents' current travel habits, in particular their patterns and level of car use, level of car ownership within their household and attitudes to climate change. Based on the principles of grounded theory research, it was not possible to predetermine the sample size with precision (see §7.4.5 below). Nevertheless, statistical advice had initially been obtained during an earlier period of the research when alternative, more quantitative social research methods were considered,

[117] In the questionnaire and interviews references to distances travelled were in terms of miles rather than kilometres, in keeping with the British imperial system of measurement, and prevalence of miles rather than kilometres in popular discourses about driving. However, for data analysis and reporting, all distances are converted into kilometres.

which suggested a sample population of 40 or more would yield sufficient data to work with should statistical interpretation be pursued. Given the high level of initial interest from potential participants, 42 interviews were scheduled in short order, on the understanding that additional respondents would be recruited if necessary.

It is important to note that the overtly qualitative interview form and method of analysis was chosen for its ability to render rich descriptive data, rather than achieve any semblance of representativeness of the wider population.

Before data collection began, three pilot interviews were conducted with members of Tyndall Manchester to allow ambiguities in the presentation of narrative scenarios to be ironed out and questioning technique refined. Pilot interviews also enabled familiarity with data capture during the interviews, which were recorded using digital audio for subsequent verbatim transcription.

7.3.3 Interview structure and narrative scenarios

Interviews were 'semi-structured', referring to the use of both set questions inviting open-ended, discursive responses, and more reactive questions which probe areas of interest that arise during the interview. Interviews revolved around the reactions of respondents to two narrative scenarios describing near futures in which demand for private car use was substantially constrained by the introduction of a range of policies and measures.

Building on expertise from previous focus groups and interviews conducted by colleagues within the Tyndall Centre, Manchester (Mander *et al* 2008b), the narrative scenarios were developed as fundamentally positive views of the future, describing changes in terms of new opportunities and improvements rather than privation and detriment. While initial resistance to policies is recognised, the scenario storylines highlight the possibility of changes which at first are seen as disruptive coming to be accepted and embraced. The full narrative scenarios are available in Appendix 8.

7.3.3.1 Scenario characteristics – step changes in car use

Two narrative scenarios were constructed to depict possible visions of life in Britain in the year 2020, in which per capita annual driving distances had reduced by one third and two-thirds respectively of their current level. These values were chosen in view of the scale of emissions reduction indicated by the budgets associated with lower probabilities of exceeding 2°C as defined in Chapter 5 (i.e. emissions reductions up to 388% of current planned savings 2008–2022), although the reductions are not calibrated to a particular budget. Both levels of reduction undoubtedly represent step-changes in levels of per capita car use, and whilst it was not anticipated that many respondents would immediately embrace the suggestion of such dramatic reductions, raising the possibility of large changes was intended to open up a discussion of how far respondents believed the scenario policies would move them towards these outcomes. Personal experience suggests that people are better able to estimate proportions than absolute distances, so the levels of demand reduction described in the qualitative scenarios (one third and two thirds of current use) were intentionally relative and coarse-level.

Several of the quantitative fleet emissions scenarios (described in the previous chapter) estimate the potential mitigation effects of reductions in VKM_{fleet} of 25% and 50%. Others estimate the effects of reductions in mean age-proportionate annual distance driven per vehicle (VKM_{veh}) under a variety of fleet profiles (static, growth, contraction, increased turnover). However, it should be noted that for several reasons the demand reductions discussed in the qualitative interviews cannot be directly equated as a comparable reduction in VKM_{fleet}, or even strictly speaking as VKM_{veh}. First, the fleet model is based on *vehicle* kilometres, whereas interviews are conducted with drivers who may not be the main driver within their household, nor the only driver of their car[118]. Consequently their *personal* reduction in car use is not necessarily equivalent to a reduction in total household VKM of the same proportion. Second, even while per capita VKM declines, if total fleet size increases due to population growth, VKM_{fleet} may also increase (or in the case of large reductions in per capita distance, return lower levels of reduction in VKM_{fleet}).

Therefore, one third and two thirds reductions were based on critical judgement as to levels of reduction that would be perceived as highly challenging, consistent with the quantitative scenarios, but of sufficient scale to generate reductions in VKM_{fleet} in the order of 25%–50%, if enough drivers were able to participate.

7.3.3.2 Scenario elements

The qualitative scenarios were constructed to convey these changes by describing a vision of personal travel in the near future in an informal, easy-to-relate-to storyline style. Scenarios are written in the present tense as if in 2020, looking back at changes since 2011 and referring to the respondent in the second person. An introductory paragraph, common to both scenarios was prefaced with the context in which they are meant to be read: "*The following describes a vision of personal transport in the UK for the year 2020. It is a purely hypothetical scenario – there is no suggestion that this it is likely or desirable, but you are asked to consider how it differs from your current driving habits and lifestyle."* The principal elements covered between both narratives are outlined below.

i. Introduction – what has happened since 2011 (common to both scenarios)
   - New cars have become much cleaner, best available technology used across all vehicle market segments.
   - Large four wheel drive (4WD) sports utility vehicles have been effectively phased out.

[118] 71% of interview respondents identified themselves as the main driver within their household (i.e. drive the greatest annual distance), while 74% reported being either the sole driver of their car or that one other person occasionally drives their car (less than once a week).

- Battery electric vehicles still a make up only a small minority, other sectors also decarbonising rapidly and placing large demands on low-carbon electricity.

ii. Main scenario differences in level of use compared to present day:

- Respondent asked to imagine that they are driving one third or two thirds less than in 2011.
- Relative cost of public transport is less than car travel.
- Several examples of day to day differences in travel practices are suggested – including in scenario 2 the possibility of no longer owning a private car but participating in a pay-per-use car club.

The foregoing introduction and headline changes in demand were arranged on one side of A4 paper for each scenario, and presented to respondents to read before an initial discussion of their immediate reaction to where such cuts might be found in their current driving itinerary, if indeed it they could envisage such a possibility at all. Once the scale of reductions involved had been satisfactorily covered, the remainder of the narrative description was revealed, detailing the key policy interventions imagined in order to bring about the changes indicated. The policies and interventions included in the scenarios are summarised in Table 7.1.

Table 7.1: Policies and interventions described in the narrative scenarios

Scenario 1 – reduction of ⅓ driving	**Scenario 2 – reduction of ⅔ driving**
Coercive policies	
Fuel tax – petrol costs over £3 a litre	Personal carbon allowance scheme
Parking restrictions	
65 mph speed limit enforced	
Minimum occupancy lanes and tolls	
Enabling and persuasive interventions	
Public transport improved and extended through ringfencing of fuel tax revenue	
Hire and ride city bikes widely available in metropolitan areas	
Municipal buses and escorted 'walking buses' for school children	
Roadspace reallocated in favour of unpowered modes	
Easy to use real time information on public transport and lift share via mobile phones	
Car clubs more prevalent (much more prevalent in scenario 2)	
Multi-mode travel smartcard and regulated flat fares on public transport	

7.3.4 Role of public transport in the scenarios

Both scenarios included references to ‘improved’ public transport and greater use thereof. The precise nature of the improvement was intentionally left open, as respondents’ previous experience of and current relationship with public transport was expected to vary considerably. Hence the question of what would it take to shift a proportion of current driving to public transport did not prejudge the nature of possible structural or qualitative changes. Inevitably, modal shift to public transport is a central element of portrayal of step change reductions in driving distances in which personal mobility is preserved. Expansion of public transport provision is not a zero-emissions option, since additional services are likely in the near future to be conventionally fuelled, either by petroleum or fossil-fuel dependent electricity. This analysis does not attempt to quantify the possible increase in emissions from public transport that would arise should services be extended sufficiently to absorb demand for private car kilometres, an indication of scale is offered in the discussion of interview results (Chapter 9).

In constituting the narrative scenarios, it should also be noted that descriptions of policies and interventions are not intended as scientific predictions or estimations of the precise financial level of, for instance, fuel tax, required to produce the headline reduction in driving distance. Rather the scenarios function as a means to introduce concepts to respondents in an accessible format and to elicit reaction and discussion.

7.3.5 Interview core questions

Following any points of clarification once respondents had read the introduction and scenario headline changes, interviews proceeded via preset questions probing how respondents perceived the hypothetical scenarios would impact their lives, specifically focussing on propensity to continue to use private car travel in the same way and to the same extent as at present. All questions were structured to allow open-ended answers in conversation with the researcher, rather than confining responses to predefined categories.

Initial questions in the first section relate to the extent to which participants perceive the narrative scenarios differ from their current levels car use, exploring those scenario elements that struck the respondents as most salient. During the early stages of the interview a picture of respondents’ current travel habits and car use was built up, adding to pre-interview questionnaire information already obtained. Further questions focussed on respondents’ sense of how feasible it would be for them to adapt their current lifestyle within the constraints of the scenarios. Here questions aimed to draw out the perceived obstacles and barriers that the scenarios would present to participants. In addition, any perceived benefits of reduced car travel were also drawn out. This stage of the interview explored respondents’ preferences, estimated price sensitivities and, in particular, any structural constraints on reducing car use by mode shift, increased car occupancy or foregoing ‘non-essential’ trips.

The concluding section of the interview probed the degree to which respondents are engaged with the need to reduce emissions from private transport in principle (if this had not already emerged during the interview), and explored respondents' level of concern about climate change, and their sense of agency with regard to emissions reduction.

7.3.6 Examples of non-car mobility

While the main selection criterion for interviewees was the extent of car use for regular commuting trips, a small sub-set of respondents had already changed their main commuting mode from single-occupancy car driving to public transport. While these respondents remained regular car drivers for non-commuting journeys, their inclusion was considered worthwhile in order to gain insight into the factors that led to their well-established routines of car commuting being replaced with a preference for other modes. By contrast, it emerged that several respondents had recently shifted from public transport to car driving (both single occupancy and multiple-occupancy).

7.3.7 Representativeness of the sample and possible biases

As noted above, sampling actively sought to identify respondents who are higher than average mileage car drivers. All respondents are employees within the university higher education precinct (the second largest employer in the region after Manchester City Council), representing a range of salary bands and job areas, although manual and unskilled staff were unrepresented in the sample[119]. As such, no claim of broad societal representivity can be made with regard to data gathered from the sample. The sample was otherwise relatively heterogeneous, with no discernable biases towards gender, life stage, income, household composition, residential area or environmental disposition. No attempt was made to disguise the objectives of the research, indeed respondents were provided with a research information sheet explaining the basic premise of the insufficiency of climate change mitigation through technology measures alone. This raises the possibility that a self-selection bias may lead to over representation of people who identified with these issues, giving a preponderance of 'aspiring environmentalists' in the interview sample. The uncertain relationship between attitudes and behaviour, raised in §1.4.2, forms the basis for further discussion in Chapter 9 (discussion). In the meantime it is noted that a broad range of opinions regarding the appropriate level of personal responsibility for transport emissions was expressed by the respondents, who were reassuringly forthright in making their own suggestions as to possible policies and measures.

7.4 **Analysis**

The limited number of preset questions and semi-structured nature of the interviews were designed to allow interesting and unexpected angles and opinions to be followed during the course of each interview. This was with a view to subsequent analysis of the

[119] Not deliberately, this simply reflected the responses from the staff travel survey.

data using grounded theory principles. As such, particular hypotheses and conjectures about what the content of interview dialogues were not formulated in advance, so as to allow the data 'to speak for themselves'.

7.4.1 Grounded theory

Grounded theory is a useful *approach* to social research where outcomes are either unpredictable or in danger of being obscured by the researcher's own world view. Rather than presenting a theory of behaviour to be proved or falsified *per se*, it refers to the generation of theories from data. Glaser and Strauss's (1967) formulation of grounded theory has been augmented and diversified by subsequent qualitative researchers to embody a set of broad principles of 'data-driven' analysis and theory building (Gardner and Abraham 2007). The principles are adopted here follow those established by Strauss and Corbin (1990), whereby qualitative interview data are subject to initial 'open coding' in which descriptive and conceptual labels are applied to the themes and topics raised. This is an iterative process, refined as the dataset is reviewed. Secondary 'axial coding' is a meta-analysis of the relationships that can be drawn between the conceptual open coding categories, forming overarching category families. Coding labels are unique to the dataset, reflecting the issues and concerns of the sample population (a full list of primary codes generated during this stage of the analysis is presented in Appendix 9).

7.4.2 Data preparation

Interviews were digitally recorded and subsequently transcribed verbatim into rich text format documents. All transcripts were then loaded into *Atlas ti*, a software package specifically designed to facilitate analysis of rich qualitative data, with several features that lend themselves well to grounded approaches. Pre-interview questionnaire data were compiled separately as a spreadsheet.

7.4.3 Primary (open) coding

The first round of 'open coding' consists of reviewing each transcript line by line, highlighting sections of dialogue and assigning summary codes (or categories) that succinctly capture the issues and concepts expressed by respondents. The name open coding refers to the fact that no predetermined or preset codes are brought to the analysis; codes are created *ad hoc* to reflect the substance of the raw data being interpreted. This painstaking process is conducted iteratively, as new concept codes are created to suit later interview material, so they must be retrospectively applied where appropriate to earlier transcripts. This tends to occur where a broad concept code is subsequently refined into sub-categories, or where subtleties which were not obviously important start to emerge as a consistent theme. To facilitate uniform application of codes, new codes were noted on a list beside the stage in the process at which they were first created. New codes were then applied to preceding interviews on the second pass through the transcripts for axial coding. In total 337 individual codes were created.

In order to adequately capture the complex issues and concerns within the interview material, in many cases several codes are required in combination. To allow subsequent analysis of co-occurrence of codes, it is necessary to ensure that codes are applied to sections of dialogue in a consistent manner with regard to the length and repetition of issues. For instance, it is necessary to consider what counts as separate occurrences – in a section of conversation about introducing road charging in Britain, does a brief deviation onto a separate tangentially related or unrelated matter (such as holiday driving), mean that the previous topic of conversation constitutes a separate instance when resumed? To ensure that code frequencies were not misrepresented by repetitious application to contiguous sections of dialogue, on the second coding pass through the dataset a process of standardisation was implemented. This involved extending the assignment of codes to immediately adjacent instances, which both considerably reduced the number of separate 'quotations' (from 3,500, to approximately 2,200) and ensured a more even, uniform application to the dataset of the full range of codes in use at the end of the primary coding.

7.4.4 Secondary (axial) coding

The main objective of the second pass through the dataset is to examine the relationships that exist between the codes already created. This is facilitated by the grouping of codes into code families, of related concepts and elements (such as 'driving characteristics', 'outlook and engagement', etc). Where certain concepts are considered especially salient within the context of the dialogue and where consistent relationships between codes suggest a more subtle or explanatory theory, theme 'memos' are attached to the dataset, which also include the constituent individual concept codes.

Thus, the raw interview transcripts are transformed into a rich qualitative dataset comprising an organised database of discrete quotations, which are connected with:

- primary concept codes;
- secondary 'theme codes' (relationships between primary codes)[120]; and
- meta data relating to the interrelationships between the above elements.

In combination with other contextual data from pre-interview questionnaires, this data is presented in the following chapter, with interpretation and discussion in the subsequent Chapter 9. Figure 7.2 shows a simple example of the network of codes and quotations that constitute an emergent theme, and represents the process of distilling thousands of quotations into hundreds of codes and subsequently tens of themes.

[120] In *Atlas ti* they are 'theory' memos, but for conceptual accuracy they are referred to here as 'themes'.

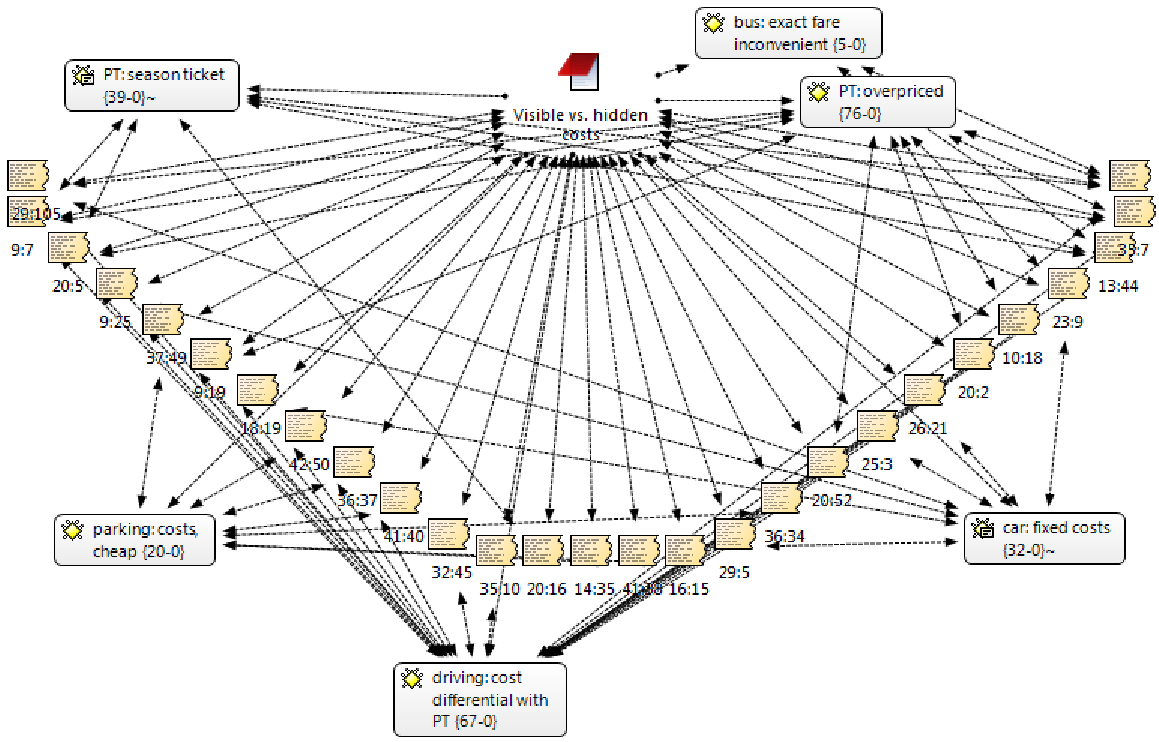

Figure 7.2: Example of a network view of an interview theme (red icon: 'visible vs. hidden costs'), codes (grey text boxes) and quotations (yellow icons) as built up in *Atlas ti* qualitative analysis tool during secondary coding. NB: each quotation and code may be also connected to multiple other themes and codes either related to or independently of this network.

7.4.5 Saturation of categories

One of the principles of grounded theory research is that key issues and theories generated in the early stages of primary research are probed in later stages. The scheduling of interviews was over a condensed timeframe, which did not allow for data analysis to take place between interviews or blocks thereof. However, the approach taken to analysis of the interview data was similar to the iterative principle of grounded theory, insofar as evidence was sought in each subsequent interview for instances of concepts which emerged previous transcripts. As noted above, the possibility of further interviews was kept open, in case of particularly intriguing concepts emerging which were not commonly expressed throughout the dataset. In the event, the majority of concepts were identified early in the primary coding pass through the dataset, and became well saturated with instances during the subsequent iterative stages of primary and secondary coding. While a limited number of additional concepts arose in each subsequent interview, these were in many case more nuanced versions of existing concept codes, which simply called for category codes to be split or merged. Saturation of categories refers to the 'diminishing returns' offered by continued mining of the interview data for additional concepts (Robson 2002). Of 337 discrete concept codes or categories, 263 were identified in the first dozen interviews, with 78 further codes being added during the next thirty interviews.

7.5 Feedback into the fleet emissions model

As shown in Figure 7.1, evidence for the potential to increase vehicle occupancy was sought through the qualitative interviews. The mechanism by which occupancy feeds into the quantitative fleet emissions model is described in the previous chapter. With regards to the primary research into this line of enquiry, interview transcripts were also coarsely summarised to capture the headline reactions of each respondent to the various policies and measures described in the narrative scenarios at discussed at interview (see Figure 8.37 in the following chapter). It should be noted that these findings are the summary interpretation of the researcher based on detailed review of the transcripts – respondents were not asked to register a preference on a Likert scale or other preference ranking system, and no respondents gave opinions on all policies and measures. Nevertheless, for those who expressed clear opinions or provided information relevant to journey sharing, a summary encapsulation was made of their in-principle willingness and ability to participate in either carpooling or car sharing schemes for their commuting journeys (over and above the extent to which this is already occurring). This enabled a coarse measure to be made of the proportion of interviewees who responded positively to suggestions of increasing occupancy, or who acknowledged that they could adapt to increased occupancy in light of other policies introduced to facilitate and encourage it.

CHAPTER EIGHT – RESULTS

8.1 Overview

This chapter brings together findings from the three principal lines of enquiry in this research:

i. Literature-based calculations from Chapter 5 - emissions budgets for passenger car sector.
ii. Fleet model based emissions scenarios from Chapter 6 – estimated sectoral emissions under a range of assumptions about near term available supply and demand-side measures.
iii. Empirical results of qualitative interviews from Chapter 7– drivers' reported willingness and ability to adapt to reductions in annual driving distance.

8.2 Emissions budgets

The emissions budgets outlined in Chapter 5 are instrumental to informing the specification of fleet emissions scenarios and creating narrative scenarios which form the basis of the qualitative primary research. Table 8.1 recaps the emissions budgets and the associated core assumptions, while Figure 8.1 makes clear the shortfall between the respective budgets and planned abatement measures within the *Low Carbon Transport* strategy.

The ‘counterfactual baseline’ is the DfT’s estimate of emissions that would have occurred had the measures in the *LCT* strategy not been implemented, under their predicted VKM_{fleet} growth conditions (see §2.2.4.1).

Table 8.1: UK passenger car sector (MPT, motorised private transport) emissions budgets for 2008–22, based on national and global budgets with named probabilities of exceeding 2°C

	Counterfactual baseline	*LCT*	***MPT1***	***MPT1a***	***MPT2***	***MPT3***	***MPT4***
'Parent' national pathway and probability of exceeding 2°C in 'grandparent' global budget	~	*'Interim' 63%*	*UK1 56%*	*UK1a 56%*	*UK2 56%*	*UK3 52%*	*UK4 36%*
Deforestation treated as a global overhead in parent national budget?	~	No	No	Yes	Yes	Yes	Yes
non-Annex emissions peak year	~	~	N/A	N/A	2025	2025	2020
***MPT* (no prime) core pathways** no special treatment for IA&S $MtCO_2$ 2008–22	1,088	1,011	**920**	**840**	**937**	**869**	**789**
***MPT′* (prime) pathways** *IA&S #1* bunkers estimate, plateau by 2020 $MtCO_2$ 2008–22	~	~	912	824	930	857	770
***MPT″* (double prime) pathways** *IA&S #2* hybrid estimate, low growth $MtCO_2$ 2008–22	~	~	896	807	915	840	751

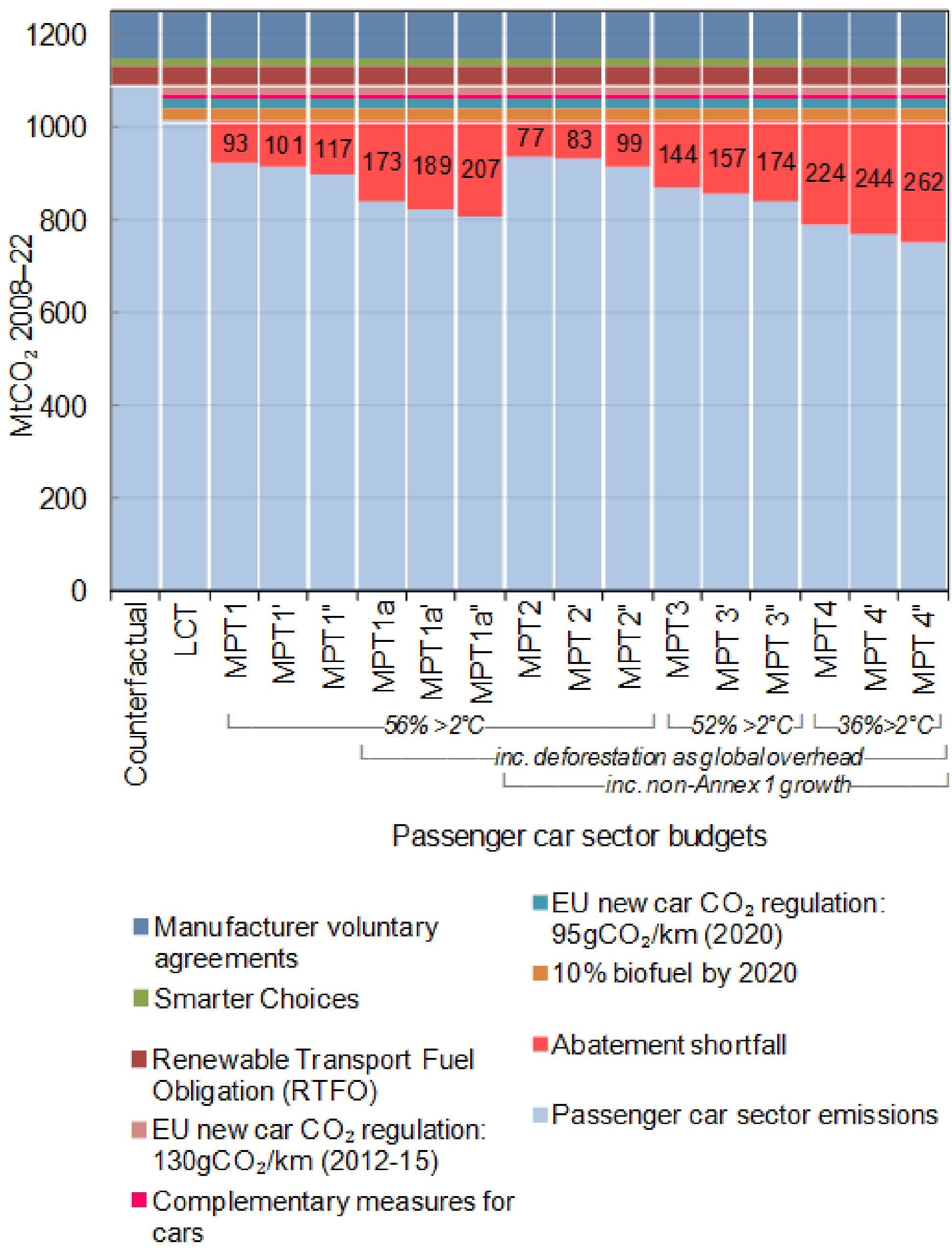

Figure 8.1: Passenger car sector emissions budgets 2008–22 and planned abatement measures. Numbers on chart indicate the shortfall in $MtCO_2$ between the expected savings from planned measures in the *LCT* strategy and the respective budgets. (NB slight rounding error compared to Table 5.3).

8.3 Fleet emissions model scenarios

Table 8.2 gives the main outputs of the fleet emissions model scenario runs, based on assumptions founded in the scientific literature on technology readily available in the next decade and on the potential for demand reduction beyond that currently envisaged by policymakers. Figure 8.2 to Figure 8.9 depict the fleet profiles behind each scenario.

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Table 8.2: Cumulative emissions outcomes of selected fleet emissions scenario runs, with key parameter assumptions

No.	Scenario family and descriptive title *(RW= real world; TA= type approval; AVO = average vehicle occupancy factor, or trip occupancy)*	Cumulative $MtCO_2$ 2008–22	'Real world' gCO_2/km in 2020 *(Δ p.a.)*	TA gCO_2 /km in 2020	Fleet Profile (§8.3.1.1 to §8.3.1.4)	Change in VKM_{fleet} by 2022 (cf 2011)	Total fleet size in 2022 (millions) *(Δ 2011–2022)*	Max. new cars in a single year (millions)	Annual rate of change in fleet size
	Scenario family: Baseline fleet profile		*(a) from 90g in 2015*						*(b) from 2013*
1.1	Type approval baseline: EU targets at TA values	***873***	102 (*-4.1%*)	95	A	0%	29.3 *(0%)*	2.44	0%
1.2	Real world baseline: EU targets +RW uplift	**945**	102 (*-4.1%*)	95	A	0%	29.3 *(0%)*	2.44	0%
1.3	Intentional baseline: EU targets realised as RW values	**935**	95 (*-4.8%*)	88	A	0%	29.3 *(0%)*	2.44	0%
	Scenario family: technology push from 2015								
2.1	90gkm -3% p.a. +RW uplift	**914**	84 *(-3%)(a)*	77	A	0%	29.3 *(0%)*	2.44	0%
2.2	90gkm -3% p.a. realised as RW emissions	**904**	78 *(-3%)(a)*	71	A	0%	29.3 *(0%)*	2.44	0%
	Scenario family: 'per vehicle' demand reduction								
3.1	Baseline +RW -25% VKM_{veh}	**856**	102 (*-4.1%*)	95	A	-25%	29.3 *(0%)*	2.44	0%
3.2	Baseline +RW -50% VKM_{veh}	**751**	102 (*-4.1%*)	95	A	-50%	29.3 *(0%)*	2.44	0%
	Scenario family: fleet growth from 2013								
4.1	EU +RW, fleet growth, no VKT cap	**970**	102 (*-4.1%*)	95	B	8.4%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
4.2	EU targets realised as RW, fleet growth, no VKT cap	**959**	95 (*-4.8%*)	88	B	8.4%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
4.3	EU targets, fleet growth, total VKT cap	**944**	102 (*-4.1%*)	95	B	0%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
	Scenario family: increased occupancy								
5.1	Baseline +RW uplift, +33% commuting AVO	**927**	102 (*-4.1%*)	95	A	-5.7%	29.3 *(0%)*	2.44	0%
5.2	Fleet growth, +RW uplift, +33% commuting AVO	**945**	102 (*-4.1%*)	95	B	-0.5%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
5.3	EU targets as RW, fleet growth, +33% comm. AVO	**933**	95 (*-4.8%*)	88	B	-0.5%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
	Scenario family: technology push, fleet growth, demand reduction								
6.1	90gkm -3% p.a. +RW, fleet growth, +50% comm. AVO	**902**	84 *(-3%)(a)*	77	B	-2.6%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
6.2	90gkm -3% p.a. +RW, fleet growth, -25% VKM_{veh}	**845**	84 *(-3%)(a)*	77	B	-20%	31.1 (*6.2%*)	2.62	+0.6% *(b)*
	Scenario family: alternative retirement								
7.1	Scenario 1.3, at 10-year historical mean retirement rate	**931**	95 (*-4.8%*)	88	C	0%	29.3 *(0%)*	2.56	0%
7.2	Scenario 1.3, holding 2010 retirement & new additions	**905**	95 (*-4.8%*)	88	D	-10%	26.2 *(-10.5%)*	1.98	-1.6%

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8.3.1 Model fleet profiles

8.3.1.1 Fleet profile 'A' – no change in current fleet size or rate of retirement.

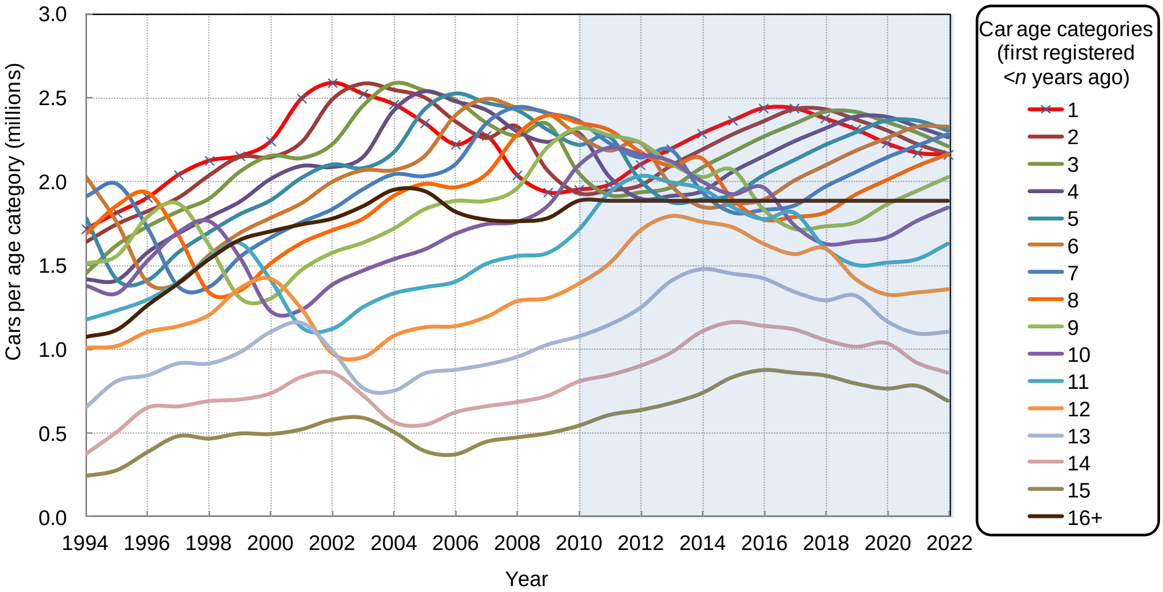


Figure 8.2: Historical fleet composition, showing number of cars in each age category 1994 to 2010 (source DfT vehicle licensing statistics), and model baseline fleet composition (profile A) from 2011 to 2022 (shaded area indicates profile assumed in model).

Figure 8.2 is the baseline profile for all fleet emissions model scenarios that do not assume growth in the total fleet size or change in retirement rates. Total fleet size remains steady at 29.3 million, as shown in Figure 8.3

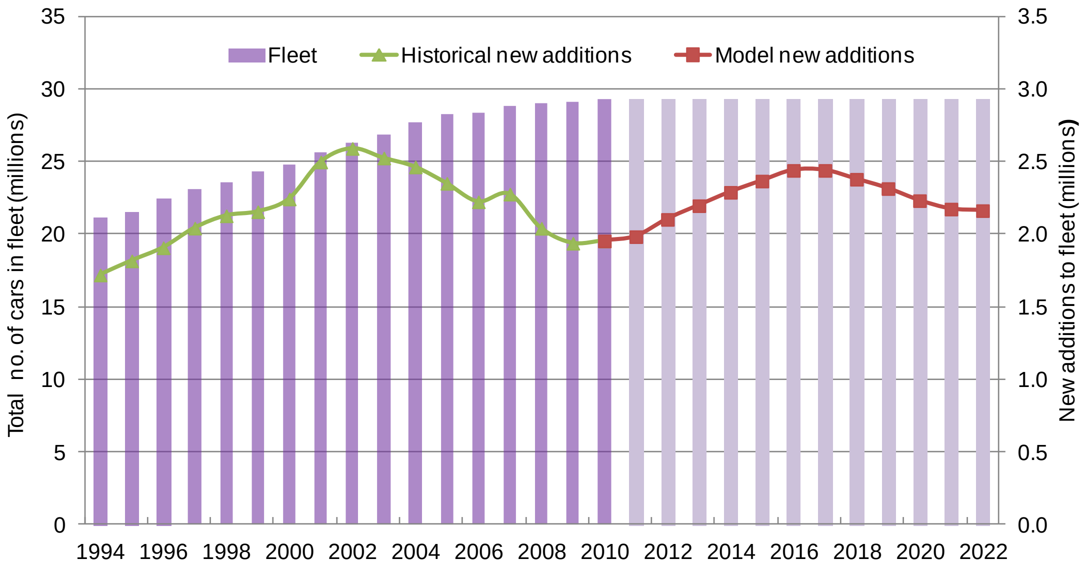


Figure 8.3: Historical total fleet size and annual new additions, and model baseline total fleet size and annual new additions 2011 to 2022 in fleet profile 'A' (lighter bars indicate values assumed in model).

8.3.1.2 Fleet profile 'B' – fleet grows at 0.6% p.a., no change in current rate of retirement

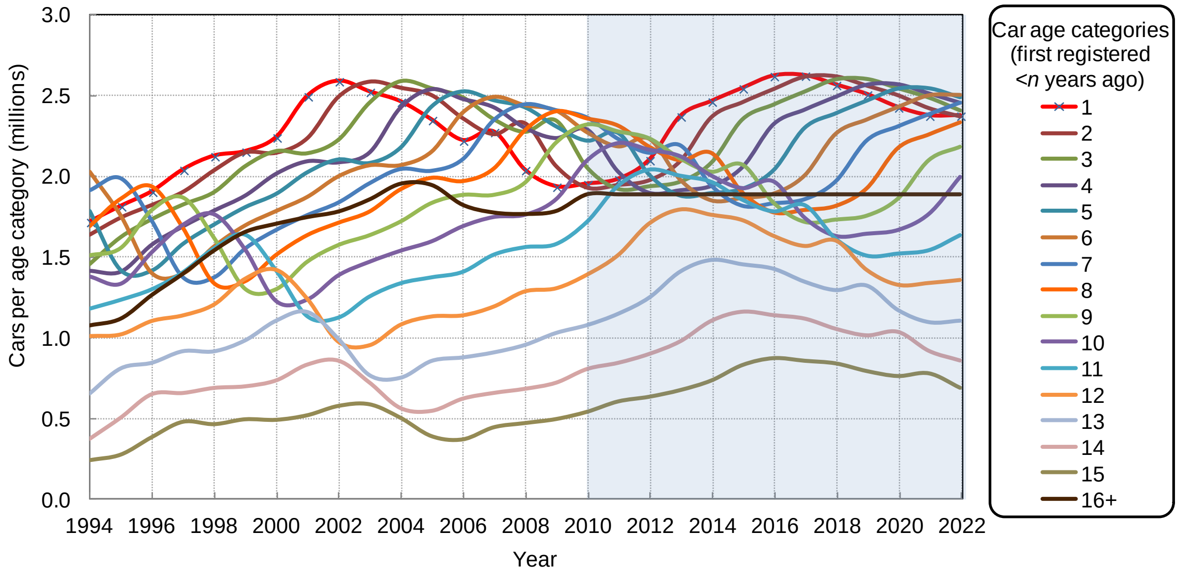


Figure 8.4: Historical fleet composition, showing number of cars in each age category 1994 to 2010 (source DfT vehicle licensing statistics), and model fleet composition from 2011 to 2022 under modest growth conditions of 0.6% p.a.(profile B) starting in 2013 (shaded area indicates profile assumed in model runs featuring fleet growth).

All fleet emissions model scenarios which assume overall growth in the total fleet size over the next decade (scenarios 4.1, 4.2, 4.3, 5.2, 5.3, 6.1 and 6.2) are based on the fleet composition profile in Figure 8.4. Total fleet size gradually increases to 31.1 million by 2022, as shown in Figure 8.5

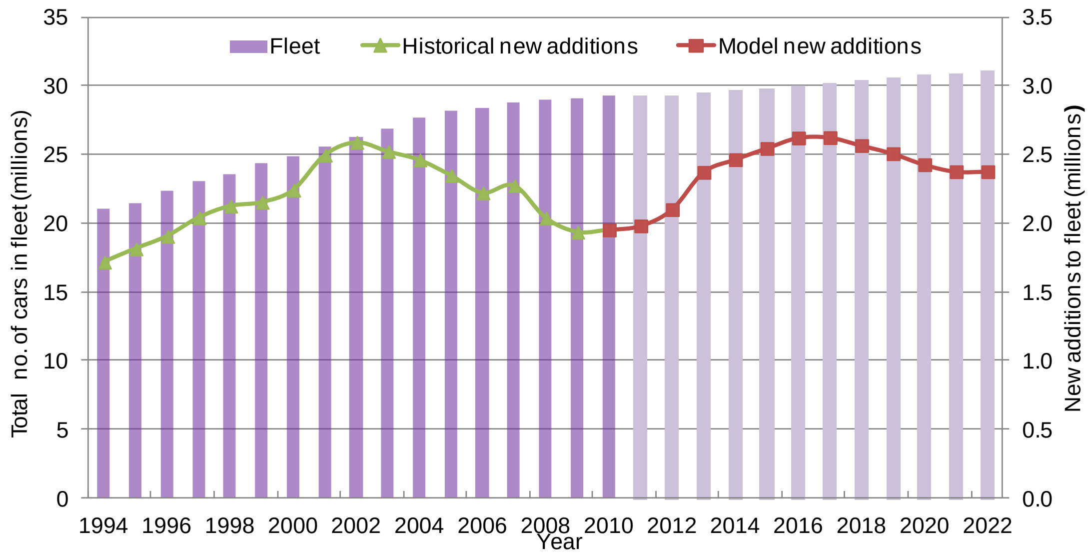


Figure 8.5: Historical total fleet size and annual new additions, and model growth scenario total fleet size and annual new additions 2011 to 2022 in fleet profile 'B' (lighter bars indicate values assumed in model).

8.3.1.3 Fleet profile 'C' – retirement rate at 10 year historical mean, no fleet growth

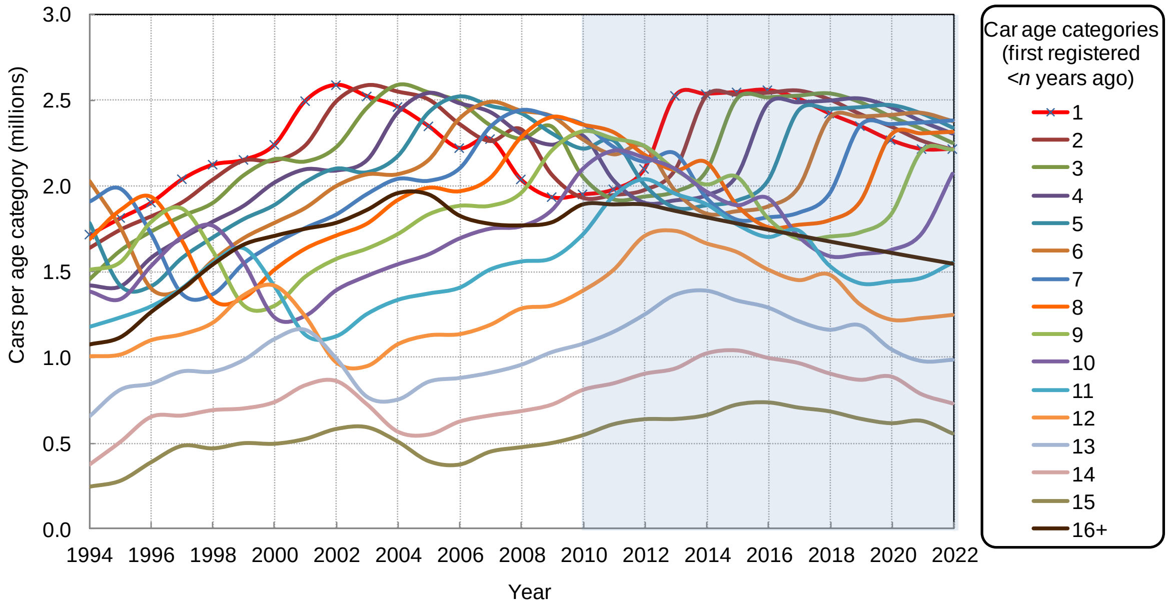


Figure 8.6: Historical fleet composition, showing number of cars in each age category 1994 to 2010 (source DfT vehicle licensing statistics), and model fleet composition from 2011 to 2022 under increased turnover conditions (profile C) (shaded area indicates profile assumed in model runs featuring fleet growth).

Profile 'C' (Figure 8.6) applies only to fleet emissions model scenario 7.1, which assumes that the current low (2010) rate of retirement increases to the mean rate of years 2000–2010 from 2013 onwards, while annual new additions are ramped up to balance the total fleet size, which remains constant at the current level (29.3 million), as shown in Figure 8.7. Whereas the oldest vehicle age category (cars first registered 16 years ago or more) has historically grown, in this accelerated turnover profile, the 16+ category is set to decrease by 2% per year, in keeping with a hypothetical push to replace older, more heavily emitting cars with newer low emissions models.

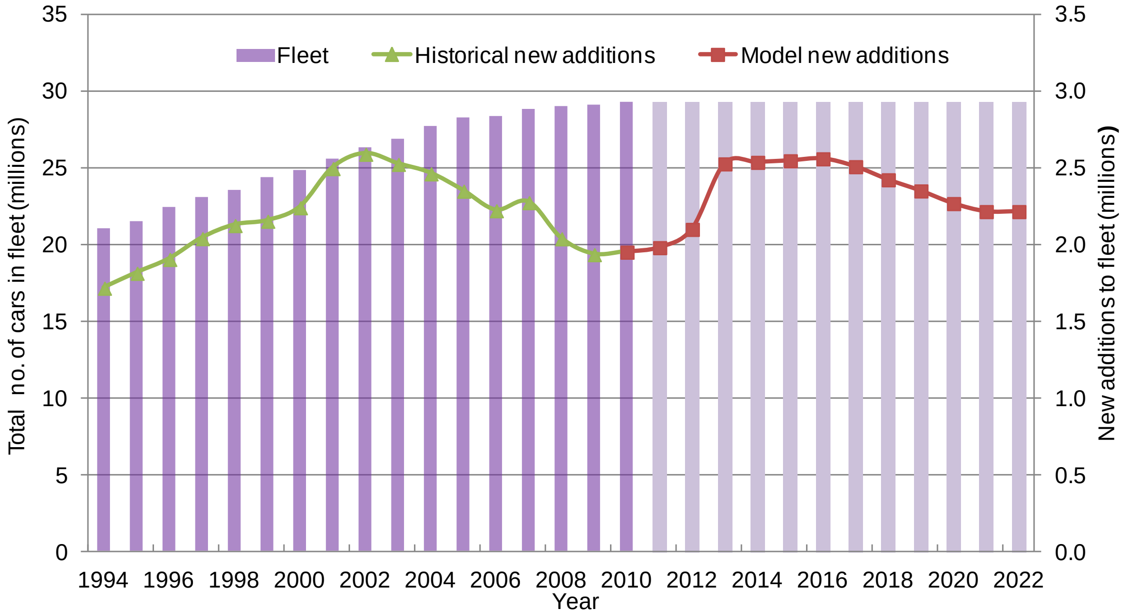


Figure 8.7: Historical total fleet size and annual new additions, and model growth scenario total fleet size and annual new additions 2011 to 2022 in fleet profile 'C' (lighter bars indicate values assumed in model).

8.3.1.4 Fleet profile 'D' – continuation of current rates of retirement and new additions

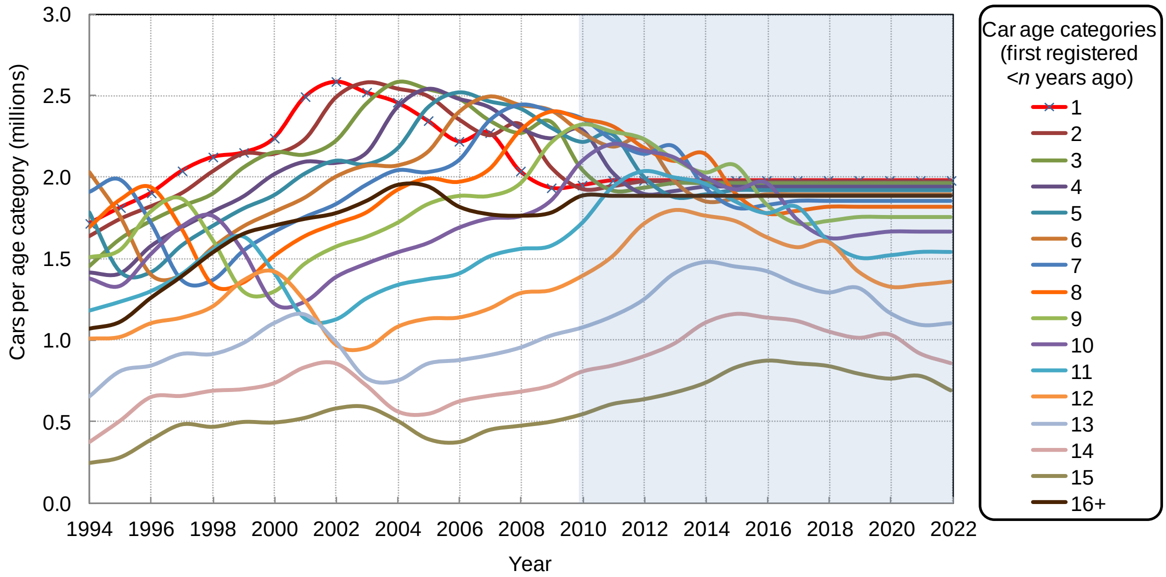


Figure 8.8: Historical fleet composition, showing number of cars in each age category 1994 to 2010 (source DfT vehicle licensing statistics), and model fleet composition from 2011 to 2022 with current (2010) rates of retirement and new additions held constant (profile D) (shaded area indicates profile assumed in model runs featuring fleet growth)

Profile 'D' (Figure 8.8) applies only to fleet emissions model scenario 7.2, which assumes that the present rate of vehicle retirement from each age category and the number of new additions to the fleet each year remain constant until 2022. Total fleet size declines as a result of the recent decline in the levels of new additions from the previously high influxes in the middle part of the previous decade. Total fleet size begins to equilibriate at around 26 million by the early 2020s, as shown in Figure 8.9.

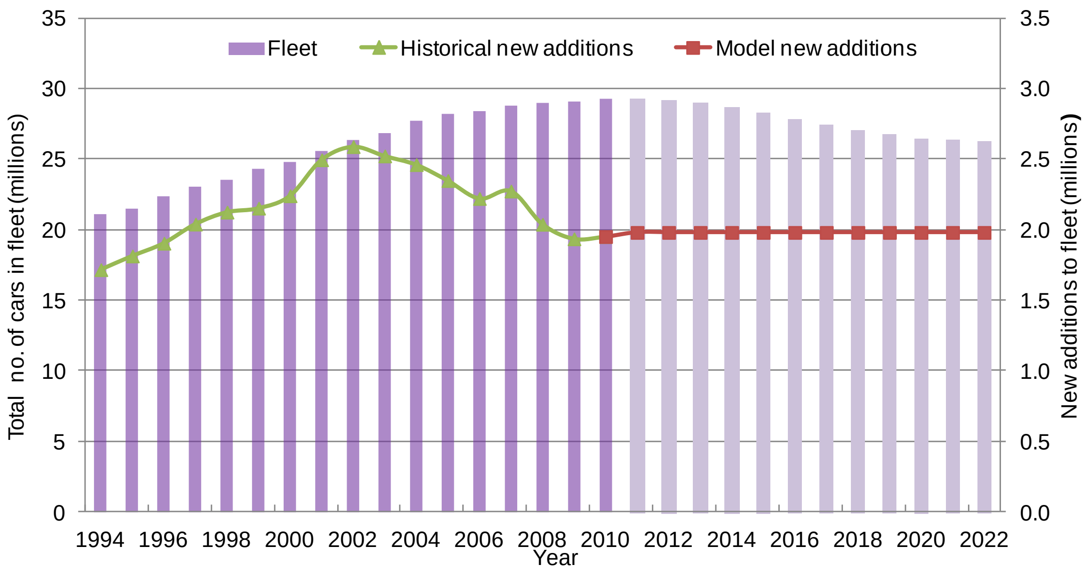


Figure 8.9: Historical total fleet size and annual new additions, and model 'current trends' scenario total fleet size and annual new additions 2010 to 2022 in fleet profile 'D' (lighter bars indicate values assumed in model).

8.3.2 Model outcomes

The following pages present the key outputs from the quantitative fleet emissions modelling exercise. These include the relative position of the model scenario cumulative emissions outcomes within the series of emissions budgets indentified in Chapter 5, summarised in Table 8.1 above.

8.3.2.1 Ranking of model scenarios against emissions budgets

The cumulative emissions outcomes of the seventeen model scenarios are shown in relation to the emissions budgets from Table 8.1, with budgets grouped by the assumptions made with respect to international aviation and shipping (see §5.3.3), in Figure 8.10 to Figure 8.12 below. The quantitative fleet model **scenarios (shown red in the charts)** are the outputs from the quantitative fleet model, whereby scenarios are ‘backcast‘ from a range of designated **emissions budgets** over a set period **(shown blue in the charts)**. Of the model cumulative emissions totals, only Scenario 1.1 emissions are estimated according to type approval-based per kilometre emissions factors (in light blue). All others include a ‘real world’ uplift of 8.4% (see Chapter 6).

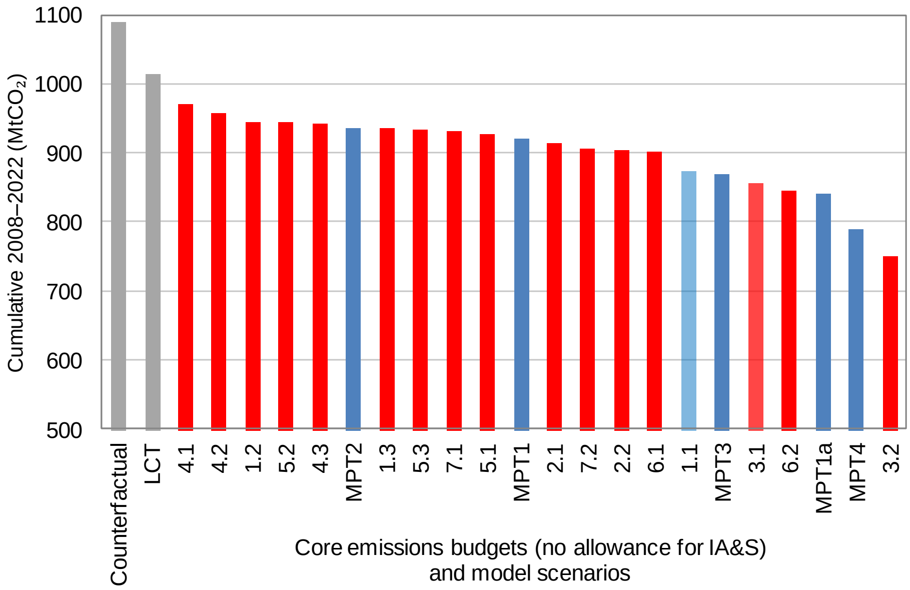


Figure 8.10: Model scenarios (1.1–7.2) compared to ‘core’ emissions budgets (*MPT…*), which assume no special treatment for international aviation and shipping (IA&S).

Figure 8.10 shows that three model scenarios (3.1, 6.2 and 3.2) produce cumulative emissions over the fifteen years 2008–22 which fall inside the emissions budgets associated with a lower than 56% probability of exceeding 2°C and accounting for non-Annex 1 emissions growth (‘motorised private transport’, or car sector budgets *MPT3* and *MPT4*). Eleven of the model scenarios based on real world uplifted vehicle emissions factors produce cumulative totals that fall within at least one of the core sectoral budgets.

Once allowance is made for international aviation and shipping to maintain its 2005 (absolute) level of emissions, the same three model scenarios (3.1, 6.2 and 3.2) remain within the scope of budgets with a sub-56% probability of exceeding 2°C and accounting for non-Annex 1 growth (Figure 8.11). Of all model scenarios using real world uplifted vehicle emissions, eight fall within at least one budget that allows for international aviation and shipping to continue at 2005 levels (subject to caveats in Chapter 5).

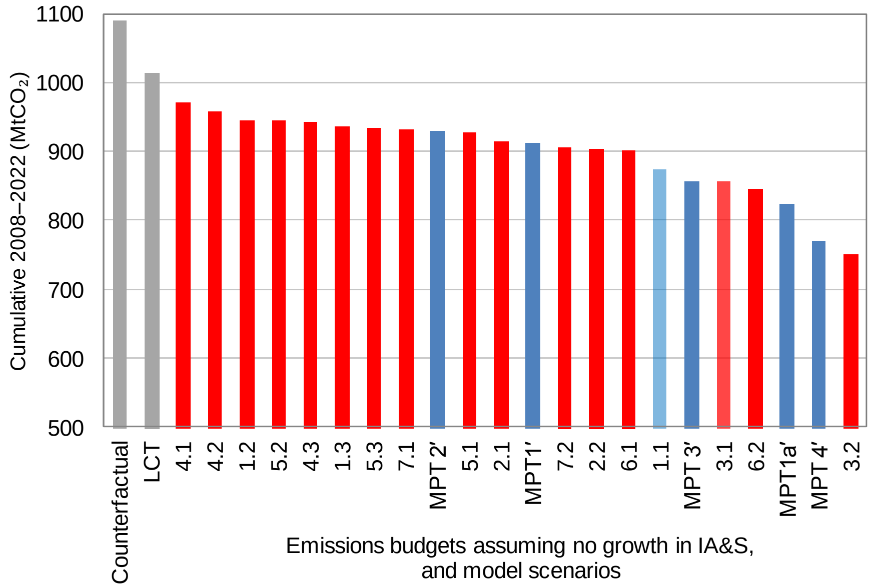


Figure 8.11: Model scenarios (1.1–7.2) compared to emissions budgets (*MPTx′…*)assuming international aviation and shipping emissions scenario *‘IA&S#1’,* i.e. IA&S emissions are estimated from bunker sales and assumed to revert to their 2005 levels by 2020 (see Chapter 5).

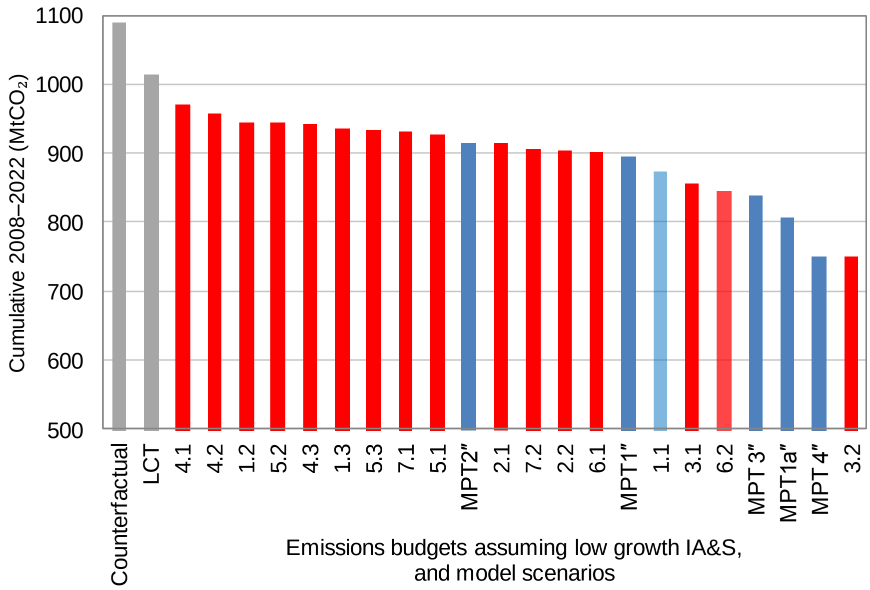


Figure 8.12: Model scenarios (1.1–7.2) compared to emissions budgets (*MPTx″...)* assuming low growth international aviation and shipping (‘*IA&S#2*’), based on bunker sales for aviation and GDP-weighted shipping emissions (see Chapter 5).

Figure 8.12 shows that, compared to the emissions budgets based on conservative growth assumptions of *IA&S#2*, only model Scenario 3.2 falls within budgets associated with sub-56% probability of 2°C and accounting for non-Annex 1 growth. Seven of the real world emissions scenarios fall within at least one of the budgets.

8.3.2.2 Model scenarios – detailed 15 year outputs

The following seven pages give a detailed overview of each of the model scenarios over the timeframe of interest, 2008–2022. Scenarios outcomes are depicted in Figure 8.13 to Figure 8.29, each as a panel of three plots:

a. Annual passenger car sector emissions 2008–22 (blue dashed line, left-hand *y*-axis).
   Total annual vehicle kilometres travelled by passenger cars in the UK (yellow dashed line, right-hand *y*-axis).

b. Ranking of scenario cumulative emissions (the blue shaded area under the dashed line representing annual emissions in plot a.) against the emissions budgets from Table 8.1.
   Scenario cumulative emissions are shown as data point (red), with values of the next closest budgets also shown as data points (grey) for ready comparison. Note that the position of the scenario higher up or lower down the list is less significant than its proximity to specific emissions budgets, given the important differences in background assumptions included in each budget (see Chapter 5, and Table 8.1 above).

c. Trajectory of mean new car bulk emissions factor per kilometre travelled (gCO_2/km, blue line, left-hand *y*-axis).
   Annual rate of change in mean new car bulk emissions per kilometre (green dashed line, right-hand *y*-axis) – ultimate long-term trend is given as data label (excepting any obvious spikes due to scenario assumption of new regulation being introduced to limit new car emissions from 2015).

In Scenarios 5.1–6.1, where an increase in average vehicle occupancy (AVO) for commuting trips is assumed, this is against the 2010 mean trip occupancy for commuting trips, of 1.18 persons per vehicle.

NB: In captions to Figure 8.13 to Figure 8.29, all comparisons of distance per vehicle (VKM_{veh}) and total distance driven on UK roads (VKM_{fleet}) in 2022 are against 2011, the most recent year for which officially reported data are available.

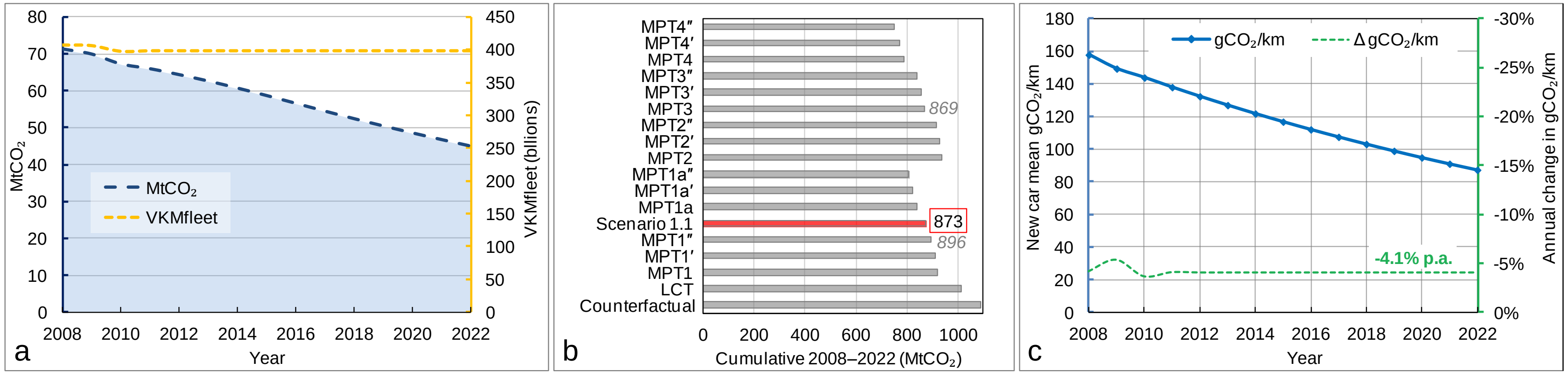


Figure 8.13: Scenario 1.1 – *Type approval baseline*

- type approval (TA) monitoring and accounting
- EU mean new car emissions targets 'met'
- fleet profile 'A' (no growth)
- no growth in VKM_{fleet}

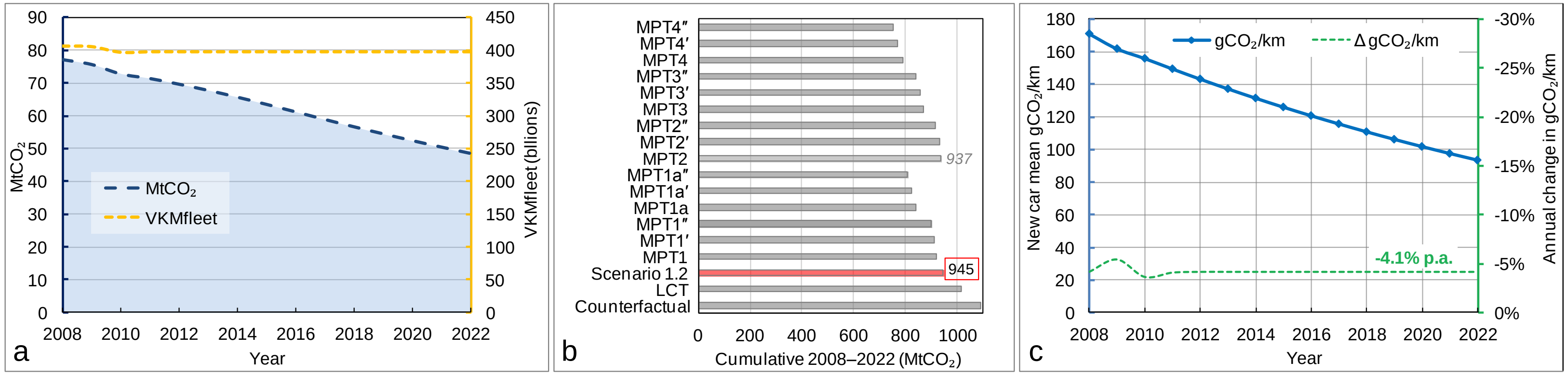


Figure 8.14: Scenario 1.2 – *Real world baseline*

- Mean gCO_2/km emissions factor uplifted +8.4%
- EU new car targets are not met in real world emissions
- fleet profile 'A' (no growth)
- no growth in VKM_{fleet}

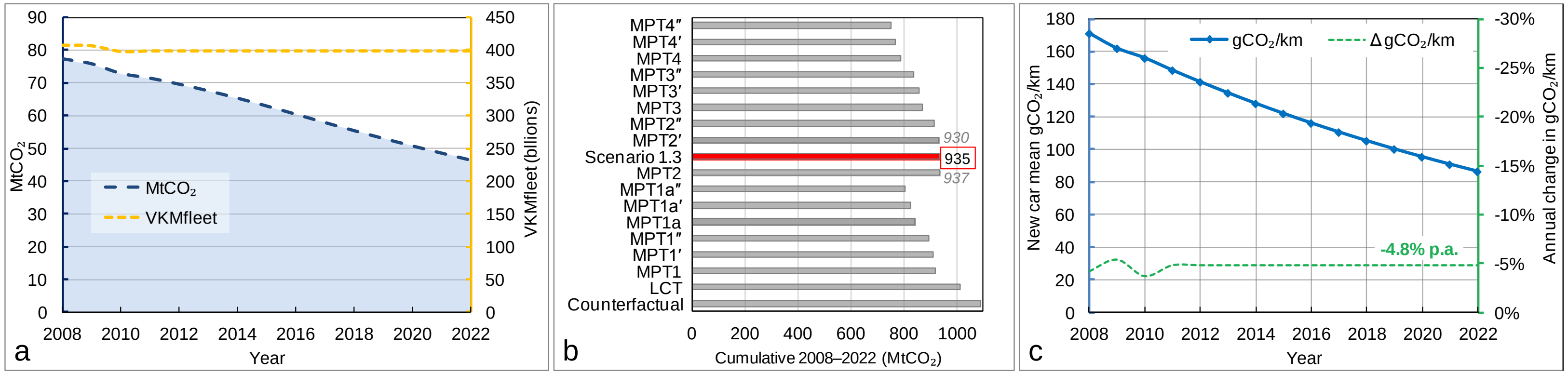


Figure 8.15: Scenario 1.3 – '*Intentional baseline*'

EU new car emissions targets realised as real world values

- targets delivered for real world uplift of +8.4%
- fleet profile 'A' (no growth)
- no growth in VKM_{fleet}

Figure 8.16: Scenario 2.1 – *Technology push, new car emissions restricted to 90 gCO₂/km (TA) in 2015*

- +8.4% real world uplift
- new car emissions decline by 3% p.a. from 2015
- fleet profile ‘A’ (no growth)
- no growth in VKM_{fleet}

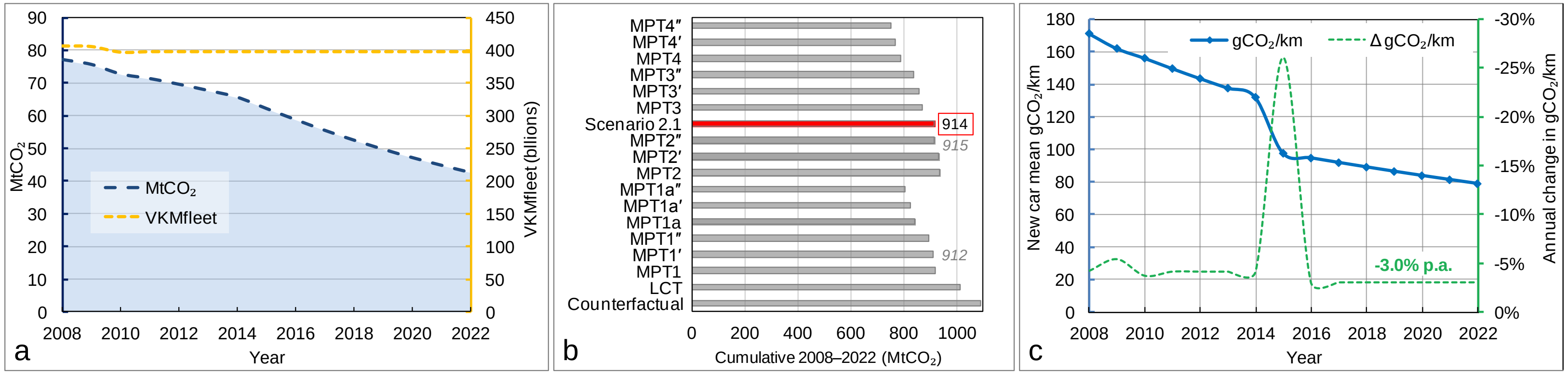
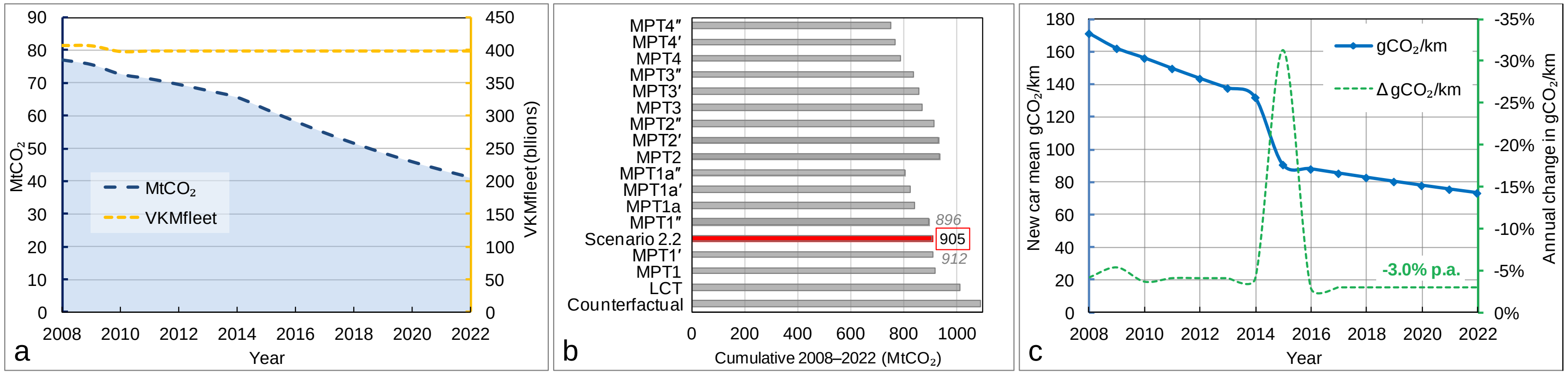


Figure 8.17: Scenario 2.2 – *Technology push, new car emissions restricted to 90 gCO₂/km (RW) in 2015*

- new car emissions decline by 3% p.a. from 2015
- fleet profile ‘A’ (no growth)
- no growth in VKM_{fleet}



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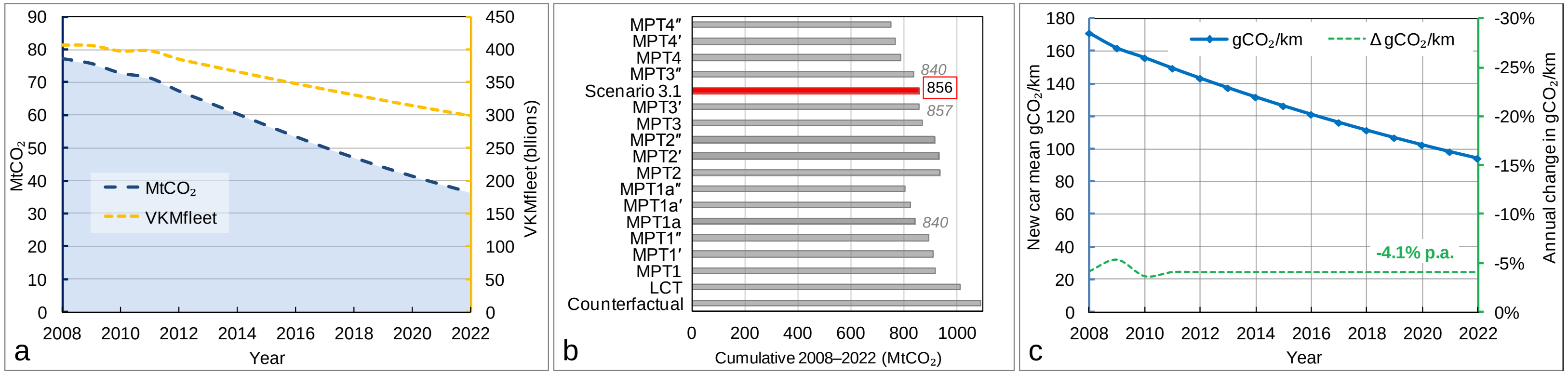

Figure 8.18: Scenario 3.1 – *25% demand reduction by 2022*

- New car emissions as scenario 1.2
- Fleet profile ‘A’ (no growth)
- VKM_{veh} declines to 75% of 2011 distance by 2022

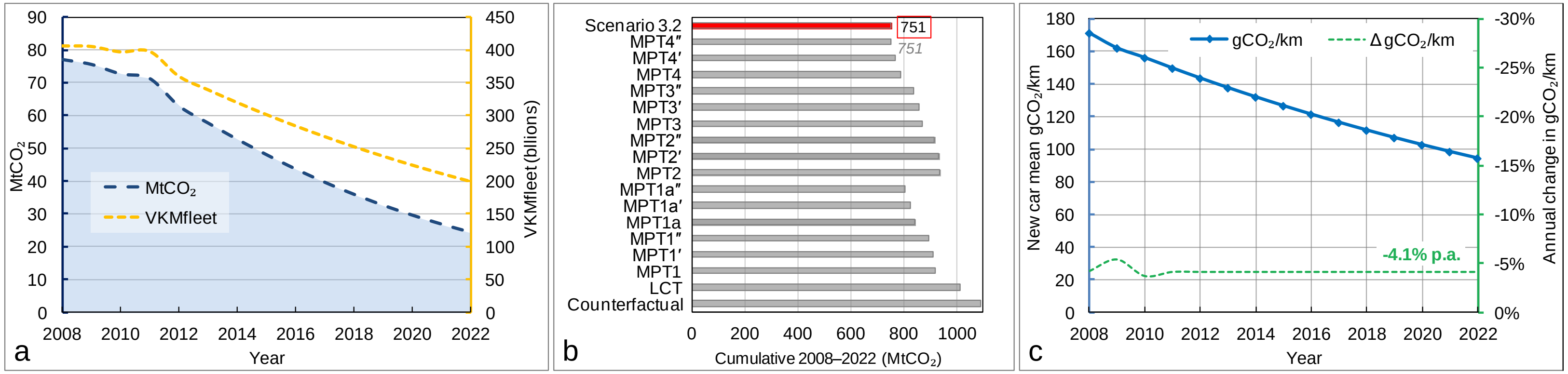

Figure 8.19: Scenario 3.2 – *50% demand reduction by 2022*

- New car emissions as scenario 1.2
- Fleet profile ‘A’ (no growth)
- VKM_{veh} declines to 50% of 2011 distance by 2022

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Figure 8.20: Scenario 4.1 – *Fleet growth, VKM_{veh} constant at 2011 level*

- New car emissions as scenario 1.2
- Fleet profile 'B' (0.6% p.a. growth)
- VKM_{fleet} +8.4% by 2022

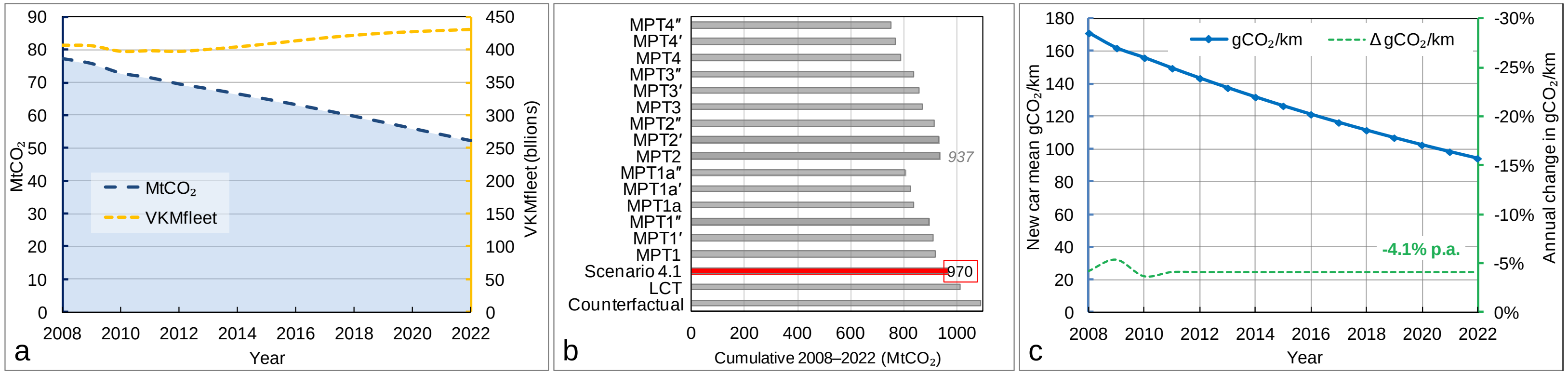

Figure 8.21: Scenario 4.2 – *Fleet growth, VKM_{veh} constant at 2011 level, EU targets realised as RW values*

- New car emissions as scenario 1.3
- Fleet profile 'B' (0.6% p.a. growth)
- VKM_{fleet} +8.4% by 2022

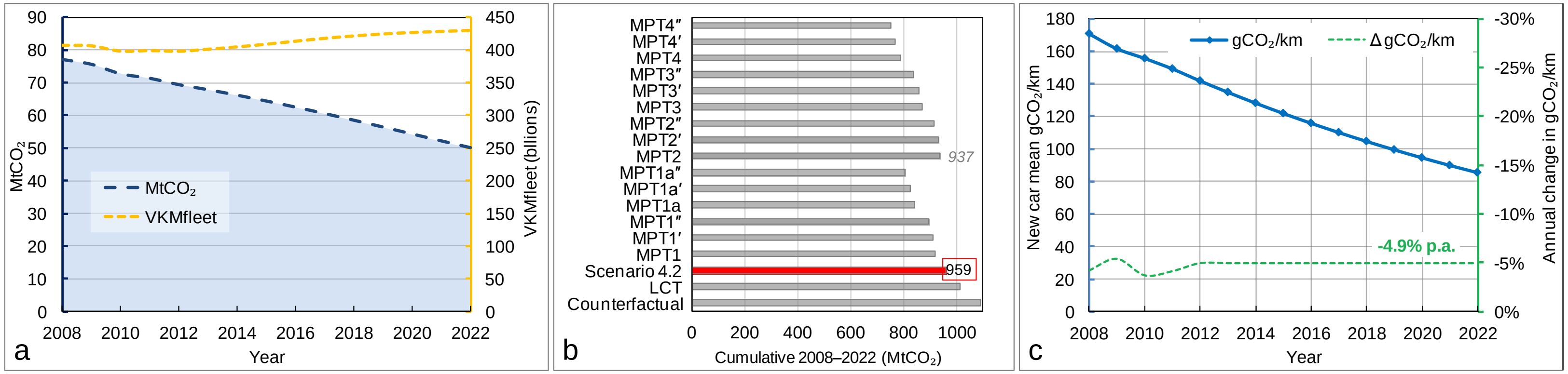

Figure 8.22: Scenario 4.3 – *Fleet growth, VKM_{fleet} capped at 2011 level*

- New car emissions as scenario 1.2
- Fleet profile 'B' (0.6% p.a. growth)
- VKM_{fleet} capped, assumes reduction in VKM_{veh} -6.6% by 2022

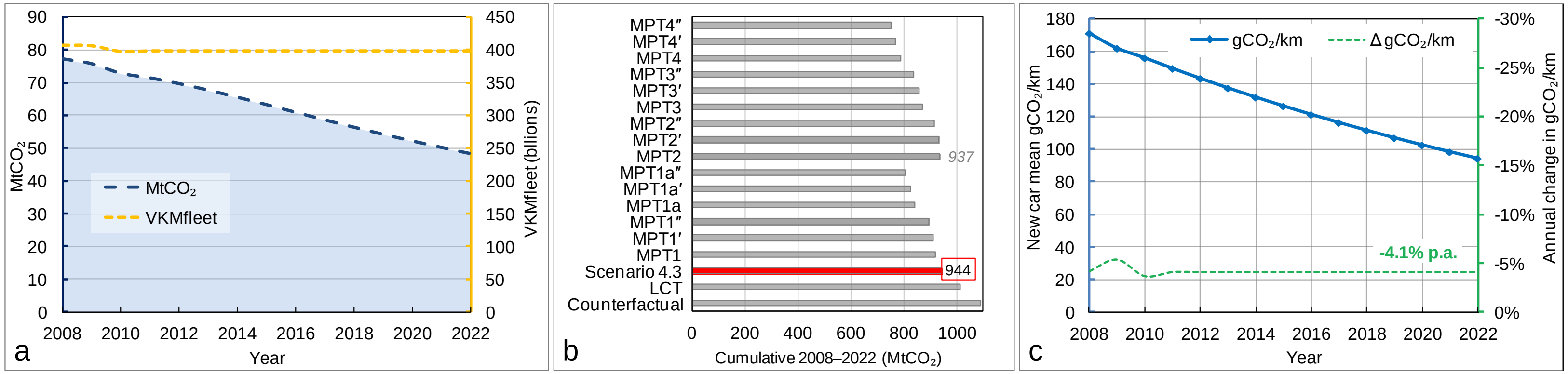

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Figure 8.23: Scenario 5.1 – *No fleet growth, +33% commuting occupancy*

- New car emissions as Scenario 1.2
- Fleet profile 'A' (no growth)
- Increased AVO for commuting trips yields reduction in VKM_{fleet} of 5.7% by 2022

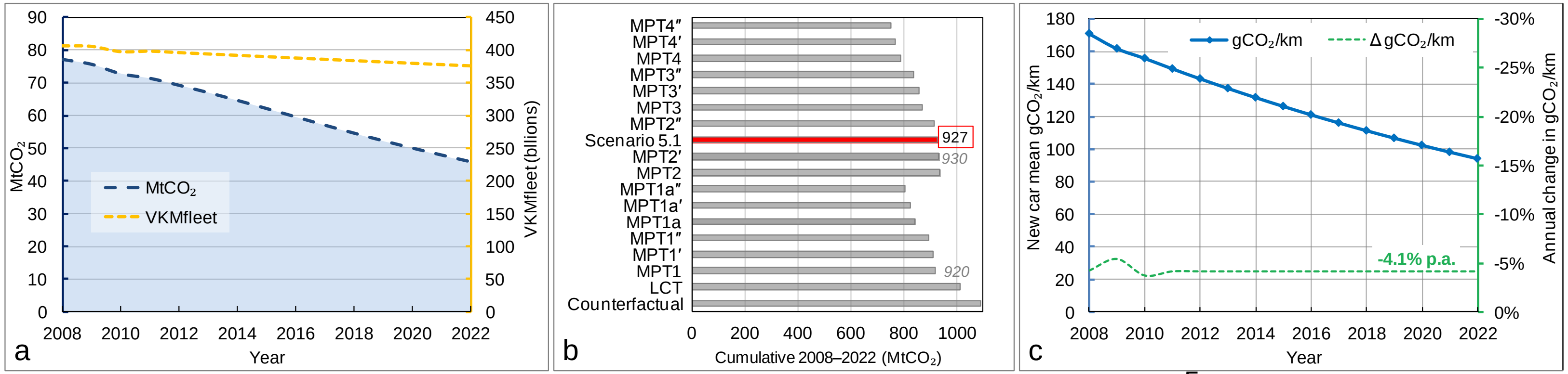

Figure 8.24: Scenario 5.2 – *Fleet growth*, *+33% commuting trip occupancy*

- New car emissions as Scenario 1.2
- Fleet profile 'B' (+0.6% p.a.)
- Increased AVO for commuting trips cancelled out by fleet growth
-

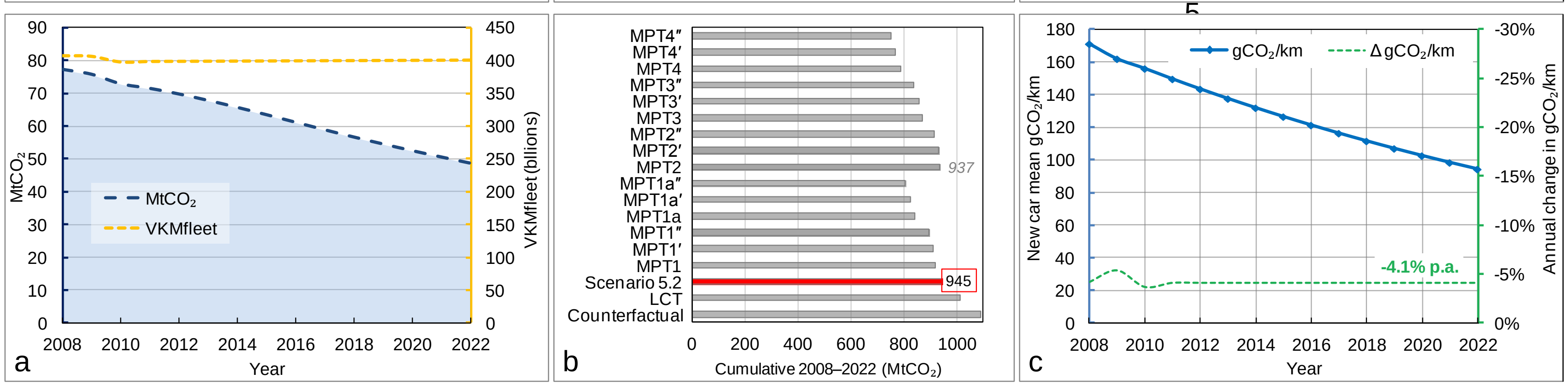

Figure 8.25: Scenario 5.3 – *+33% commuting trip occupancy, EU targets realised as RW values*

- New car emissions as Scenario 1.3
- Fleet profile 'B' (+0.6% p.a.)
- Increased AVO for commuting trips cancelled out by fleet growth

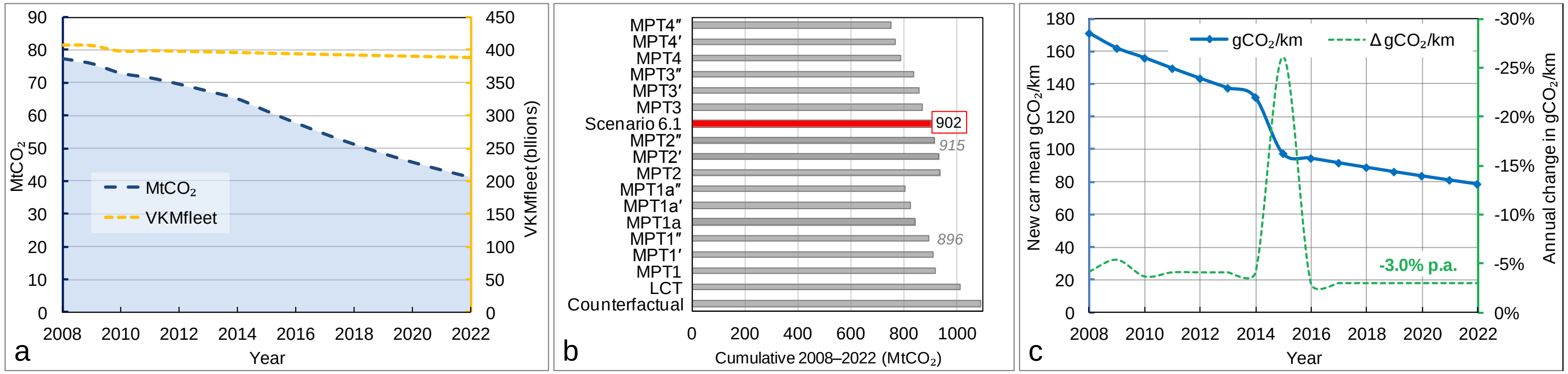

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Figure 8.26: Scenario 6.1 – *Fleet growth, technology push, +50% commuting trip occupancy*

- New car emissions as Scenario 2.1
- Fleet profile 'B' (+0.6% p.a.)
- Increased commuting AVO gives reduction in VKM_{fleet} of 2.6% in 2022

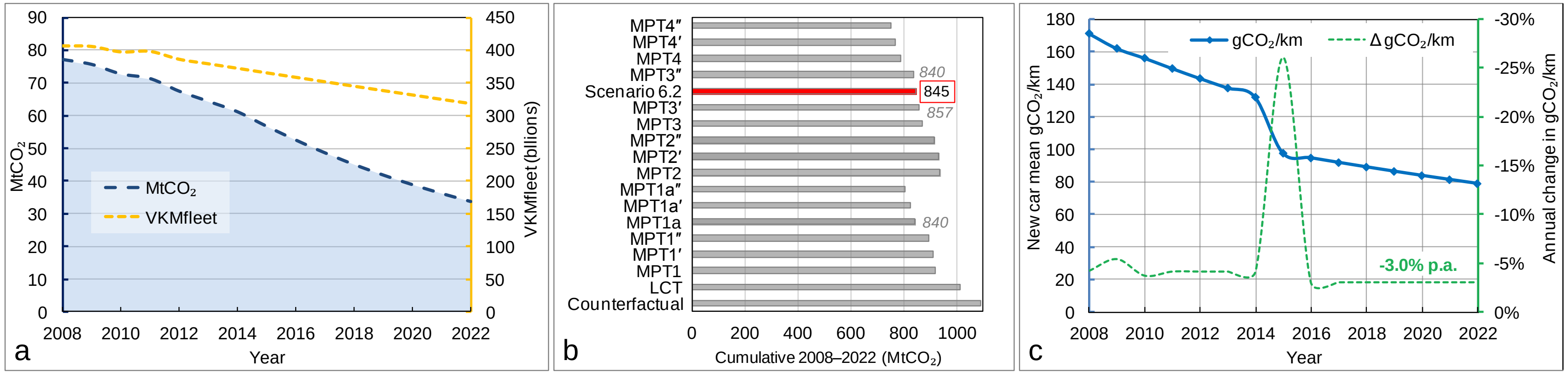

Figure 8.27: Scenario 6.2 – *Fleet growth, technology push, 25% demand reduction by 2022*

- New car emissions as Scenario 2.1
- Fleet profile 'B' (+0.6% p.a.)
- VKM_{veh} declines to 75% of 2011 distance by 2022, giving VKM_{fleet} reduction of 20% in 2022

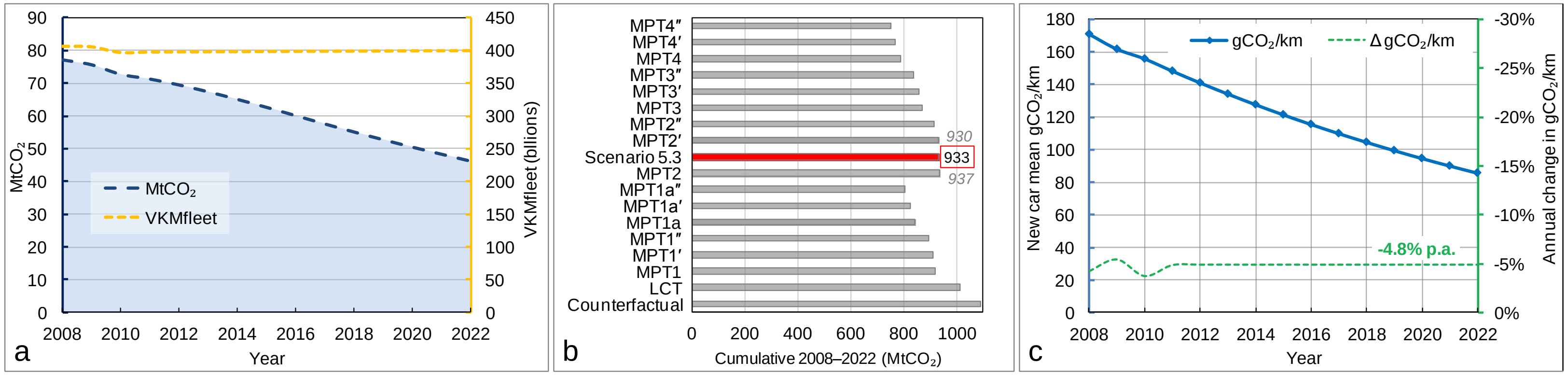

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Figure 8.28: Scenario 7.1 – *Retirement at 10 year historical mean*

- New car emissions as Scenario 1.3
- Fleet profile ‘C’ (no growth, increased turnover)
- VKM_{veh} held constant at 2011 level, no change in VKM_{fleet}

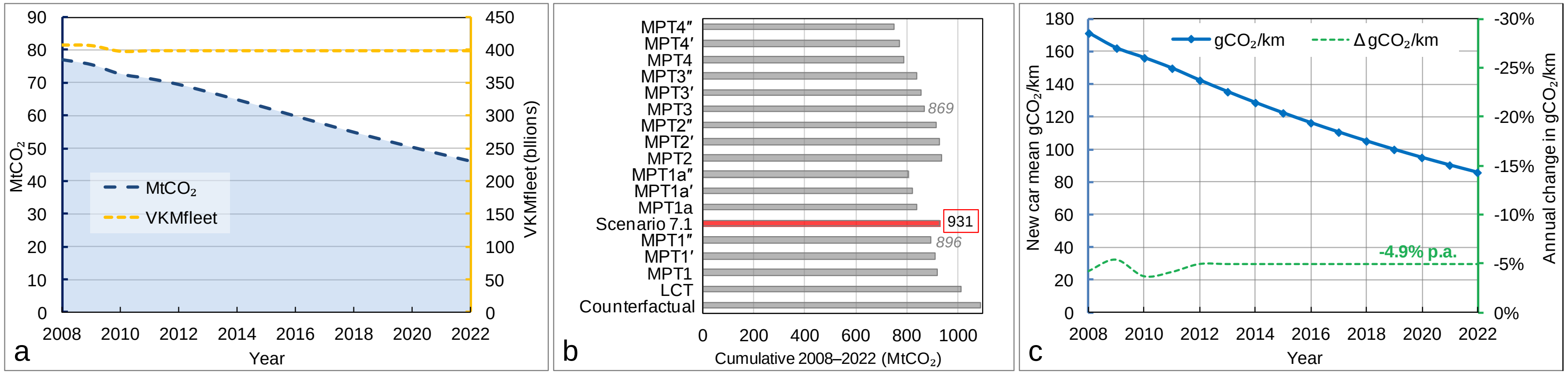
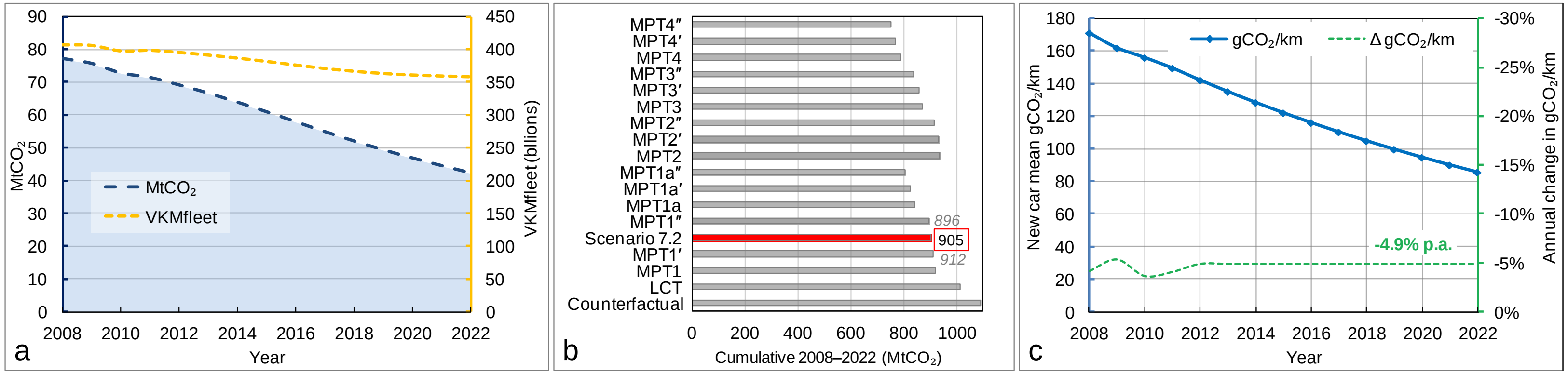


Figure 8.29: Scenario 7.2 – *2010 retirement and new additions held constant*

- New car emissions as Scenario 1.3
- Fleet profile ‘D’ (fleet contraction)
- VKM_{veh} held constant at 2011 level, VKM_{fleet} reduction of 10% in 2022



8.4 **Primary research interviews results**

This section summarises the key findings from the qualitative primary research task, based on a series of 42 interviews with car drivers (referred to throughout the remaining chapters by sequential reference number R01–R42), designed to explore the potential for the achieving levels of demand reduction at the scale and timeframe of those posited in the fleet emissions scenarios.

8.4.1 Interview sample characteristics

While the sample was drawn entirely from staff within the Manchester higher education precinct (University of Manchester, teaching hospitals, music college, museums, galleries, corporate and hospitality groups), the following section shows how the sample population breaks down in terms of key demographic characteristics and car use, and compares to the national averages where appropriate.

8.4.1.1 Gender, household type, car ownership

Of the 42 respondents interviewed, 18 (43%) were male, 24 (57%) female (Figure 8.30). This partly reflects the gender split in the initial responses expressing willingness to participate (44% male, 56% female), but more significantly reflects the main driving mode and daily distance of those initial email respondents. Quantity of car use was the main determinant of selection, while maintaining broadly representative shares of both genders.

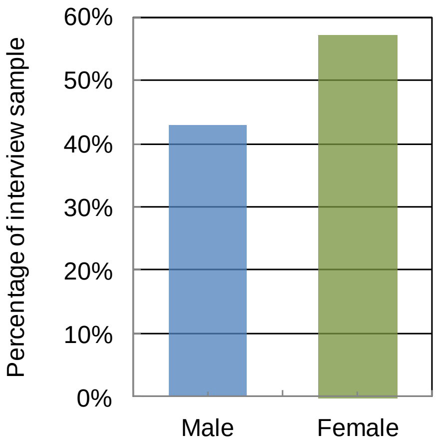
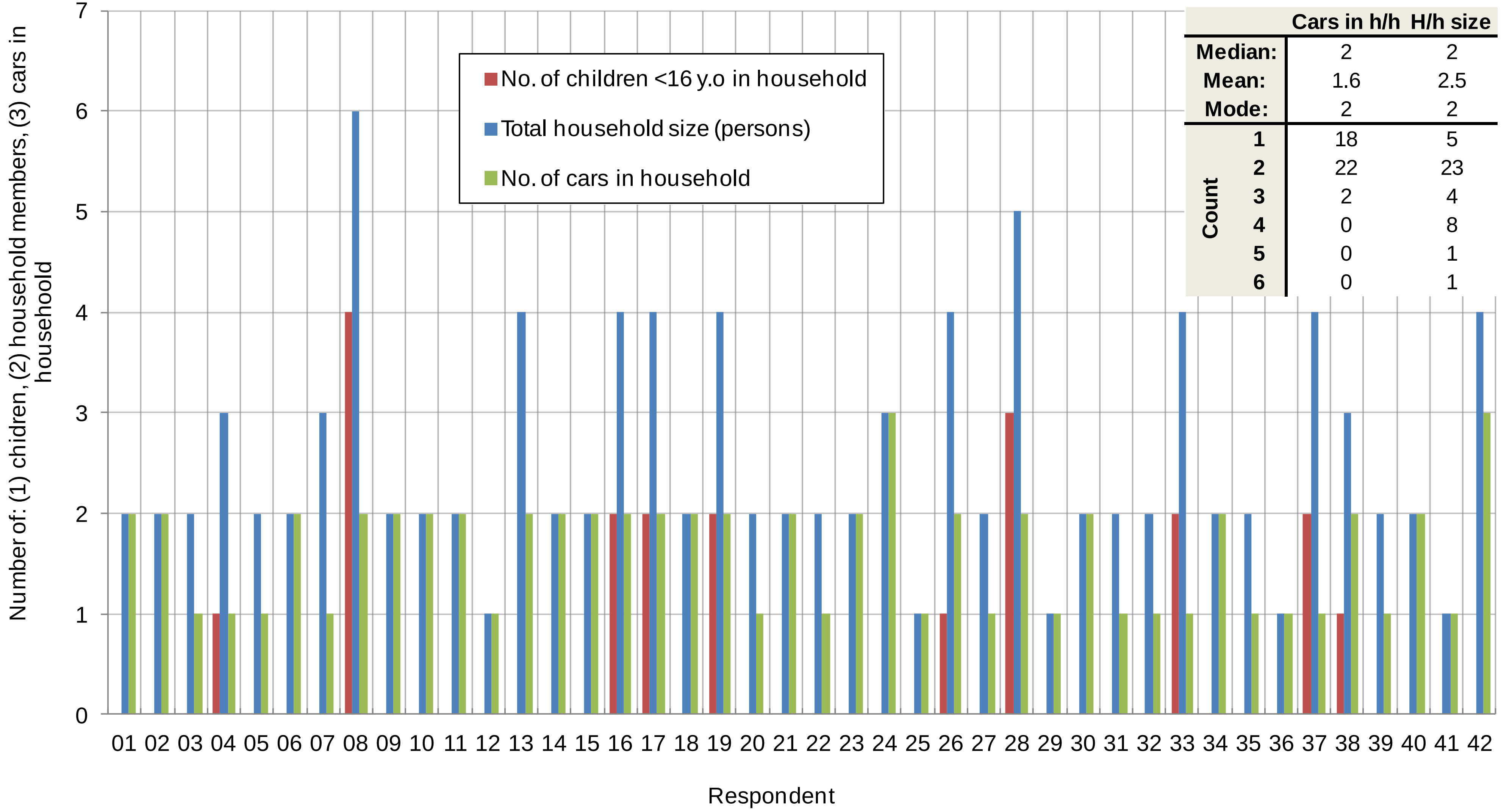


Figure 8.30: Interview sample proportion of men to women.

Data were not collected on respondents' ages, although the interviews themselves confirmed wide representation of age groups – from PhD students in their early twenties to members of staff about to retire, with an even continuum in between. Importantly, respondents' household types and immediate family groups were diverse (Figure 8.31), with mode and median values for household size and cars per household coinciding at 2. While households with two adults, two cars and without children were the commonest form in the sample (13 respondents), around one quarter of respondents' households included school-age children and several others included older children.



		Cars in h/h	H/h size
Median:		2	2
Mean:		1.6	2.5
Mode:		2	2
Count	1	18	5
	2	22	23
	3	2	4
	4	0	8
	5	0	1
	6	0	1

Figure 8.31: Respondents' household compositions and car ownership.

8.4.1.2 Job area

While respondents were not asked to provide details of salary or household income, the sample included representatives of various points on the staff pay scale, being drawn from support, academic related, academic and estates and facilities (with ‘junior’ and ‘senior’ staff members within each category), as shown in Figure 8.32. This was confirmed in interviews using salary-banded staff car parking charges as a proxy for salary. The full range of parking charges (from approximately £12 a month to £33 per month) was represented in the sample.

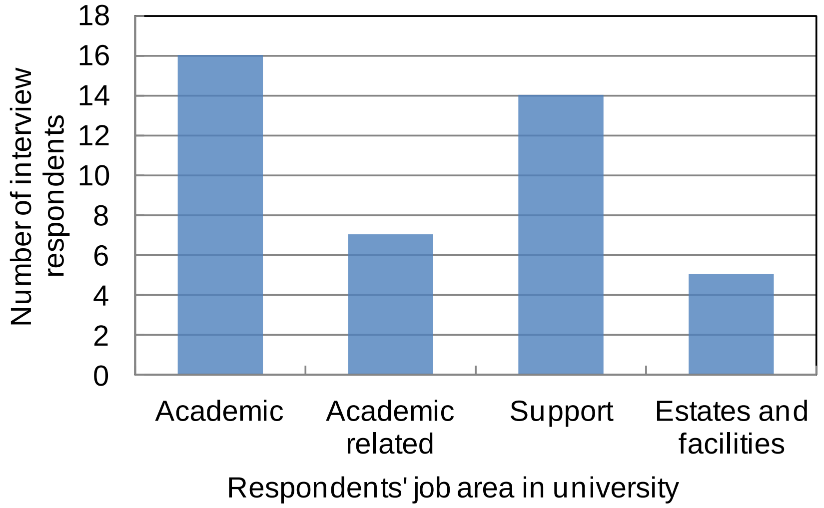


Figure 8.32: Interview respondents’ job areas within higher education precinct.

8.4.1.3 Geographical coverage

The University of Manchester and wider higher education precinct employs over 11,000 people, drawn from a large geographical catchment centred on the main campus in south Manchester, lying approximately 1.6 km from Manchester city centre. Figure 8.33 shows the approximate position of respondents’ home locations relative to the campus, with an indicative categorisation of residential density and settlement type. All respondents except two make return trips for each working day on campus. Respondent R18 makes a return trip from Hull (East Yorkshire, approx. 160 km from Manchester) once a week, residing near to the campus in South Manchester during the week; R21 travels in from Northallerton (North Yorkshire, also approximately 160 km from Manchester) and remains in Manchester several days at a time.

8.4.1.4 Daily and annual car use

Based on pre-interview questionnaire answers and interview dialogues, estimates were obtained for each respondent’s annual distance travelled as a driver, and their daily return trip commute by car (Figure 8.34). For the small minority of respondents who use another mode of transport for part or all of their commuting journey, only the distance travelled by car is used here. Figure 8.34 also compares the mean and median values both daily and annual driving distance in the sample with equivalent estimates of national means per driver.

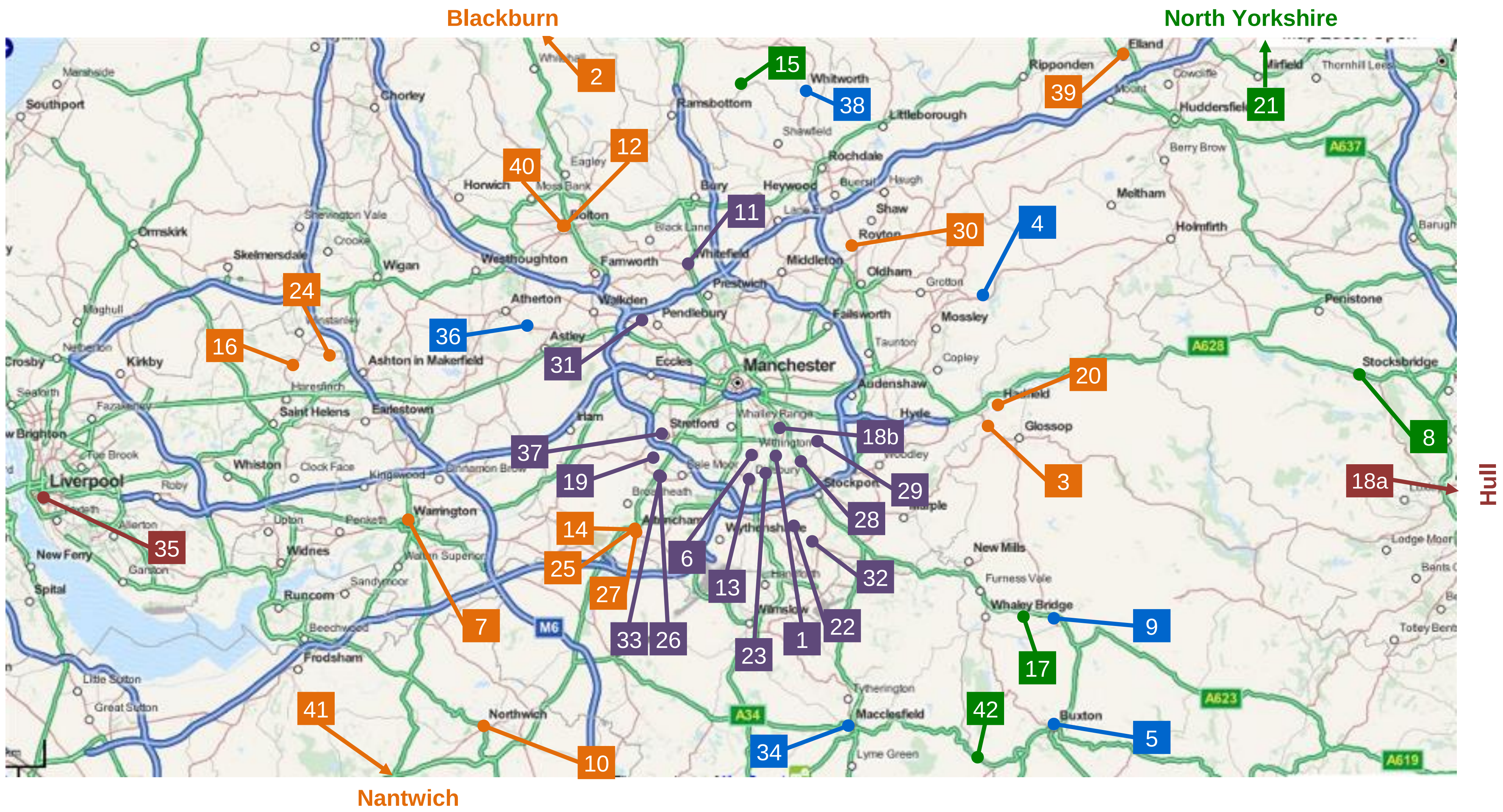


Figure 8.33: Relative positions of interview respondents' home and University of Manchester (U of M), and classification of home area by housing density and settlement type. (Base map: Openstreetmap) Sub-urban Satellite town Urban Semi-rural Rural

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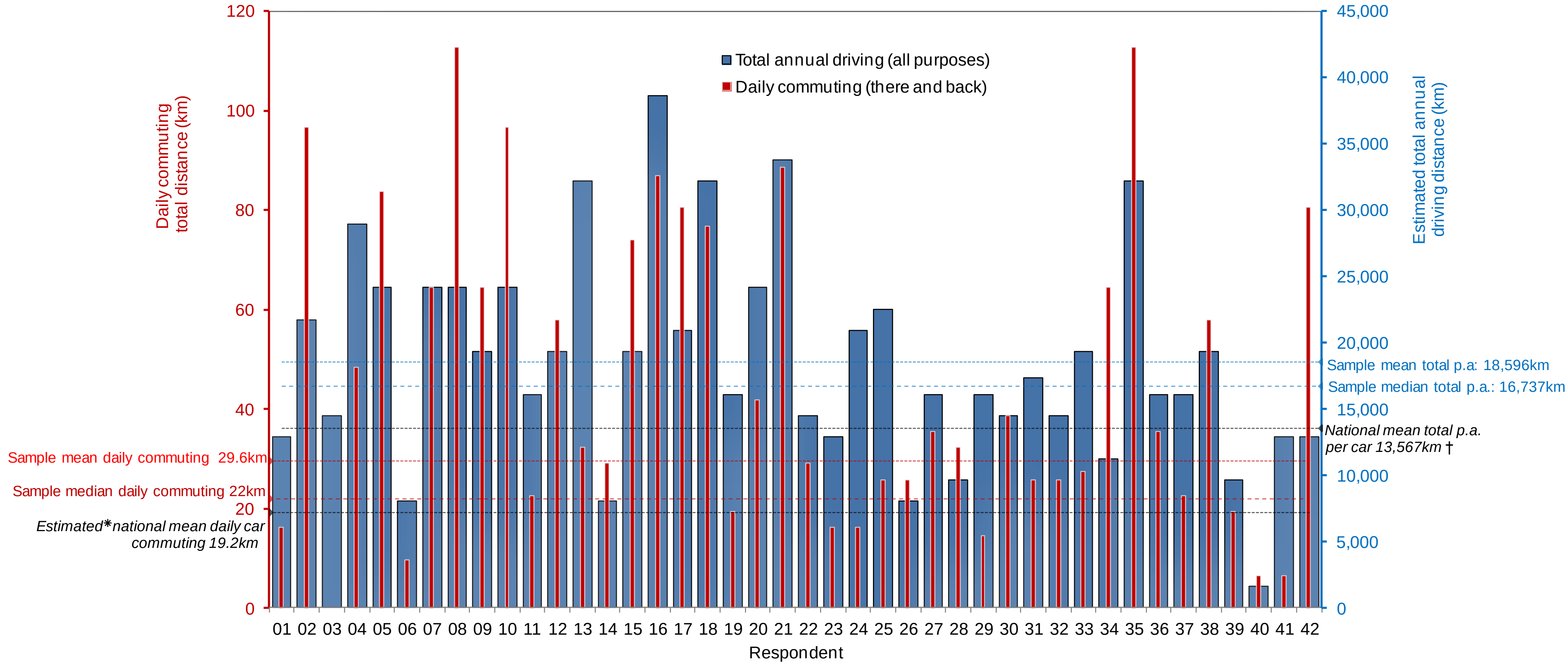


Figure 8.34: Respondents' annual driving distances and daily car-commuting distances, with sample mean and median values, and national means

✱ National daily mean car-commuting round trip distance is estimated from NTS data (NTS0901) on the proportion of mean annual distance travelled for commuting purposes by cars, shared over 220 working days (see discussion §9.4.2).

† National mean annual distance per car is taken directly from NTS0901. The values given for respondents' annual driving distances are based, in most cases, on car odometer and MOT records, insurance statements of fact etc. Where respondents have access to multiple vehicles, an estimate was made of mean distance travelled by all cars.

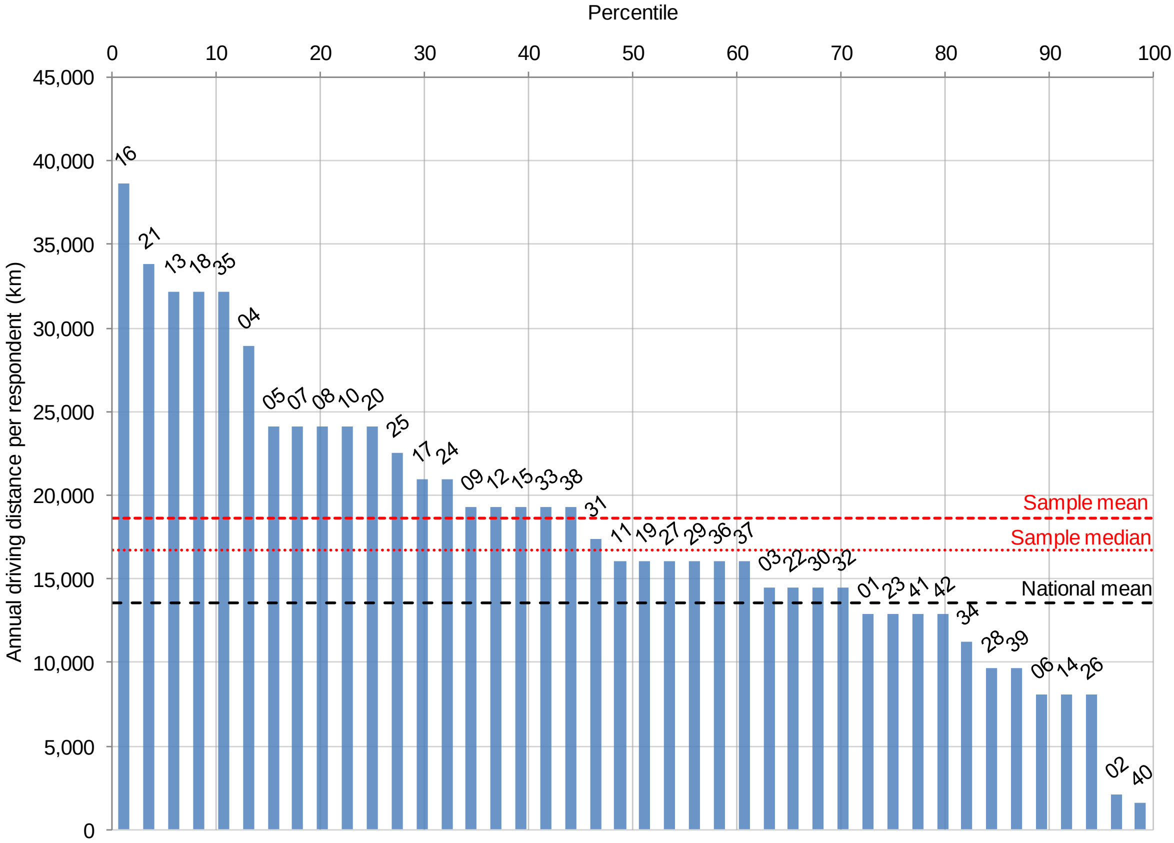


Figure 8.35: Respondents' annual driving distances arranged by percentile. Data labels on columns are respondent reference numbers.

The key feature of the annual distance data (arrange by percentile in Figure 8.35) is confirmation that the sample population contains a majority of respondents who drive more than the national mean. As can be deduced from Figure 8.36, the national median lies close to the national mean, indicating that the sample also includes representatives of the upper quartile of annual distance drivers nationally. It is also noteworthy that the highest annual distance drivers do not correspond in every case to the highest daily commuting distance drivers in the sample, although there is a broadly strong correlation between daily car-commuting distance and total annual distance.

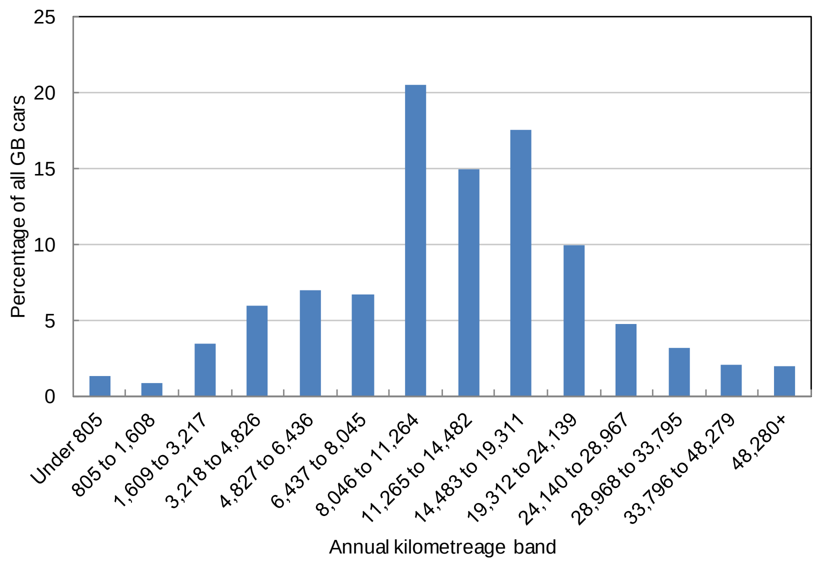


Figure 8.36: Distribution of per car annual driving distances of all GB cars. (DfT 2011b: NTS0902)

8.4.2 Limitations of the sample

As noted in §7.3.1 and §7.3.2, respondents were selected primarily for their regular car drivership. As acknowledged in §7.3.7, the upfront provision of information about the purpose of the study creates the possibility that a self-selection bias may be present in the sample, favouring people with strong views about transport policy and environmental issues, or simply biased towards those with more flexible work patterns that allow them to participate in an interview. The former bias was certainly detected at interview – opinions and beliefs were strongly held, but not discernibly for or against particular agendas. The latter bias is also in evidence insofar as no manual staff were amongst the respondents to the initial contact email (indeed none were amongst the long list of potential candidates who provided their contact details in the staff travel survey), and there is a decidedly professional and academic skew to the sample job types (Figure 8.32), which may also speak of higher than average incomes amongst the sample.

The focus on commuting in the selection process as a proxy for annual distance is admittedly crude, but proved effective in targeting ‘higher than average’ annual mileage respondents (see Figure 8.34 and Figure 8.35). Note that interviews covered the full extent of respondents’ driving for all journey purposes, and were not limited to the commuting portion of their driving.

Other groups of drivers may exist whose annual mileages are considerably higher than any of the respondents interviewed here, such as company car drivers with a generous private mileage allowance. However, while the sample does not attempt representativeness (see §7.3.7), nor does it claim to capture the very highest mileage drivers in the country. It is notable that several respondents had experience of much higher annual mileages, either from personal history or through an immediate family member or spouse. Nonetheless the inclusion of six respondents whose annual mileage is over twice the national mean – and 70% of respondents having annual mileages above the mean – offers some reassurance that insight into the issues relevant to higher mileage drivers should be obtainable from the sample.

The foregoing considerations notwithstanding, it should be reiterated, as stated in §7.3.7, the sample is in no way intended to represent the university staff, the population of the local area or the UK driving population at large. The purpose of the semi-structured interviews is to yield descriptive, highly nuanced, understanding of the issues that pertain to rapid demand side reductions in emissions from passenger car use from the point of view of regular car drivers. Summaries and highlights of the qualitative findings are presented below in §8.5.

8.4.2.1 Car dependence

Question 14 in the pre-interview questionnaire asked respondents if they considered that their current lifestyles *required* the use of a car. Thirty–five of the forty-two respondents (83%) answered with an unequivocal ‘yes’. Of the seven respondents who said their current lifestyle did not, in truth, require the use of a car, two answered conditionally, saying that better provision of public transport – if made available – would mean they could cope satisfactorily without a car.

8.5 **Qualitative interview findings**

The following sub-sections present findings from analysis of the extensive qualitative dataset extracted from the transcripts of the interview dialogues. Comprising in excess of 2000 discrete quotations, the dataset is too large to attempt comprehensive representation; indeed there is considerable scope for further analysis to yield useful insights on a wider range of transport and behavioural issues than are at stake here. For this analysis focus is restricted to the potential for achieving reductions in per person driving distance at non-marginal rates in the next decade, especially amongst the highest annual distance car drivers.

Results are presented as an overview of conceptual themes that emerged from the data during the iterative process of primary and secondary coding and grounded 'theory building'. Quotations from the interviews, which exemplify and illuminate these themes, are provided as appropriate. Within the terms of the analytical framework sketched out in Chapter 1, §1.4, interview dialogue themes fall into three distinct groups, pertaining to:

i. contextual, structural and lifestyle constraints, or 'lock-ins' to driving;
ii. reasoned resistance to demand reduction, based on individual preferences and 'motivations' for driving;
iii. suggestions and indications of potential for overcoming resistance or forming new habits.

Arranged in these groups, themes are identified separately below. In each case a short descriptive title is given and a measure of the 'density' of each theme is given as number of separate primary (open) codes linked to each theme during textual analysis of the interview transcripts (the list of codes associated with each is tabulated at the start of each subsection). A measure of the 'groundedness' of each theme is given as the number of discrete quotations from the interview database to which the theme directly applies[121].

Quotations are drawn from the full pool of respondents at large, without differentiation along socio-economic, attitudinal or other categorisation or segmentation line. As noted in Chapter 7, the sample targeted specifically drivers who deemed car use an essential feature of their lives, so further segmentation is not pursued as the basis for analysis of these findings. However, particular characteristics of respondents' backgrounds are flagged up where they are especially germane to the themes and quotations presented below. The themes identified are discussed critically in the next chapter, which brings the findings of each stage of this research together with observations from the wider literature. Quotations are offered as instantiations of the themes presented, and it should

[121] Quotations are heavily elided for clarity and concision in reporting, although every care is taken to faithfully preserve the original meaning in context.

be noted do not always capture the complexity of the position espoused by the respondent in question. To attempt to preserve something of the narrative thread of each individual interview, brief summaries of the key themes of each interview are provided in Appendix 11.

8.5.1 Structural constraints and lifestyle-based lock-ins

Themes relating to infrastructural, socio-economic and personal circumstance, which are typically described by respondents as beyond their control, feature strongly in many descriptions of car use in the interview dialogues.

8.5.1.1 Lock-ins to driving

Groundedness: 25 quotations

Density: 21 codes

Associated primary codes:

car: as a utility vehicle	PT: difficult with luggage
car faster door-to-door	PT: difficult with young children
dependent on car	PT: poor rural service
driving: children necessitate car	PT: takes too long
job prospects depend on car	PT: unreliable
job: commuting requires car	PT: unusual hours
job: influence on home location	rural location
job: work requires car	social group: older generation
job: irregular / antisocial hours	social group: restricted mobility
land use: car-centric development	station / stop: distant
personal security	

Implicit references to structural lock-ins recur throughout the interviews, including proximity of home to amenities, employment, schools and leisure venues. Respondents who live outside of the Greater Manchester conurbation and those with dependents appear especially subject to travel constraints that are perceived as ‘externally imposed’. This theme reflects both how the availability of relatively cheap and time efficient private transport affects decisions about work, schools, proximity to family, etc, as well as how those factors themselves influence transport mode choice.

8.5.1.1.1 Employment

Noting the employment options opened by access to driving, R01 talks about their partner’s 110km daily roundtrip drive to work: “*You can’t even do your job [using public transport]. And my partner [a teacher]...there is just no way. She can do it now by using a powerful fast car to cut down the time and so she is less tired, she can do the job and come back ... so she is on time. But unless Doctor Beeching never existed and there was a train line ...one change and then it goes to Accrington [place of work]. So you know, you go into a central hub, and it may exist, but then you get to Accrington and the bus in the suburb of Accrington – how many tickets have you got to do that? You know, there is no bus to [nearby station], so she'd have to walk ... carrying a load of books or* *whatever, it's just impossible. So there are large groups of people it seems to me, for whom it is impossible not to use private transport.*"

R40 tells a similar story about their partner's 90km roundtrip daily drive to and from work: "*I mean, he looked into [public transport] because he really hates driving. But he'd have to get like a... I think he'd have to... get a train into [Manchester] to get out to Warrington, and then he'd have to get like a bus down to Daresbury [town near place of work] and then he'd have to get a taxi from there to where he works. ...I think there's a hotel there, and various other offices and that's it. Because...there's nothing else around and that's why he just has to drive – he literally looked into and worked out it would be about three and half hours...to get there...[without driving]. Maybe he could just live at work*."

Speaking about the mutual influence of work, home and school locations, R04 also reflects: "*Part of it is that a house was bought when someone worked in that locality, they've taken a promotion or different job for whatever reason, but they want to keep hold of that house that's theirs. And the kids in the schools that they're settled in. Rather than relocate for work, if you can still do a 40 mile each way commute*. *I don't know to what extent housing policy and the finances of housing and the sociology of home ownership influences employment and mobility. Those three are related to each other.*"

Others speak of compromises in selecting home and work locations between themselves and their partners. R07, for example, explains their choosing to live at a distance from Manchester: "W*e moved to Warrington because my husband worked in Liverpool, and I work in Manchester. So we live literally halfway between the two. But now, he's changed his job now, so my husband's got a work van, which he does travel to work in. So he has a works van parked on the drive. But he travels a lot further than I do every day because his job is ... [in] grounds maintenance.*" Housing costs in desirable areas of suburban Manchester also feature as a reason for choosing to live at a distance from one's place of work. R09 recalls: "*I live 20 odd miles away, because when we were looking for a house, we lived in the centre of Manchester... and we decided we wanted to move out that bit further, but prices go up and up and you've got to go a certain distance before it drops so you can afford it. I don't particularly want to live that far away, it was just for affordability...when we were looking to buy a house 12 or 15 years ago. We are actually looking to move now, to move closer so our journey time is shorter, because now we can afford a more expensive house*."

R18 argues that, "*People have... started to build up a lifestyle based on what's available, and they started to make a contributions and work with their communities and now suddenly that's being withdrawn from them, because of the pricing. The easiest way is like... if you think back to the First World War when the government issued cigarettes, for example. And now people of older ages are getting lung cancer and being told they shouldn't smoke, and they're saying, 'well the government issued cigarettes'. So it's a little bit like having a set of policies in place for one thing, that later in your life actually change. And you're being told to reverse those. And actually what you've been doing is following what you thought was right, and the consequences then have to reverse it. ... I think the issue with some of the agendas is that you're being led one-way, work very hard for it, and then the policies switch. And people are actually being discredited for the things they worked for, simply because new consequences have arisen, from the fact that people are doing things*"*.*

R14 observes that a difficult, competitive job market may be responsible for causing people to travel to work further afield than they would choose otherwise, saying, "*My dad lives in Manchester...and drives to the other side of Birmingham every day to work. So for these kind of things, they would have a massive impact on him. Because of the kind of work that he does, it's the only place that he could get a job, he'd been made redundant. And for him not to be able to drive, or to have to... if he couldn't commute, it's impossible for him to get to where he does for nine o'clock in the morning... So he would be vehemently against anything like this, because it would massively... it would either mean he lost a hell of lot of money or he wouldn't be able to do that job*"*.*

R18 speaks from first-hand experience: "*Because I work in innovation and innovations translation and scaling, and also development of technology, to actually move to an area where there is sufficient people and dynamic resource, and a density of population, I have to be either in somewhere like Manchester or London. That can't actually be done in somewhere like Hull [their primary residence]. It's the need for the size, that actually effectively demands that I have a car. And that affects the emissions. So in one sense I pay for the emissions as a result of my job and my profession*".

R15 comments on the social and economic mobility that come with having a car in formerly industrial, now economically depressed areas, describing the area in which they live as, "*a steep-sided valley that few people escape from...You can escape from it if you have a car....When I grew up there were slipper factories and a few shops. So if you wanted to get a decent job you had to have access to transport outside of the area, which is still really by a car. ... When I was growing up, there wasn't proper public* *transport in place. There wasn't even the motorway, so you'd have to go by bus to Bury, then by bus from Bury to Manchester. So...having a car gives you the privilege of being able to seek better employment outside of the area that you're living. And Rossendale is increasingly an overspill from Manchester, there's a lot of people that commute into Manchester. But [for] the Rossendalians who are [left] behind, it's quite a deprived area. I mean...a massive rate of unemployment*".

R11 sums up the bind they see in terms of their current daily travel options: "*I suppose it's because I feel that I can't do anything. Because, as I've said before, the Metro is too dear, buses are uncomfortable and slow - it's probably not that much, it's probably about the same as the car - but highly uncomfortable. You know, and they don't turn up. And the whole waiting for a bus as well, you had to add that to your time, to your journey time. So no, I wouldn't do anything, I may cycle into town occasionally, but I just know that that will stop once the traffic picks up again, because it's just not safe. Well, it's not pleasant. So I'm in this situation now whereby I feel that the government has to make some changes and put some money into public transport before I could really do anything*".

8.5.1.1.2 Business

Several respondents report regularly needing to make impromptu work trips off-campus to unfamiliar areas, often carrying equipment. R02 describes their work duties in education: "*I'm driving around going out from the university, out to visit students in school when they're on teaching practice*." Similarly, R28 explains: "*We have two cars because my husband has a company car and has to have a car for work, and he works in construction, so it could be anywhere. He uses the car 24/7. The car's given to him and he has to use that, we couldn't do without that car at all. And similarly the car couldn't be unavailable to him during the day*." R32 recalls that until recently their livelihood depended on driving a relatively high annual mileage: "*I've only been at the university for three years; before that I was self-employed selling carpets, so my annual mileage was about 25,000 a year, because I had to obviously travel around to see people My mileage has decreased from 25,000 to nine [thousand]*".

8.5.1.1.3 Security

Others noted personal security issues with respect to walking and cycling, making driving appear a relatively more secure option. R30, for example, points out: "*The reason that I drive in is because where I live is down in a valley, that is woods, a river and woods right at the back of my house, and the only way that I could get to a bus stop in a morning is to walk through those woods and they're unlit. It's an absolute no, no. I could possibly do it in the summer but I'd still feel extremely concerned and be walking about with alarms and everything*."

8.5.1.1.4 Geography and terrain

Having recently moved from Manchester into a semi-rural area nearby, R03 admits to having taken for-granted the opportunities for non-car mobility in the city: "*To be honest in the rural areas, that's the other thing I underestimated, is a proper load of shopping, four miles across hills is a lot more effort than one mile on the flat...by bike. I was looking at getting a cargo bike when I was in [Manchester] for making it even easier. But now I kind of look at the bike and look at the car, and I think 'oh, it's four miles ...over a big hill, and I want to get some beers'*".

Conversely, others commented on the urban and sub-urban landscape as militating against non-car mobility, with edge of town retail and employment hubs in particular requiring a car to access them. R05 states: "*I struggled living in Liverpool in that you were doing quite massive journeys it felt like, to go and do the shopping and everything had to be car or public transport based. There was no local or no feasible local shopping for example."*

8.5.1.1.5 Physical mobility

Several respondents described close family members who depend on driving (or lifts from drivers) due to restricted physical mobility. R03 states: "*My parents' lives wouldn't operate without their vehicles. They couldn't do their jobs. Partly because of where they live and where they've chosen to work. Partly because my mum's got arthritis...*". R05 reflects that a combination of factors including old age, remote rural location, hilly terrain and harsh winters make driving a necessity: "*Having been brought up in the middle of nowhere, literally in the middle of nowhere on top of a hill...a [four wheel drive car] is... certainly is quite useful. We never bothered with one when we were little, because it was only a mile and a half, two miles to walk to the nearest town. But now they're in their 70s, I keep pushing them ...to get something that's a bit more sturdy, because ...they can't get up and down the hill in snow. I think they're too old to cope now.*" R20 relates the difficulties of hospital visits without use of a car from outlying areas: "*My [mother-in-law] who was elderly... had to go on a bus to go from Tintwistle to Wythenshawe – it was just easier to go to the moon and back*."

Others, such as R22, relate how they support people who are physically reliant on door-to-door car transport: "*I mean the only reason really I have my car is my partner, who is quite a bit older than me and he struggles to walk any considerable distance so, he is more dependent than me on the car really. So it is really for him that I keep the car. ... He wouldn't be able to get out and about to the same degree ... if he is going through a bad phase then he is just not mobile at all so relies on me and the car.*"

8.5.1.2 Time constraints – 'driving as a necessary evil'

Groundedness: 29 quotations

Density: 26 codes

Associated primary codes:

bus: takes too long	driving: wasted time
car: as utility vehicle	job prospects depend on car
car faster door to door	job: commuting requires car
cut driving: recognise need, but..	job: work requires car
cycling: would if I could	job: workload dictates commuting mode
dependent on car	PCT: beyond my control
driving: as social enabler	PT: poor rural service
driving: children, necessitate car	PT: takes too long
driving: cost differential with PT	PT: willing to pay for better
driving: difficult to reduce	PT: would prefer to use, but...
driving: dislike	scenario: mixed reaction
driving: lifts for other people	snapshot
driving: stressful	time constrained, busy

Closely related to the structural lock-ins theme above, there is also a strong thread of evidence suggesting that car driving enables respondents to meet their family and work obligations and responsibilities in a time-effective way that would not be possible without driving. Furthermore, the travel obligations placed by employment (and self-employment, in several cases reported directly and indirectly) are effectively 'fixed points', which are, in many respondents' experience, not open to negotiation.

There was also a palpable sense that while many respondents saw driving as a means to an end, it was not always their preferred choice of mode, if indeed the journey in question would even be made at all for preference. This theme reflects both the time pressures felt by many respondents, as well as the 'conflicted' perspective reported by many who professed either an active dislike of driving itself (often due to perceived stressful aspects of driving), or a desire to find less polluting or otherwise less environmentally detrimental means of travelling. Often driving is effectively a compromise between personal preferences and the obligations placed by daily schedules of work, family and social life. Respondents who acknowledged being consciously aware of undesirable structural lock-ins to driving often viewed them as temporary, arising from particularly busy periods in their life, relating to demands placed by combining work and childcare for young children, or supporting elderly relatives, or during transient career stages such working away from home.

For example R27 describes juggling their busy schedule: "*I think it very much depends on where you are in your life at the time and what commitments you've got around it and I see what you say about school buses, etc, etc, but speaking from the point of view of a woman, a woman generally doesn't just go from A to B. ...You'd be perhaps going to school, you'd perhaps then be going to do the shopping, you'd then be doing something else. So it's a myriad of trips isn't it.. each outing isn't one trip. ...That would not be possible on public transport ... And when you've got those commitments, one thing you don't have is the time... if you had time on your hands then you could be more open to structured timetables etc. I think busy lives... For ten years I used to drop my son into... drive into Manchester, drop my son at school, I'd be doing shopping into school, I'd be coming into work, going back, picking him up, perhaps to after school clubs, different things. And eventually you'd get home. But that car was a tool.*"

In a similar vein, R28 is typical of several respondents with young families, when they observe: "*The issue we have at the moment is the age of the [three] children, and the amount of junk they have to bring with. So things like the travel cot, the pushchair, obviously x-number of clothes. That's actually where it becomes quite hard, because you couldn't just pack a bag and go.*"

Nearing the end of a fixed term contract during which they commute from Liverpool to Manchester, R35 observes "*Now I'm in a situation where I've had to take this decision [to travel] by car and all this stuff, but...in my next stage in life I'm going to try not to be in that situation again. You know, so hopefully I won't and then I can get rid of the car. So it definitely has... yeah, it is part of how I plan my life.*"

R07, a reluctant driver, notes the impracticality of using other modes for their daily commute: "*I mean I'd be more than happy to get public transport, if it was easier ... If I had to come on public transport ... I'd be getting up at 04:30 in the morning to get in to work. So there is no other way of me getting to work other than by car.... The other problem with that is that the public transport costs are going up as well."*

R17 describes a preference for using public transport: "*I do use the train when my wife's not going to work, because she can take the kids. And I thoroughly enjoy it. I prefer it to driving, [which] most of the time is really unpleasant, I much prefer using the train. But parking is an issue down there. At the times when you're travelling it would be already full, because most people get the earlier train*". The same respondent goes on to say that driving is "*not healthy, apart from anything else, as an individual. All that driving isn't* *good for you. It's a time thief. I don't get home until half past seven*." Many respondents referred to driving in similarly negative terms, but simply see no alternative. R19, for example, says "*Actually all I'm thinking of when I'm in the car is getting to work, it's not* my *time. It's just stressy traffic time*." R18 is even more reluctant: "*If I could I would ditch my car, quite happily I would ditch my car, I think that's the first thing to say. Not particularly from a 'green' perspective, but I hate driving. I absolutely would, point blank, not drive if I didn't have to*."

A working mother of two, R37 is sharply aware of the pollutant emissions from driving and regrets that she sees no alternative to the time effectiveness of driving for combining work, household and childcare responsibilities: "*cars churn out disgusting stuff that makes you sick, unfortunately. But sometimes there's nothing else you can do. [Q: You're quite aware of the local air pollution then?] Yes, husband who is asthmatic ...you know, we've got eczema in the family and it makes a big difference... a massive difference.... It's just hard having those principles and fitting it in with everyday life. There's got to be some give and take and at the moment I'm doing the best that we can. It would be great if we could all give up driving*."

8.5.1.3 Urban–rural differences in public transport (PT) availability

Groundedness: 27 quotations

Density: 21 codes

Associated primary codes:

bus: deregulation problems	PT: for long trips
complex journey	PT: London is better
car faster door to door	PT: poor rural service
driving time more predictable	PT: requires familiarity
lack of integration	PT: takes too long
PT journey time more predictable	rural location
transfer time	scenario: urban bias
driving: long trips	station / stop: distant
parking: park & ride	station / stop: nearby
pre-planning	train: to London
PT: for business trips	

There is noted a repeated willingness and claimed preference for train transport for less frequent longer distance journeys which terminate at an urban hub. Almost without exception, respondents who regularly visit London for personal or business reasons stated a preference for travelling by train. Nevertheless, several respondents regarded relatively poor provision of public transport outside major towns and cities as a specific limitation on non-car mobility, making driving a necessity for journeys which do not warrant a multi-stage approach.

Discussing the possibility of using public transport, R15 for example, states: “*I don’t live near a train station, it’s not accessible. That’s just the main issue... The nearest train that has links to anywhere... is 9 miles away. And it would be hard to get there on a bus, to get to the train. And it’s a problem, which is the bigger issue for me, for people who live in rural areas who just don’t have the access to public transport. And it looks as though it’s being cut down.*”

Similarly, speaking of their parents, R03 observes: “*I can’t imagine how you would improve the public transport to do the journeys that they do because - just to explain, they live on the edge of Newcastle in a commuter village, 10 or 12 miles ... but they work in and around Durham and Darlington. So all of the present public transport and all that I could see improvements being made to are arterial into Newcastle. So you’d have to travel into Newcastle, and then from Newcastle to one of the main urban centres, Durham or Darlington, and then from there – because they work public sector jobs, hospitals and schools – then from there out to [their end points]”*.

R39, who car shares to rail station before commuting the main stage of the journey by train, observes that, “*I think people will endure the trains because of the time efficiency it gives them to a degree. But there is another part of the journey, isn’t there for a lot people? It doesn’t end at the railway station, so depending how you get to your first rail station and where you go from there. If you’re trying to travel into a city, it’s not too bad because generally radial routes are well provided for, but if you’re travelling in towards to your first railway station and you want to ditch the car at that end, for instance, then that’s a problem isn’t it? For me especially, because they’re pulling rural routes all over the place in West Yorkshire at the moment, so there is a reduction in existing timetables, but some services are going altogether. So the trend isn’t in keeping with this kind of ideology [of reduction in private vehicle kilometres]*”.

8.5.1.4 Sunk costs of car ownership

Groundedness: 16

Density: 20

Associated primary codes:

car: fixed costs	keep car: as a back up
car-club: inconvenient	non-car mobility
carsharing: loss independence	other people's cars
dependent on car	partner's car is main family car
driving: leave at will	partner is main driver
in case of emergency	PT: unreliable

job: pool car	PT: unusual hours
keep car for: holidays	PT: weather dependent
keep car for: leisure trips	two car household
keep car for: visiting family	

When asked to consider the possibility of no longer retaining a car for their exclusive use, many respondents found it hard to imagine being without a car within the household. Leisure trips and holidays were frequently cited as the journeys that would merit keeping a car. R02, for example, while happy to find other ways of travelling for day to day journeys, is resistant to the idea of relinquishing car-based holidays: "*I'd be reluctant to give up my driving round Europe holidays. And it would probably mean then going in the plane, or something like that, which I wouldn't be dead keen on*". Likewise, R03 finds the idea of a future restriction on driving problematic insofar as it may affect their preferred holidays: "*I wouldn't be able to do road trips with friends; I would feel a bit aggrieved about that*". Considering the potential effects of a personal carbon allowance scheme, R38 suggests: "*I could save my carbon credits to use for my own leisure purposes, on my holidays I want to go out for the weekend, camping or whatever, where again, because it's the countryside I'm going to, I'm not going to get public transport to it*".

Several respondents also consider having a car at their disposal a necessity in case of emergencies or unexpected family or work obligations. Parents of young children especially relate a 'just-in-case' rationale. R28 for example: "*What if one of the kids fell off the trampoline and needed help?*". Speaking of growing up in Canada, R18 reflects that driving and car ownership "*comes with being an adult. Because if you're out in the middle of nowhere, and something happens, for emergency purposes you have to be able to drive*".

Maintaining a private car for restricted use or 'just in case' of emergency entails many of the same fixed overhead costs as running a car for regular use (initial purchase, annual circulation tax / VED, insurance, annual servicing and maintenance). The sunk costs of buying and running a car were highlighted repeatedly by respondents as weighing *against* using other modes of transport for any given trip, making other modes appear much less attractive once these fixed overheads are paid. R18 relates the additional travel generated by car ownership: "*I wasn't doing things I wanted to do before because I didn't have the car, I didn't really want to get a car. But now I've got the car, I may as well do them anyway, and that ups the carbon thing*". R22 reflects that their total costs of car-commuting are greater than by bus, "*but then again I have to run the car anyway*". In the same way, R23 observes that, "*it is difficult to say that you are never going to use that* *car... So you are going to pay the overheads anyway. Then you might as well make more use of it to save you money*".

Arguing resolutely against cutting back on driving distance in response to increasing fuel prices, R29 states: "*If you consider the cost of car insurance, the cost of the car ...not just costing the price of petrol...if you have got a resource sat there on the drive doing nothing, then why pay out them hundreds/thousands a year to have something sat there doing nothing?*".

8.5.2 Resistance to demand reduction – reasons, preferences and habits

Whereas the preceding interview themes relating to structural lock-ins suggest that a range of factors 'external' to individual car drivers are ranged against rapid and large scale demand reduction, interview dialogues also reveal abundant evidence of rationalisations as well as preference and habit-based accounts of why respondents' current level of driving is necessary. Recalling that the concept of habit occupies a pivotal role in both structuralist and individualist accounts of action (§1.4.2, p.34), several noteworthy themes emerge from the dialogues suggesting that habit-based car driving, even where consciously acknowledged as problem-causing, is resistant to alternatives that require additional effort or the foregoing of personal convenience. Given the nature of the discursive interviews, elective resistance to change is inevitably expressed in terms of reasoned arguments reflecting respondents' sense of choice and agency.

8.5.2.1 Outright disengagement – 'why do I need to cut my driving?'

Groundedness: 17 quotations

Density: 17 codes

Associated primary codes:

congestion: not really a problem	intervention: persuasion
driving: enjoy	intervention: political leadership
driving: low annual mileage	intervention: resistance
emissions: aware but not motivated	intervention: technological fix
emissions: question re car sector	intervention: to enable driving
environmental concern: privileged	motoring 'enthusiast'
fuel £+: would absorb	refuse to change
individual action: sceptical	speed limit: too low as it is
intervention: conflicting messages	

Before looking at resistance to change *per se*, there is evidence within the interviews that for several respondents at least, a need to reduce driving distances is not something they are aware of in the first place, or indeed that they do not see why they would do so other than being compelled by legislation. R08 sums it up: "*So you're saying that the scenario is that it's enforced? Or what?*". R29 is similarly perplexed: "*You say you drive* *two thirds and one third of the way. Is that because you're forced or is it an imaginary person that's chosen? Or is it me? I drive that much because I have to, because of the law or something? Is the answer really the law?*".

Others see emissions reduction as a problem for government, not individuals, as R20 elaborates: "*I need to get from A to B and I need to do it in a reasonably efficient and cheap manner. The environment is something that I do think about but I feel that it needs to be led by government much more so. I think the problem we have is the government talk a lot".*

Alternatively, while some respondents do not themselves espouse this position, they refer to other people's outlook as being disengaged and indifferent. Speaking of his father's large executive saloon car, R06 recalls: "*He was a businessman... round Manchester he'd used it all the time for any journey, my father didn't use public transport at all. And even to mention that to him, it would have been 'is there such a thing as public transport?'. He was that far removed*". In a similar way, R14 speculates: "*I think most people, most of my friends and definitely my colleagues here... if you were talking about [the scenario policies and interventions], they'd think they were good ideas and they can see why other people do it. But they almost don't relate things like this to them, they kind of think other people should be doing it*".

8.5.2.2 Mistrust of government initiatives

Groundedness: 58 quotations

Density: 15 codes

Associated primary codes:

Congestion charge (general)	intervention: private finance
Congestion charge: Manchester	intervention: public subsidy
individual action: sceptical	intervention: punitive
intervention: collective action	intervention: regulate
intervention: conflicting messages	intervention: resistance
intervention: mistrust of government	scenario: mixed reaction
intervention: need to see the benefit	scenario: negative reaction
intervention: political leadership	

Whereas a number of respondents clearly see action to mitigate the passenger car sector as the responsibility of government rather than individuals, it is significant that an almost universal theme in the interview dialogues is a strong sense of mistrust of both the government's ability to deliver and its mandate for intervening in car use. This was especially evident in relation to the coercive policies and measures described in the narrative scenarios. While it may be tempting to take this as evidence of a tendency amongst respondents to attribute particular attitudes and beliefs as the precursors of their behaviour (see §1.4.2.1, p.34), it should also be borne in mind that deliberative interviews, in which attitudes and beliefs of individuals are probed, cannot but help to cast such concepts as trust and confidence as influential.

R09 for example is wary of financial instruments: "*The thing that politicians always use is the stick rather than the carrot, because they always use tax as a way of dissuading you to do something. So all the things in here were about it costing more to drive*". R20 uses similarly graphic language: "*Yes price is a blunt stick, but at the moment it's just stick, there's no carrot. So we need to kind of, if they can kind of bring ... some carrots in, then I think you've got a chance... but people will get fed up if it's just being beaten with a stick all the time*".

R09 goes on to explain their mistrust of coercive measures as stemming from an apparent inconsistency in the messages being delivered by policies: "*Looking at vehicle license tax, it's now phased according to emissions. New cars pay twice as much in the first year, but there are still lots of new cars being sold.... I mean, mine comes into the highest band. Okay, I still don't like paying that amount of money, but there are still new cars being sold where people are paying £900 in the first year. If you can afford a £30,000 car, then up to £1000 tax is absorbed into it. I guess if you can afford that, then you can afford to take the hit. But it's a contradiction of measures, because not so long ago new cars were positively encouraged, weren't they? Because it was to help the car industry... [through the scrappage incentive scheme]. They were pushing that. What is the priority this week?*"

Noting that coercive measures need to be prefaced by increased public transport provision, R15 goes on to suggest that people are simply not prepared to take this on faith: "*I think that interim period where, if you started charging for use of roads, but there wasn't an alternative that would create a real brouhaha. That could bring down governments. ... I think people are very sceptical these days about governments' intentions. They know that they say one thing and then down the line change their minds and say 'oh we didn't really say that'*."

R13 reflects on the referendum on the proposal for a Manchester congestion charging cordon in 2009: "*I must admit I was dead against it and voted no along with everybody else. ... I would have crossed it twice, so it would have been maximum. ... Perhaps I'm just too cynical, but...I didn't believe what they were saying. And I thought right, it's going* *to cost me a hell of a lot more to come into work, it's going to cost me a hell of a lot more to do what I want to do, because of where we live. I even considered moving, to make it cheaper to come into work. But then again, I don't want to move - I like where I am. ... I don't want to move, why should I move? So, no, I didn't believe what they were saying*".

Respondents frequently suggested that mistrust is founded on long experience of promises broken by government. R38 for example, who for six months recently travelled their daily 36 miles roundtrip commute by bus – a trip which crosses transport authority boundaries – gives a catalogue of examples of undelivered pledges: *"The one thing I said, in view of the congestion charge was that I would have wanted to have seen proof of the public transport way before... because I have distrust of what they said they were going to do. Because they make these promises and they never happen. They promised us we were going to have...a joined-up transport service so we would pay, like I said, one third between areas. That was promised, but it's never happened. They promised us we would have two buses every hour, never happened. They [the local authority] promised we were going to have four buses in a morning to Manchester, four buses back at night, never happened. And you think, well, why don't we trust you? They promised these things... Since I've been in Whitworth ... in the last, what, fifteen years we've had Conservative, Liberal and Labour all lie to us. You know, they're all saying we're going to do this, this, this, we had GMP Transport: 'we're going to do this for you'; it never happened. We've had Rossendale [borough council] going 'we're going to do this for you'; never happened. So from my point of view, why am I going to be convinced they are going to do it, they've never done it yet? They've never lived up to it yet*".

Again, referring to the 2009 referendum on the Manchester Transport Innovation Fund bid (popularly, or rather unpopularly, known as the congestion charge), R27 also demands proof of investment in and improvements to alternatives to driving before granting consent for coercive measures: "*I didn't vote for that because I questioned the commitment for the upgrades. Had the upgrades been done and therefore people were given option to take those improved methods, then people had a choice. I didn't see the point of, you know, filling up the tin and then deciding how the money was going to be spent. I didn't like that at all. Because they were talking about putting the congestion charge in place with all promises about what would happen. ... I don't agree with that at all,...I don't believe them. No confidence whatsoever. ... I don't think they are that unorganised, I just think there's too many stakeholders and not enough drive or determination. And therefore other things would come in the way.*

Discussing the possibility of a tradable personal carbon allowance, R27 was equally resistant: "*I'm very supportive in general of us doing whatever is possible to be more sustainable, more environmentally friendly, more engaged in the future. I'm very much into that. But I don't see, I don't think I'd take very lightly to my politicians telling me that I have a certain limit and there will be sections of the population who will be, shall we say, carbon hungry... I think there will be members of the population, probably families with young children, their costs will be huge at a time when you are going to then add extra costs when they can't make the savings. ...What is that going to cost you to organise? It is like blooming, child credit, I applied for child credit once and was given it. Fantastic, spent two years paying it back! I think administratively this will just be a joke! I think we have to be more prescriptive in... I think this is great about having single lanes going through the tolls paying more, yes. Put it on petrol! But I think if you put another administrative burden... I just see that as being an absolute nightmare*".

Also speaking about the possibility of personal carbon trading, R35, a Swede who has lived in the UK for several years, wonders if there are cultural tendencies towards inequality in the UK which make implementing such a system problematic: "*It could easily become an unfair system I think. Especially here! I shouldn't say that but... [Q: Why, do you see the UK as more unfair than other countries?] Just more concentrated on the individual having more rights than the overall good, you know. Like the individual's need is more important than... Then the one who screams the loudest gets what they want kind of atmosphere. So, most people are very happy driving to work... and they'd be outraged if they had pay road tolls and whatever and they'd be the ones with the money and they would just yell the loudest, so it wouldn't actually happen, because politicians would commit ...political suicide by just suggesting it*".

8.5.2.2.1 Public transport capacity concerns

Several respondents voiced serious doubts about ability of public transport modes to cope with the increase in demand for travel that would result from reductions in driving demand. Comments typically focussed on the government's commitment and vision.

R09 is concerned that public transport measures must preceded driving reductions: "*Because obviously infrastructure changes take time to develop and are expensive so unless we are economically in a position to be able to afford to double the amount of rolling stock on the railway, if it can take that capacity in the first place, or if it means building more lines or what have you, that's got to happen first. Or at least parallel with the increasing charges, so people can see it's not just you are charging me more for doing what I was doing already. [Show that] there is a viable alternative. It's the phase in of all these things that really is the key to PR*".

R39 sees a stark regional disparity in investment in alternatives to car travel "*It's a question of whether or not there is actually a commitment. These words are fine, you hear scenarios and policies presented all the time but the reality doesn't meet with the expectation does it? I don't have any faith in at all. It's reversing at the moment – they're pulling bus services all over the place at the moment, so there's a reality check with the economy isn't there really? ... It's absolutely ridiculous that all money's thrown into London. They'll think nothing about spending money on, for instance, spending half a billion pounds doing up one terminal station in London, when in fact that could probably ... do a lot of service to changing signalling across a whole major trans-Pennine route in the north. There is a lot of bias towards London per capita ... they must have four and a half times spent on them per capita than anywhere else in the country. And the idea that rolling stock can migrate to places that are less worthy than the capital is ridiculous. The idea that you can think of grand schemes that come into London, like the new North Rail Network, without thinking first of all about stimulating things more provincially. I think it's really quite wrong and I think every government's guilty of it. Regardless of, you know their colours. Um so I'm not sure that we think positively enough and long term enough in this country to be able to bring these things in*".

R27 is sceptical that modal shift could be sufficiently supported to deliver the scale of driving demand reduction discussed: *Well, you know, like there are going... if there are going to be...many more people using public transport and the need to travel to greater locations, we've shrunk...all these services have shrunk in effect. And basically we're going to have to expand those services again but we're going to have to have the infrastructure in place to enable that expansion. And, I think, you know, politically there are too many short-term aims and not enough long term plans which people will see through*".

8.5.2.3 'Be like me'

Groundedness: 26

Density: 13

Associated primary codes:

individual action: sceptical	social group: pedestrians
scenario: mixed reaction	social group: poor
social group: cyclists	social group: PT users
social group: environmentalists	social group: rich
social group: families	social group: working people
social group: motorists	social group: younger generation
social group: older generation	

Review of the interview dialogues reveals a tendency for respondents to be more supportive of interventions and measures that are in keeping with their existing patterns of behaviour and technology use. That people should prefer policies requiring little change over those that impose an additional burden of effort or cost is not in itself surprising, but the approach taken to justifying particular positions is, to an extent, revealing. R1 suggests: "*Legislate against 4x4s. Just ban 4x4s. Or any 4x4 with engine bigger than 2 litre, I mean my car's 2.2, but anything bigger than 2.2*." This lends credence to the practice theory interpretation of behaviour whereby attitudes are more likely to follow a particular course of action than to precede it (§1.4.2.2, p.1.4.2.238).

It is interesting to note that there is often a sense of 'us and them', with respondents' identifying with a particular group, which is portrayed as unduly penalised by particular policies. Repeatedly 'the motorist', 'the poor', 'hard working people' and families, are contrasted with 'the rich', 'private business interests' and the 'ruling classes' in government.

R13, who through supporting and helping to run a professional sports team accumulates one of the highest annual mileages of all those interviewed, speaks of the sense of being an easy target for taxation and charging, "*A fairer way of doing it, instead of hitting your car driver, who is not going to use public transport, then, would be to perhaps increase how much people actually pay. I mean I was really annoyed when they were talking about the congestion charge and they said they'd charge you for driving into Manchester, and then it would go on public transport. And I said, 'well okay, I'll pay for the tax coming in and out, but I would never benefit from using public transport'. And then all the money that they would take on the car driver would go on public transport, but the private companies, they wouldn't pay for any of it. I mean that private companies that would have the money that I'm paying for my congestion charge, that I'm never going to use public transport, but these private companies are getting the money from Manchester City Council, 'thanks very much', for improving their fleet. … So they are on a double winner; they are having their money from the government to improve their fleet, they're having money from the general public who are actually going to be using the buses. ... You know, they're just going to get richer and richer and richer. It's not going to help me, it's not going to help Manchester City Council, it's just going to help private bus companies*".

Referring to roadspace reallocation in favour of non-car modes, R32 describes a recently constructed scheme where traffic calming measures before a pedestrian crossing impede driving progress: "*Where they widened the pavement, I can't imagine* *there are that many pedestrians but they've narrowed the road, again causing issues with either buses or cyclists or whatever where you think, well, why have you done that? Why have you spent money that the council doesn't necessarily have to throw around on a widening a pavement where you can't see an increase in pedestrians. The pavement was already six foot wide why do you need it ten foot wide? And you can't ... well I can't see a reason. If you say well there's a safety reason because these people here have to get across.... where there are schools and things I can understand that. You know, your 20 mile an hour zone... but then again... Because you could have sailed through usually, but where [the] high school is, they put these bollards in the road, which is all well and good, but the lollipop man doesn't stand there at the bollards; he stands twenty yards down the road, and you're thinking, 'why?' ...They put the bollards in the wrong place, you see, it's a planning thing isn't it*".

Otherwise supportive of many policies and measures described in the narrative scenarios, R30 is sceptical about roadspace segregation: "*I genuinely think that the bus lanes have a caused a lot of the congestion. Every bus lane I drive through in a morning, I would say 97% of the time is empty. ...[Q: How would the buses get through otherwise? I mean, what would be the point of having a bus service if it was subject to congestion as badly as everybody else?] If the buses were... if the transport system was much improved I could understand it ... but they're not used*".

Conversely, R24 is much more supportive of roadspace reallocation: "*That scenario, as a cyclist, to see more people on two wheels, or even if it was motorbikes, would be preferable to me than seeing thousands of cars on the road. ... It's a bit like birds of feather flock together, isn't it*".

R29 takes a staunchly pro-motoring stance: "*I think the argument about public transport or gimmicks and slogans doesn't wash, because the evidence is that car drivers don't get out of their cars*". Nevertheless, discussing their preferred mitigation strategy, R29 explains, "*I'm vegetarian, so I'm biased. I don't know how valid the facts are, but apparently because of the cattle consumption and all that and they fart a lot. So, the methane. Apparently they say – I read somewhere – I don't know whether it's public transport or...if it's just all transport, you know, but I read...that actually if everyone became vegetarian that the actual [saving of] greenhouse gases and all that would match...all the public transport.. do you know? ... But you don't hear anyone saying 'go veggie'. ... I don't hear people saying we need to reduce our consumption of meat. ... I do hear the message all the time [that] we must leave the car at home, we must use public transport, and we must stop turning the lights on. And that message is massive, it* *keeps coming. Whether or not people are doing it, but I keep hearing the message everywhere, but I don't hear the message about less meat*".

However, responding to the suggestion of a reduction in the national speed limit, R29 offers this perspective, "*I think if the tree-huggers team up with the safety people, yeah, then you might get somewhere with that, because with two converging interests groups... But from...a car drivers point of view; to me, a car – what's it designed for? To get you there faster. So to me...as a car driver, I should be allowed to have... I should be allowed to drive a car as fast as I can, as long as it's safe. Otherwise, um... and if it did have to be at a slower speed limit then it would have to... someone would have to prove that it made a massive difference. If it made just a negligible incremental difference, you know...*"

8.5.2.4 'Change cars not drivers'

Groundedness: 37 quotations

Density: 15 codes

Associated primary codes:

car: EV	fuel £+: switch car
car: fuel efficient car	fuel £+: would absorb
car: inefficient car	intervention: technological fix
car: new car	intervention: to enable driving
car: VED	motoring 'enthusiast'
driving: difficult to reduce	refuse to change
driving: enjoy	scenario: negative reaction
driving: increase driving	

The notion that supply-side measures should bear the burden of emissions abatement is a resonates throughout the interview texts.

R12 is of the opinion that electric vehicles are a more effective mean of cutting emissions than demand management: "*We were...discussing this, and I think we were both of the opinion that electric cars that are comparable to current petrol cars... Congestion charging might, or toll roads or... all those things will have an effect, but the fact that we will get electric cars will have a bigger effect than any of those would*". R14 confesses conflicting interests: "*But then looking at new cars... if I am to replace my car, or not have a car, I'd be looking at super-minis with high efficiency. But one day I want an Aston Martin. This is the problem, you see*". R30 holds out hope for low carbon biofuel: "*Do you think there would be any need for all this if they could develop some kind of, is it biofuel, or whatever that is more sustainable?*". R5 is similarly optimistic about the potential for supply-side mitigation: "*I think in such a crowded country as we are, somebody's got to do something at some stage, because it can't keep... But I think part of the trick has got to be to be slightly more innovative, more inventive with solutions. So maybe we're not just looking at cars and buses, we're maybe looking at all sorts of different things*". Asked about what sort of things, R3 goes on: "*I've no idea! I don't know, but I can't help feeling that there's some kind of futuristic something just round the corner that you know will help to... There has to be some innovation at some stage that involves a completely renewable form of transport. For instance... I can't kind of... isn't there a hover-craft type...?*".

R21 takes a broader view of the need to bring alternative fuels to bear on passenger transport energy: "*Diesel cars, if you look at it in the UK is just a tiny amount worldwide, sorry in Europe. Diesel cars are just a tiny amount in relation to the rest of the world. ... The most likely [alternative to petrol] is actually bio-ethanol, sugar cane, with the European Union importing, buying from Brazil and US*", later also suggesting "*shale gas is about the only thing you might bring through on the timescale or wave stabilisation*".

A similarly techno-centric thread is evident in R18's comments: "*Well the Prius isn't bad, that's quite nice actually... those technologies. Because like when you're in underground parking, there's no emissions. ... I just feel really bad that I look at [the policies and measures in the narrative scenarios] and I always have this initially negative feeling, because for years I've looked at and I always thought if they are going to be something in there that I can actually really, really use. Because I love transport innovations, I loved it when they got those low step buses.*"

Others, such as R17, are less confident: "*Because at the moment electric cars are just moving the pollution out of the city. They're not changing the carbon output*". R19 puts it: *And even when they come in, these new super duper cars, they're still cars. And to be honest, what's the point? You've got to change your attitude. ... So what you need to do is to change your whole mindset. Rather than going on a diet, as it were, has a healthy lifestyle".*

R03 considers the need to mitigate emissions from all sectors of the economy: "*Yes, but why specifically cars? If we could spend the same money to invest in radically more efficient homes, reduce gas burned in heating and electricity used in lighting, from a climate change perspective that's arguably got a similar benefit. I think the most pressing thing with cars is health and live-ability ... It just strikes me that there's so much room for* *improvement in efficiency, that could be done immediately. That you could quite happily have fleets of electric cars that would still have the same health, noise, congestion... ...and still have a negative social impact. You know that advert, 'Let's have drive through everything' ... about a very efficient Fiat. So they've created a vehicle that neutralises the big objection, the climate change objection*". Pressed on whether they think there is really any need to reduce emissions from the private transport sector, R03 explains: "*I'm convinced of the case for that. But I think that's a trivial exercise in this sector ... It could so readily be achieved with performance standards*".

Conversely, commenting on the financial premium associated with replacing older vehicles, R37 describes their current family car: "*It's eleven years old so ...[VED] stayed the same because it's an old car. ... Hammered a bit. Yeah it'd be great to afford a new, you know, shiny, low emission one, but you know*".

R38 however has a different take on acquiring new technology: "*To be honest... if they came up with a car that was totally electric that I could use, I'd be happy. I haven't got a problem. To be honest, it's not thinking, oh... I know the fuel emissions are bad and if I could get rid of them altogether I'd be a happy man. If someone gave me an alternative to it I'd use it. It wouldn't matter to me if the electric car was slightly more expensive than I'm using, if it was quite a bit more expensive, I'd be happy to use it so long as it's a vehicle I could use. So with me, it's not, not particularly, it's not at the forefront of my mind; what's at the forefront in my mind is how I get from A to B. ... It isn't the love of the petrol consumption; it's the love of the freedom. ... And I will admit I enjoy driving it. You know I could probably get as much enjoyment out of driving an electric car ... but it's the drive, it's the journey*".

Stalwartly resistant to all suggestions of coercive measures to constrain total driving distance, R29 describes their current car and their thoughts on lower emissions vehicles: "*[It's a] Peugeot 207, so I mean it's about 1400, so I don't mind a small engine car. I mean that's where – I would say – that's where some progress should be made. Because it's all through marketing as well, I mean all these idiots who drive these 4x4s when they live in the suburbs and stuff. I think to me, I think there's almost a macho thing in the adverts and stuff about driving cars. And I've never had a car with more than a 1400 engine, for the simple reason: why pay the petrol? It's 1.4, but I drove a 1.1 before. But I suppose the image of 'a woman's car' if you have a metro or fiesta or something I think would put... well it doesn't put me off, because at the end of the day I look at it and I think it's my bubble, it's still my freedom, and that wouldn't bother me. But I think it would bother a lot of men. But I think if they incentivise more and more small* *engines, I think that would... I think people, especially in this day and age, I think would switch more to lower [emissions] vehicles*.

The pervasive confidence in the potential for supply-side measures to obviate demand management is encapsulated by R27: "*But maybe I'm going to get an electric car, maybe I'll get a much smaller car, maybe I'll do those elements*".

8.5.2.5 'Cars are private'

Groundedness: 16 quotations

Density: 11 codes

Associated primary codes:

carpool: problem	carsharing: with family member
carsharing: loss independence	driving: high occupancy
carsharing: loss of personal space	driving: lifts for other people
carsharing: problems	driving: low occupancy
carsharing: sees value..	driving: personal space, time
carsharing: social benefits	

The possibility of increasing the occupancy rate by means of participating in carsharing schemes received a decidedly mixed response, with many respondents seeing the carsharing with a non-family member as defeating much of the value of the private car. Often the burden of inconvenience was cited, whilst the sense of imposition or loss of personal space was a dissuader for others, with some respondents suggesting that they would rather take public transport than share their private transport. For example R12, who for several years made their daily 36 mile round trip commute by public transport until a change of hours prompted a change of mode, suggests that under conditions of considerably increased costs of road fuel, "*under these circumstances, I think I would be doing the public transport before I would be doing the carsharing. I don't think it would come up in my circumstances. If somebody absolutely had to keep hold of their car, and carsharing was the cost of doing that, people would. But I don't*".

R25, a self-confessed car enthusiast, takes a similar view: "*The bus would be ten times more likely to happen than car share I think. Because, I could then still shoot into my requirements and if I wanted to come and go. Yeah. Car sharing's a long way down actually*". The sentiment is echoed by R40: "*I think [an] improved public transport system is more likely to catch on than the kind of carsharing scheme, because then you're still getting in on your own steam and your own time*".

R01 sees a regular carsharing arrangement entailing a loss of flexibility and convenience: "A *lot of academics work at home anyway, so what would you do if on the day when it was their turn to take you, they're working at home? Or when it's your turn, you're working at home? So part of the point being an academic is that you've got the flexibility, so again that wouldn't appeal to me*"*.*

R17 also sees carsharing as less flexible than public transport, and potentially less stressful, depending on the driver: "*My preference would always be for public transport ... [rather than] sitting in someone else's passenger seat, being frightened out of your life while they're driving like an idiot. ... I'm an awful passenger. And the roads that get me home are dangerous B roads where people just haven't got a clue".* R17 goes on to explain: "*For me public transport is a more attractive option, because it's quicker, because it's more relaxing, and because I can sit there and be antisocial and read newspapers. I think actually being in a car with somebody is quite personal -- personal space. I wouldn't want to have to keep a conversation every morning with somebody who... the only thing we've got in common is that we get the same route to work*".

R22 takes a similar view: "*It is all very well I think sharing public transport with other people but in the close confines of a car I wouldn't be so comfortable I don't think. ...It think it is just that intimacy I think. ... I like to listen to, you know, what I like listening to on the radio I wouldn't necessarily like to talk to the passenger if I didn't know them that well. I mean if it was a close friend then it would be a different matter. But just car sharing generally wouldn't appeal to me personally. It is something I thought about but I thought no, it is not for me*. ... *I mean I'm in the car on my own every day and I do have a conscience about it and I'm conscious that it's wrong, but for me, really... When for example I'll make a motorway journey, so I'll go and see my sister... why would I want anyone else in the car when I make that journey?*".

R26 wonders if casharing in the modern age may be held back by issues of trust: "*I definitely think the phone apps to match your requirement and drivers and passengers in your vicinity that's a really good idea. I think that does raise issues of trust though. Because, car sharing with people that you know requires some level of commitment, so you need to be able to plan in advance, which is fine if you've got a very regular job, if you don't work shifts, if you never have to go in early or work late, but it's much more complicated if you're depending on people or they depend on you. But... think if this much more ad hoc thing of matching your journey requirements with drivers and passengers in the vicinity who you don't know, then that's about building trust I think. It's a very interesting question, how you build a trust in a digital age*".

R29 suggests that workplace norms and culture need to change to accommodate carsharing, but is more receptive to the notion of 'casual carsharing'[122]: "*You've got to be very organised and I wouldn't want someone to rely on me to pick them up. ... To be fair, I've always [worked]... in quite a chilled environments, so I can come in a bit relaxed, you know, but if you're actually in job where you've got to... It's like a lot of people if you've got to be in work for nine o'clock or you're in big trouble or people notice, then... or you've got to be in work at ten, or eight, if it's more sensible, staggered then I can see how car sharing would work. How you avoid any arguments if somebody's late, because it's a new excuse isn't? 'My carshare didn't turn up this morning, it's not me that's late'. But I think on the other side of the coin with a carshare, I think... if you had registered users who were CRB checked or, at the extreme, then I suppose I could see an argument for almost like bus stops or where people could drive in on the edge of town and pick people up*".

R42 ponders the national psyche: "*I don't know how well it would fit with the sort of British culture, I think this was a really interesting point about you could use your mobile to find somebody who might be wanting to do a similar journey as you. ... I cannot imagine anything worse. ... Oh, the thought of sitting in a car with somebody I don't know all the way into anywhere. I mean to me... maybe you don't have to make the conversation but I would feel... I don't know how, just as nation I don't think we're that sort of nation that would find that easy*".

R03 remarks that carsharing is likely to remain a difficult proposition for many drivers, even with financial inducements: "*To get people to share cars with strangers, is going to take a serious set of tolls, I imagine. People are going to be much more likely to go for the smaller, lighter, higher mileage cars. Because I think car ownership is a lot about liberty and ownership. They're the two things that aren't separable from the personalised vehicle. And that is quite distinct from socialised transport.*"

R09 concurs: "*I think probably my first strategy would be buy a more fuel efficient car.* ... *I think the way to reduce emissions rather than reduce driving is to have improved fuel efficiency and improved hybrid and alternative sources of electric cars. Because people always going to want a personal choice and convenience of having their vehicle. That's why cars have grown exponentially, ownership has grown exponentially since it was first introduced. And I think it's not going to help congestion but it's going to help reduce*

[122] Referred to as 'slugging' in the USA, where such systems exist.

emissions: I think that would be something that people would be much more willing to buy into. Phasing out everything other than hybrid cars for example, it's a first stage, and then if electric cars become a practical reality for anything more than just short distances, that would potentially reduce emissions more effectively. And people would be more willing to sign up to that because you still have your vehicle, and the benefits of that, without necessarily so much associated pollution."

8.5.2.6 Accustomed / deprived

Groundedness: 21 quotations

Density: 11 codes

Associated primary codes:

carsharing: loss of personal space	intervention: gradual
driving: as a luxury	intervention: punitive
driving: new driver	intervention: resistance
historical transition	old travel habit
intervention: feel deprived	pre-planning
intervention: go with the flow	parking: reduced availability

Interviews revealed many examples of 'habitual lock-ins', whereby respondents report having become accustomed to a particular aspect of car driving, of which they would feel deprived were they no longer able to access private transport to the same extent. Evidence was sought of the existence of a 'convenience ratchet', or even 'luxury ratchet', based on the principle that losses tend to be more keenly felt than equivalent gains, even when the thing lost is a relatively recent acquisition.

Feelings of deprivation associated with foregoing the ever-ready convenience of the private car are summed up by R24: "*I can foresee that, thinking back to just every day scenarios in life when a car is so convenient, you know. Just thinking of one, the other day thinking about it, washing machine's broke, got to go to B&Q, go and get a part, got the wrong part, had to go back again. You know, the thought of doing that by bus on New Year's Day or whatever it was, the 2nd is just, it would be impossible*".

Unusual circumstances feature in R03's explanation of their resistance to withdrawal of city-centre parking: "*For me, in my circumstances, I would personally get frustrated with reduced parking, because I'm used to... part of the thing with my cyclist's mindset it that I'm used to rocking up at where I want to arrive at. So if I was having to park out of town to go and do a quick shopping errand in town or something, if I've come in my car it's because it's going to be a large object that I would need to in any case. You know, small shopping trips I'd just do with a bag on foot. So what I'm getting at is if I'm coming to buy* *a microwave or a wardrobe. You know, the journeys that I would use a car for to town necessitate parking near the shop that I've gone to*".

Discussing the constraints and choices imposed by a cap and trade carbon allowance, R05 speaks of their reluctance to give up international travel: "*I mean that kind of... that saddens me slightly in that it would make the world a much smaller place again, wouldn't it. [Q: It would probably make the world a slower place]. That doesn't worry me at all. But in terms of having a lot of family in the States and Canada that would shrink the world for me certainly. I think people do have international family much more now. So I've got family all over the world, definitely*".

In a similar way, R18, a Canadian ex-pat, suggests, "*It's forcing people to become more local than most people ever want to be*". They go on to explain that, with regards to their preparedness to forgo, "*It depends whether it's stuff or people, as well. In the areas I've dealt with, I've had to continuously give up people, that's harder to do. ... The reason that I use air travel a lot is because I want to see my family and I want to be with them, and I'd rather see them more than once every six months. So to ask me to reduce my carbon emissions is asking me actually not to see my family. And at a period when they're older and more of them are dying. ... That's not actually something I would take too kindly if someone is saying to me, oh your plane ticket's going to cost £4000 now*".

Considering the possibility for using public transport to make their daily 40 mile roundtrip commute (which they currently carshare with their spouse), R09 views the loss of convenience as too great to make it viable: "*We're talking leaving home at least half an hour earlier to get here in time. And then at the other end of the day... Because an academic job, doing research, being in the lab, the experiment takes as long as it takes. You can't... I do whole animal work... you can't just stop to get the train. As it sort of tails off in the evening, but then again it's not really the most convenient, so given the length of journey, the time it takes, you just want to jump in the car and go home. You don't want to be waiting for half an hour or so. [Q: So how does that work, carsharing with your wife, is she able to match your flexible working times?]. Well I mean she sits and does stuff in her office. She finishes earlier... at 4:30 PM. So obviously I don't finish that early, she just has to hang around and do things*".

R10 fears the level of forward planning and loss of sponteneity entailed by forgoing car ownership: "*This [scenario] kind of frightens me in a way, the loss of the car and the fact that you would have to... I mean I'm quite an organised person, but my other half is not.*

With this kind of system you would have to really plan out everything you wanted to do to make sure that you have an opportunity to put the car or to arrange your transport. So it kind of takes out a lot of the spur of the moment... 'oh let's go', 'oh it's a great day, let's go out for the day', and you find that there was no cars available because everybody's beaten you to it. So I think it takes out that opportunity to do things on the spur of the moment, and you would have to plan your life quite dramatically.... It's going to take a long time I think for people to break their kind of habit of just getting in the car and going out into the country for the day, or whatever. It's quite a big sea change in attitudes the way that they sort of live our lives. So that's quite a scary prospect".

R27 feels similarly constrained by the prospect of regularly switching to public transport for commuting trips, something they have on occasion done, "*but I have to plan my day around it as opposed to planning my day. I can't pick-up shopping; I can't call and see friends on the way home. I can't do many things which I would do on the way home from work. Therefore I would find it at certain times very limiting ... You've got to see the total picture. If somebody is just using a car to take themselves and their briefcase from home to work and back again, then how they get there is less important. If you've got all these other aspects which your car enables...*".

Speaking of the changes implied by a cap and trade personal carbon allowance, R14 draws parallels with the rise of low-cost aviation: "*I suppose it's difficult with flying, because it's becoming so much cheaper to fly. I mean, 10 years ago you couldn't get a flight somewhere for £50. So there is a kind of balance isn't there, people are hearing that they shouldn't be flying as often because it's not very good for the environment, but at the same time you're being offered it really cheaply*". R14 goes on to note the creation of cultural norms in creating demand: "*But it's almost expected... I remember years ago, because I went to quite a nice school, someone said about having... they were disgusted that people didn't have more than two holidays a year. And I was like, 'I don't even go on holiday every year'. Whereas now, because of cheap flying, I actually do go abroad at least twice a year, even if it's only a weekend or something. But it's become the norm now to do that, rather than before it being the exception*".

Returning to the theme of structural lock-in through employment, R18 says, "*...When people are living within their means, but the level that you how to live within changes, suddenly you have the vulnerability. So this is what I mean about the implementation, it's got to be sufficiently gradual and it's got to be within certain quite reasonable limits. It's going to...be drastic it can cause a lot of damage very quickly. ... There's not enough time necessarily to think it out well. ... To do things well enough takes 10 or 20 years. A* *lot of these agendas, they want it in within five years, they want returns within 10, or even less*".

Reflecting on their lifelong relationship with car travel, R32 suggests that rather than car ownership being a lifestyle choice, "*In essence it's almost the other way round, where I've got a car, so the lifestyle reflects that I've got a car rather than I want to do this so I need a car to do it. Because I've always had... I mean, my parents both had cars when I was growing up and because the school I went to was on the way for my father going to work he used to drop me off. And then, more often than not, my mother was wandering about doing whatever she did. She used to pick me up. So my whole life has been revolved around the car. ... Public transport was not really on my radar. I mean all my friends got on the school bus and went home and I got a lift*".

8.5.2.7 Emissions ranking

Groundedness: 16 quotations

Density: 17 codes

Associated primary codes:

emissions: aware but not motivated	intervention: political leadership
emissions: consumption-based	intervention: public subsidy
emissions: other countries	intervention: reward good behaviour
emissions: question re car sector	lead by example
emissions: ranking	PCT: allocation query
individual action: sceptical	PCT: favours rich
intervention: collective action	PCT: individual upper limit
intervention: need to see the benefits	scenario: sceptical
intervention: persuasion	

A number of respondents expressed concern that the contribution that their forbearance might make to averting global warming was trivial. The argument was made by several respondents that others either drive (or consume) much more than they do, or that other countries emit much more than the UK, hence any mitigation effort on their part is a 'drop in the ocean', often going on to suggest that top-down coordination and political leadership are required to make a meaningful difference.

While otherwise supportive of measures and interventions to reduce driving emissions, R12 comments: "*That's the bit that I'm sceptical about. If there was something that could be applied on a larger scale – say on the scale of a city like Manchester – and I could say, 'well I do that and everybody else does it', I would be in favour of it. But I can't really see the rationale for just me doing something, changing anything. It's like, if I took a pay cut it wouldn't cure the national debt. With all due respect. I can't quite take a leap from* *me doing something to happening at a larger scale. I don't have that bigger picture, if you see what I mean*".

Talking about the UK's role in mitigating emissions internationally, R27 says of personal carbon allowances, "*One of the other things I feel about this quota, which I'm a little bit uncomfortable with and I think, as I say... I'm very proactive when it comes to environmental issues, but I think a lot of people would find that very difficult to accept given other parts of the world who have the same special air out there which is being...damaged... But I believe lots of people would be very cross about us having these financial, sort of, penalties given to us when you've got, you know, such poor management of resources and energy in other parts of the world*".

Others spoke of visibly poor energy resource management in the UK as discouraging changes at the individual level. R14, for example says "*One thing that really bugs me... we've got little stickers you might have seen everywhere here, like 'turn off this', because of the* CO_2 *and stuff. .. If you drive anywhere after 11 o'clock at night, loads of buildings...have lights on,...lit up for advertising and things. I don't understand why we can't have a lights out campaign, or it's compulsory to have lights out. ... That's what really frustrates me, especially when we are trying to implement this green thing here, people were getting really frustrated that we were asking them to do what they considered to be things that were going to make little difference. So say for example, turn their personal printers off. When they can then see it that someone else in the university a massive waste is happening. Because that's why they think, 'well what difference is my printer going to make?' ... Things like that [send] a big signal that this is important, that we do have to change, that's why we are doing it*".

R23 sees similar disparities between what is asked of 'big emitting' industries and private individuals: "*I think sometimes people might feel that it is unfair to ask them to make all the sacrifices for the environment when you have, you know, other people, or you have industry polluting the environment in a much heavier level than any car ever could. Or you have less taxes for aviation, which the emissions again there is a lot higher than you would have in a car. ... Then obviously if you are going to country level then you can start comparing between different countries as well, you know there are other countries that emit a lot more*". R23 sums up their sense of being an insignificant part of the problem: "*It seems a bit unfair to ask a guy who is not doing anything, he's just driving his car, whilst the rest of the country and top level decisions let so many other things go, but then pointing the finger at somebody way down the scale*".

R06, who for the majority of the interview argued that a personal carbon allowance system would likely cause more problems than it solved, came eventually to reflect: "*I suppose if I was to compare myself and the type of car I drive, my social circumstances – i.e. having children, not having children – I would probably rate as below average when it comes to the sort of carbon footprint that's being produced by me as an individual, compared to other people. [Q: In Great Britain, yes]. Yes, I would probably come somewhere particularly lower than other people. And in some ways that also makes me feel like I've got no part to play, because perhaps my footprint is less, so why do I need to care? The guy with the Jag who's ferrying his kids round, you know... But... if the message came that it's everyone's individual responsibility, which strangely enough comes back to this, doesn't it, personal carbon. So although I didn't like it for other reasons...I can see a fairness in it actually*".

R38 is also mindful of the bigger emissions footprint of others: "*It's something I'm aware of...and...I think...well, hang on a minute, I see people at [my son's] school turn up, they've got 4x4s, they've got the radio blaring out and this is like twenty minutes before he's due in school, the engine running, pumping out. And I'm thinking, 'I'm driving a small diesel, that I stopped and stepped out of', and I'm thinking, 'how much am I contributing compared to some of these people?' And I must admit I know we should all do something to help, but sometimes I look round, and think 'hang on, I'm contributing very little compared to this lot'. And thinking well, you know, 'why am I looking at doing a lot more, should these be doing something'. It's a bad way of looking at it but...*".

8.5.2.8 Visible vs. hidden costs

Groundedness: 27 quotations

Density: 7 codes

Associated primary codes:

bus: exact fare inconvenient	PT: cheaper than driving
car: fixed costs	PT: overpriced
driving: cost differential with PT	PT: season ticket
parking: costs, cheap	

Respondents widely reported a sense that public transport was more costly than driving, often comparing the incremental costs of driving with, for instance, walk on full individual fares by public transport.

R09 for example compares only fuel costs to rail fares: "*So it's £13 each per day on the train. That's the walk on price, I'm not sure how much reduction for a season-ticket. But it's still almost twice what we pay in fuel*". Likewise R11: "*What did I pay the other day? It was about £11 return. ... So that, just the walk on price, would cost about as much as the petrol that I'm paying*".

R13 notices the physical monetary cost of using public transport more than debit card transactions for fuel: "*I found when I was bussing...I actually felt that money going out of my purse more acutely than a car. Mainly because when you buy a weekly bus ticket, the money goes straight out of your purse and you can actually see it going out. When you're buying fuel, you buy fuel once - you fill up - and then you do all that travelling and you don't even think about it. You only think about it when you're filling up, and then that's it. But if you're buying a weekly ticket, the money goes straight out immediately. ... Now [when driving] I can have £10 in my purse..., and as long as I'm not sort of going anywhere in between, I'll still have £10 in my purse on Friday. I won't have actually spent anything, any serious money*".

R26 is more mindful of the 'hidden' costs of running a car: "*I think one of the difficulties about the cost of driving is that so much of it is a sunk cost because you've already bought the car, you've had to tax it, insurance and you know, get it serviced and so on. So, people never see the real cost per mile, so yes, I mean, like you say, at £3 a litre for fuel people would find very alarming, but it wouldn't surprise me to find it actually over £3 a litre to run a car [now]. ... It makes you more likely to use your car because you think, well I've got it and I've already spent all that, if I never use it that I've wasted it. So I think that would have less effect on the decision...than it ought to have*".

8.5.2.8.1 'Parking permit lock-in'

Closely related to the broader theme of hidden costs, several respondents note that the combination of the sunk costs of pre-paid staff parking permits along with the 'invisibility' of charges (deducted at source from net salary) create an inducement to prefer driving over other modes, even when they might occasionally prefer not to drive to work.

R18 indicates that the waiting list for their preferred car park means they do not wish to relinquish it even temporarily: "*I ended up getting [a permit] about three years ago, and it took me a year... For one specific job I ended up bringing the parking more, and then that's provided different flexibility, and I haven't dropped that. But what I've managed to do is to do more, because we are using the car now. [Q: So once you've got the permit, you wouldn't give it up?] Well you can't really, because then it'd be another year to get back on*".

R42 is unsure of the precise cost of the parking permit: "*because it just comes... it just comes of my salary. ... Don't think about it at all. ... I just dismiss it completely*". On the other hand, speaking of the principal drawbacks of train travel for their 50 mile daily roundtrip commute: "*The killer is paying the £6 [per day] to park your car at [the local] station*".

R36 suggests that the "*unbelievably cheap*" staff parking may "*encourage people who...probably just keep their car parking space in case they need it. It's £30 a month, or whatever is... and I don't come into Manchester shopping at a weekend, but you can imagine if somebody was simply to pop into the city centre to do a bit shopping on a Saturday afternoon, well, it would be cheaper to...continue to pay your university parking wouldn't it*". R41, for six months a train commuter at the time of interview, retains their staff permit for occasional weekend use, reckoning that to break even they need to use it "*four times a month*".

R16 compares the costs of university owned and public parking: "*I look at other places and it's around £5 a day to park.... It would just be an absolute nightmare. And I think that, because it's taken out of your salary... what you never have you never miss*".

8.5.2.9 'Driving and economic prosperity'

Groundedness: 11 quotations

Density: 10 codes

Associated primary codes:

congestion	job: company car
congestion: is a problem	job: work requires car
intervention: punitive	social group: working people
job prospects depend on car	speed limit: too low as it is
job: business trips, discretionary	speed limit: would cause delay

As evidenced in §8.5.1.1.1. above, many respondents refer to car use being instrumental to employment prospects. Several respondents also make a connection between driving and national or general economic prosperity, invoking this as an argument against coercive measures to restrict total driving demand.

Differentiating between leisure and business trips, R04 sees more value in the latter: "*If the purpose of the journey, and I'm not talking about myself now necessarily, but is to do with improving the economy and bringing finance into the economy, then to penalise* *people... [who are making] a productive trip, to penalise them several times, which is in effect what is happening, because the outcome of that is that that person will earn some money, or the company will earn some money, which will then be distributed some way through taxes anyway. And then to hammer them significantly through toll charges and so on seems to be counterproductive. Whereas if somebody is just thinking okay I'll just go and see person X in the other part of the country, just because it's a nice day, that seems to be a different motivation and therefore might involve a different way of charging*".

R09 suggests that readily available private transport has "*…clearly helped the economy, because businesses have got a larger pool of potential employees because you can commute 10 miles, 20 miles. People I know who work here live in Sheffield, who can come that far, and are prepared to do that. Whereas if you didn't have that, you were relying on public transport or cycling or walking you could probably make maybe 10 miles maximum away. 5 miles. So you're reducing the pool*".

R18 worries that slowing down the pace of travel by speed limits and increased use of public transport will damage the economy: "*I can see all of these other problems coming out of it in other areas, so you would have to counter those in some way. So perhaps you're only looking at one agenda at the expense of other agendas. I mean, I'm looking at that as a person who has to achieve certain goals in order to stay in a job, and to actually have any kind of life at all outside of still, because I appreciate you can cut all of these things and you can travel less, but ultimately the only way I can guarantee no carbon footprint is to stay at home. And if I stay at home I won't have a house, because I won't be going and I won't be able to pay the bills, and, and, and. So you can go back to where all you do is go to work and go home, and do nothing else. And if that's how a country wants to be, yes it has to make that choice. But I think some of these come down to actually slowing everything down. And when you slow everything down, you do a lot less. When you do a lot less, the country generally doesn't grow. And I would have to question whether that is a good thing. [Q: Growth measured in what terms?] Growth measured in terms of what people are able to do, what skills they have, the amount you need to use to achieve any given outcome. How efficient I suppose you are. How effective you are at work*.

The possibility that private transport restraint may exacerbate social inequalities is a concern for R34, who says, "*I can see that there would be a lot of reaction from people...who did consider it unfair...on the carbon credit system. I think people are sort of locked, would be locked in. [Q: To decisions they've already made?] Yes and I think* *that...would not be good for the economy because we ought to be able to move around to take the best jobs etc. And it would not be good for the economy because areas that are already very depressed now, there would be less incentive for people to get up and move away to get a job elsewhere. ...[Places] that are economically poor now, Hartlepool and Middlesbrough [for example]...*"

8.5.3 Potential for overcoming resistance

While preceding sections paint a picture of strong resistance to driving demand reduction, interview dialogues also yielded a wealth of evidence that in certain circumstances respondents could envisage step changes in driving distances. The following themes summarise findings.

8.5.3.1 'Could learn to live with it'

Groundedness: 31 quotations

Density: 11 codes

Associated primary codes:

cut driving: business miles	intervention-led shift
cut driving: commuting	intervention: go with the flow
cut driving: could do it	motivation: 'philosophical'
cut driving: short trips	outlook road tolls: don't mind
driving: dislike	scenario: positive reaction
get rid of car	

Many respondents expressed willingness to accept changes to levels of car use, or indicated that they could get used to at least some of the policies and measures described in the narrative scenarios.

Considering the possibility of a twofold increase in the cost of fuel, R21 says: "*That's inevitable, that's going have to happen and I'm resigned to that anyway... Well, my reaction is it is eminently desired. If we are serious about CO_2 reductions we'd have to do it. ... My philosophy, as much as I hate paying more and more for gas, is recognising that it is the only way to raise the revenue to enable investment in alternative decarbonised systems. So I would be quite happy to pay that price for diesel if I was confident that the government was taking money raised and wisely investing it in nuclear or, you know, fusion or whatever. [Q: Or in improving the rail network, say?] I'd want to see a credible plan*".

As someone who already monitors and restricts their energy use, asked whether they would buy into a personal carbon allowance scheme, R15 answers: "*Yes, definitely. Because there are things that I do already to offset stuff. Like we've got a camper van,* *we tend to have at least one of our main holidays a year in the camper van. Rather than fly anywhere. And we have short trips away that would be city breaks by aeroplane, are in a camper van. So rather than flying... we are still using fuel, but we are not flying. This weekend we went to Halifax, Ogden water, near Halifax for a weekend. Which wouldn't have taken much fuel to get there and back. And we could have flown to Prague, couldn't we. So it's different. And we have an allotment, so we grow a lot of our own food, which must cut down on something. It cuts down on our bills*".

R23, a Greek ex-pat, is more open to the possibility of regular carsharing than many respondents, "*Even in the daily use that if you can share things, you know, by getting a bit of inconvenience, to getting an extra two minutes on your travelling by picking up another person to go somewhere together, then I'd rather do that. I am not saying that I am the champion for environment. ... But if I can make the common sense I will do it, if I really have to go out of my way to do it then probably I won't do it. Put it another way, if it is an inconvenience I'll do it. If I suffer I won't do it*".

R03, who has recently acquired a car for the first time in many years, suggests that, "*The difference that personal carbon trading might make to me is that I would think about using multiple vehicles. So at the minute I have one vehicle that I use for everything. As fuel costs and carbon costs went up, I would look at ways where I would be able to pick and choose vehicle according to the purpose of the journey. So if it is just a passenger journey, then just have a passenger car, me and my partner going to visit relatives* ... *Because for the past ten years I've found ways... I'm quite an active kind of personality, I like solving problems, I like challenges. So I have found ways not to have a car. You know, almost to spite my dad, because of his nice gesture of giving me a vehicle, I had to be able to justify why I said no to that. So I have thought about how I can make my life work without the car.*

Similarly, R06, who recently switched from public transport commuting to driving (providing a lift to a fellow ex-bus-passenger) when a car parking space was offered at a site close to their workplace, is sanguine about the prospects of accommodating a reduction in driving distance of up to two-thirds, saying, "*For both of the scenarios, for me, if it was a drop of...either a third or two thirds, it would immediately mean for me...cutting the driving I do now [to work]. ... But strangely enough, I've come at this in reverse really, because I've gone from public transport to the car, so in fairness I can see that I could adapt to either of these. ... I already know I can. But for me there would have to be, the things outlined here [improvements to public transport] would have to be available, which they're not currently*".

Contemplating how a personal carbon allowance may affect them and their family, R08 is willing to make adjustments provided they are convinced of the equity of credit allocation and implementation: "*If it meant a life change, then it would mean a life change. For a lot of people I suspect that something like that is going to have a massive effect on them, because they see it as an infringement on their... liberty and all this business. That side of it wouldn't bother me at all. But it might mean that we'd have to move, we'd have to look at relocating or changing job to fit in with it*".

Many respondents reported a generally positive impression of the scenarios, with the strict proviso that public modes were dramatically increased and improved such that overall mobility remains unaffected. R11, for example, says of both narrative scenarios, "*Yes, they sound great. I love the idea of, you know you just get off the bus and hop on a bicycle. But... you see I...didn't start driving until I was about 28. And I didn't bother earlier because I thought, 'I'm working in town and I live here and I can just get the bus'. And I was really quite anti-driving. It used to infuriate me seeing all these cars with single drivers in. But then in the end you get a bit older, and you think 'oh sod it, I'm going to drive'*".

Familiar with many of the arguments for reducing passenger car sector emission, R24 accepts that more effort may be required to plan journeys without using a car, but is comfortable with the prospect: "*I'd put up with a noticeable level of inconvenience if it meant I didn't have to drive. But with [public] transport massively improved. ... Having to give a lot more consideration on how you're planning your journey... the putting up with waiting 15 minutes for a bus or something, I could probably live with that. It's just that...the benefits, you know, if we are not going to... well, we're not going to hit... we're going to go way past the 2 degree change anyway aren't we, based on current measures. If we are going to hit the four degrees mark which is what...I think...is projected for at the moment, inconveniencing yourself, moderately, is not that much of a trade-off I think*".

8.5.3.2 'Just give it a go' and 'moment of change'

Groundedness: 38 quotations

Density: 23 codes

Associated primary codes:

car-club: unfamiliar	pre-planning
carsharing: ex-car sharer	PT: deterred by bad experience
cultural norm	PT: poor image

cycling: ex-cyclist	PT: requires familiarity
cycling: would if I could	trendiness, becoming mainstream
driving: children necessitate car	snapshot
driving: new driver	social group: children (young)
experienced abroad	social group: families
habitual behaviour	social group: older generation
historical transition	social group: working people
lead by example	two car household
old travel habit	

The interview dialogues returned widespread examples of respondents finding that alternatives to driving are often not as inconvenient or onerous as they had originally assumed, once they have 'given it a go'. The impetus for change varies from being enabled and encouraged by peer pressure or the examples set by others or schemes such as free bike loans, to being induced to temporarily switch modes due to external circumstances such as weather, road closures etc. Respondents also widely confirm that key stages of change in life, such as starting a new job, moving home, starting a family, children leaving the family home, retirement etc, can be associated with changes to their travel habits and needs.

R18, for example, reports quickly adapting to commuting without a car, but suggests that coercive measures are required to prompt major and lasting changes of habit: "*I think people can do quite easily and probably more easily than they realise. But until you start to do it... When we...moved down to London, the thought of not having a car to go to work, and that sort of thing was just, well...'how will anybody get about?', and like 'how will you do the shopping and how will do this, that and the other?'. [But people imagine that things]...are harder than they are ... I believe that we will need something that is imposed, because I think most people will just... its business as usual and you just carry on, don't you? I think there will have to be something that is imposed on us as a society rather than people just saying, yeah, 'I'll tell you what, I'll do it'*".

8.5.3.3 'Information deficit'

Groundedness: 10 quotations

Density: 12 codes

Associated primary codes:

cut driving: recognise need, but...	intervention-led shift
emissions: aware but not motivated	intervention: ICT use
emissions: question re car sector	intervention: persuasion
environmental concern: privileged	pre-planning
familiar with the issues	PT: requires familiarity
habitual behaviour	trendiness, becoming mainstream

A number of respondents suggested that better access to information about the environmental consequences of certain behaviours would enable and encourage them to choose differently – a well-researched area in the psychological school of behaviour (§1.4.2.1, p.34), although there is little evidence of enhanced information provision being a particularly effective catalyst for behaviour change. This most frequently came up with during discussion of personal carbon allowances, where several respondents thought the 'awareness raising' moment of such a scheme would affect their choices.

R25, for example, says: "*Well the carbon credits just makes great sense, but I'm a scientist...So, I keep arguing with sustainability that we need the facts and that's my bent, perhaps. ... Give people the facts and some part of the population, like me, that want the facts, will react more creatively that way. So, give us some idea of the carbon issues. And how we use them. It's the same as putting in an electricity meter in and saying how many pounds it's going to cost. I've got mates who are scientists and that really appeals to them, so. And then it will make a difference. So, I think carbon credit scheme is really good*".

Similarly, R07, suggests that the budgeting aspects of personal carbon allowances would lead them to considering non-car travel options: "*You'd definitely think twice before you got in your car to drive somewhere. Because at the moment, you don't hesitate, you grab your keys and you just go. But definitely, if you'd got to go out and buy credits, if you got so many credits you could use a week and you knew you had to use them to get to work and back, and if you had to buy extra credits for anything else, I think you'd find a lot less people actually jumping in their cars and driving off somewhere*".

Information provision featured strongly in the dialogue with informatics professional R26, who also highlights the stop-and-think aspects of personal carbon allowances: "*If you have a carbon credit allocation, you will have to plan for that. ... I wonder if you could link it in some way with smart metering, so that you manage your domestic electricity needs, the kinds of fuel needs, and then you would be explicitly making that trade off wouldn't you between?... so you could turn the heating down and put a jumper on and then you could travel further if you wanted to. ... I think the thing I would find most irksome about it would be the...organisation and planning that you would have to put into that which at the moment, you know, I don't factor that into my plans at all. You know, sort of roughly how much you are paying electricity every month, you know it is a sort of set amount, um, and then they vary it depending on whether you're over paying or under paying. And I guess you'd have the same sort of system for your carbon credits, perhaps* *you'd...have to kind of allocate your carbon credits in some sort of notional way and then if you found you were way out you'd have to adjust behaviour or buy more*".

Nevertheless, R14 indicates that the current level of information provision about low emissions driving habits is not getting through as well as might be expected, and acknowledges that information is not always used when available: "*They want at least 50% of the people driving for work to have been on a training scheme for reducing fuel use. So you're kind of like not loading your boot up with stuff that you don't need, and making sure that your tyres are inflated and things. And I think people understanding the relationship between the small changes that they can make to their own cars, I think that being more widely available would be really beneficial to people. Because it reduces emissions and it reduces costs at the same time. Just making it more... if you search for it, the information is there, but it's not widely advertised and publicised. [Q: That whole 'Act on CO_2' campaign was trying to push that information across – I don't know if you saw any of that?] I noticed it, but I didn't kind of look into it. Now you mention it, it does sound vaguely familiar. ... It's almost like you need... in the big car parks, shopping centres and things, having little roadshows or things like that. And selling it as you can save yourself money kind of thing. The motivation for people isn't because they're going to save the environment, because everything is about how much things cost these days isn't it. ... To me it's a bonus if you're becoming a green, then things cost less anyway. But I'm more bothered about the green than it costing less, although I'm quite happy for it to cost less. ... We are in a really materialistic society... So when saving money, happening to be green does help. You've seen a massive move to people now using...low energy...lightbulbs and things. Because people now realise that they save money, but most people didn't like them because they didn't like the look of them, until they realised how much money they saved*".

8.5.4 Headline responses to narrative scenario measures

Interview respondents were not asked to rate scenarios quantitatively, and given the breadth of measures included in each narrative no two interviews were alike in their discussion of the material. Respondents were asked simply to focus on the elements that struck them as being most problematic or most beneficial in terms of helping them to reduce their annual driving distance by one third or two thirds for narrative scenarios one and two respectively. However, during analysis of the interview dialogues, it was possible to extract a clearly positive or negative reaction to many of the measures discussed, or in other cases an explicit acceptance that respondents could adapt to the measure in question without undue difficulty, or conversely that they could not envisage adapting to the measure. In several cases, respondents acknowledged the value or merit of particular measures, but nevertheless did not want to adapt for other reasons ('conflicted'), or acknowledged that they could adapt reluctantly. Figure 8.37 (split over two pages below) summarises these headline responses as interpreted during analysis. Blank cells indicate that either the measure in question was not discussed, or that it is not possible to ascertain with confidence the respondent’s view on that measure.

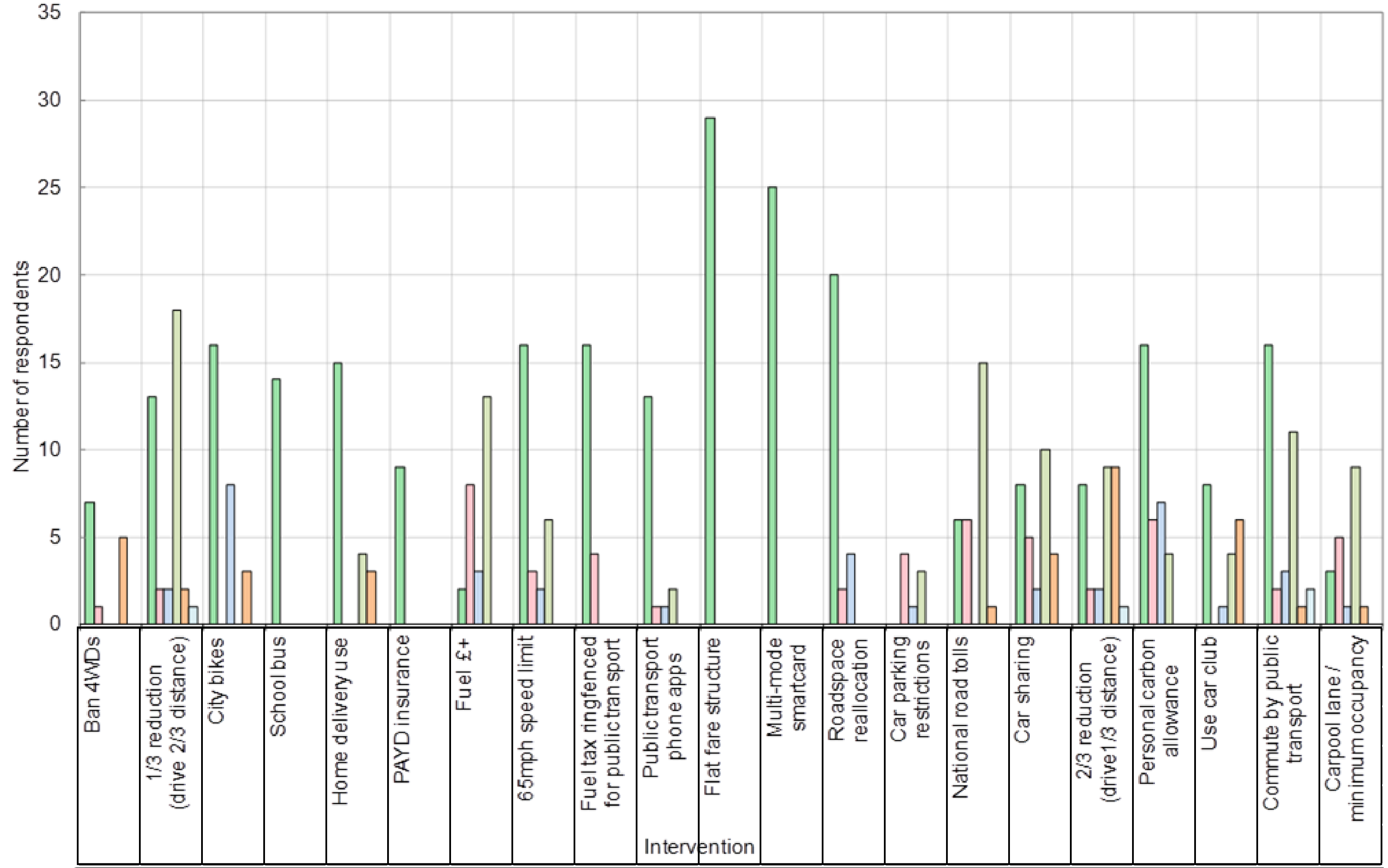
Respondent ID	Scenario 1																Scenario 2				
	Ban 4WDs	1/3 reduction (drive 2/3 distance)	City bikes	School bus	Home delivery use	PAYD insurance	Fuel £+	65mph speed limit	Fuel tax ringfenced for public transport	Public transport phone apps	Flat fare structure	Multi-mode smartcard	Roadspace reallocation	Car parking restrictions	National road tolls	Car sharing	2/3 reduction (drive1/3 distance)	Personal carbon allowance	Use car club	Commute by public transport	Carpool lane / minimum occupancy
01	P	R	C	P	P	P	Y	P			P	P	P		A	C	N	A	N	R	N
02								P	P		P	P			Y						
03		Y	P				Y	P					P	A	P	Y	R	Y	Y	P	Y
04	P	Y		P	P						P						N	C		Y	
05	N	P		P					P		P	P			Y		P	Y	C	P	P
06		Y		P			C			P	P	P				Y	Y			Y	Y
07		P	C		P			P	P				P		N		P	P		P	
08	N	P			P		Y	C								P	P	P		P	
09	N	N					A		A						A	Y	N	P	N	A	Y
10		Y	P				Y	P		Y							Y	A	N	Y	
11	P	P	P	P				P	P				P		A		P	P		Y	
12		Y			Y					P	P	P	P		Y	A	Y	P	P	Y	Y
13		C	N		Y		Y	P	A		P	P			P	Y	N		N		Y
14	P	Y	P	P			C			P	P	P	P	A		P	Y	C		Y	Y
15	P	Y	P		Y		A	P	P		P		P		Y	Y	Y	C	P	C	A
16		Y	P	P											P	Y	N	P		Y	
17	N		P				C				P	P				N	Y	P		P	
18		A	N		P		A	A	A		P	P	C		P		A	A	P	N	A
19		P	P	P			Y	P					P		A	N	P			Y	
20		Y			P		Y	P	A		P		C		A			A			
21			C	P				P	P		P	P	P		P			P		Y	

P	A	C	Y	N	R
Positive reaction	Negative reaction	"Conflicted"	Could adapt	Could not adapt	Could reluctantly adapt if forced, would possibly resist

Figure 8.37: Interpreted headline responses to policies and measures included in the narrative scenarios used in the interviews (continues on next page)

Respondent ID	Scenario 1																Scenario 2				
	Ban 4WDs	1/3 reduction (drive 2/3 distance)	City bikes	School bus	Home delivery use	PAYD insurance	Fuel £+	65mph speed limit	Fuel tax ringfenced for public transport	Public transport phone apps	Flat fare structure	Multi-mode smartcard	Roadspace reallocation	Car parking restrictions	National road tolls	Car sharing	2/3 reduction (drive1/3 distance)	Personal carbon allowance	Use car club	Commute by public transport	Carpool lane / minimum occupancy
22		P	P	P	P			P		P		P	P		Y	A	P			P	A
23		P	C		P		A		P		P	P			Y	Y	N	C	N	P	P
24		P	P				Y	Y	P	P	P		P			P	P	P		P	
25		P				P		A		P		P			Y	A	N	P		C	
26		P	P					P		P	P	P	P		Y	C	Y	P	P	P	Y
27	P	Y	P	P	N	P	Y	P	P	P	P	P	P	A	Y	P	N	A		R	Y
28		P	N		P			P			P	P			Y			P			
29		A	P	P			A	A	P	P	P		C	A	A	N	A		Y	A	A
30	A	P			P					P	P		P			P		C	P	P	
31		Y	C		P	P				P			P		Y	Y		P			
32					P	P	A	P					A			A		P	P	Y	
33		Y	C		P	P	Y	Y	P			P	P		Y	P			P	P	
34		Y					A	Y	P		P	P				A		A		P	
35		Y	P	P	P	P	A	C	P		P		P	Y			C			C	
36		Y					Y			Y	P	P	P	Y	Y		Y	P	Y	P	
37		C				P				P	P	P	P				C	C			
38	P	Y	P	P	P						P	P	A			P		Y			
39		Y	P				P	Y	P		P	P				P			P	P	P
40		Y	C		Y	P	Y	Y	P	C	P	P	P		Y	Y	Y	Y		P	C
41		P	C		N		Y	Y	P	A	P	P	C	C	P	Y	P	P	Y	P	Y
42	N	N			N		P			P	P	P		Y	Y	N	N	C	N	Y	A

Figure 8.37: Interpreted headline responses to policies and measures included in the narrative scenarios used in the interviews (continued from previous page)



	Ban 4WDs	1/3 reduction (drive 2/3 distance)	City bikes	School bus	Home delivery use	PAYD insurance	Fuel £+	65mph speed limit	Fuel tax ringfenced for public transport	Public transport phone apps	Flat fare structure	Multi-mode smartcard	Roadspace reallocation	Car parking restrictions	National road tolls	Car sharing	2/3 reduction (drive 1/3 distance)	Personal carbon allowance	Use car club	Commute by public transport	Carpool lane / minimum occupancy
P	7	13	16	14	15	9	2	16	16	13	29	25	20	0	6	8	8	16	8	16	3
A	1	2	0	0	0	0	8	3	4	1	0	0	2	4	6	5	2	6	0	2	5
C	0	2	8	0	0	0	3	2	0	1	0	0	4	1	0	2	2	7	1	3	1
Y	0	18	0	0	4	0	13	6	0	2	0	0	0	3	15	10	9	4	4	11	9
N	5	2	3	0	3	0	0	0	0	0	0	0	0	0	1	4	9	0	6	1	1
R	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0

Figure 8.38: Summary of interpreted responses to policies and measures in the narrative scenarios. Note that higher counts for respondents affirming or disapproving of measures does not necessarily indicate the level of overall support within the sample, since some measures were not discussed in each interview, or a simple ‘headline response’ could not be adequately discerned from the interview dialogue.

Of particular note, however, is the number of respondents (18 in total) who clearly expressed willingness and ability to engage with carsharing schemes.

CHAPTER NINE – DISCUSSION OF RESULTS

9.1 Introduction

This chapter relates findings from the three principal elements of the research (quantification of budgets, fleet emissions modelling, qualitative interviews) to the wider issues noted in the literature (Chapters 2–4), and to each other. Implications are first elaborated for each of the principal elements separately, before key issues in the literature are addressed by synthesising findings from the quantitative and qualitative research, forming the basis for conclusions in the next chapter.

9.2 Budgets

The passenger car sector emissions budgets for 2008–22 (Tables 5.3 and 8.1) form the basis for the analysis of mitigation potential in this work. The assumptions which underpin the budgets are in many ways as important as the quantitative values themselves, since pathways assume different roles and obligations for Annex 1 and non-Annex 1 nations, for already deforested nations versus those with remaining carbon sinks, and for the high growth international aviation and shipping sectors versus all other national economic sectors.

9.2.1 Implications of budgets

To frame quantitatively the scale and timing of mitigation at the sectoral level, it is essential to have a robust methodology for translating international climate commitments to national and sectoral levels. The approach outlined in Chapter 5 offers a transparent method for achieving this. A fundamental assumption underpinning the proposed method is that for any major sector to decarbonise at less than the mean rate required for a given national budget, other major sectors must decarbonise at above the mean rate.

Given there is such little scope for sectors to decarbonise faster than the 8% p.a. national mean rate associated with lower than 50% probabilities of exceeding 2°C (Table 5.1), opportunities do not exist for significant asymmetrical division of mitigation effort (in other words, for ‘passing the buck’ between sectors). Nevertheless, the scientific literature on technical improvements from the aviation sector offers little prospect of delivering any significant abatement in the short-term (next decade). Although rather more technical potential is observed for shipping, moves towards a low-carbon shipping sector have yet to begin in earnest and international shipping emissions are expected to continue to grow at a faster rate than global emissions (Gilbert and Bows 2012). Furthermore, there is presently no political appetite for radical demand management of international aviation and shipping – arguably even less so than for the passenger car sector.

These assumptions about international aviation and shipping are consistent with those made in the orthodox contemporary economic analyses of national mitigation potential, in which cuts are advocated where they cost least. Due to putative importance of international aviation and shipping as an engine of economic growth, strenuous abatement via costly and limited technological means in these sectors are therefore deemed unlikely in this analysis. Consequently, other sectors will be forced to compensate through tighter mitigation, or the UK will renege on its various climate change commitments by default. Whether the emissions reduction potential of the passenger car sector, along with other sectors, is sufficient to make good this sectoral budgetary overspend by international aviation and shipping, is a key question in this research.

The method presented in Chapter 5 demonstrates the contrast between emissions reductions planned for the UK car sector and what is necessary to stay within the government's existing but relatively weak statutory carbon budgets. The contrast is all the more pronounced between planned mitigation and the cuts required to conform to a pathway with a lower than 50% probability of exceeding 2°C – starker still when compared with the much more stringent commitments under the Copenhagen Accord and allowing for realistic growth in non-Annex 1 emissions.

§5.1.2 applies four key reasons for increasing the ambition of passenger car sector mitigation, particularly over the next decade. It shows that to follow a national decarbonisation pathway consistent with a *low probability of exceeding 2°C*, with *no special treatment for any sector* and accounting for *non-Annex 1 emissions growth*, the necessary reduction in cumulative emissions over the period to 2022 is four times greater than the 'abatement opportunities' currently identified by the government.

Whilst the *LCT* strategy measures form part of the government's *Low Carbon Transition Plan* for delivering emissions savings commensurate with the interim pathway (63% probability of exceeding 2°C), they do not contribute mitigation at the mean national rate, the additional effort being expected to come from the power sector. Hence the 2008–2022 budget for the passenger car sector under the government's chosen 'interim pathway' is equivalent to the *entire* 2008–2050 passenger car budget on a 36% probability pathway assuming all sectors decarbonise by at least the mean national rate – even without special treatment for international aviation and shipping. Therefore, following the interim pathway to 2022 locks out all future possibility of a low (36%) probability of 2°C pathway for the passenger car sector. Accordingly, if the UK is committed to its 2°C obligations, it is vital that no sector is given an 'easy ride'. Assuming that the commitment stands, the obvious corollary of following the interim pathway to 2022 is that other sectors must make up the shortfall in abatement effort. Given the large size of the passenger car sector (one eighth of all UK CO_2 emissions, the single largest sectoral emitter after the power sector), and the extremely challenging rate at which all sectors would need to decarbonise in order to conform to a lower probability pathway, such compensatory abatement from other sectors cannot be safely assumed. Certainly, available evidence suggests that mitigation in the key sectors such as power generation and general surface transport is falling behind a schedule consistent with meeting lower probability pathways (§3.4.1.1).

Cumulative emissions 2008–22 under the current set of policies and growth assumptions in the *LCT* strategy will overshoot sectoral budgets with better than 63% probability of exceeding 2°C by between 77 $MtCO_2$ and 262 $MtCO_2$ (depending on assumptions about the role of Annex 1 vs. non-Annex 1, international responsibility for global deforestation, and the mitigation assumed for the UK's international aviation and shipping sectors) (Table 8.1 and Figure 8.1). However, the selection of baseline is critical in estimating the effects of mitigation policies – note that the *LCT* baseline includes strong growth in aggregate demand (§2.2.4.1). The *LCT* policies are compared with a 'static' baseline in §9.3.2 below, to more clearly illustrate the relative contribution to emissions savings by supply-side efficiency improvements and changing levels of end use.

9.3 Fleet emissions model – discussion of outputs

To investigate the potential for amplifying passenger car sector mitigation in the short term, the fleet model described in Chapter 6 was used to estimate a series of alternative emissions pathways for the UK car fleet, based on a range of assumptions about the following parameters:

(i) the system used to estimate new car emissions, whether based on legislative 'type approval' stylised driving cycle, or with an uplift factor to reflect real world driving conditions
(ii) the rate of growth of the total fleet (whether due to increasing ownership or citizen and driver population growth), in combination with the rate of retirement of vehicles from each age category (or vintage) within the fleet
(iii) the extent of per vehicle usage, proportionate to vehicle age (VKM_{veh})
(iv) the total extent of vehicle usage on UK roads (aggregate demand, or VKM_{fleet}).
(v) the annual rate of penetration of low emissions vehicles into the fleet (new additions)
(vi) the rate of change of vehicle bulk emissions factor (gCO_2/km)

This produced a series of corresponding quantified fleet cumulative emissions outcomes for the period 2008–22 (using consistent historical data for 2008–10), summarised in Table 8.2, illustrated in Figures 8.13 to 8.29. From the fleet emissions model scenarios presented, the following implications may be inferred.

9.3.1 Prospects for delivering on *LCT* strategy levels of mitigation

The *LCT* baseline and counterfactual (the emissions that 'would have occurred', had it not been for the measures in the *LCT* strategy) both assume 30% growth in total vehicle kilometres by 2025 (cf. 2003), in keeping with the central expectation in the DfT's 2008 Road Transport Forecast – equivalent to a 20% growth on 2011 levels by 2022. While that prediction was made before the extent of the economic recession was clear, the most recent iteration of the DfT's RTF series (RTF–2011, published in April 2012) nonetheless forecasts a 23% increase in 'car traffic volumes' (VKM_{fleet}) by 2025 over 2003 level (all road types, all GB regions), equivalent to an increase of 17% on 2011 levels by 2022 (§2.2.4.1).

Recreating the *LCT* growth scenario in the fleet model by applying steady growth in VKM_{fleet} amounting to a 20% increase on 2011 levels by 2022, and using type approval values for new car emissions (assuming no growth in fleet size, as per profile 'A', §8.3.1), returns cumulative emissions of 924 $MtCO_2$ between 2008 and 2022 (not shown in Chapter 8). Uplifting new car emissions factors by 8.4% to reflect real world emissions returns a cumulative total of 1001 $MtCO_2$ for this recreated *LCT*-style growth scenario. As such, the fleet modelling exercise confirms that, assuming new additions to the UK's fleet conform to EU new car emissions regulations, then *LCT* measures look set to deliver emissions savings against the counterfactual baseline as intended by the *LCT* strategy[123]. That these savings appear possible even while allowing for the strong growth in VKM_{fleet} predicted by the DfT's successive Road Transport Forecasts is rather more interesting, suggesting the potential for much greater savings if growth were curtailed. The lack of demand management interventions in the *LCT* strategy hints at the underlying tension in government between the conflicting agendas of emissions mitigation on one side and economic growth and popular aspirations of 'unrestricted' mobility on the other (§4.1.3). Dominated by supply-side measures, the *LCT* strategy fails to address growth in aggregate demand as the underlying driver of emissions from the passenger car sector.

However, the *LCT* target of 14% reduction in annual road transport emissions by 2020 has no foundation in climate science, nor does it correspond to the mean national rate of mitigation (29% reduction in CO_2 by 2020) planned for the UK to follow the 'interim pathway', associated with a 63% probability of exceeding 2°C. Reliance on the power and heavy industry sectors to deliver the savings necessary for more challenging budgets is a high risk strategy, considering the slow progress made in those sectors to date (§2.2.5).

9.3.2 Appropriate scale of mitigation to meet emissions budgets

The *LCT* strategy measures appear on course for cumulative emissions between 2008–22 of approximately 1,011 $MtCO_2$ against a baseline of strong growth in demand. Consequently, under low growth or no growth conditions it is reasonable to assume a significantly reduced emissions total follows. This is essentially the premise of the 'real world baseline' Scenario 1.2, which estimates emissions with aggregate demand (VKM_{fleet}) held constant, while EU new car emissions targets are met at type approval

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[123] The *LCT* strategy is expected to return savings of 77 $MtCO_2$ against a counterfactual baseline of around 1088 $MtCO_2$ (Table 5.3).

levels and uplifted to real world equivalents (Scenario 1.1 gives the cumulative emissions if EU regulations are achieved in full using type approval values). For the purposes of estimating the cumulative effects of supply-side measures, Scenario 1.2 is the more realistic baseline than the potentially misleading counterfactual demand growth-based forecast used by the DfT. Figure 9.1 shows how Scenario 1.2 compares to budgets with a range of probabilities of exceeding 2°C and indicates the 'abatement shortfall' for each budget if EU targets are pursued as the sole means of mitigating UK passenger car emissions.

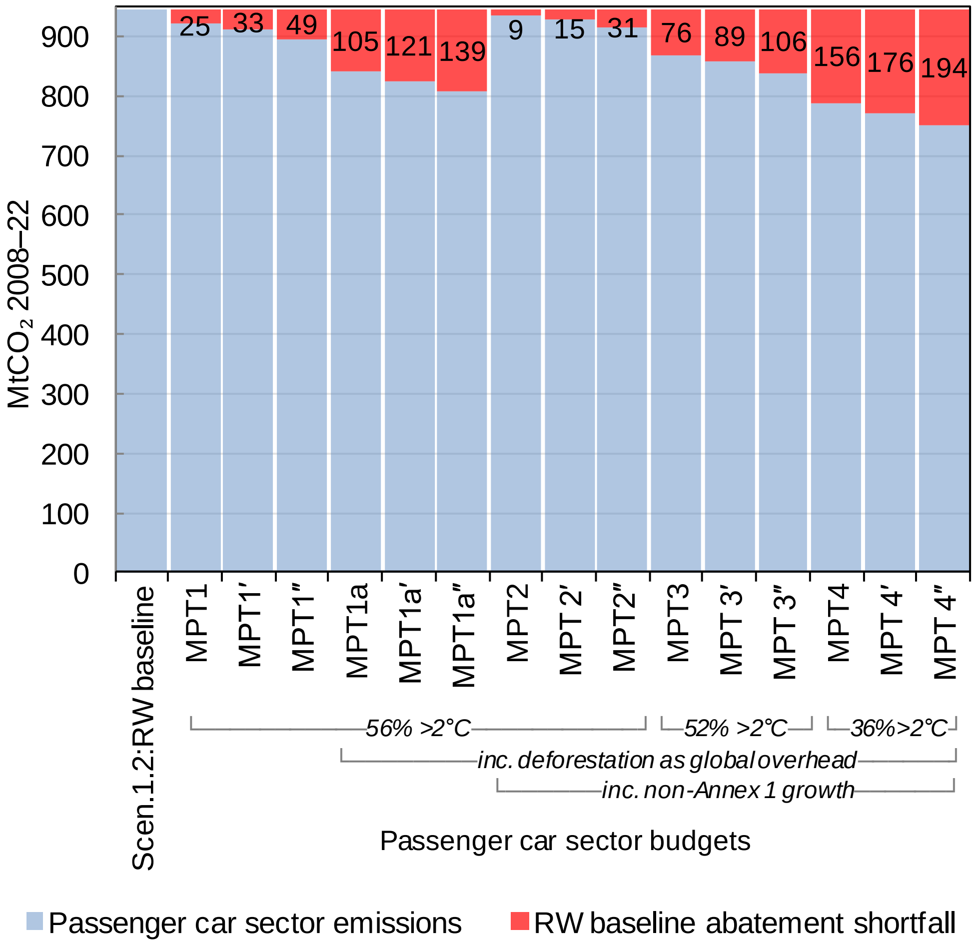

Figure 9.1: Real world baseline Scenario 1.2 in relation to cumulative emissions budgets associated with various named probabilities of exceeding 2°C. Budgetary assumptions about international aviation and shipping (IA&S, see §5.3.3) are as follows:

- no-prime: no special treatment (IA&S decarbonise at national mean rate);
- prime (′): no growth (IA&S emissions fall back to 2005 levels by 2020 and then hold constant, using bunker estimates for shipping);
- double-prime (″): low growth IA&S (emissions increasing at 1.2% p.a., shipping estimated by GDP share).

For reference, the 'holding all things constant[124] counterfactual to Scenario 1.2 (i.e. new car emissions remain at 2011 levels for the remainder of the budget period, no growth in

[124] Strictly speaking all key parameters are not held constant in this counterfactual, as current fleet size and retirement rates are maintained in profile 'A' by altering the rate of new additions to the fleet (see Figure 8.3).

VKMfleet, fleet profile 'A') gives cumulative emissions of 1,004 $MtCO_2$ (not presented in the results section). This indicates that the reduction in new car emissions factors (driven by the EU regulations) from 2011 to 2022 delivers savings of 59 $MtCO_2$[125]. *MPT2* appears 'within reach' of Scenario 1.2, requiring an additional 9 $MtCO_2$ (14%), while *MPT4″* requires a *further* 194 $MtCO_2$ of mitigation effort – a more than threefold increase in abatement effort on Scenario 1.2.

9.3.2.1 Particular features of *MPT2* budget

Eleven of the sixteen model scenarios based on real world uplifted emissions factors fall within budget *MPT2*, the highest of the budgets calculated in this analysis, assuming no special treatment for aviation and shipping (§8.3.2.1, see also Table 9.1, below). *MPT2* is based on a national pathway, *UK2*, derived from the CCC's global 21st century emissions budget associated with a 56% probability of exceeding 2°C. The global budget is shared between Annex 1 and non-Annex 1 groups according to the assumptions used by Anderson and Bows (2011) for their 52% probability pathway, with the UK receiving 1/26th of the Annex 1 budget. The difference between the CCC's 56% pathway and Anderson and Bows' 52% pathway is then apportioned between Annex 1 and non-Annex 1 on a per capita basis, with the UK's share of this additional amount being applied to the short term budget (to reflect the lead time involved in decarbonising energy infrastructure). Hence, while assumptions in *UK2* (and its cognates, *MPT2, MPT2′* and *MPT2″*) about deforestation and non-Annex 1 peak year are more 'demanding'[126] than in *UK1* and *UK1a*, the 'temporal redistribution' or 'future discounting' of emissions space from the longer term to the near term makes the *UK2*-derived passenger car sector budgets for 2008–22 slightly less demanding than for *UK1* and *UK1a*-derived budgets. With a smaller emissions budget 2008–2050, *UK2* assumes that greater mitigation will follow once progress is made in decarbonising the electricity grid.

9.3.3 Implications of scenario assumptions for budgetary compliance

This section considers the sensitivity of cumulative emissions outcomes to changes in the key fleet parameters. Depending on the nature of assumptions made about parameters (i)–(vi) (§9.3), scenarios stand either closer to or further from the budgets in Figure 9.1 than the baseline. The following subsections consider the implications of the various scenario assumptions, with reference both to the ranking of the model scenarios against budgets as shown in §8.3.2.1, and to the absolute abatement shortfall that results with respect to each scenario's set of assumptions, as shown in Table 9.1.

[125] Comparable to the DfT's expectation of 61 $MtCO_2$ savings from the combined effect of the EU 2015 and 2020 target for new cars, plus all complementary non-powertrain measures (DfT 2009a) – see Figure 2.4.

[126] Although more demanding in the short term, these assumptions are also arguably more realistic; the less immediately challenging assumptions in the *UK1* and *UK1a* budgets being much more challenging in the long term, and likely to necessitate precipitously steep cuts in emissions by *all* countries in later years.

Table 9.1: Matrix of fleet model scenarios ranked against passenger car sector emissions budgets 2008–22 and resultant abatement *shortfalls* in $MtCO_2$. Negative values (red cells) indicate a shortfall in abatement required to meet the budget in question; positive values (green cells) indicate the amount by which scenarios fall within the budgets in question (i.e. abatement 'surplus').

		Emissions budget	MPT2	MPT 2′	MPT1	MPT2″	MPT1′	MPT1″	MPT3	MPT 3′	MPT1a	MPT 3″	MPT1a′	MPT1a″	MPT4	MPT 4′	MPT 4″
Model scenario	Assumptions	$MtCO_2$ 2008–22	937	930	920	915	912	896	869	857	840	840	824	807	789	770	751
4.1	▲🡡	970	-33	-40	-49	-55	-58	-74	-101	-113	-130	-130	-145	-163	-180	-200	-219
4.2	▲🡡🌢	959	-22	-29	-38	-44	-46	-63	-90	-102	-119	-119	-134	-152	-169	-189	-208
1.2		945	-9	-15	-25	-31	-33	-49	-76	-89	-105	-106	-121	-139	-156	-176	-194
5.2	▲⇩	945	-9	-15	-25	-31	-33	-49	-76	-89	-105	-106	-121	-139	-156	-176	-194
4.3	▲	944	-7	-13	-23	-29	-31	-48	-74	-87	-104	-104	-119	-137	-154	-174	-192
1.3	🌢	935	2	-5	-15	-20	-23	-39	-66	-79	-95	-96	-111	-129	-146	-165	-184
5.3	▲🌢⇩	933	3	-3	-13	-19	-21	-37	-64	-77	-93	-94	-109	-127	-144	-164	-182
7.1	🌢↻	931	6	-1	-10	-16	-18	-35	-62	-74	-91	-91	-106	-124	-141	-161	-180
5.1	⇩	927	10	4	-6	-12	-14	-31	-58	-70	-87	-87	-102	-120	-137	-157	-175
2.1	🌢🌢	914	23	16	7	1	-2	-18	-45	-57	-74	-74	-89	-107	-124	-144	-163
7.2	🌢▼	905	32	25	16	10	7	-9	-36	-48	-65	-65	-80	-98	-115	-135	-154
2.2	🌢🌢	904	32	26	16	10	8	-8	-35	-48	-64	-65	-80	-98	-115	-135	-153
6.1	▲⇩🌢🌢	902	34	28	18	12	10	-6	-33	-46	-62	-63	-78	-96	-113	-133	-151
1.1	✳	873	63	57	47	41	39	23	-4	-17	-33	-34	-49	-67	-84	-104	-122
3.1	🡣	856	80	74	64	58	56	40	13	0	-16	-17	-32	-50	-67	-87	-105
6.2	▲🡣🌢🌢	845	92	86	76	70	68	51	24	12	-5	-5	-20	-38	-55	-75	-93
3.2	🡣🡣	751	186	179	170	164	161	145	118	106	89	89	74	56	39	19	0

For budgetary assumptions, refer to *x*-axis and caption of Figure 9.1. Scenario assumptions are marked by the following symbols denoting:

- ▲ Fleet growth (profile 'B', §8.3.1.2)
- 🡡 Growth in aggregate demand (VKM_{fleet}), resulting from fleet growth
- 🡣 25% reduction in annual distance per vehicle (VKM_{veh}) by 2022
- 🡣🡣 50% reduction in annual distance per vehicle (VKM_{veh}) by 2022
- ⇩ Reduction in aggregate demand (VKM_{fleet}) expressed as an increase in mean trip occupancy for commuting (level of reduction / increase varies. See Table 8.2)
- 🌢 EU 2015 and 2020 new car emissions targets realised in terms of real world emissions
- 🌢🌢 Mean new car emissions 90 gCO_2/km from 2015, falling by 3% p.a. thereafter (use of type approval or real world basis for 90 gCO_2/km varies, see Table 8.2)
- ↻ Increased rate of fleet turnover (profile 'C', §8.3.1.3)
- ▼ Fleet contraction (profile 'D', §8.3.1.4)
- * Cumulative emissions based on type approval gCO_2/km values (Scenario 1.1 only – all others are uplifted by 8.4% to reflect real world driving conditions)

9.3.3.1 Type approval vs. real world emissions values

The 'type approval baseline', Scenario 1.1, is presented for reference using per vehicle kilometre bulk emissions factors that assume EU new car regulations are met in full, and that CO_2 emissions accord with NEDC-based type approval values. This scenario illustrates that the EU new car regulations appear to deliver cumulative emissions of

873 $MtCO_2$ in the absence of growth in VKM_{fleet}. However, the type approval test poorly recreates real world driving conditions and thus gives a false impression of emissions. NEDC-based values were discarded by the UK Transport Research Laboratory in their revised method for estimating all other forms of vehicle emissions (bar CO_2) for precisely this reason. The DfT nevertheless requested that type approval values be retained as the basis for calculating CO_2 emissions from the passenger sector (§6.3.7). The fleet model calibration and validation process in this work corroborates the growing disparity found elsewhere between fleet total emissions under mean vehicle emissions factors adjusted for real world conditions and those expected from type approval emissions factors (Mock *et al* 2012). Therefore, the purpose of Scenario 1.1 is to serve as an illustrative baseline, to better appreciate the potential scale of under-achievement of mitigation effort if decarbonisation of the passenger car sector is left solely to EU type approval targets. Hence, the 72 $MtCO_2$ difference in 2008–22 cumulative emissions between Scenario 1.1 (type approval baseline, 873 $MtCO_2$) and Scenario 1.2 (real world baseline, 945 $MtCO_2$) represents the quantity of actual CO_2 likely to be emitted *over and above* that predicted by EU target-achieving type approval scenarios. This 72 $MtCO_2$ overestimate of the mitigation potential of type approval-based monitoring is a very serious issue if allowed to go unrecognised, being of similar magnitude to the total 'emissions saving' expected from all the *LCT* strategy measures combined (77 $MtCO_2$). Table 9.1 shows that, were type approval values accepted as a reliable indicator of true emissions, Scenario 1.1's achievement of EU new car emissions targets would appear to deliver budget *MPT1″* (56% probability of exceeding 2°C, allowing for growth in international aviation and shipping), with budget *MPT3* within reach, requiring further abatement of only 4 $MtCO_2$. In reality, cumulative emissions in the real world equivalent, Scenario 1.2, would exceed all budgets in Table 9.1.

All remaining scenarios therefore apply a real world uplift of 8.4% to type approval mean emissions factors. Consideration of the possibility of reproducing type approval values in the real world through wider application of highly efficient driving styles is discussed in §9.3.4 below.

A further possibility for applying the EU emissions targets is that the type approval test is revised to correspond more closely to real world driving conditions, while the same target vales are delivered in real world terms (scenarios with green boxes in Tables 6.6 and 8.2). This is the main assumption behind Scenario 1.3, which otherwise follows the same assumptions as Scenarios 1.1 and 1.2, and results in cumulative emissions just inside the core *MPT2* budget, but outside all non-future discounted budgets, and all budgets in which allowance is made for aviation and shipping to mitigate their emissions at below the national mean rate.

The upshot of these findings is that real world emissions scenarios which rely entirely on delivery of the EU 2015 and 2020 standards alone, without some form of aggregate demand reduction, do not meet even the most generous budget associated with a 56% probability of exceeding 2°C (i.e. *MPT2*, which assumes increased mitigation in future).

9.3.3.2 Growth in fleet size

It is striking that the scenarios which incorporate growth in fleet size, even while total VKM_{fleet} holds constant, fall outside the majority of the emissions budgets defined. This is principally due to the greater proportional use of new cars, to an extent negating savings from their lower bulk emissions factors (§6.3.4). The only two scenarios which incorporate fleet growth while remaining within any of the emissions budgets, namely Scenarios 6.1 and 6.2, do so through a combination of considerably intensified regulation of new car emissions and – importantly – a reduction in total VKM_{fleet}. Note that Scenario 6.2, which assumes a schedule of new car emissions improvement of -3% p.a. from 90 gCO_2/km in 2015 allied to an outright reduction in VKM_{veh} of 25% by 2022, results in cumulative emissions of 845 $MtCO_2$. Compare this to cumulative emissions of 914 $MtCO_2$ under Scenario 2.1, which follows the same programme of new car emissions improvement but *without* fleet growth or restriction in VKM_{veh}. It thus becomes clear that the bulk of the emissions savings in Scenario 6.1 and 6.2 are derived from the reduction in demand, rather than from the considerable push in vehicle efficiency improvement.

Despite achieving the EU vehicle emissions targets in real world terms (i.e. mean new car emissions of 95 gCO_2/km in real world values in 2020), with 0.6% p.a. fleet growth and no change in per vehicle driving distance, Scenario 4.2 emerges as the second highest emitting of all model runs – second only to the equivalent Scenario 4.1 based on uplifted type approval values. Scenarios 5.2 and 5.3 also include fleet growth at 0.6% p.a. with no outright restriction on VKM_{veh}, and again assume EU new car targets are achieved at type approval (then uplifted) and real world values respectively. Scenario 5.2, despite a small reduction in total VKM_{fleet} resulting from a one third increase in mean trip occupancy for commuting journeys, exceeds all budgets presented. Scenario 5.3, based on EU targets realised in on the road emissions, falls just within the scope of 'future discounted' budget *MPT2*.

The implications of fleet growth on cumulative emissions in the model scenarios are clear: without a constraint on annual distances per vehicle (VKM_{veh}), fleet growth (even at levels much lower than typically seen in the last decade) is liable to be accompanied by aggregate demand growth (VKM_{fleet}) which swamps the mitigation effects of planned new car efficiency improvements. The prevailing trends in car ownership and use in Great Britain are towards more cars per household and lower per capita annual driving distances and per vehicle distances (§4.2.1.1, Figure 4.2). At the same time, the UK citizen population trend since the turn of the century has been steady growth (mean 0.6% p.a. and rising), due in large part to growth in net inward migration during the early 2000s (Figure 4.3). As long as these drivers of fleet growth prevail, the current prospects are very poor for meeting sectoral emissions budgets associated with lower than 63% probability of exceeding 2°C, unless annual distances per vehicle decline much more steeply than the recent downward trend.

To put it another way, insofar as citizen population growth translates into fleet growth, to assume static aggregate demand (VKM_{fleet}) is also to assume a reduction in annual distance per vehicle (VKM_{veh}). Although the DfT's counterfactual baseline arguably overplays the size of increase in aggregate demand likely to result from citizen population growth alone (as opposed to per capita increases in annual driving distance), it must be acknowledged that growth in VKM_{fleet} is a realistic prospect under continuing citizen population growth conditions, whether or not pre-recession conditions resume.

9.3.3.3 Per vehicle and aggregate demand

All modelled scenarios which assume no change in fleet VKM_{veh} use the current 10-year historical low values for (age proportionate) annual distance per vehicle for each future model year. Since increasing annual VKM_{veh} is neither consistent with recent historical trends nor desirable from a mitigation point of view, none of the scenarios assume that vehicles are driven further than at present. As previously noted, several scenarios include a reduction in annual VKM_{veh}, the most ambitious of which are Scenarios 3.1, 3.2 and 6.2, respectively assuming a 25%, 50% and 25% reduction in VKM_{veh} by 2022. In these scenarios the EU 2015 and 2020 targets are assumed to be met at type approval, then uplifted to reflect real world driving. Unsurprisingly, only these three scenarios, which assume an outright step reduction in per vehicle demand, result in cumulative emissions that fall within *MPT3′* – that is, within a 2008–22 budget associated with a 52% probability of exceeding 2°C, while allowing space for IA&S emissions to continue at their 2005 levels. Based on what can only be described as a *radical transformation* of private car use, Scenario 3.2 is the sole modelled scenario conforming to any of the *MPT4* budgets (associated with a 36% probability of exceeding 2°C).

The implications of this are hard to overstate – for sectoral emissions to be associated with a lower than 50% probability of exceeding 2°C, then *a non-marginal reduction in aggregate demand in the short term is essential.* Furthermore, without contraction in total number of vehicles in use, this implies reduction in annual distance per vehicle (VKM_{veh}).

Whilst the scale of aggregate demand *reduction* required to meet the lower probability of 2°C budgets is an order of magnitude greater than anything seen in the history of UK passenger car use, much lower levels of absolute aggregate demand have been observed in previous years, albeit during the steady, year on year upward progression of demand. With no growth in total fleet size, Scenario 3.2's 50% reduction in annual distance per vehicle by 2022 results in aggregate demand also falling by 50%, to approximately 200 billion vehicle kilometres – a level of aggregate demand (VKM_{fleet}) last seen in the UK in 1977 (DfT 2011e, TRA0201).

In appraising the possibility of reductions in annual VKM_{veh} at the scale of those modelled in Scenarios 3.1, 3.2 and 6.2, it is useful to recall the trend in vehicle ownership and use described in §4.2.1.1. Figure 4.3 shows no post-war analogue for either the *rate* of reduction in levels of car use implied by these scenarios, nor evidence of *actual* mean annual distance per vehicle (VKM_{veh}) having been as low as the net result of a 50% reduction in current mean VKM_{veh}. On the other hand, Figure 4.5 shows no post-war analogue for the currently high mean levels of car ownership per adult and per household. This latter trend suggests scope for reduction in mean VKM_{veh} whilst leaving PKM, even car-based PKM, untouched, through more efficient resource utilisation of the fleet – in other words if mean bulk occupancy (AVO_{VKM}) were to increase at the expense of single occupancy trips.

Scenarios in which a reduction in VKM_{veh} was modelled assume that the specified level of reduction is applied across the fleet in proportion to the typical annual distances travelled by cars in each one-year age category (§6.2.3). Mean VKM_{veh} ascribed to each category is therefore assumed to be progressively reduced in each successive model year until the target level of reduction is reached in 2022 (50% in Scenario 3.2, for example). However, clearly there are other ways of achieving an equivalent reduction in aggregate demand that do not assume *mean* vehicle use is cut by 50% – many of which arise from the variations in annual driving distance noted in §4.2.1.3. The possibility of demand-side interventions that target the highest annual mileage drivers whilst allowing a minimum level of mileage to be maintained is a particularly interesting idea, which recognises the value of social and economic mobility associated with access to car travel. The possibility of delivering such interventions and their foreseeable consequences are a central part of the rationale for a cap and trade system of personal carbon allowances, discussed in the context of the qualitative interview findings in §9.4.5 below.

9.3.3.4 Increased rate of fleet penetration of new vehicles

Cumulative emissions mitigation by supply-side improvements to new vehicles is limited by the rate at which new cars penetrate the fleet. Recent years have seen a decline in both the annual rate of new additions to fleet (number of first registrations, see §8.3.1), and the rate of retirement for the majority of vehicle age categories (§6.3.2 and Appendix 4). If current trends continue, this would effect a slowdown in the turnover rate of the fleet, meaning that the full mitigation potential of innovations in efficient vehicle technology may not be realised in practice. The sensitivity of cumulative emissions in the quantitative model to rates of fleet turnover is tested in Scenario 7.1, which assumes that current total fleet size is maintained, but that the mean rate of retirement 2000–2010 applies from 2013 onwards with new additions increasing to balance total fleet size

(§8.3.1.3). New car emissions are assumed to follow the same regime as Scenario 1.3, i.e. EU emissions standards are realised in real world terms. A further crucial assumption in Scenario 7.1 is that, although aggregate demand is 'capped' in the model at the current 2011 total VKM_{fleet}, annual mean VKM_{veh} is specified in proportion to vehicle age, based on the 2010 age proportionate VKM_{veh} curve (§6.3.4). With fewer vehicles in older categories in later model years due to the enhanced rate of retirement (Figure 8.6), the net result in terms of VKM_{veh} is minimal, even given the c.20% increase in the rate of new additions in 2013 (to 2.5m new cars). This is because removing more older cars from the fleet creates room within the aggregate demand cap for new cars to continue to be used at levels very close to 2010–11 (minus one percent for most model years). The upshot of the increased rate of new additions is that the fleet contains a higher proportion of cars that attract higher annual VKM_{veh}, in keeping with typical use patterns of cars by age category.

Revealingly, this high turnover scenario does not rank particularly well in the overall series of emissions budgets, falling just outside of the second-least demanding budget *MPT2′* (56% probability of exceeding 2°C, allowing for IA&S emissions to continue at 2005 levels). Scenario 7.1 illustrates that even with a regime in which new car emissions factors are reduced at a rate beyond the *de facto* EU regulations, any absolute reduction in fleet emissions that might otherwise be achieved by retiring older, higher emitting vehicles from the fleet is overshadowed by the increased number of new cars. As a result, this potentially costly-to-deliver scrappage scenario returns but a meagre additional reduction in cumulative emissions (4 $MtCO_2$) relative to the 'low-scrappage' Scenario 1.3 on which it is based.

Clearly the emissions outcome of Scenario 7.1 is contingent on the assumption that new cars will be driven proportionally greater distances in their first few years of registration than in later years. Although the scenario does not include an explicit estimation of the potential *rebound* effects of more fuel efficient new cars entering the fleet, it recognises that in all likelihood, without a constraint on either per capita or per vehicle annual distance, then new vehicles will *at least continue* to be used proportionally more than existing older vehicles. Rebound effects – expressed as increase in extent of use of new vehicles over an above their typical age proportionate VKM_{veh} – would mean that Scenario 7.1 results in cumulative emissions greater than modelled, making it a less effective mitigation option still.

9.3.3.5 Continuation of current trends – declining rate of new vehicle penetration

By contrast to the step-up in rates of retirement and new additions in Scenario 7.1, Scenario 7.2 assumes that the current historically low rates of annual vehicle scrappage and new additions persist for the coming decade, while following the same new car emissions schedule as Scenarios 1.3 (and Scenario 7.1). Here, the declining number of annual new additions since 2003 is not compensated by increased purchasing rates in modelled future years, and as a result total fleet size declines until reaching equilibrium (of new additions and retirement) in around 2020, at approximately 90% of current fleet size. Holding VKM_{veh} constant, Scenario 7.2 returns a reduction in overall VKM_{fleet}, proportionate to the decline in total fleet size. As a result, total emissions fall within the MPT1′ budget, indicating that Scenario 7.2 is commensurate with a national pathway based on a 56% probability of exceeding 2°C while allowing for IA&S to continue at 2005 levels – although making no allowance for non-Annex 1 nations to increase their share of global emissions, nor for global deforestation.

It is telling that, through delivery of EU new car emissions targets as real world values and maintaining current levels of annual new additions and rates of retirement, Scenario 7.2 delivers greater cumulative savings than the much more technologically ambitious Scenario 2.1, which assumes mean new car emissions of 90 gCO_2/km from 2015 (at type approval values) falling at 3% p.a. thereafter. Indeed, in terms of mitigation, Scenario 7.2 is virtually the equal of Scenario 2.2, which delivers 1 $MtCO_2$ additional abatement by pushing mean new car emissions factors to 90 gCO_2/km in real world values from 2015 falling at 3% p.a. thereafter, from a fleet profile which only differs from Scenario 7.2 in boosting new additions to a level which maintain current fleet size.

9.3.3.6 Rapid reduction in mean bulk emissions factors

Scenario families 2 and 6 assume a rapid step change in mean bulk emissions factors (gCO_2/km) of new cars entering the fleet in each model year from 2015. In Scenario family 2, total fleet size and aggregate demand are assumed to remain static (fleet profile ‘A’, §8.3.1.1), but EU targets for new car emissions are assumed to be replaced with a national standard of 90 gCO_2/km from 2015, declining annually by 3% thereafter. In Scenario 2.1, the 90 gCO_2/km benchmark is based on type approval emissions – in keeping with the manufacturer-claimed emissions factors seen amongst the best available superminis in 2012. Scenario 2.2 goes even further, assuming that the 90 gCO_2/km benchmark is delivered in real world emissions – in keeping with what may be expected by 2015 through 3% p.a. improvement from the current (2012) real world approximation of best-in-class superminis, c.98 gCO_2/km. (Scenarios 6.1 and 6.2, discussed in §9.3.3.2 above, follow the same emissions factor regimes as Scenario 2.1 and 2.2 respectively, but assume very different characteristics of fleet growth and demand.)

Modelled cumulative emissions for Scenarios 2.1 and 2.2 fall close to budget *MPT1′* (56% probability of exceeding 2°C, allowing for 2005-levels of IA&S, but no concession to emissions growth in non-Annex 1 countries, nor accounting for global deforestation). This indicates that stringent supply-side improvements to new car bulk emissions factors, even at the maximum level considered feasible in the immediate future for ICEV technology, applied through strong (assumed effective) regulation of national car sales, are unable to deliver the abatement necessary for a short term sectoral budget with a lower than 56% probability of 2°C.

Scenario 6.2, despite allying a 25% reduction in VKM_{veh} with rapid implementation of challenging supply-side measures, still exceeds core budget *MPT4* (36% probability of exceeding 2°C) by 55 $MtCO_2$, and the equivalent budget allowing for low growth IA&S (*MPT4″*) by 93 $MtCO_2$. If fleet growth is excluded from Scenario 6.2, it produces cumulative emissions of 831 $MtCO_2$ (not shown in Chapter 8 results), still exceeding the core *MPT4* budget by 42 $MtCO_2$. Thus supply-side measures, even implemented at the considerably enhanced rates assumed in Scenarios 2.1, 2.2 and 6.2, are incapable of adequately mitigating sectoral emissions without a step change in aggregate demand.

9.3.4 Reproducing type approval emissions factors in the real world

The use of uplifted real world emission factors is intended to reflect the emissions of vehicles in typical use rather than under stylised test-bench conditions. The user-generated data on fuel consumption gathered by members of the public and collated on internet databases such as www.honestjohn.co.uk and www.spritmonitor.de give a truer picture of typical in-use emissions for a wide range of vehicles. Whatcar.co.uk's recently launched 'TrueMPG' calculator (What Car? 2012) now openly acknowledges the inevitable disparity between 'operating conditions' under ideal lab-based simulations and real world patterns of use, whether arising from road type (affecting average speed and level of transient operation), level of congestion (affecting the frequency and duration of stop–start cycles and idling), or driving style of the individual user (affecting aggressiveness of acceleration and braking, propensity to high speeds). Arguably, for a given vehicle even a single instance of type approval mean emissions per kilometre being achieved in real world use might be considered vindication of the type approval process and method. However, to be a useful guide to ultimate emissions, type approval emissions would have to be matched over a range of trip types, durations, occupancy levels, speeds, etc. Many household cars fulfil a range of functions, and the mean emissions per kilometre of use for such vehicles must be considered over the range of uses to which the car is put.

Internet fuel economy databases are populated by drivers who are by definition already interested in the fuel efficiency of their vehicle. In all likelihood, such drivers may typically adopt a more conservative driving style than those who are not especially interested in fuel efficiency. Thus the mean values for fuel consumption and emissions emerging from these informal datasets are potentially skewed by drivers who adopt a more economical style than the 'average driver' on the roads. Nevertheless, the sizeable variance inherent in the data provided by different users of identically configured vehicles (Mock *et al* 2012) indicates that road conditions, auxiliary equipment use and driving style may all potentially exert more influence over ultimate emissions per kilometre for a given vehicle than a single type approval or other unitary value might suggest.

With respect to driving style, tendencies towards inefficient driving may be partly addressed through new driver training and testing – for example by including 'eco-driving' awareness and skills as part of the standard driving test (introduced in the UK in 2008). Propensity to exceed legal speed limits may be partly addressed through better enforcement of existing speed limits using automatic number plate recognition (ANPR) and average speed cameras on motorways and A-roads, or through on-board vehicle tracking and sensing technology. Inefficient driving style may be affected more profoundly still by the roll-out of a range of on-board vehicle technologies that may be described as 'informative' at the least intrusive end of the spectrum, through 'persuasive', right through to systems which automate or override user inputs to the vehicle controls. Many new vehicle models even at basic trim levels include trip computers which give average fuel consumption over the trip[127], and gear shift indicators which prompt the driver to change gear at the most appropriate point during acceleration and deceleration. Satellite navigation devices commonly alert drivers to current road speed limits. At the more persuasive end of technological interventions to improve driver efficiency, speed limit detection can be linked via the vehicle's engine management computer to regulate the speed of travel to that of the road limit (§4.4.2.2). Engine management and semi-automatic gearbox control systems[128] may also be configured to delay or even ignore aggressive acceleration inputs by the driver. Such systems may or may not be configured to allow manual override – without override facility they effectively govern the behaviour of the vehicle, optimising driving style efficiency.

As a minimum specification on new vehicles, gear change indicators and fuel consumption trip computers would ensure that 'motivated' drivers are given useful information on how to improve their driving efficiency. Mandating maximum-speed-limiting engine-governors has the potential to go considerably further. However, if offered on an optional basis, technological interventions that effectively override operator inputs are likely to be a 'tough-sell' (to both public and government), since they go against the libertarian 'spirit of motoring' promoted through car advertising and the motoring press. Moreover, applied electively, they are also unlikely to affect the driving styles of the most inefficient drivers, whose preference is for fast, 'sporty' acceleration, high top speeds and heavy braking.

Based on the assumption that such technology interventions in their most effective form are likely to be publicly and politically resisted, they are not explicitly assumed in any of the quantitative scenarios discussed above, although positioning such technology as safety-enhancing rather than 'freedom-constraining' may yield more positive public acceptance.

[127] And indeed real time consumption, although this tends to be of limited value.

[128] For example continuously variable transmission (CVT) and electronic gearbox control (EGC) systems.

In assuming that type approval targets are realised in terms of real world emissions, Scenarios 1.3, 4.2, 5.3, 7.1 and 7.2 may be delivered by new vehicles capable of performing at type approval target levels under real world driving conditions partly through implementation of technological interventions that restrict inefficient driving styles to more closely replicate type approval testing.

9.4 **Qualitative interviews**

This section discusses the findings from the qualitative interviews in light of the model outputs and their implied necessity of aggregate demand reduction for lower probability of 2°C sectoral emissions pathways.

9.4.1 Metrics of demand reduction in the qualitative interviews

The quantitative fleet model scenarios above assume reductions in demand expressed both as aggregate demand (VKM_{fleet}) and per vehicle demand (VKM_{veh}). With respect to absolute emissions, aggregate demand is of first importance. However, a more subtle and disaggregated measure of demand is required to capture the many ways in which a given fleet profile could deliver the same overall distance travelled, or indeed the variety of fleet profiles and patterns of use that could deliver the same aggregate demand outcome.

The distinction between VKM_{fleet} and VKM_{veh} is particularly pertinent when it comes to assessing the possibility of delivering the assumed levels of aggregate demand reduction from the quantitative scenarios through interviews with individual *car drivers*. Even assuming a 'no growth' fleet profile, the reductions in car use contemplated by individual interview respondents cannot be directly equated with comparable reductions in VKM_{veh}, since respondents themselves may not be the sole or even main driver within their household (§7.3.3.1). Hence, respondents cannot necessarily speak for other household members who use 'their' car. However, in practice around three quarters of interview respondents reported being the main driver in their household, and that either no one else drives their car or that others drive their car occasionally or rarely (less than once a week, or less than once a month respectively). Respondents typically based their estimates of annual driving distance on the annual distance of 'their' cars. Few respondents in multi-car households where another household member is the main driver were confident of giving an accurate estimate of the annual mileage of the 'main' household vehicle, where this was not the car they drive. Thus the mileages described by respondents are taken to be broadly representative of the annual distances accumulated by 'their' main vehicles, and are thus treated as a proxy both for per capita and per vehicle annual driving distances in the sample.

9.4.2 Sample targeting and representivity

As illustrated in Figure 8.34, the interview sample mean and median daily commuting distance is higher than the estimated national mean commuted by car, based on NTS statistics on the typical annual commuting mileage travelled by cars as reported in

NTS0901 (annual mileage of 4-wheeled cars by type and trip purpose: Great Britain, 1995/97 to 2010) divided by 220 working days – a conservative estimate of full time employment, 5 days a week, 44 weeks of the year. While it is recognised that NTS0901 statistics are *estimates* of annual car mileages and proportions thereof for commuting, business and other journey purposes as provided by NTS respondents, this is considered more representative of car commuting mileage for drivers in full time employment than the statistics in NTS0410 (average distance travelled by purpose and main mode) divided by NTS0409 (average number of trips (trip rates) by purpose and main mode).

The estimate of 'mean commuting distance per trip as driver' that emerges from NTS0409 and NTS0410 is 10.21 miles, based on a mean annual trip rate of 87 per year (Table 9.2). Such low trip rate[129] for commuting as driver in NTS409 suggests that the survey sample for these statistics comprises many respondents who are neither daily commuters nor car drivers. By contrast, the survey sample for NTS0901 by definition comprises only car drivers. The proportion of total mileage of cars for commuting purposes in NTS0901 is consistent with other datasets on vehicle distance by trip purpose (such as that behind Figure 4.6).

Table 9.2: Comparison of NTS statistics on car commuting distances

	Business	**Commuting**	**Other private mileage**	**Annual total**
NTS0901 **annual kilometres of 4-wheeled cars** by trip purpose	1,432	4,313	7,821	13,567
NTS0410 average **distance as driver** by purpose, 2010 (km)	694	1,431	3,355	5,481
NTS0409 average **number of trips as driver** by purpose, 2010	20	87	297	405

Figure 8.34 also shows that interview sample mean and median annual driving distances were also significantly greater than the national mean annual distance for cars as given in NT0901. Higher than average daily and annual driving mileages, in conjunction with the self-identification by the large majority of respondents as having lifestyles that required the use of a car (§8.4.1.5), as well as a broad geographical spread and mix of rural versus sub-urban and peri-urban home locations (as illustrated in Figure 8.33), suggest that sample may be considered broadly representative of higher-mileage car drivers nationally.

[129] A trip is one-way, therefore 87 trips per year is equivalent to 43 daily round trips – not representative of patterns of commuting as practised by drivers in full time employment.

9.4.3 Relating quantitative model scenarios to qualitative interview findings

To relate findings from the quantitative fleet model scenarios regarding levels of demand reduction required to meet short term budgets (with various probabilities of exceeding 2°C) to qualitative findings from the interviews (based on narrative storyline scenarios of future reductions in car use), this section first considers the terms on which comparisons can meaningfully be made.

The scale of individual demand reduction described in the narrative scenarios was gauged according to an estimated level of cuts that, if applied across a sufficient portion of high annual mileage drivers, would yield reductions in aggregate demand of the scale assumed in the most ambitious quantitative scenarios (§7.3.3.1). Quantitative Scenarios 2.1 and 2.2, for example, assume that 25% and 50% reductions in mean annual distance per vehicle (VKM_{veh}) translate into equivalent reductions in aggregate demand (VKM_{fleet}), based on a static total fleet size. Growth in fleet numbers would mean that the same reduction in VKM_{veh} returns a smaller reduction in aggregate demand. For the reasons noted in §6.5.3 and §9.3.3.2, fleet growth must be treated as a real possibility, if not likelihood. Given the need to present concise, coherent narratives to interview respondents, the range of possible demand reductions required to meet the lower probability of 2°C budgets was simplified to one third and two thirds of current use, informed by the assumptions that:

(i) many respondents would simply be unwilling or unable to envisage step changes in their levels of car use at the required level to deliver mean reductions in VKM_{veh} of 25% and 50% (as assumed in a number of the quantitative scenarios);

(ii) fleet growth would necessitate even greater reductions in VKM_{veh} to return the same level of VKM_{fleet};

(iii) EU 2015 and 2020 targets for mean new car bulk emissions factors may not be met in full in the UK, given that the UK market currently lags behind other European countries in terms of 'national compliance' (§3.5.1 and §4.2.2); and

(iv) quantitative scenarios relying on enhanced rates of technology improvement to achieve a given level of mitigation may not be realised in full, hence requiring reductions in VKM_{fleet} of 50% or more to deliver a given emissions pathway.

9.4.3.1 Headline responses to the levels of demand reduction in the narrative scenarios

At a basic – if rather simplistic – level, the perceived feasibility of the most challenging rates of demand reduction assumed in the quantitative scenarios can be estimated from the headline reactions of respondents to the proposed one third and two thirds reductions in their current levels of car use. As such, Table 8.37 and Figure 8.38 show that thirteen respondents (31%) expressed a broadly positive reaction to the notion of their reducing their annual driving distance by one third, with a further eighteen respondents (43%) indicating that they could adapt to the level of car use described in the one third reduction narrative scenario, whilst not necessarily finding it an appealing prospect (one additional respondent indicating that under duress they would reluctantly be able to make the adjustment without significant hardship). Two respondents suggested that they could not adapt to such a reduction, the same number indicating that they found the scenario unappealing and would prefer not to cut their driving as described. Four respondents were ambiguous in their response and two others were openly conflicted – seeing some benefits in the scenario, but seeing no viable alternative to their current level of car use in their circumstances. In short, however, almost three quarters of the respondents registered their perceived capacity to adjust to a reduction in their current driving distance by one third.

As might be expected, the approval rating for the narrative scenario describing a two thirds reduction in car use was considerably lower: eight respondents (19%) expressing a largely positive reaction to the scenario, with a further nine (21%) indicating that they could adapt, whilst not necessarily embracing the scenario. Nine respondents could not envisage adapting to the scenario even under the additional provisions (e.g. of public transport, widespread car club, increased use of ICT), while perhaps surprisingly only two were unequivocally opposed to the scenario. Two were openly conflicted, whereas the reactions described by eleven respondents (26%) were more ambiguous and uncertain (blank cells[130] in Table 8.37).

However, the temptation to read relative levels of support for the two narrative scenarios into this coarse summary should be resisted, since it was not the purpose of the interviews to quantify popular support for the hypothetical scenarios or packages of policies. Rather the interviews qualitatively explored the elements of respondents' current car use that would either facilitate or impede moving to such dramatically reduced levels of driving. The following sections therefore address the significance and implications of the key themes distilled from the interview dialogues (as presented in §8.5), before synthesising findings from the interviews regarding the possibility of increasing vehicle occupancy for certain trip purposes with findings from the fleet emissions model scenarios which included increased commuting occupancy as a mitigation measure.

9.4.4 Contextual, structural and lifestyle constraints

9.4.4.1 Geographical, employment, security and other physical lock-ins

Structural lock-ins to driving featured strongly within the interview dialogues. Many respondents emphasise the aspects of their daily current car use that are instrumental (if not essential) to meeting their duties and obligations with respect to employment,

[130] In the case of the headline reactions to the reductions themselves – in the case of individual policies or measures, blank cells are more likely to indicate that respondents did not alight on that particular element of the narrative scenario.

education, household management and health – classic cases of demand for private transport being *derived* demand. These sources of derived demand may rightly be considered lock-ins insofar as they are accepted as 'non-negotiable'. For instance, a number of respondents expressed preferences for living in semi-rural areas while working in the city, thus necessitating private transport (in the absence of public transport alternatives at the rural point of departure). Common push factors were the higher price of housing in desirable (suburban) areas of the city, perceived social and health impacts of urban life, and balancing the distance to another household members' workplace. Pull factors (away from the city) include the perceived 'wholesomeness of country living' (especially with reference to young children), the desire for land to practise small-holding or self-sufficiency, and family connections to a particular area. Given that the sample population was drawn entirely from University of Manchester staff, there is an inescapable bias towards drivers whose employment preferences are for skilled academic, research and administrative positions – jobs concentrated in the higher education precinct located within city. Thus, to access suitable employment, travelling into the city from the rural hinterland becomes a trade-off between the perceived advantages of the rural 'good life' versus the availability of satisfying and sufficiently remunerative employment in the city. Access to private car transport removes the need to trade-off the one against the other – both 'needs' can be met.

From an individualistic perspective, arguably these opposing pressures – preferences for extra-urban home location on one side and greater availability of well-paid employment in urban areas on the other – present *choices,* bringing into play attitudes and beliefs about the value of space, privacy, health, amenity, security, career and so on. From a structuralist perspective, the (growing) separation between home and work locations in post-industrial nations such as the UK can be seen as arising from a range of interconnected factors in the housing market. For example, the expense and concomitant scarcity of family housing in desirable neighbourhoods in the city, the growth of the knowledge economy and decline of regional industries and local skills bases, and the prevalence of distance commuting as a daily occurrence all serve to legitimise and promote the dislocation of home from work as a 'fact of working life'.

While both perspectives offer useful insights into the 'reasons' for the status quo with respect to constraints on non-car modes for daily commuting from rural to urban areas, they offer rather less in the way of practical solutions for near term step-change. Where home and work locations are already chosen, the prospects for reducing annual driving distances are limited by the availability of alternatives to the car. Interview respondents often spoke of the sparse provision of public transport in rural locations as being the main barrier to reducing their annual driving distances. In these cases, private transport is regarded as a necessity to access the public transport network in the first place, which may then entail a complex, multi-stage journey across regional transport authority boundaries, with a final onward stage to the respondent's place of work often being made on foot. At least seven (17%) of the respondents live in areas where access to public transport services into Manchester depends on access to private transport, as attested in quotations cited in §8.5.1.3 (including wishing to avoid unlit and unfrequented walking routes). The habitual aspects of car driving in these circumstances are arguably much less salient than the existence of public transport infrastructure and services. In considering the possibility of reducing their current levels of car use by either one third or two thirds, positive reactions to the narrative scenarios were without exception caveated with the proviso that public transport provision is *vastly improved* from its current state, often the cue for a detailed, impassioned excursus into the failings of public transport in the UK. Respondents often appeared to be 'suspending disbelief' while discussing the possibility of improvement and extension of rural public transport provision in the narrative scenarios – certainly the historical trend is one of retrenchment, not growth, usually attributed to the unprofitability of providing regular services in areas of low population density.

From the point of view of rapid reductions, these contextual factors are likely to be costly to address with new public transport services. When asked about the possibility of relocating home or work, several respondents reported strong attachment to their home location due to the proximity to employment and education for other household members. This led some respondents to speculate that they may be forced to take up less skilled and fulfilling employment nearer home if their use of private transport was curtailed (for instance by means of a quantity constraint such as a price mechanism or carbon allowance).

It might be argued from an individualist perspective that the relative proximity of home to work location is chosen by people at key life stages, choices they then live with and rationalise thereafter. The interview findings, however, reveal a different picture about the level of free or active choice exercised with regard to home and work locations, which are often a compromise between the needs of several household members. In a number of cases, even where respondents report having exercised deliberation with respect to home and work locations, influences beyond the immediate control of the individual themselves intervene to render the decision less convenient than originally intended.

For example, R10 has begun to consider moving home, commenting: "*When I moved here my role was very different... I was involved in working at a partnership project with other universities. So...being in Northwich was quite handy because I was travelling up to…Lancaster and Cumbria as well as Manchester. A lot of my time was actually on the road, and the time that I spent here was minimal, maybe a day a week… I was on the road quite a lot at that stage, hence the [Ford] Focus. But the way that my job has now changed, I'm basically in Manchester every day – whether I'm out visiting companies, I'm* *coming in here every day. It has sort of made me aware of ...whether we need to stay where we are or whether we need to move*". R10 is unusual amongst respondents in being in a position to consider relocating, whilst accepting that, as things stand, moving closer to Manchester would mean their partner would have to travel further to their place of work. §9.4.4.3 below discusses the potential demand-generating implications of being dependant on car use to access the public transport network.

9.4.4.2 Time constraints

Many respondents were resigned to persevering with their current home–work set up, even under pressure of additional costs of driving as described in the narrative scenarios (through increasing fuel taxes or a cap and trade carbon allowance), often seeing no realistic alternative to driving as a means to discharging their responsibilities in work and family life within the time available. This view chimes with Southerton (2003), who finds that the extent of 'time squeeze' experienced by people is increasing, as ever greater expectations are made of what can be accomplished within a set period (an hour, a day, a week etc). Undoubtedly, 'time-saving' technology such as the car, which potentially offers door-to-door convenience and speed almost impossible to match using other modes, only increases popular expectations of how many tasks and how much associated travel can be fit into an already busy daily schedule. Time pressures – having to arrange things around work and school timetables, household duties, as well as social and leisure activities – and valuing the time saving potential of private car use above public transport feature strongly in the interview dialogues, especially for multi-stage journeys, where waiting time and headway[131] affect total journey times. Frequently respondents report finding the experience of driving stressful, expensive, dangerous or otherwise undesirable, but suggest that there is no other reliable means of combining the many demands made on their time, regarding driving as a 'necessary evil'.

In conjunction with the contextual lock-ins to car use mentioned above, time constraints can be seen as the product of contemporary *expectations of convenience and utility* that have evolved in step with the growth of the automobility regime. Access to private transport facilitates increased possibilities for employment, leisure, education, etc by extending the geographical radius of travel that can be undertaken from a given home location, whilst still covering other responsibilities. In so doing, the car also opens up home locations which would be inaccessible otherwise, for instance in rural and semi-rural locations that have lost their principal public transport links with neighbouring conurbations. Ostensibly the result of cheaply available private transport, increasing separation of home and work locations and greater demands on personal daily 'time budgets' are *long term* social trends. The present state of affairs, whereby car use is considered a necessity by many people (as evidenced in §8.5.1), is the culmination of

[131] Refers to the frequency of service.

decades of growth in passenger car use, making automobility the dominant personal transport regime (Geels 2012).

As such, transitioning from car-dependent patterns of home and work separation to a future scenario that does not rely so heavily on private car use is likely to require changes in a host of factors external to any individual car driver (i.e. lock-ins identified in §8.5.1). Tangible changes to trends in relative proximity of home, work and school locations, provision of new public transport services and infrastructure are difficult to imagine without instigation of broader shifts in a diverse range of cultural values such as popular perceptions of convenience and luxury, housing density, wealth and status. Even assuming that a policy toolset could be implemented to adequately engender such fundamental societal shifts in values and practices, transformation cannot be expected to occur rapidly. Furthermore, potentially negative and divisive social and welfare consequences of ‘pricing people off the roads’ were repeatedly highlighted by interview respondents in connection with the inclusion in the narrative scenarios of fuel prices doubling. Concerns such as exacerbating rural (and regional) unemployment, intensifying ‘poverty of mobility’ or ‘transport poverty’ (Lucas and Le Vine 2009) and diminishing access to services and amenities would likely become a reality for many if fuel price was used to quickly restrict access to private car mileage without supporting measures and alternatives in place.

The extent to which the aforementioned negative consequences are deemed unacceptable acts as a brake on social shifts, preventing them from outpacing the implementation of supporting measures. Nevertheless, it might be argued that negative health consequences of high levels of car use already affect people who live in close proximity to busy roads (as attested by R37 in §8.5.1.2), not to mention the mobility impeding effects of extensive car-based infrastructure for non-drivers (Kay 2011), and the detrimental health effects for users of passive modes of travel (e.g. Jacobson *et al* 2011; Lubans *et al* 2011).

9.4.4.3 ‘Sunk costs of driving’ and ‘visible vs. hidden costs’

Many of the structural and temporal constraints discussed above mean that, for at least some trips, many respondents clearly saw retaining the use of a car as a necessity. As observed by R18 in §8.5.1.4 and R32 in §8.5.2.6, ready access to a private car opens up new possibilities for travel. New trips may be generated as the driver’s lifestyle adapts to these new possibilities for leisure, employment, shopping etc. However, whether new trips are generated or not, car ownership attracts overhead costs (vehicle purchase price, insurance, VED if applicable, maintenance, parking permit), making the prospect of using public transport appear as an additional and unjustifiable expense. Thus the very fact of car ownership acts as a lock-in to driving for the majority of trips made by many respondents, as neatly summed up by R29 in §8.5.1.4, “*why pay out... thousands [of pounds] a year to have something sat there doing nothing?*”.

The ‘sunk costs of driving’ theme relates closely to the theme of ‘visible versus hidden costs’ (§8.5.2.8). Whilst this latter theme reflects respondents’ tendency to view public transport as costly in comparison to driving, due to public transport’s “linear cost-mileage relationship” (Hoogma *et al* 2002: p.128), sunk costs refer to the lock-in effect of having committed personal financial resources to keeping a car on the road in the first place. Assuming households have a finite (financial) travel budget, then such upfront costs may well preclude extensive public transport use. The university’s system of administering staff car parking permit charges as a monthly fee deducted at source from net salary was found to contribute to the upfront, sunk costs of driving that respondents take into account when considering how to travel to work. Nonetheless, respondents were often unsure as to the exact amount they paid per month for their permit and were unanimous in the opinion that university parking is cheap in comparison to nearby private parking. The university does offer a 21 use permit, but restricts this to three uses per week and seven permits per year.

The key implication of sunk costs for the possibility of large scale reductions in per person (or per vehicle) annual driving distances is that the current configuration of the automobility regime, with private car ownership at its centre, is likely to remain resistant to incursions by public transport. Simply reducing their total number of trips (as a proxy for total VKM_{veh}) was acknowledged as a possibility by some respondents, especially for short trips where low-cost unpowered modes are most easily substituted for the car. However, from an emissions mitigation point of view, short trip substitution offers limited potential. As illustrated in Figure 4.6, the vast bulk of passenger car sector emissions (c.87%) are generated on trips longer than 5 miles, with around three-quarters of sectoral CO_2 from trips longer than 10 miles – a distance not commonly perceived as suitable for unpowered modes. Many respondents expressed a strong preference for retaining their car for holiday and occasional leisure trips, typically longer journeys into rural locations, and some were willing to accept a degree of forbearance with regard to their remaining car travel in order to preserve such trips in a scenario where fuel prices or a personal carbon allowance constrained their ability to maintain current levels of driving. Both ‘sunk costs’ and ‘visible vs. hidden costs’ themes support findings in the literature on the strong influence on usage of particular modes exerted by upfront commitment of financial costs (e.g. Simma and Axhausen 2001).

9.4.5 Reasoned resistance to reducing end use

9.4.5.1 Disengagement – ‘why do I need to reduce my driving?’

While there was a definite bias towards willingness to engage with environmental issues within the interview sample, there was also clearly outright resistance to reducing personal driving distance amongst a few respondents. In some cases, environmental engagement and resistance to driving reduction went hand in hand, with respondents arguing that the emissions contribution of their own driving was negligible in the greater scheme of things, or that technological improvements will offer more than sufficient means of reducing emissions, without any change in end use. In a small number of cases, respondents were simply unsure why they would either wish to or need to reduce their level of car use. The extent of this 'honest disengagement' in the interview dialogues was lower than might be expected, but this must be viewed in light of the recruitment process, in which respondents to the university staff travel survey who had already *volunteered* to discuss their travel habits were provided a pre-interview information sheet which elaborated the rationale for rapid emissions reduction and the likely requirement for non-marginal reduction in aggregate demand. Thus respondents had already effectively self-identified as interested in the issues and had been primed on the background of the research. The discursive, informal tone of the interview dialogues was intended to counter the possibility that respondents may feel under pressure to conform to a perceived 'green agenda'. On the whole this approach was deemed successful with respondents giving candid answers to a final set of questions about the extent to which they considered individual action to reduce emissions a worthwhile enterprise and whether they saw any need to reduce their driving.

9.4.5.2 'Mistrust of government interventions', 'be like me' and 'emissions ranking'

Of the reasoned accounts given by respondents of why personal driving distances could not be reduced (or why it would be problematic to reduce) by one third or two thirds, one of the commonest themes was the 'mistrust of government initiatives', particularly with reference to coercive policies to curtail aggregate demand. Although a minority of respondents were sceptical about the rationale for attempting mitigation via demand reduction at all, respondents almost unanimously reported little or no confidence in the ability of government (local and central) to effectively and equitably administer coercive policies and interventions to reduce aggregate demand. Respondents expressed a range of concerns, from feeling unduly penalised by road charges and fuel tax – which they saw themselves as unable to avoid in the absence of a convenient, quick and low marginal cost[132] alternative to car travel – to a history of administrative incompetence in managing public services. Unsurprisingly, respondents tended to be supportive of measures which required little change from their current lifestyle, but dismissive of those which imposed a change (§8.5.2.3).

It is salient that many respondents saw (central and local) government as the appropriate level at which to address mitigation, whilst at the same time referring to top-down interventions – particularly restraint measures – with deep mistrust. While, as noted in §9.4.5.1 above, evidence of true disengagement is limited in the interview sample, the interview theme of 'emissions ranking' (§8.5.2.7) also reflects the position adopted by several respondents, who argued that their own contribution to mitigation as

[132] Assuming the sunk costs mentioned above.

an individual is negligible, placing the injunction on government to undertake any necessary large scale mitigation and ensure the cooperation of all. These findings go some way to explaining the deadlock described in §4.1.3, whereby policymakers are simultaneously obliged to address emissions reduction and threatened with electoral dismissal if they pursue the restraint-based policies most likely to be effective.

9.4.5.3 ‘Change cars not drivers’

Following directly on from the preference for ‘minimally disruptive’ policies, there is abundant evidence in the interview dialogues of support for policies which promote increased fleet penetration of low emissions vehicles, at least where this is offered on a voluntary basis. Encouraging uptake of low-carbon vehicles by means of a price instrument was predictably unpopular. As such, many respondents believed that low-carbon vehicles were the most realistic mitigation strategy in terms of their personal circumstances (although often agreeing that aggregate demand reduction may also be necessary). Again this is entirely to be expected, given the wide dissemination of information about vehicle emissions and fuel consumption compared to the political taboo surrounding demand reduction as a policy objective (see §4.1). Detailed information about respondents’ current main vehicles were not collected in standardised form, although current car make and model were noted for 40 of the 42 respondents during the interviews themselves. In retrospect this was perhaps an omission from the pre-interview questionnaire, which gathered information on current use but avoided emphasising supply-side factors such as current vehicle, fuel consumption and so on, as it was a central premise of the narrative scenarios that best available technology was assumed to be maximally deployed. As such, respondents were encouraged to focus on the potential for demand reduction under the two narrative interview scenarios, and reminded of the core assumption about best available technology. Nevertheless, it is noteworthy that respondents expressed considerably more support for regulating vehicle sales (choice editing) to reduce car sector emissions than might be expected given the level of mistrust of administrative competence noted above.

It is also salient to note that several respondents related recently swapping higher fuel consumption (hence emitting) cars for what they expected to be more fuel efficient lower emissions vehicles, most observing that the fuel efficiency improvement has not lived up to expectations. A case in point is described by R30, who recently traded in their 1.8 litre-engined BMW for a 1.25 litre Ford Fiesta: “*the fuel consumption is down but to be fair it isn’t down as much as I thought. I thought, ‘oh it will be reduced by a half’ and it isn’t*.” Similarly R10 reports, “*Part of the reason I changed ...it was getting old, bits dropping off; but also decided to downsize for fuel efficiency. But I'm not sure I've achieved it to be honest with you. ...I was going to fill up the tank for the Focus, I've no idea what the miles per gallon was, but I spent about £55 a week on petrol... and I used* *to basically empty the tank every week... But I think I'm paying now about £43 to fill the tank, and that just does me...if I'm really careful".*

These findings resonate with the contention in Anable *et al* (2008; 2009) that fuel economy expressed as miles per gallon is a poorly understood metric amongst end users, suggesting it does not lend itself to use in promoting uptake of more efficient vehicles. However, the experience of respondents who have recently switched to cars they were encouraged to believe would return better fuel efficiency than they have so far achieved is itself of significance. It indicates that although there is growing awareness that official type approval-based fuel consumption and emissions figures are inaccurate, the discrepancy between type approval values and real world fuel consumption is not always made explicit to car buyers, who are frequently led to expect better fuel efficiency by promotional material. It is also interesting that while R10 and R30 both cite fuel economy as a key decision criterion in their new car choices, both ultimately opted for petrol ICEVs with type approval emissions around 124 gCO_2/km – below the mean for new UK cars in 2011, but considerably higher than the best available.

First-hand experience of attempting to buy a low emissions car reveals that the motor trade is not currently set up to promote the lowest emissions vehicles, even to customers who state a preference for them. Dealership sales staff often actively counsel against small diesels, arguing in favour of small to medium petrol engines on grounds of lower initial purchase price and 'sportier' performance[133]. This 'anti-efficiency sales pitch' is compounded by manufacturers positioning their lowest emissions cars (typically small diesels) as niche products – usually by assigning them an 'eco-badge', which is then used to justify a price premium[134].

Despite media advertising space increasingly given over to manufacturers' lowest emissions cars, such vehicles often have much more limited production runs than other models in the same range, making them relatively scarce within the new and used car markets, adding to their niche status as a 'specialist' option and preserving their relative price premium. While lower fuel consumption is widely acknowledged as a desirable attribute in the motoring press, on car review websites and in advertising material, performance characteristics such as acceleration, top speed, road handling and trim level (often bundled together in terms of 'driver satisfaction' or 'engagement'), are routinely given higher priority in vehicle recommendations. Emissions *per se* are factored into car marketing insofar as vehicle excise duty is paid according to emissions band, with sub-100 gCO_2/km cars being exempt from vehicle excise duty and the London

[133] It should be noted that modern diesel engines are not without their drawbacks – for those who drive only short distances at urban speeds, cars fitted with a diesel particulate filter (DPF) and exhaust gas recycling (EGR) system are likely to result in considerably greater servicing and maintenance costs than small petrol-engines, which are better able to tolerate such use conditions.

[134] For example, models such as Volkswagen Group's BlueMotion-, Ecomotive- and Greenline-badged cars; Ford's Econetic; GM-Vauxhall's Ecoflex, etc.

congestion charge, but an overtly environmental rationale for reducing emissions is rare in car advertising and marketing – although increasingly it is suggested that lower emissions models are 'good for your wallet' while simultaneously somehow 'good for the planet' (e.g. Fleury 2009).

While 'eco-badged' versions of popular car models are typically more expensive than the standard, higher emitting versions, hybrid vehicles attract a greater price premium still, making them too expensive a proposition for many car buyers. In comparison, ICEVs are seen as a more familiar and hence financially safer option. For example, new prices for Toyota's small cars in the Yaris range start from around £10,500 for a petrol ICEV with type approval emissions of 111 gCO_2/km, to around £15,000 for a hybrid petrol version with type approval emissions of 79 gCO_2/km (Parkers 2012b). The hybrid Yaris costs 43% more than the basic version – an additional outlay hard to justify on grounds of emissions (or fuel consumption) alone, especially in light of functionally comparable models such as Hyundai's i20 Blue 1.1l diesel ICEV, with claimed emissions of 82 gCO_2/km at £11,700 new (Parkers 2012a).

The upshot of the prevalence among respondents of confidence in the ability of low emissions technology to deliver the necessary abatement is that the importance of demand reduction is correspondingly downplayed. Several of the fleet emissions model scenarios discussed in §9.3 include a schedule of new car mean fuel efficiency improvement which goes beyond the current EU regulations by assuming type approval target values are realised in terms of real world emissions (Scenarios 1.3, 4.2, 5.3, 7.1 and 7.2), while others go further still by assuming regulation of emissions to 90 gCO_2/km from 2015 (Scenarios 2.1, 2.2, 6.1, 6.2). As discussed in §9.3.3 and summarised in Table 9.1, in each of these fleet emissions scenarios technology improvement alone is incapable of bringing sectoral emissions within a budget associated with a lower than 56% probability of exceeding 2°C (even assuming zero growth in fleet size, and no change in annual distance per vehicle). Aggregate demand reduction is required in order to achieve lower probabilities. Note also that all fleet emissions model scenarios assume *as a minimum* that the UK's new car emissions fall into step with EU mean new car emissions, in itself likely to require demand-side changes in consumer preferences, such as differentiated fuel tax to increase diesel penetration, while curbing the tendency towards higher powered vehicles.

The 'change cars not drivers' theme identified in the interviews is consistent with other primary research in the broader transport studies literature, in which supply-side fixes and non-coercive policies (such as public transport provision) are found to be more publicly acceptable than restraint based measures (e.g. Thorpe *et al* 2000). Similarly, these findings echo Hagman's (2003) analysis of drivers' conceptions of the advantages of driving as being non-negotiable 'facts of the matter', whilst disadvantages and negative consequences are referred to in relative terms, suggesting room for manoeuvre with regard to the level of personal restraint required. Certainly, in keeping with Hagman's contention, analysis of interview dialogues in this research found broad support for general reduction in aggregate demand frequently co-occurring with resistance to personal demand reduction.

9.4.5.4 'Cars are private'

Exploring the possibility of increasing car occupancy for certain trip types was a key aim of the qualitative research interviews. Reactions were notably varied to the suggestion of coercive policies to engender higher occupancy rates, such as high-occupancy (or minimum occupancy) toll roads as well as more pervasive restraint policies such as increased fuel duty and personal carbon allowances. Figures 8.37 and 8.38 summarise the headline responses to interventions described in the narrative scenarios discussed in the interviews. Eighteen respondents in total (43%) expressed willingness and ability to engage with carsharing in some shape or form, eight of whom already carshare with a family member or friend. When reflecting on their perceptions about carsharing, it is possible that this subset of eight respondents may be projecting their present experience rather than considering sharing journeys with non-family members[135]. By contrast one respondent, R32, who already carshares with their partner on their daily commuting trip, was decidedly against the possibility of carsharing with non-family members, in keeping with the negative reaction garnered from nine other respondents.

It is noteworthy that many respondents express a clear preference for public transport over carsharing, viewing public transport as more 'impersonal' than sharing the confines of a private car with a non-family member as passenger, or being a passenger in someone else's car. Nevertheless, 43% were content to share car journeys, subject to vetting of passengers, which offers some prospect for increasing mean trip occupancy for the most routine journeys such as commuting. That so many respondents were at least amenable to carsharing for certain routine trips suggests the possibility of a significant increase in trip occupancy under a policy mix which includes interventions to encourage such shifts. However, the scale of increase in commuting trip occupancy rates assumed in fleet emissions Scenario 6.1 (+50%) and Scenarios 5.1, 5.2 and 5.3 (+33%) does *not* appear to be supported by the views expressed in the interviews. With 43% of respondents willing to take up carsharing, a trip occupancy rate increase of 21.5% follows if it is assumed that all eighteen positive respondents are single occupants at the outset, and recruit only other single-occupancy drivers as carshare partners. Thus even as a broad approximation, this follows only from a speculative interpretation of the baseline conditions for the respondents in question – as noted

[135] A handful of respondents reported having already signed up to the university's carsharing database, which aims to put potential carsharing partners in touch, but none reported having had any uptake.

above several already carshare with family members – and the optimistic assumption that participants remain committed to carsharing on a daily and long-term basis.

While the interviews were emphatically not an attempt to elicit stated preferences with respect to the policies in the narrative scenarios, this coarse level assessment of 'willingness to participate' in carsharing accepts at face value respondents' accounts of their likely reponses to coercive interventions. Quantity constraints such as pay per mile, fuel tax increases or personal carbon trading may ultimately stimulate a greater level of participation in carsharing than suggested by these findings if car drivers see value in retaining use of a private car for specific trips, the costs of which can be offset by sharing other journeys. On the other hand it is also possible that coercive policies may not produce anything like so significant an increase in trip occupancy as described above, if the widespread preference for modal shift to public transport over carsharing is provided for.

Nevertheless, even a generous interpretation of the 'latent potential' for increasing mean trip occupancy for commuting journeys suggests that the higher occupancy rates in fleet emissions model Scenarios 5.1, 5.2, 5.3 and 6.1 appear unlikely in the absence of an effective quantity constraint on per capita driving distance, administered either as a fuel price increase or cap and trade carbon allowance. However, while fleet model Scenario 5.1 includes an increase in commuting trip occupancy of 33% by 2022 (cashed out as a 5.7% reduction in aggregate demand, VKM_{fleet}, cf. 2011), cumulative emissions in this 'real world baseline plus higher occupancy' scenario are 927 $MtCO_2$, outside all budgets bar *MPT2* and *MPT2′*, both of which rely on steeper cuts in emissions in later years to deliver a 56% probability of exceeding 2°C. Therefore, increasing mean commuting occupancy by 33% by 2022 (in the absence of fleet growth) produces insufficient reduction in aggregate demand to yield cumulative passenger car sector emissions which comply with a national pathway consistent with a lower than 50% probability of exceeding 2°C.

This analysis focuses exclusively on the potential for increasing occupancy rates for commuting trips because they represent such a large portion of total aggregate demand (the largest distance travelled for a single journey purpose), whilst at the same time having one of the lowest mean trip occupancy rates for any journey purpose. Only business trips have lower mean trip occupancy, but are likely to be subject to different economic and time management issues than all other personal driving trips, so were not included when calculating the effect on aggregate demand of increasing the currently low trip occupancy values for commuting (while holding passenger kilometres constant, see §6.5.4). Commuting trips are also amongst the most routine, habit-based trips, being typically made at the same time each day, with fixed origin and destination. Other journey purposes (e.g. shopping, school escort, personal business, leisure) typically have occupancy rates above the mean for all trips (AVO_{trip}) and for all distance

(AVO_{VKM}), while being variously less routine or otherwise less amenable to regular carsharing. While there is undoubtedly potential for increased occupancy to some extent in all trip types, commuting trips are judged to have considerably more potential to admit of higher occupancy and deliver a measurable reduction in aggregate demand as a result, by virtue of their large share of all VKM_{fleet}.

Despite commuting trips accounting for more than a quarter of total VKM_{fleet} (Table 6.3), the mixed response to the possibility of carsharing in the interviews, as applied to commuting distance (see Table 6.4), appears relatively inconsequential when set against the potential for even modest fleet growth to counteract the effects of occupancy-based reductions in per capita (or per vehicle) annual distance on aggregate demand – as illustrated by Scenarios 5.2, 5.3 and 6.1. Additional user demand under 0.6% p.a. fleet growth means that even a 50% increase in commuting trip occupancy (Scenario 6.1) delivers only a 2.6% reduction in aggregate demand by 2022. Thus it appears that fleet size and outright restraint of annual distance per vehicle exert much greater influences on aggregate demand, and on hence emissions, than does the presently low occupancy rate for commuting trips, despite such trips accounting for over a quarter of aggregate demand.

9.4.5.5 'Accustomed / deprived'

There was a strong thread of evidence in the interviews for respondents being resistant to reducing their level of car use based on their impressions of the extent to which doing so would entail an unwelcome loss of mobility, convenience, utility or liberty. This aversion to potential 'deprivation' particularly applies to the suggestion of relinquishing car ownership for exclusive private use and using a car club instead. The interview dialogues were found to contain many references to the private car acting as a 'back up' or 'safety net' in case of emergencies, such as children falling ill or accidents in the home and so forth. The private car also offers the security of being available for any trip to be made at any time. Respondents often speak of the inability of other modes to match this range and flexibility, especially with reference to unplanned, impromptu trips that would either require careful planning to complete by non-car modes or would simply not be possible at the time the perceived need to travel arises.

A number of respondents acknowledged the rarity of truly urgent circumstances requiring an unplanned long trip, but nevertheless argued that the very possibility of such eventualities make forgoing ownership of a private car unacceptable. It is also interesting to note that the suggestion in the narrative scenario introduction that large 4-wheel drive (4WD) vehicles are phased out in future was viewed as problematic by several respondents. Five respondents owned at least one 4WD utility vehicle, two respondents having two 4WDs within their household, and argued that true 4WD capability is a necessity for accessing rural home locations, especially during winter months. Several respondents who do not own or use 4WD vehicles themselves also raised similar concerns in relation to others who genuinely require rugged 4WD functionality to safely access rural locations. This is in stark contrast to the frequent disparaging references to 4WD sports-utility vehicles found in the interview dialogues, usually directed towards urban dwellers who were perceived as neither requiring nor using the 4WD functionality of these large vehicles. Four of the five 4WD owners interviewed use another vehicle for commuting for most of the year, resorting to 4WD for commuting during winter only; one uses theirs as their primary household vehicle. All 4WD owners reported using the 4WD vehicle year round for non-commuting trips.

These findings run counter to evidence in the literature that larger sports-utility and other 4WD vehicles are not differentiated in their patterns of use from ‘ordinary’ cars, despite being perceived to offer greater additional utility (Lamb *et al* 2010; Walton *et al* 2012)[136]. The findings in this research suggest that the additional utility offered by 4WDs *is* used to an extent. Moreover, this additional measure of 4WD utility, combined with preferences amongst dual income households with young children for home locations in semi-rural and rural locations, facilitates work-home configurations which come to depend on the availability of all terrain or ‘all weather’ vehicles, which are effectively over-specified for daily use for the majority of the year.

9.4.5.6 ‘Driving and economic prosperity’

The last ‘reasoned resistance’ theme encompasses arguments about whether passenger cars ought to be exempted from mitigation due to the contribution to economic growth that is perceived to flow from car-based mobility. However, rather than taking a simply GDP-based view of economic growth, a number of respondents argued that demand restraint policies could negatively affect people’s ability to earn a living if applied without consideration being given to the ‘special needs’ of certain types of business. To some extent these arguments may represent either a lack of knowledge about the scale and urgency of the mitigation task implied by a commitment to avoiding more than 2°C global warming, or a fundamental misunderstanding of the economics of climate change, insofar as the costs of mitigation are expected to be a fraction of the costs of adapting to future warming of more than 2°C (Stern 2006). Nevertheless, the concerns voiced by respondents under this theme may also be seen as acknowledging the important role played by private transport in ensuring economic and social mobility amongst communities poorly served by public transport. Comments in this theme also acknowledge the lock-in effects of selecting geographically separated home and work locations (as highlighted in §9.4.4.1 above) based on the availability of affordable private transport. A number of respondents expressed concerns that the rapid implementation of demand-restraint policies would be detrimental to people who had made choices about

[136] Both of these studies are set in New Zealand, where baseline driving conditions are likely to be different from the UK, rural travel distances potentially greater and rural roads of poorer quality. Comparable UK-based studies could not be found.

home and work ‘in good faith’, seeing the increased costs of driving under such policies as penalising people in this situation who would have little alternative but to continue driving and pay the tolls, taxes or carbon credit premium, or relocate home or change job, both of which were regarded as being a serious imposition.

The lock-in effect of prioritising home–work separation and earnings over mitigation also relates back to the deadlock referred to in §9.4.5.2, whereby restraint-based mitigation policies are supported in principle but resisted in practice. The concerns raised by respondents about the *rapidity* of implementation highlight important issues about the potential for negative social and welfare consequences from introducing quantity-constraints and other demand-restraint interventions intended to produce step changes in demand. Such concerns are likely to seriously hamper the ability of such policies to find public and political support – over and above the counter-aspirational aspects of demand reduction and the ensuing loss of convenience (as noted in §9.4.5.5).

9.4.6 Themes suggesting potential for overcoming resistance

As noted in §9.4.3.1, the majority of respondents interviewed indicated that they could ‘learn to live with’ a reduction in their annual driving distances of one third (approximately 74%). While the majority of those who said they could envisage adapting to such a reduction did not wholeheartedly embrace the prospect, this headline response suggests that the structural and behavioural lock-ins described above do not necessarily preclude reductions of a third or more. Naturally, respondents cannot be expected to accurately envisage the effects of policies with which they are not entirely familiar, nor can their reactions to the narrative scenarios be taken as a reliable predictor of their actions under such policies in future. Nevertheless, the widespread acknowledgement by respondents that such a reduction in car use could be accommodated without unacceptable detriment to their quality of life gives reason for optimism with regard to step change at this scale. This preparedness to tolerate or engage with restraint policies must be taken in the context of the improvements to public transport (in terms of frequency, standards of service and regulation of fares, extent of network) and the other innovations described in the narrative scenarios (greater penetration of ICT into public transport and carsharing, car clubs, etc). As noted in §9.4.4.1, in estimating their ability to adapt to reductions in annual driving distance respondents were effectively ‘suspending disbelief’ about enhancements to public transport services and infrastructure. The implication being that respondents’ mobility would be unacceptably restricted if quantity constraints on driving were introduced in the absence of such improved public transport provision.

9.4.6.1 ‘Could learn to live with it’

A notable theme amongst respondents when considering the impacts of restraint policies in the narrative scenarios is the tendency to distinguish between those which are seen as merely causing *inconvenience* and those imagined to cause unacceptable disadvantage or ‘*suffering*’. Many respondents acknowledged willingness to take on some additional burden of forward planning and the minor inconveniences of using non-car modes for routine trips, on condition that they were satisfied that their 'sacrifice' was matched by others and that the effort was not rendered futile by mismanagement of resources elsewhere. Several respondents whose current driving habits have been formed relatively recently were noticeably more tolerant of the possibility of reduced car use in future – observing that their lives have not been dramatically improved by the acquisition of a car or by increasing their annual mileage.

9.4.6.2 Life-course variations in car use, 'moments of change' and 'giving it a go'

Respondents frequently refer to their present level of car use as temporary, arising from particular circumstances within their household or job. Taken in conjunction with other evidence in the literature on improving the success rates of travel demand management interventions by targeting key 'stages of change' within the life-course (e.g. starting a new job, moving home, graduating from university, starting a family, retiring, etc) (Bamberg 2006; Thøgersen 2009; Schäfer *et al* 2012), it is salient that many respondents view their current levels of use as atypical. That is, they view their current level of use as being symptomatic of their current life-stage, which is regarded as impermanent, hence amenable to demand reduction in future.

Other respondents give accounts of having overcome their own initial reluctance to make use of non-car modes, either following some financial inducement, or through being persuaded of the possibility of an alternative by the example of a trusted friend or relative. Thus, R11 and R14 both report having recently taken up cycling to work on at least one day a week, the former prompted by the offer of a free 2-week bike loan to members of staff, the latter persuaded to give it a go by a colleague who already regularly cycles to work. This essentially supports evidence in the literature that non-car modes are anticipated as being more onerous, expensive, difficult and dangerous than they prove to be once actually undertaken, as noted in §4.1.1 (Møller and Thøgersen 2008). Stradling (2011) identifies three types of 'personal energy costs' associated with trip making – physical, cognitive and nervous – each of which is greater for non-car modes for travellers who are familiar only with driving.

Significantly, one respondent, R41, reported having recently changed their main commuting mode from single occupancy driving on a 76 mile daily roundtrip, to driving to a local railway station (2 miles) and taking the train into central Manchester, walking from the city centre to the university (less than one mile). Originally prompted to leave the car at home by the severe winter weather in early 2012, R41 found train travel to their advantage both in terms of creating time to read for pleasure (something that had been squeezed out of their routine previously), and financially, finding the cost of monthly season ticket much less than they had imagined. Significantly, R41 maintains their staff parking permit at a cost of several hundred pounds a year to cover the possibility that their new public transport habit may not last, as well as the occasional car journey into the city at weekends. Nevertheless, over the six months since making the switch to predominantly train-based commuting, R41 has effected a pro rata reduction in their annual driving distance of approximately two thirds. More importantly, they also reported an improvement in their quality of life as a result. However, it should be noted that R41's family non-work obligations are relatively slight, whereas in previous years they had responsibilities as a carer which necessitated both the time-flexibility and load carrying utility of a car. Thus is it important to temper such demand reduction 'success stories' with acknowledgement that for many people at different life and career stages, such shifts remain subject to the contextual and structural constraints discussed in §9.4.4.

9.4.6.3 Information provision

Respondents make frequent references to preferences for information provision, to guide low-carbon choices and enable more efficient decision making, over restraint-based policies. While there is little evidence in the behavioural literature to support information provision as an effective demand management intervention (at least not at the scale under consideration in this analysis), there is rich evidence that voluntary measures are widely preferred to coercive measures by both public and policymakers – as noted in §4.3.2. Nevertheless, it is notable that several respondents alight on the habit-breaking potential of information provided as feedback about their energy use, in the form of quantity constraints such as a cap and trade personal carbon allowance system. This they suggest may prompt reflection on the relative 'necessity' of various types of personal energy use (and hence emissions).

However, while some respondents spoke positively about having the ability to exercise control over their energy use and emissions under the personal carbon trading system (described in Narrative Scenario 2), the mitigation effectiveness of such an intervention primarily derives from its fundamentally constraining properties, rather than its granting of budgetary control to participants. Nonetheless, insofar as such a system may gain popular support through its ceding control (over finite personal carbon budgets) to participants, this feature should be regarded as a valuable attribute in obtaining an electoral mandate. While the mitigation effectiveness of personal carbon trading as an intervention lies in capping the total quantity of carbon within the system, its prospects for generating popular (and hence political) support will be influenced both by the extent to which allocation of emissions rights is perceived to be fair, and the level of choice extended to individuals about how to use their allowance. Critically, only respondents who accepted that such a system could be administered fairly, transparently and enforceably saw the 'personal control' features of personal carbon trading as potentially offering a 'wake up call' or 'stop and think' moment with respect to energy use and emissions. Many more respondents were concerned that initial allocation of carbon credits may be unfair to those who needed greater allowances to accommodate their current lifestyles[137], or would be open to abuse by by wealthy or powerful individuals.

9.5 Summary

This chapter explored the significance of findings from the three principal stages of this research, namely:

(a) quantification of sectoral emissions budgets for the period 2008–22 associated with varying probabilities of exceeding 2°C;

(b) quantification of fleet emissions during this period, estimated according to different rates of technological improvements to vehicle-fuel carbon intensity, new vehicle penetration, fleet growth and retirement, and levels of use per vehicle; and

(c) qualitative analysis of the constraints that affect levels of per capita (in this case per vehicle) demand, and the ability to make rapid changes thereto.

The emissions budgets (a) were placed at the centre of the subsequent analysis (b), with fleet emissions scenarios assessed in relation to their ability to deliver savings commensurate with respecting the budgets, while simultaneously recognising the important differences in background assumptions between budgets. Grounded theory-based analysis of the qualitative interview dialogues (c) was used to generate a series of analytical themes relating to structural and habitual lock-ins to driving. These themes were discussed in relation to their bearing on the scope for delivering demand reductions at the *scale and rate* indicated in the limited set of fleet emissions scenarios that remain consistent with budgets having lower than 50% probability of exceeding 2”C.

Synthesis of budgets, fleet emissions model scenarios and qualitative interview findings shows that, of the range of possible combinations of supply-side measures and demand interventions, certain scenarios are more promising than others. Of those that fit within at least one of the cumulative emissions budgets specified here, scenarios that include a measure of outright demand reduction – expressed in the fleet model as age-proportionate reductions in per vehicle kilometres (VKM_{veh}) – offer the greatest theoretical potential for achieving step reductions in emissions within a decade. However, the scale and rate of reductions in per vehicle use required for budgets associated with lower than 56% probability of exceeding 2°C are likely to be infeasible for many ‘car-dependent’ households unless fundamental structural changes in lifestyle are also accepted (job, education, leisure activities). Such changes are to a large extent found to be *unacceptable* and likely to generate resistance. Scenarios which rely solely on EU new car targets at type approval levels do not deliver any of the budgets in question. Savings compatible with a 56% probability of exceeding 2°C are achievable by

[137] Inclusion of housing and domestic energy use in personal carbon trading was the most frequently raised objection, where respondents were concerned that the energy efficiency of their own house, or others' houses, would mean they were negatively affected. Families with young children, and rural residents, were also frequently perceived as having greater energy needs than the ‘average household’.

regulating mean new vehicle bulk emission factors to the level of current best available internal combustion technology, assuming no increase in aggregate demand. Inclusion of per vehicle demand reduction in these technology-push scenarios offers the strongest prospect for limiting sectoral emissions.

The final chapter draws out further conclusions from this discussion and highlights key issues relating to supply-side innovation and demand-side interventions from previous chapters.

CHAPTER TEN – CONCLUSIONS

This research has investigated the potential for non-marginal reductions in CO_2 emissions from the UK car sector in the next decade, consistent with named probabilities of exceeding 2°C. Specifically, it has sought to quantify the potential for radical emissions reductions from both technical improvements in the energy intensity of passenger cars and changes in patterns of end use. This chapter briefly draws out key conclusions by addressing the core research questions set out in §1.2.

Each question proceeds from the premise, 'for the UK to follow an emissions pathway consistent with a given probability of exceeding 2°C...'.

10.1 What cumulative emissions budget is required of the car sector in the next decade?

In reviewing the climate science, mitigation policy and the passenger transport literatures, Chapter 2 identified a serious mismatch between the scale of emissions reductions required to deliver a national pathway consistent with better than 50% probability of exceeding 2°C and planned mitigation in the UK's decarbonisation strategy, the *Low Carbon Transition Plan*. A science-based approach to mitigation calls for cumulative constraints rather than end point reductions for distant future years – an approach largely absent from the transport energy research literature (§2.3).

Mitigation from the passenger car sector, as set out in the *Low Carbon Transport* strategy, is currently planned at a rate lower than the mean rate for all sectors required to meet the 'interim pathway' currently adopted by the government (63% probability of exceeding 2°C), with the bulk of mitigation effort over the next decade expected to come from the power sector and heavy industry. Although current transport mitigation policy assumes negligible direct savings from low-carbon electricity in the next decade, the assumption that electricity decarbonisation will deliver cross-sectoral mitigation in the medium term is conventionally used to justify lower short-term objectives in non-electricity sectors, including cars. However, reliance on emissions savings from decarbonisation of the power sector is a high-risk strategy. Even the more optimistic scenarios of new renewable and nuclear capacity show little penetration of low-carbon *electricity* (as a proportion of UK *energy* demand) over the coming decade. In practice low-carbon generation faces persistent financial and regulatory barriers to rapid rollout and commissioning (§3.4.1.1).

Pathways with lower probabilities than the 63% of exceeding 2°C underpinning the interim pathway entail much lower cumulative budgets even in the short term, in turn implying higher rates of mitigation. As one of the highest emitting sectors in the first place, for passenger cars to fail to decarbonise at the mean national rate would necessitate unfeasibly large emissions cuts in other comparably large sectors to compensate. Since, for lower probability pathways, all sectors are being pushed to decarbonise harder than previously contemplated, asymmetrical division of mitigation is not regarded as a realistic option if the cumulative budget is to remain viable (§5.1.2.4 and §5.3.1).

While lower probabilities of exceeding 2°C place greater mitigation obligations on all sectors, so too sectoral emissions space is further reduced by accounting for emissions growth in non-Annex 1 countries (budgets *MPT2* to *MPT4*) and global deforestation (*MPT1a* to *MPT4*). Privileging particular sectors such as international aviation and shipping (IA&S) by allowing them to decarbonise below the mean national rate, whether for strategic, political or practical reasons, shrinks the remaining emissions space for all other sectors still further.

The stark conclusions that emerge from this process of quantifying short-term sectoral budgets illustrate the problematic effects of below-the-mean rates of mitigation by even relatively small sectors such as IA&S. Assuming equal treatment of all domestic sectors, pursuing a pathway with a 36% probability of exceeding 2°C as opposed to 56% reduces available emissions space for the car sector over the decade to 2022 by 14%; or by 18% if IA&S were to follow a low-growth emissions trajectory (§5.3.4). In the medium term, the implications of allowing an individual sector to mitigate below the mean national rate become inescapable – on pathways *MPT2*, *MPT3* and *MPT4*, IA&S emissions exceed the total available UK CO_2 emissions space for 2008–50 as early as 2032 (Figure 2b).

These findings are especially salient given that other analyses of passenger car emissions focus, almost without exception, on end point target reductions, taking no account of the effect of short-term cumulative emissions on the prospects for staying within a longer term sectoral budget. Furthermore, this analysis represents a significant departure from the conventional ‘asymmetrical’ approach to inter-sectoral burden sharing (based on marginal costs of abatement), which is argued to be incommensurate with the scale of mitigation required for pathways associated with lower probabilities of exceeding 2°C. Hence, the passenger car sector emissions budgets quantified according to the mean national rate of decarbonisation for a given pathway are considerably more challenging than the relatively ‘easy ride’ accorded to the sector in other contemporary analyses. In brief, if UK climate change commitments are taken seriously and science rather than politically-expedient 2050 targets informs mitigation rates, the implications for all sectors, including the car sector, are for mitigation four times greater than has thus far been countenanced.

10.2 How much of the necessary mitigation could be achieved through new and existing technology?

The short term mitigation potential of a range of technologies was assessed from evidence in the literature (Chapter 3). Despite a culture of optimism amongst some scientists, policymakers and the public alike, little evidence was found to support the expectation of significant emissions reductions in the next decade from technologies currently occupying niches within the wider system of automobility. In the case of electric vehicles, for example, obstacles relating to carbon intensity and capacity of the grid, battery energy density, charging infrastructure and unit price must be overcome before such technology can break through into the mainstream. Slow progress in decarbonising the electricity grid and unresolved issues of storage similarly hamper the short-term mitigation potential of the hydrogen economy. Elsewhere, evidence suggests that biofuels and synthetic liquid fuels carry greater CO_2 emissions penalties than conventional petroleum – not to mention other serious environmental and social costs. Moreover, biofuel is touted as a low-carbon solution for aviation and shipping, as well as cars, and is the principal route suggested for carbon sequestration via ‘biomass and carbon capture and storage’ (BACCS). At the same time, net yields are predicted to fall as consequence of climate change impacts and increased food production will be necessary to feed a rapidly rising population.

The passenger car sector is expected to remain dominated by petroleum-fuelled internal combustion vehicles (ICEVs) over the next decade, albeit with increasing penetration of petrol and diesel hybrid-electric vehicles (§3.3). European data on national differences in engine power, fuel use, vehicle size and mass (all of which affect fuel consumption and emissions) reveal the UK fleet to be amongst the highest powered in Europe (§3.5.1), whilst having one of the lowest levels of diesel penetration (§3.3.3). Thus there exists considerable mitigation potential from increasing penetration of best-in-class, or, going further, ‘best available technology’. Despite the maturity of ICEV technology, studies in the engineering literature support the expectation of further incremental gains in vehicle-fuel efficiency. Implementation of best available technology as a minimum standard (or maximum emissions threshold) for new cars could therefore deliver emissions savings in proportion to the rate at which new vehicles penetrate the fleet. Such technology is commercially available and could be rapidly deployed as lower-powered, lower-mass, diesel-fuelled vehicles with ‘complementary’ design features to improve aerodynamicity and reduce rolling resistance. Incremental gains are available through further improvements to the conversion efficiency of ICEs themselves, and through increasing use of hybrid-electric technology.

The mitigation potential of various schedules of vehicle-fuel carbon intensity improvement is quantified in a number of fleet model scenarios. The least challenging assumes full compliance with EU new car emissions regulations (either at face value or uplifted to reflect real world driving conditions). The most challenging assumes the best currently available official value for new car emissions (approximately 90 gCO_2/km) as the mean for new cars from 2015, reducing by 3% per annum thereafter (in line with observed historical and expected future efficiency gains). While it is recognised that achieving 90 gCO_2/km under real world driving conditions will require some immediate technical adjustments, the main challenge in implementing the latter ‘technology push’ scenario is deemed to be in establishing the appropriate regulatory framework for the UK new car market, rather than engineering or resource restrictions on building cars that conform to these standards.

Any mitigation strategy based on reducing the emissions of new vehicles delivers mitigation only in proportion to the rate at which new vehicles enter the fleet ('new additions'). Thus Scenario 2.2, the most demanding of the technology-push fleet model scenarios in this analysis, returns cumulative emissions 2008–22 of 904 $MtCO_2$, assuming a rate of technology penetration typical of the UK car market in recent years (and no change in the level of aggregate demand). Although compatible with a 56% probability of exceeding 2°C (assuming IA&S emissions fall back to 2005 levels by 2020), even such an aggressive 'efficiency ratchet' as in Scenario 2.2 cannot bring sectoral emissions within a budget associated with a 52% or lower probability of exceeding 2°C in the absence of demand restraint (Table 9.1).

Although accelerating the rate at which older vehicles are scrapped and replaced may increase the rate at which new technology penetrates the fleet, this does not necessarily increase the mitigation potential of a given technology. A somewhat counterintuitive finding from the fleet modelling exercise is that simply increasing the rate of penetration of new technology is insufficient to return significant emissions reductions, if it is also assumed that new vehicles will be used to their typical extent. The fact that new vehicles tend to be driven more than older vehicles (the candidates for scrappage) means that simply boosting the rates of new additions and retirement results in negligible additional emissions savings in the absence of a constraint on per-vehicle driving distance. This 'system-level rebound' is illustrated by Scenario 7.1 (increased rates of retirement and new additions from present base rate, no increase in aggregate VKM_{fleet}) resulting in cumulative savings against the corresponding baseline[138] of less than half a percent (4 $MtCO_2$). Restraint-based interventions such as road user charging, taxes or carbon allowances are therefore an essential adjunct to policies seeking to deliver savings through increasing the rate of technology penetration.

10.3 **What, if any, shortfall remains between budget-based sectoral mitigation goals and available technology savings in the next decade?**

The shortfall in abatement required to meet the various emissions budgets and the maximum extent of supply-side savings in technology-push Scenario 2.2 is between 8 $MtCO_2$ (for a 56% chance of exceeding 2°C whilst allowing for low growth IA&S) and 153 $MtCO_2$ (for a 36% chance of exceeding 2°C whilst allowing for low growth IA&S) (Table 9.1). Compared to the 'holding all things constant' counterfactual (§9.3.2), these shortfalls represent a requirement for *additional abatement effort* of between 8% and 153% over and above the measures in Scenario 2.2.

[138] Scenario 1.3, with current low rates of new additions and turnover.

The *de facto* policy scenario, 'real world baseline' Scenario 1.2, falls short of *all budgets* quantified in this analysis, representing an *additional abatement* burden of between 14% and 329% over and above planned measures.

Putting these abatement shortfalls into perspective, short-term emissions under 'real world baseline'[139] Scenario 1.2 leave less than two-years worth of emissions[140] for the period 2022–2050 for a 36% probability pathway if IA&S decarbonise at the mean rate, or uses up the entire budget if allowance is made for low growth IA&S.

Similarly, even at maximum extent of technology deployment, short term emissions under Scenario 2.2 leave just over two years worth of emissions[141] for 2022–50, assuming IA&S decarbonise at the mean rate, or again using up the entire budget if allowing for low growth IA&S.

Thus, if aggregate demand continues *at its current level*, both of these supply-side scenarios – the *de facto* policy scenario and maximum deployment of best available technology – are not only inconsistent with budgets associated with lower probabilities of 2°C, they put such pathways permanently beyond reach.

10.4 What are the emissions implications of assumptions about future demand for car travel?

The conventional approach to estimating the effect of policies and measures on sectoral emissions is to make assumptions about future demand, and quantify emissions savings against the resulting counterfactual level of emissions, i.e. the emissions that 'would have occurred' had it not been for implementation of the policies, under given demand conditions. This tends to obscure the mitigation potential of the measures in question, as even small fluctuations in aggregate demand can exert greater influence on absolute emissions than new technology incrementally penetrating into the fleet. Therefore, this analysis modelled a range of demand assumptions, including: (i) a 'static baseline', in which aggregate demand (VKM_{fleet}) is held constant at its 2011 level of approximately 400 bn vehicle kilometres; (ii) a historically conservative rate of growth in fleet size, resulting in an 8.4% increase in aggregate demand by 2022, while per vehicle driving distances (VKM_{veh}) remain constant; (iii) various rates of aggregate demand reduction, based on either outright restraint in per vehicle driving distances, or by increasing mean occupancy rates of certain trip types.

The implication of an 8.4% increase in aggregate demand by 2022 (cf.2011), assuming compliance with EU new car regulations at type approval (Scenario 4.1), is that

[139] Scenario 1.2 uses the same schedule of supply-side measures as the *de facto* policy strategy in the *LCT*, but assumes no growth in aggregate demand.

[140] 67 $MtCO_2$ remaining in budget for period 2022–50; annual emissions in 2022 in Scenario 1.2 are 48 $MtCO_2$.

[141] 108 $MtCO_2$ remaining in budget for period 2022–50; annual emissions in 2022 in Scenario 2.2 are 41 $MtCO_2$.

cumulative emissions 2008–22 increase by 3% on the 'real world baseline' (Scenario 1.2). This effectively locks out any realistic prospect of staying within a long-term sectoral budget associated with a lower than 56% chance of exceeding 2°C. The strong growth in aggregate demand[142] assumed in the DfT's Road Transport Forecasts 2011 results in serious overshoot of all short-term budgets in this analysis. Unrestrained demand growth therefore places ever greater reliance on increasingly steep rates of mitigation post-2022 to allow even a 56% probability budget to remain viable in the long-term, placing the budget seriously in doubt if IA&S mitigate at below the mean rate.

Even as annual per capita driving distances have declined in the last decade, aggregate demand has continued to express strong growth (until the start of the economic recession), primarily underpinned by citizen and driver population growth, but also affected by other demographic trends such as declining mean household size. Thus, in the absence of a much steeper decline in per capita driving distances, future increases in aggregate demand must be regarded as the likely outcome of continued growth in UK citizen population. This is especially likely where growth is based on net inward migration, directly and immediately contributing to growth in the number of households.

No fleet growth scenario in which annual per vehicle distances remain at their current levels is compatible with any budget identified in this analysis. The clear implication is that, to maintain a given emissions pathway under fleet growth conditions, per vehicle distances must decline proportionally.

10.5 How might changes in patterns of car use contribute to or detract from meeting sectoral mitigation goals?

Interviews with car drivers qualitatively explored the possibility of step changes in end use. Analysis of interview dialogues revealed widespread in-principle affirmation of restraint, but relatively low levels of support for specific restraint policies and measures. Similar results are widely reported in the transport studies literature. However, findings of particular interest from the end-user research are the elaboration of constraints and structural lock-ins to driving – barriers to rapid reductions (step changes) in outright levels of per capita demand. Frequently reported structural lock-ins include dependence on car use for accessing work and essential services where no practical alternatives currently exist, for example in rural areas with limited public transport networks, and for people with restricted physical mobility. Socio-demographic trends including increasing geographical separation of work and home, urban flight, and relative spatial locations of housing, amenities and employment centres also serve to lock-in the need to have access to a private car. The fixed costs of car ownership itself are found to further tie people in to driving in preference to public transport use, since the latter appears expensive when compared only to the marginal costs of driving. In addition to physical

[142] RTF 2011 assumes approximately 17% increase in aggregate demand by 2022 cf.2011(§2.2.4.1),

and personal financial constraints, daily time pressures also make slower modes difficult to substitute for private transport.

The system of automobility, as the incumbent (dominant) personal transport socio-technical regime, is found to possess large inertia. While step reductions in per vehicle or per capita demand were considered possible by some interview respondents (on condition that public transport provision is adequately extended and enhanced), many others claimed nothing short of moving home and job would permit such large cuts in their annual driving. The disruptive effects of such relocations were widely regarded as too high a price to pay to reduce emissions from driving. Strong preferences for supply-side fixes were common.

It remains an open question whether such widespread restructuring of work, home, family and social life for large sections of the population is feasible within a decade. Step reductions of one third and two thirds of current personal driving distances were largely regarded as infeasible without a corresponding step change in provision of alternative modes *and* the ability to tolerate the inevitable negative consequences. Negative consequences were widely perceived to include increasing inequalities under the various quantity constraint-based interventions discussed (fuel tax increases, road user charging, personal carbon allowances), both financially and in terms of 'life-chances', employment and social opportunities. Unsurprisingly, demand restraint interventions were routinely viewed with suspicion and resisted by interview respondents.

The key conclusion from the end-user research is therefore that per capita demand reductions are not found to be feasible at the scale required to permit fleet growth, driven by a rising citizen population, to remain consistent with sectoral emissions budgets associated with lower than 50% probabilities of exceeding 2°C. Two principal findings underpin this conclusion.

First, despite a groundswell of support for mitigation in principle, the extent to which individual respondents report being able to curtail their annual driving distances varied considerably. Hence families in rural, semi-rural and outlying towns with two or more adults travelling daily to geographically separate places of work were amongst the most prolific car drivers, while also being amongst the most 'car dependent', i.e. most constrained by current location (and public transport availability), jobs, schools and family responsibilities to continued car use. Limited prospects for major reductions in car use for many of the highest annual mileage divers suggest that the mean rate of potential restraint 'across the board' is likely to be well below the one third reduction discussed in interviews, in the absence of radical reform in the extent and standard of public transport provision.

Second, nothing in the interview findings suggests that a popular mandate could be successfully obtained for coercive, restraint-based policies at a national level. Insofar as the democratic process means that policies require electoral support to survive (if not for their instigation), then the findings from this work do not support optimism for imminent implementation of restraint policies at the extent necessary to render the reductions described. Furthermore, evidence from the literature is unambiguous regarding the ineffectiveness of voluntary measures in producing anything but marginal reductions in demand – although it is important to bear in mind that none of the leading theories of behaviour and practice adequately capture the concept of step-change, which was the focus of this research. The modelled cutbacks of 25% and 50% in annual distance per vehicle by 2022 are not considered achievable as a mean rate of *voluntary* reduction.

Nevertheless, findings from the end user research indicate considerable untapped potential for demand reduction through systematic improvement of public transport. Transformation of the extent of provision and standards of service could enable large sections of the population to relinquish car-dependent mobility and deliver emissions savings in the passenger car sector compatible with lower than 50% probabilities of exceeding 2°C.

Whilst inclusion in the quantitative fleet model scenarios of increased rates of commuting trip occupancy (by 33%) brought about a 5.7% reduction in aggregate demand by 2022 (in the absence of fleet growth), the corresponding reduction in emissions was insufficient to bring cumulative sectoral emissions within a non-future discounted budget of less than 56% probability of exceeding 2°C. However, in model scenarios that assumed fleet growth, a 33% increase in trip occupancy for commuting journeys effectively cancelled out resultant aggregate demand growth. As with outright reduction in annual driving distances, interviews found widespread general support for the concept of carsharing in principle, but much less evidence of willingness to actively engage with the practice in the absence of coercive interventions. Assuming the introduction of restraint policies to coerce increased rates of occupancy, a 33% increase in mean occupancy for commuting trips is tentatively supported by the acceptance levels recorded at interview. Increased occupancy for such trips, therefore, in combination with continued incremental reductions in per capita annual driving distance offers a possible solution to the otherwise damaging increase in aggregate demand arising from citizen and license holder population-driven fleet growth. However, achieving a popular mandate for such coercive policies is likely to remain as problematic as for outright restraint.

10.6 What are the implications for policy of findings from all of the above?

The review of climate and policy literature in tandem with quantification of budgets for the passenger car sector in this analysis highlight the disjuncture between the UK's adoption of the 'interim pathway' and political commitments to avoiding dangerous climate change. Adopting the *LCT* strategy measures and following the 'interim path' to 2022 *locks out any prospect of conforming to a low probability of exceeding 2°C in future*

– even without special treatment for international aviation and shipping. Expected cumulative emissions 2008–2022 from the passenger car sector on the current *LCT* pathway are only 1 $MtCO_2$ less than the *entire* 2008–2050 budget of 1,012 $MtCO_2$ on a 36% probability pathway of exceeding 2°C. If IA&S follow a low-growth trajectory, the equivalent passenger car sector budget 2008–2050 shrinks to 828 $MtCO_2$ (Table 5.3). The consequences for inter-sectoral burden sharing, therefore, are profound. To allow certain strategic sectors, such as IA&S or passenger cars, to mitigate below the mean national rate required for a given probability pathway – even in the short term – effectively sacrifices future prospects of respecting the corresponding emissions budget.

There exists abundant scope for much more substantial supply-side mitigation than currently planned, reducing mean new car bulk emissions factors by using best available, commercially mature, internal combustion technology and increasing hybridisation. Technical and manufacturing cost-related barriers to production of low-emissions ICEVs are found to have been exaggerated. The UK's cumulative emissions from passenger cars over the next decade could be brought within a 56% probability of exceeding 2°C budget through deployment of best available technology and an efficiency ratchet, lowering the mean threshold for new car sales by 3% annually (assuming restraint policies to curb rebound effects).

Type approval values are shown to be an inappropriate basis for sectoral emissions accounting and mitigation. While type approval compliance with the EU new car emissions regulations (Scenario 1.1) *appears* to generate cumulative emissions well within a budget with 56% probability of exceeding 2°C, uplifting the type approval emissions factors to reflect real world driving conditions puts such a pathway out of bounds. By staking the entire sectoral mitigation strategy on compliance with the EU new car regulations at type approval only, current UK passenger car mitigation policy commits the sector to *overshooting all short-term budgets quantified in this analysis*.

With regard to demand-side mitigation, in the absence of a concerted programme of investment in public transport expansion and improvement, the deep-rooted structural limitations to step-changes in per capita driving distance make it infeasible to deliver a low probability of exceeding 2°C budget in the short term through outright restraint – at least not without negative social, economic and welfare consequences. Nevertheless, policies to constrain driving distances – whether in terms of outright abstention from car use for certain trips or through increased mean occupancy – are essential to counter increases in aggregate demand if projected citizen population growth translates into continuing fleet expansion.

To fall into step with a 'reasonable chance' of a 2°C future, the system of automobility must itself rapidly undergo step changes in both supply and demand. However, the urgency of mitigation limits the scope for revolutionary changes in technology, whilst transformations in use are potentially as challenging given the embededness of the car regime. While a step change in use is not impossible, for many people who consider themselves 'car dependent', it represents deeply unfamiliar territory. Nevertheless, there exists a very real likelihood that failure to meet this challenge simply entrains even greater disruptions in future, as the impacts of global climate change are felt around the world. The difficult changes in end use required of wealthy countries such as the UK must be considered against a backdrop of life-changing impacts for people on the front line of climate change.

New cars alone will not produce a rapid transition to a low-carbon passenger car sector. Only a new approach to mobility, in which private transport is increasingly replaced by shared, public and unpowered modes, can deliver such a future. It is the job of governments to facilitate this transition by regulating the availability of high-carbon goods and services, and by securing the requisite means, infrastructure and skills for low-carbon alternatives to prosper.

10.7 **POSTSCRIPT**

10.7.1 Further work

A number of areas have been identified in the course of the research that warrant detailed further academic investigation, in particular:

i. Place of step change in theories of transitions in behaviour and practice

Conventional accounts of behaviour and practices – psychological and structural – struggle to deal adequately with the concept of step-change, or rapid large scale transformations of practices to produce radical reductions in energy use and emissions. The area is ripe for further scholarly investigation – in practical terms, identifying relevant historical analogues could be illustrative in distilling what is required to engender such step changes.

ii. Emissions accounting methods for the passenger car sector

As noted in Chapter 6, the current default method for attributing emissions from road transport to the passenger car sector involves several dubious assumptions (in particular the use of homologated type approval values for vehicle emissions). Further work would be useful using more detailed industry data and national statistics to ensure that future estimates of emissions from this sector more accurately represent real world emissions.

iii. Bulk car occupancy

Also highlighted in Chapter 6, current data on car occupancy by aggregate distance is opaque at best, and further work on analysing available NTS data would be useful to gain better insights into the baseline bulk occupancy values of vehicle kilometres travelled by trip purpose.

iv. Development of the fleet model

The fleet model devised for this research is effectively a work-in-progress. Several of its key assumptions (e.g. annual km per vehicle, as opposed to trips by distance and purpose per driver; see Table 6.7) are simplifications that would benefit from further disaggregation of component variables to test their relative influences on model outputs. Extending the model time horizon beyond the short term, and incorporating uptake of alternative powertrain vehicles and LGVs would further develop the usefulness of the model (this process is already well underway).

v. Re-visiting and re-analysis of qualitative data

A huge amount of qualitative data was gathered from the interview transcripts, with much falling outside the purview of the narrow focus of the immediate questions posed in this research. The raw and analysed datasets constitute a sizeable repository of empirical evidence on a wide range of travel related issues, including highly relevant primary material on personal carbon trading, road user charging, public transport, public referenda and confidence in elected bodies. Re-approaching the data sets afresh to analyse the responses relating to these issues could reveal a host of currently overlooked themes and theories.

vi. Extending the sectoral apportionment methodology to other sectors

Applying the principles of sectoral apportionment described in Chapter 5 to other sectors of the UK economy would provide highly informative baselines against which to evaluate proposed sectoral mitigation plans. These would have real value in ensuring that ‘special derogations’ are not claimed by all sectors to the detriment of the national emissions budget. Other researchers in Tyndall-Manchester have already begun to apply this principle in research into decarbonisation pathways for the UK’s electricity sector.

10.7.2 Final reflections

It is recognised that alternative perspectives and interpretations regarding the framing of the decision criteria (§1.2.2, p.19 and §3.1.1, p.67) could potentially affect the ranking of measures and interventions investigated. In particular, the first criteria (after the overriding objective of achieving the necessary emissions reductions to meet a given budget) of ‘promoting rather than restricting mobility’ can be contrasted with the accessibility perspective, whereby travel needs are addressed as required to meet the needs and aspirations of citizens. Accessibility portrays travel as inherently derived demand, as opposed to a potential end in itself. As such, addressing the spatial and temporal location and distribution of amenities, residences, business, commercial, leisure and other key destinations, along with provision of means of access other than by private car, could potentially reduce aggregate demand (VKM_{fleet}) while maintaining or improving levels of access to services afforded by the respective destination types.

By contrast, the dominant policy paradigm, as evidenced by several decades of predict and provide road building, has been that of facilitating private car-based mobility, effectively as a socio-economic good in its own right. However, while the primary decision criteria specified in this work is to ‘promote rather than restrict mobility’, in practice the criteria has been applied more in keeping with the broad thrust of the accessibility paradigm than the ‘travel for its own sake’ mobility paradigm. The criterion was included primarily to capture the important distinction between *access to mobility* as a passenger and low-occupancy private car-based mobility – in other words the distinction between passenger kilometres travelled and vehicle kilometres travelled, where mobility was taken as a broad synonym for travel by any mode. On reflection, the decision criteria could have been phrased differently to avoid the interpretation that it uncritically endorses the mobility paradigm. For all practical purposes the role of this criterion in the analysis was to uphold the principle that policies and measures should not impinge people’s ability to gain access to the benefits that accrue from being able to travel, but that this travel need not necessarily be as the sole occupant of a private car.

This leads to a related issue of the sometimes uneasy equivalence drawn in the thesis between people’s use of car travel and vehicle kilometres travelled. A refinement to the fleet model, using trips by distance and purpose per driving license holder as the basic unit in the calculation of VKM_{fleet}, would remove the need to make coarse assumptions about the relationship of VKM_{veh} to per person annual car kilometres travelled. Re-focussing the fleet emissions model in this way to be ‘people-centric’, rather than vehicle-centric, would more adequately reflect the mobility paradigm and allow per person driving distances to be manipulated in proportion to ‘off-model’ assumptions about destination switching and land use change.

Furthermore, introducing people into the model would allow temporal variations in annual per capita driving distance to be factored into the calculation – particularly salient in light of the findings in this analysis that, *ceteris paribus*, growth in fleet size in proportion to a conservative estimate of growth in UK citizen population will apply more upward pressure on aggregate demand and emissions than can be counteracted by even the most optimistic improvements in technology. The recent historical decline in per capita driving (so-called ‘peak car’), along with variations in the incidence of license holdership, could thus be factored into the model to temper the demand-swelling effects of overall growth in citizen population on aggregate demand. The model in its current form is not entirely without nuance in this regard: note that while several model scenarios assume that citizen population growth results in fleet growth, many scenarios also assume that per vehicle driving distance declines, in order to return a prescribed level of aggregate demand (see Table 8.2). Nonetheless, introducing a person-centric unit of analysis into the fleet emissions model[143] would facilitate more sophisticated investigation of the potential combined effect on aggregate demand of recent trends in per capita driving distance, changing patterns of license holdership amongst the younger generations and headline ONS projections of citizen population growth. It would be particularly illuminating to compare how these demographic trends stack up against the high-demand projections still favoured by the DfT. The 'eye-watering' increases in aggregate demand projected by edition after edition of the DfT's RTF run contrary not only to the observed trend of declining annual per capita driving distances, but also evidence of the limits to people's appetite for driving. This latter is highlighted in §4.1.4 (p.103), where the literature on the finiteness of individuals' travel time budgets is referred to.

It is, however, highly unlikely that the demand suppressant effects of gently declining per capita driving distances and license holdership amongst the youngest eligible age group could produce anything like the level of demand reduction that would constitute 'step change' – notwithstanding overall growth in citizen population. As such, the need for policies to both promote alternatives to driving and constrain car use is unavoidable if a low probability of exceeding 2°C pathway is to be obtained. The current party political system with five year electoral cycles is arguably inimical to such bold policymaking. In the absence of constitutional reform, there is an urgent need to 'de-politicise' the step-change agenda, or at least to build cross-party support for policies introducing new statutory instruments such as personal carbon allowances, road user charging or other restraint measures.

[143] Perhaps 'fleet demand and emissions model' would be a more appropriate nomenclature

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APPENDICES

APPENDIX 1 – INTERPOLATED ANNUAL VKM_{fleet} & EMISSIONS (FROM DFT ROAD TRANSPORT FORECASTS)

	$MtCO_2$				VKM_{fleet} actual			VKM_{fleet} (UK)		
Year	**Actual**	**RTF 2008**	**RTF 2009**	**RTF 2011**	**GB**	**Northrn Ireland (per cap.)**	**Actual**	**RTF 2008**	**RTF 2009**	**RTF 2011**
1990	71.8	71.8	71.8	71.8	336	10.0	346	346	346	346
1991	71.7	71.7	71.7	71.7	335	10.0	345	345	345	345
1992	73.0	73.0	73.0	73.0	338	10.1	348	348	348	348
1993	73.8	73.8	73.8	73.8	338	10.1	348	348	348	348
1994	72.8	72.8	72.8	72.8	345	10.3	355	355	355	355
1995	72.0	72.0	72.0	72.0	351	10.5	362	362	362	362
1996	74.9	74.9	74.9	74.9	360	10.7	371	371	371	371
1997	75.5	75.5	75.5	75.5	366	10.9	377	377	377	377
1998	75.0	75.0	75.0	75.0	371	11.0	382	382	382	382
1999	76.5	76.5	76.5	76.5	377	11.3	389	389	389	389
2000	76.3	76.3	76.3	76.3	376	11.2	387	387	387	387
2001	76.1	76.1	76.1	76.1	381	11.4	393	393	393	393
2002	77.3	77.3	77.3	77.3	391	11.6	402	402	402	402
2003	76.0	76.0	76.0	76.0	390	11.6	402	402	402	402
2004	76.4	76.4	76.4	76.4	394	11.8	406	406	406	406
2005	75.6	75.6	75.6	75.6	393	11.7	404	404	404	404
2006	75.1	75.1	75.1	75.1	397	11.8	409	409	409	409
2007	74.5	74.5	74.5	74.5	398	11.9	410	410	410	410
2008	72.3	72.3	72.3	72.3	395	11.8	407	407	407	407
2009	69.7	*71.1*	*71.5*	*70.7*	394	11.7	406	*410*	406	406
2010	67.4	**69.9**	*70.7*	***69.1***	386	11.5	397	**414**	*408*	**397**
2011		*70.7*	*69.9*	*68.4*	387	11.5	398	418	*410*	*400*
2012		*71.4*	*69.2*	*67.8*				*427*	*412*	*403*
2013		*72.2*	*68.4*	*67.2*				*437*	*414*	*406*
2014		*73.0*	*67.7*	*66.5*				*447*	*416*	*409*
2015		**73.7**	**67.7**	**65.9**				**462**	**418**	**412**
2016		*73.7*	*66.8*	*65.0*				*468*	*424*	*419*
2017		*73.7*	*65.9*	*64.2*				*473*	*431*	*427*
2018		*73.7*	*65.0*	*63.4*				*479*	*437*	*435*
2019		*73.7*	*64.2*	*62.5*				*485*	*444*	*443*
2020		*73.7*	*63.3*	**61.7**				*491*	*451*	**451**
2021		*73.7*	*62.5*	*61.8*				*497*	*457*	*459*
2022		*73.7*	*61.7*	*61.9*				*503*	*464*	*467*
2023		*73.7*	*60.9*	*61.9*				*509*	*471*	*476*
2024		*73.7*	*60.1*	*62.0*				*516*	*479*	*484*
2025		**73.7**	**59.3**	**62.1**				**522**	**486**	**493**
2026			*59.3*	*61.9*					*492*	*499*
2027			*59.3*	*61.7*					*497*	*504*
2028			*59.3*	*61.6*					*503*	*510*
2029			*59.3*	*61.4*					*509*	*515*
2030			*59.3*	**61.2**					*515*	**521**
2031			*59.3*	*61.6*					*521*	*526*
2032			*59.3*	*61.9*					*527*	*532*
2033			*59.3*	*62.3*					*534*	*537*
2034			*59.3*	*62.6*					*540*	*542*
2035			**59.3**	**63.0**					**546**	**546**

Δ p.a. 2003–08		-1.0%								
Δ p.a. 2003–10		-1.2%								
Δ p.a. 2008–10								0.8%		
Δ p.a. 2009–15			-1.1%						0.5%	
Δ p.a. 2010–15		1.1%		-0.9%				2.2%	0.5%	0.7%
Δ p.a. 2015–20				-1.3%						1.8%
Δ p.a. 2015–25		0.0%	-1.3%					1.2%	1.5%	
Δ p.a. 2020–25				0.1%						1.8%
Δ p.a. 2025–30				-0.3%						1.1%
Δ p.a. 2025–35			0.0%						1.2%	
Δ p.a. 2030–35				0.6%						1.0%

Northern Ireland population			
NI popn 2009	**1,788,896**	**2.98%**	**of GB**
UK as whole	**61,792,000**	**2.81%**	**of UK**

Car ownership rate NI	**1.16**
Car ownership rate GB	**1.14**

NB Highlighted (boxed) values are DfT projected changes (see Table 2.1); values in italics are interpolated.

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APPENDIX 2 – GB AND NI FLEET MATRICES

GB Fleet Matrix

Total number of cars

Licensing year / Year first registered:	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980
1994																	1,718	1,641	1,453	1,417	1,783	2,029	1,912	1,690	1,510	1,381	1,180	1,009	654	375	245
1995																1,741	1,746	1,621	1,412	1,417	1,756	1,987	1,859	1,556	1,337	1,235	1,019	809	506	279	
1996															1,827	1,758	1,732	1,579	1,414	1,399	1,722	1,935	1,791	1,532	1,300	1,103	844	652	387		
1997														1,956	1,834	1,759	1,692	1,579	1,396	1,372	1,679	1,869	1,702	1,405	1,138	916	659	482			
1998													2,036	1,964	1,835	1,732	1,699	1,564	1,371	1,337	1,619	1,767	1,552	1,205	915	690	467				
1999												2,063	2,069	1,991	1,821	1,751	1,695	1,550	1,349	1,302	1,549	1,636	1,365	983	700	497					
2000											2,153	2,067	2,082	1,955	1,832	1,733	1,666	1,512	1,300	1,229	1,416	1,420	1,105	737	494						
2001										2,404	2,157	2,067	2,028	1,961	1,817	1,710	1,635	1,471	1,239	1,134	1,240	1,158	835	522							
2002									2,495	2,408	2,151	2,020	2,037	1,943	1,786	1,667	1,574	1,389	1,125	974	992	860	579								
2003								2,428	2,497	2,375	2,078	2,012	2,006	1,901	1,732	1,594	1,472	1,255	952	768	724	589									
2004							2,369	2,459	2,506	2,352	2,106	2,005	1,986	1,867	1,677	1,506	1,337	1,079	751	565	506										
2005						2,252	2,414	2,461	2,464	2,358	2,089	1,974	1,935	1,790	1,563	1,346	1,131	856	548	392											
2006					2,118	2,269	2,405	2,403	2,448	2,327	2,044	1,913	1,837	1,654	1,377	1,116	877	624	373												
2007				2,162	2,164	2,266	2,351	2,393	2,422	2,284	1,990	1,836	1,707	1,481	1,169	892	659	448													
2008			1,946	2,224	2,183	2,221	2,349	2,370	2,380	2,223	1,909	1,720	1,524	1,261	936	674	473														
2009		1,853	1,978	2,245	2,151	2,227	2,336	2,341	2,336	2,154	1,813	1,540	1,277	1,009	711	490															
2010	1,875	1,854	1,971	2,198	2,135	2,197	2,295	2,291	2,264	2,049	1,675	1,359	1,054	794	534																

Data source: (DfT 2011f: VEH0207)

NI Fleet Matrix

Total number of cars

Licensing year / Year first registered:	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980
1994																															
1995																73	64	55	49	47	48	43	38	29	23	19	13	7	4	1	2
1996															78	66	60	52	45	42	43	39	33	25	18	14	9	5	2	3	
1997														85	71	63	58	49	42	39	40	35	29	20	14	10	6	3	3		
1998													89	73	65	59	53	44	37	34	34	29	22	14	9	6	4	4			
1999												91	79	69	62	56	50	41	33	29	28	23	16	9	6	4	5				
2000											89	79	73	64	58	51	45	36	28	24	21	15	10	5	3	5					
2001										92	79	74	68	61	55	48	42	33	25	19	16	10	6	3	5						
2002									95	83	74	70	64	57	50	44	36	27	19	14	10	6	4	5							
2003								96	87	80	73	68	63	55	47	40	32	22	14	9	6	4	6								
2004							93	88	83	77	69	64	59	50	42	35	26	17	10	6	4	6									
2005						97	87	84	80	72	65	59	54	45	36	28	19	12	6	4	7										
2006					104	91	84	80	76	69	60	55	48	39	30	22	14	8	4	8											
2007				113	97	86	80	76	71	64	56	49	42	32	23	16	10	5	8												
2008			93	105	92	83	76	72	66	59	51	43	36	26	18	11	7	9													
2009		83	87	100	89	80	73	68	63	55	46	39	29	20	12	8	12														
2010	77	77	82	96	84	76	69	64	58	50	41	32	23	14	9	14															

Data source: (DRDNI 2000; 2005; 2008; 2009; 2012)

APPENDIX 3 – COMBINED UK FLEET MATRIX

Total number of cars

Licensing year	Year first registered:	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	1982	1981	1980	16 years + and 'unknowns'
	("n" years ago)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+																
1994																		1,718	1,641	1,453	1,417	1,783	2,029	1,912	1,690	1,510	1,381	1,180	1,009	654	375	245	1,072
1995																	1,815	1,746	1,621	1,412	1,417	1,756	1,987	1,859	1,556	1,337	1,235	1,019	809	506	279		1,115
1996																1,905	1,824	1,732	1,579	1,414	1,399	1,722	1,935	1,791	1,532	1,300	1,103	844	652	387			1,262
1997															2,040	1,905	1,823	1,692	1,579	1,396	1,372	1,679	1,869	1,702	1,405	1,138	916	659	482				1,395
1998														2,125	2,038	1,900	1,791	1,699	1,564	1,371	1,337	1,619	1,767	1,552	1,205	915	690	467					1,539
1999													2,154	2,148	2,061	1,883	1,806	1,695	1,550	1,349	1,302	1,549	1,636	1,365	983	700	497						1,655
2000												2,241	2,146	2,155	2,019	1,889	1,784	1,666	1,512	1,300	1,229	1,416	1,420	1,105	737	494							1,706
2001											2,496	2,236	2,141	2,097	2,022	1,872	1,758	1,635	1,471	1,239	1,134	1,240	1,158	835	522								1,748
2002										2,590	2,491	2,225	2,090	2,102	2,000	1,836	1,711	1,574	1,389	1,125	974	992	860	579									1,783
2003									2,524	2,585	2,455	2,150	2,080	2,068	1,955	1,780	1,635	1,472	1,255	952	768	724	589										1,858
2004								2,462	2,548	2,589	2,429	2,175	2,069	2,044	1,917	1,720	1,541	1,337	1,079	751	565	506											1,955
2005							2,349	2,502	2,545	2,543	2,430	2,153	2,033	1,989	1,835	1,599	1,374	1,131	856	548	392												1,948
2006						2,222	2,360	2,489	2,483	2,524	2,396	2,105	1,968	1,885	1,692	1,407	1,138	877	624	373													1,824
2007					2,275	2,261	2,353	2,431	2,469	2,493	2,348	2,046	1,885	1,750	1,513	1,192	908	659	448														1,776
2008				2,039	2,329	2,274	2,304	2,425	2,442	2,446	2,282	1,960	1,763	1,559	1,286	954	685	473															1,767
2009			1,936	2,065	2,345	2,240	2,307	2,409	2,409	2,400	2,209	1,859	1,578	1,305	1,028	723	498																1,785
2010		1,952	1,931	2,053	2,294	2,219	2,273	2,364	2,355	2,322	2,100	1,716	1,390	1,077	808	543																	1,890

Highlighted values show where there are more cars 'first registered in year *x*' at the end of year *x*+1 than at the end of year *x* itself. This is believed to occur when cars bought by dealerships are immediately declared off road and withheld for later release into the market as pre-registered vehicles (see §6.3.1 and 6.3.2)

Based on: (DRDNI 2000; 2005; 2008; 2009; DfT 2011f: VEH0207; DRDNI 2012)

APPENDIX 4 – HISTORICAL UK FLEET RETIREMENT RATES

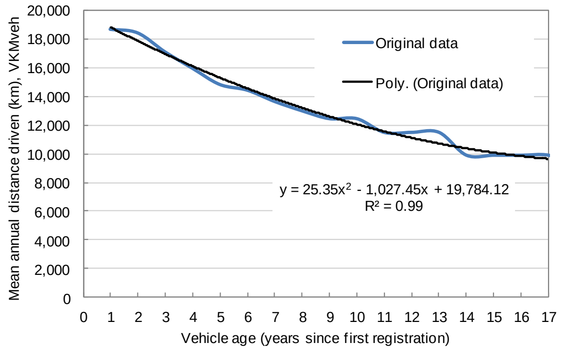
Retirement rates

	Year first											Percentage of all cars														16 years
Licensing	registered:	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	+ and
year	("n" years ago)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+									'unknown
1994																										
1995																										
1996																										
1997																										
1998																										
1999																										
2000																										
2001											0.0%	0.2%	0.2%	2.7%	-0.2%	0.9%	1.5%	1.9%	2.8%	4.7%	7.8%	12.4%	18.4%	24.4%	29.2%	-2.4%
2002										0.0%	0.2%	0.5%	2.4%	-0.2%	1.1%	1.9%	2.7%	3.7%	5.6%	9.2%	14.0%	20.0%	25.8%	30.6%		-2.0%
2003									0.0%	0.2%	1.5%	3.3%	0.5%	1.6%	2.2%	3.1%	4.5%	6.4%	9.6%	15.4%	21.2%	27.0%	31.4%			-4.2%
2004								0.0%	-0.9%	-0.2%	1.0%	-1.1%	0.5%	1.2%	1.9%	3.4%	5.7%	9.2%	14.0%	21.1%	26.3%	30.1%				-5.3%
2005							0.0%	-1.6%	0.1%	1.8%	-0.1%	1.0%	1.7%	2.7%	4.3%	7.0%	10.9%	15.4%	20.7%	27.0%	30.6%					0.4%
2006						0.0%	-0.4%	0.5%	2.4%	0.8%	1.4%	2.2%	3.2%	5.2%	7.8%	12.0%	17.2%	22.4%	27.1%	32.0%						6.3%
2007					0.0%	-1.7%	0.3%	2.3%	0.6%	1.2%	2.0%	2.8%	4.2%	7.2%	10.6%	15.3%	20.2%	24.8%	28.3%							2.6%
2008				0.0%	-2.4%	-0.6%	2.1%	0.2%	1.1%	1.9%	2.8%	4.2%	6.5%	10.9%	15.0%	20.0%	24.6%	28.2%								0.5%
2009			0.0%	-1.2%	-0.7%	1.5%	-0.1%	0.7%	1.3%	1.9%	3.2%	5.2%	10.5%	16.3%	20.1%	24.3%	27.3%									-1.0%
2010		0%	0.3%	0.6%	2.2%	1.0%	1.5%	1.9%	2.2%	3.2%	5.0%	7.7%	11.9%	17.5%	21.5%	24.9%										-5.8%

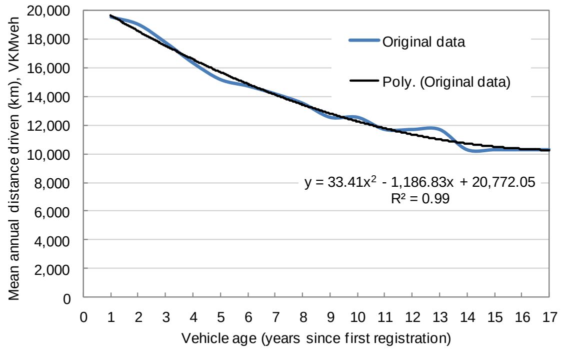
Based on data in Appendix 3.

APPENDIX 5 – RAW VKM_{VEH} DATA AND INTERPOLATED VALUES

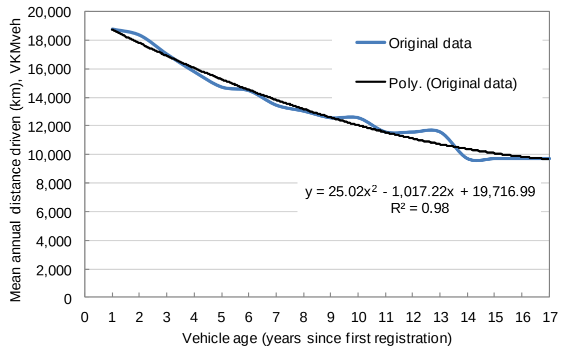
Mean all years



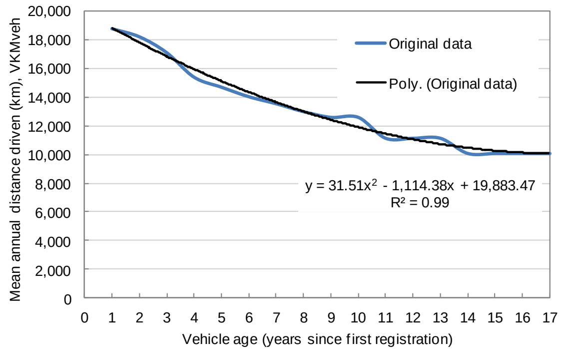
2002/04



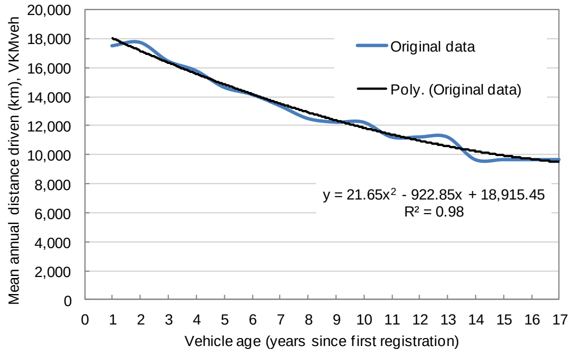
2005/07



2006/08



2008/10



Data source: (DfT 2011c)

APPENDIX 6 – SAMPLE EMAIL AND RESEARCH INFORMATION SHEET

Dear colleague,

You kindly indicated in the university's staff travel survey last year that you would be prepared to give further feedback about travel. I am conducting academic research independently of the university's travel survey, into the feasibility of UK national policies intended to influence personal travel choices (such as road user charging, personal carbon allowances, integrated public transport, etc). As part of my primary research, I would like to invite you to participate in an informal face-to-face interview / conversation about your thoughts and comments on a number of hypothetical policies designed to influence driving behaviour.

The meeting can be arranged at a time and place on campus to suit you, and will likely last around an hour to an hour and a half (based on pilot interviews). If you are willing to take part, please drop me an email to let me know when in the course of the next four weeks you would be able to meet up. I would be very grateful if you would also let me know:

1. your main mode of transport to work (e.g. car as driver, car as passenger, walk, bus)
2. how far you travel to work (one way, from home to work)
3. your job area within the university (e.g. academic, support, STARS, etc)

Full details are in the attached information sheet, but please feel free to contact me if you want further information before deciding whether to take part.

I look forward to hearing from you.

Thanks and kind regards,

Dan Calverley

Dan Calverley
Researcher - transport policy
Tyndall Centre for Climate Change Research
Pariser Building, H1
University of Manchester
Sackville Street
MANCHESTER
M13 9PL

MANCHESTER 1824

The University of Manchester

School of Mechanical, Aerospace and Civil Engineering

Personal transport research – information sheet

Introduction

Cars are responsible for one in eight tonnes of CO_2 produced by the UK, more than any other single sector apart from energy generation. Reducing emissions from the use of cars is therefore an environmental and political priority, but the sector has so far proved resistant to change. Although new vehicles are nowadays significantly more fuel efficient than a decade ago, overall emissions from the UK's car sector have not fallen as you might expect. This is because more of us are driving, and we are driving greater distances. Improving vehicle technology is likely to continue to bring better fuel efficiency in coming years, and new technologies like electric vehicles and hydrogen fuel are expected one day to make a major contribution to cutting emissions from driving. But if the world is to avoid the worst impacts of climate change, then emissions need to come down much faster than can be achieved by technology alone – in short we need to drive less. Numerous policies have been suggested for discouraging private-car use while encouraging lower-carbon forms of transport. Some even claim to do so in a way that does not penalise poor, or car-dependent social groups. This study seeks to gain an understanding of how members of the public view such policies, and how travel choices would be affected.

What will I have to do if I decide to take part?

The researcher, Dan Calverley, will arrange to meet with you for an informal interview to discuss your reactions to hypothetical transport related policies. At the interview, you will be asked to read two short scenarios describing life in the UK as if the theoretical policies have been introduced. The researcher will then lead the conversation by asking a series of open-ended questions about how you envisage these policies would change your travel choices. In particular, the study is interested to understand whether such scenarios would be likely to affect the amount that you drive, compared to your current situation. The meeting will take around one and a half hours, and the researcher will make notes and audio-record the conversation to ensure that they can draw out the key issues that you raise. Interviews can be arranged at a time convenient to you (either during the day or after your usual working hours) and venue within the University of Manchester (either within the School of MACE or near to your place of work, as preferred).

Will my data be confidential?

The audio recordings of the interview conversations will be transcribed by Dan Calverley for the purposes of qualitative data analysis. Only Dan Calverley and his two PhD supervisors at the University of Manchester, Professor Kevin Anderson and Dr Alice Bows, will have access to the audio recordings. All identifying personal information will be removed when transcribing the information for use in future reporting and publication. Recordings will be stored in a secure location within the School of MACE in an anonymous format. If you wish, you can receive a copy of the recording at the end of the period of data collection and transcription. If there are sections that you do not wish to be used for the study, you may request that these sections are removed and not used in the research.

Do I have to take part?

It is entirely up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. If after agreeing to take part you decide that you no longer wish to continue, you are free at any point to withdraw from the study or end the interview.

Where can I obtain further information?

If you require more information, please contact Dan Calverley

Tyndall Manchester, School of Mechanical, Aerospace and Civil Engineering, Pariser Building, Room H1.C

email: xxxxxxxxxxx@xxxxxxxxxxxxxxxxx.uk telephone: xxxxxxxxxx

Supervisors: Prof. Kevin Anderson, Dr Alice Bows

This project has been approved by the university senate research ethics committee

APPENDIX 7 – PRE-INTERVIEW QUESTIONNAIRE

MANCHESTER 1824

The University of Manchester

Pre-interview questionnaire

Thank you for agreeing to take part in this study. To save time in the face-to-face meeting, it would be helpful if you would complete this short questionnaire and return it by email to xxxxxxxxxxxxx@xxxxxxxxxxxxxxxxxxxxuk.

1. How do you normally travel to and from work? (e.g. drive; by car as passenger; by bus; by train; by bicycle, walk, etc)
2. How far do you travel from home to work (one way trip) in miles?
3. If your usual trip to and from work involves more than one mode of transport (e.g. train and bicycle), please say how far in miles you travel by each mode on a one way trip.
4. In an 'average week' roughly how far do you drive for the following purposes (i.e. other than travel to and from work)?

Trip purpose	Estimated weekly mileage
work business (not commuting)	
shopping	
school run	
other lifts for family members / friends	
other personal business (appointments, errands etc)	
visiting friends / relatives	
other regular leisure trips (including exercise, getting into the countryside)	
holidays	

5. How far do you estimate that you drive in an average year?
6. If you drive to work, how many other people are normally in the car with you?
   - No one else □
   - One passenger □
   - Two passengers □
   - Three or more passengers □
7. How many other cars are there in your household (beside the one you drive)?
   - There are no other cars □
   - One additional car □
   - Two additional cars □
   - Three or more additional cars □
8. Are you the main driver in the household? (i.e. do you drive the furthest?)
   - Yes □
   - No □
9. How many other drivers (not including you) drive your car?
   - Regularly (once a week or more) □ (no. of other drivers)
   - Occasionally (less than once a week) □ (no. of other drivers)
   - Rarely (less than once a month) □ (no. of other drivers)

10. How far do you estimate that others sharing your car drive it in an average year?

………….. miles

11. What other modes of transport do you regularly use? and for what trip purposes?

Mode	Trip purposes	Frequency (no. of times per week / month / year, please say which)
Car as passenger		
Motorcycle		
Bus		
Train		
Tram		
Plane		
Ferry		
Bicycle		
Walk		
Other		

12. In your household:
how many adults are there (including yourself)? ….
how many children are there (under 16 years)? ….

13. What are your main reasons for driving, rather than using another mode of transport?
e.g. convenience (it's there when I need it)
personal space
cost of public transport
any other reasons …………

14. Would you say that your current lifestyle *requires* the use of a car?

15. Which if any of the following factors currently make it less likely that you would drive for any given trip? (i.e. more likely to use a form of transport other than car) Choose as many as apply.

price of fuel □
concern for the environment / emissions □
desire to take exercise □
traffic congestion / delays □
(lack of) availability of cheap parking at destination □
cheap public transport □
any other factor affecting your decision to drive □
… please state………………

APPENDIX 8 – FULL TEXT OF NARRATIVE SCENARIOS

NARRATIVE SCENARIO ONE

The following describes a vision of personal transport in the UK for the year 2020. It is a purely hypothetical scenario – there is no suggestion that this it is likely or desirable, but you are asked to consider how it differs from your current driving habits and lifestyle.

Introduction

Hard to believe that not so long ago, back in the days of cheap road fuel in the early 2010s, most cars were only managing around 40 to 50 miles per gallon. Nowadays, on the open road, you can get over 100 miles per gallon out of your modern super-efficient diesel hatchback. Since the new regulations for car makers came into force in the middle of the decade, new cars have to meet demanding standards for fuel efficiency, which get stricter every year. Although it's hard for the youngsters to imagine, enormous gas-guzzling 4 wheel drive SUVs making the school run were an everyday sight only eight years ago, sharing the roads (and the traffic jams) with frustrated commuters going nowhere fast. You hardly see 4WDs any more. Car makers stopped bothering with them, as there are no exceptions to the new manufacturing rules and they just can't make those big, heavy vehicles run efficiently enough to get a sales permit in the UK. In towns and cities more and more people are driving plug-in hybrids and electric cars, but they're still pricey in comparison to conventional-engined cars. And electricity prices haven't settled down yet, since there's so much more demand for green electricity from all the new electric cars, on top of all the factories and industry that have switched over to renewable electricity sources. So most people drive highly efficient diesel cars that look and feel much the same as their older polluting counterparts, except for clever features like fuel consumption displays, advisory gear change indicators and cruise control.

Scenario 1

You **drive about 2/3 as much** as in 2011. Daily trips to and from work can now be done more cheaply by rail and bus than by car, and you can always grab a **city-bike** from one of the many bike docks around the city if you need to make an errand. No longer having to drop kids off at school on the way to work is also a burden off the shoulders for many, due to the widely available **municipal school buses**, and school-organised walking crocodiles for the younger kids picking up door to door. Supermarket **home deliveries** take the hassle out of the weekly shop for most food shopping these days, although the car is still handy for the occasional impromptu shopping trip and for shared intercity journeys, getting into the country and for holidays. Nevertheless, keeping your own car on the road is a costly business these days, despite **pay-as-you-drive insurance** giving a healthy discount in proportion to the distance you drive each year; only around two thirds what it once was.

Policies in scenario 1

When you think of the changes over the last eight years, it seems amazing how cheap fuel was in the first decade of the twenty-first century, when we happily filled up for less than £70 a tank. **Diesel is £140** a tank (over £3 a litre) now. As a result people seldom choose to drive alone for great distances any more; and motorway journeys are far more relaxed, especially since the 65 mile an hour **speed limit** is strictly enforced. **Public transport** has been transformed too, now that road fuel **tax revenues are ring-fenced for investment** into improving services and increasing the number of trains and buses. No longer costly and inconvenient for users, today our integrated public transport network is fast becoming the envy of other countries. Now making an intercity journey without a car is no longer a mystery tour: your mobile phone shows instantly how to get to the nearest public transport stop, as well as the connection options to any destination in the country. And the regulated **flat fare structure** and the multi-mode **travel smartcard** in your wallet mean that you can be sure that you only ever pay the fair fare.

The reprioritisation of **roadspace** in favour of walking and cycle traffic means that those intrepid souls who do venture into the city by car are now obliged to give way to everyone else. Urban driving is tricky now that many public and private car parks have disappeared, since their owners are subject to a car parking tax levy. Nowadays councils and businesses tend to keep only those **car parks** they have to provide by law for disabled drivers, service vehicles and the like.

It's true that **fees for road users** were fiercely resisted by hauliers and the public when they were introduced in the middle of the decade, but nowadays about half of the freight that used to be on the roads has been shifted to rail and waterways, and people generally accept that it's worth the tolls for the lack of congestion. Most noticeably the peak time rush hours where queues of cars once seethed with the frustration of lone drivers, is now almost a distant memory. Road-tolls fall steeply with each additional car passenger present, and are waived entirely for full cars, leading to the popularity of car-share clubs and phone apps to match your journey requirements with drivers and passengers in your vicinity, linking with public transport as necessary, and calculating cost to enable easy comparison with the equivalent drive alone trip. When travelling by car is unavoidable, your travel smartcard gives passage through the road-toll paystations on motorway exit ramps and main trunk roads and debits the fee straight from your bank.

NARRATIVE SCENARIO TWO

The following describes a vision of personal transport in the UK for the year 2020. It is a purely hypothetical scenario – there is no suggestion that this it is likely or desirable, but you are asked to consider how it differs from your current driving habits and lifestyle.

Introduction

Hard to believe that not so long ago, back in the days of cheap road fuel in the early 2010s, most cars were only managing around 40 to 50 miles per gallon. Nowadays, on the open road, you can get over 100 miles per gallon out of your modern super-efficient diesel hatchback. Since the new regulations for car makers came into force in the middle of the decade, new cars have to meet demanding standards for fuel efficiency, which get stricter every year. Although it's hard for the youngsters to imagine, enormous gas-guzzling 4 wheel drive SUVs making the school run were an everyday sight only eight years ago, sharing the roads (and the traffic jams) with frustrated commuters going nowhere fast. You hardly see 4WDs any more. Car makers stopped bothering with them, as there are no exceptions to the new manufacturing rules and they just can't make those big, heavy vehicles run efficiently enough to get a sales permit in the UK. In towns and cities more and more people are driving plug-in hybrids and electric cars, but they're still pricey in comparison to conventional-engined cars. And electricity prices haven't settled down yet, since there's so much more demand for green electricity from all the new electric cars, on top of all the factories and industry that have switched over to renewable electricity sources. So most people drive highly efficient diesel cars that look and feel much the same as their older polluting counterparts, except for clever features like fuel consumption displays, advisory gear change indicators and cruise control.

Scenario 2

You now **drive only about 1/3** of the distance you did in 2011. Rather than automatically reaching for the car keys, people are now just as likely to reach for their travel smartcard, which gives access to a **public transport** network that has improved almost beyond recognition in recent years. Now that the chore of the school run is a thing of the past thanks to municipal high **school buses** and **escorted 'walking-buses'** from home to primary school, it is more and more the norm for people make their regular commuting trips and longer recreational trips by rail, bus or intercity coach than by car.

It is easy to understand why so many of your colleagues and neighbours have **gotten rid of their own cars** entirely. They find it more cost-effective and convenient to join a **car club** instead for the times when they need a vehicle – they just hire a suitable car for their needs for the required time using their phone, and either pick it up in town or have it sent to them. The local carpool company is offering a free trial for a month and so far the reviews have been positive. Since you already make most of your **commuting trips by bus and tram** and frequently use the help-yourself **'city-bikes'**, you are seriously considering ditching your own car too, as you find you need it less and less. The idea of no longer having to pay to service, tax and insure your own private car for the limited amount of use it now gets is becoming increasingly attractive.

Policies in scenario 2

Along with air travel and domestic energy, road fuel is now included within the **personal carbon allowance** system. Everyone gets an equal allocation of carbon credits, and most people find that after they've heated their homes and covered their domestic electricity needs, they have enough credits left for about a third of their weekly mileage before road fuel was fairly rationed. The overall amount of credits in the system is capped by the government at a level in line with climate change targets. Those who want more fuel than their yearly allowance either buy extra credits at the till, paying full current market value, or top up their carbon accounts in advance by buying more credits on the *c*-Bay trading website, where people who don't use their entire allowance sell off their excess credits. It's hardly surprising that people tend to be much more cost-conscious in their driving habits these days – there is certainly no longer any incentive to break the strictly enforced 65 mile an hour speed limit. **Road tolls** and **minimum occupancy** vehicle lanes on motorways and main roads mean that car-sharing is the only sensible option for those trips that require the flexibility of a car. Tolls for lone drivers are high at peak times and fines for lone drivers using the carshare lane are punitive. Tolls fall by 25% for each car passenger, leading to the popularity of car-share clubs and phone apps to match your journey requirements with drivers and passengers in your vicinity, linking with public transport as necessary, and calculating cost to enable easy comparison with the equivalent drive alone trip.

Revenue from road tolls is ring-fenced and used to maintain a **vastly enhanced public transport** system, with improved service and provision of passenger spaces, along with user-friendly mobile phone apps that show at a glance how to get to the nearest public transport stop, as well as the connection options to any destination in the country. A regulated flat fare structure makes the cost of travelling by public transport predictable and transparent; and it doesn't require you to use any of your personal carbon allowance either, so valuable carbon credits can be saved to spend on other less mundane trips like holidays.

It's true that charging for the use of roads was pretty unpopular to begin with, but people were more supportive once the benefits to public transport were visible, not to mention the radical **improvements in air quality, noise and visual appearance** that have come about by alleviating the traffic congestion that once blockaded many towns. Places that used to be gridlocked for half the day are now pleasant areas to live and work, and it is actually enjoyable to make short errands by bike or on foot now that road priority has been given to cyclists and pedestrians.

APPENDIX 9 – QUALITATIVE INTERVIEW PRIMARY CODES

Picklist of primary codes arranged by family. C=no. of codes in family. Q=no. of quotations associated with codes in each family.
NB families are not exclusive, some codes appear more than once. There are 337 separate, unique codes.

	car type
	C13, Q247
1	car: 4x4s
2	car: comfort, high spec
3	car: EV
4	car: hire car
5	car: large car
6	car: MPV (people carrier)
7	car: new car
8	car: old car
9	car: performance
10	car: small car
11	job: company car
12	job: pool car
13	motorcycle
14	taxi

	car costs
	C5, Q170
15	car: fixed costs
16	car: fuel consumption
17	car: fuel efficient car
18	car: inefficient veh.
19	car: VED

	PT use
	C26, Q511
20	bus: express bus
21	bus: user
22	conxn: transfer time
23	conxn: uni to Piccadilly
24	non-car mobility
25	PT: ex-PT user
26	PT: for business trips
27	PT: for going out
28	PT: for long trips
29	PT: more frequent service needed
30	PT: needs major improvement
31	PT: new service
32	PT: occasional user
33	PT: other countries
34	PT: peak / off-peak
35	PT: regional boundary
36	PT: requires familiarity
37	PT: season ticket
38	PT: unusual hours
39	PT: use time to read, etc
40	PT: weather dependent
41	PT: willing to pay for better
42	PT: would prefer to use, but...
43	train: regular user
44	train: to London
45	tram

	unpowered modes: incentives
	C7, Q77
46	city bikes: good idea
47	cycling: as exercise
48	cycling: to shops
49	cyclist: leisure
50	walking: as exercise
51	walking: as leisure activity
52	walking: as social activity

	unpowered modes: inhibitors
	C10, Q92
53	city bikes: problems
54	cycling: air quality
55	cycling: bike theft
56	cycling: bus danger
57	cycling: dangerous
58	cycling: dislike
59	cycling: inconvenient
60	cycling: stressful
61	cycling: terrain dependent
62	cycling: weather dependent

	car: user value
	C9, Q189
63	car: as status symbol
64	car: as utility vehicle
65	car: other values
66	car: special criteria
67	conxn: car faster door to door
68	conxn: driving time predictable
69	driving: as a luxury
70	driving: as social enabler
71	employment prospects depend on car

	driving: inhibitors
	C15, Q281
72	congestion
73	congestion: is a problem
74	congestion: peak / off-peak
75	driving: dislike
76	driving: sedentary
77	driving: stressful
78	driving: wasted time
79	fuel £+: reduce mileage
80	home delivery: user
81	ICT: internet shopping
82	parking: costs, expensive
83	parking: reduced availability
84	roadspace reallocn: bad idea
85	roadspace reallocn: good idea
86	weather: severe winter

	PT: incentives
	C10, Q89
87	bus: good service
88	conxn: PT journey time more predictable
89	job: interest free loan for PT
90	PT: cheaper than driving
91	PT: children prefer
92	PT: good service
93	PT: London is better
94	PT: personal time
95	PT: pro-social / sociable
	PT: use time to read, etc

	purpose of journey
	C22, Q348
96	driving: children, necessitate car
97	driving: lifts for other people
98	holiday
99	holiday: driving holiday
100	in case of emergency
101	job: business trips, discretionary
102	job: commuting requires car
103	job: work requires car
104	keep car for: holidays
105	keep car for: leisure trips
106	keep car for: visiting family
107	keep car: as a back up
108	school run
109	school run: disapprove
110	school run: on way to work
111	school run: share with partner
112	school: distant from home
113	school: walk to school
114	shopping: on foot
115	shopping: on way home in car
116	shopping: req's car
117	sports and leisure interests

	road user charges
	C9, Q118
118	C-charge
119	C-charge: London
120	C-charge: Mcr
121	road tolls: dislike
122	road tolls: don't mind
123	road tolls: M6 toll
124	road tolls: penalise poor
125	road tolls: problem
126	road tolls: too complicated

	driving: incentives
	C21, Q470
127	complex journey
128	congestion: not really a problem
	conxn: car faster door to door
	conxn: driving time predictable
129	dependent on car
	driving: as social enabler
	driving: children, necessitate car
130	driving: cost differential with PT
131	driving: difficult to reduce
132	driving: enjoy
133	driving: increase driving
134	driving: leave at will
135	driving: personal space, time
136	intervention: to enable driving
	job: commuting requires car
137	job: mileage reimbursement
	job: work requires car
138	land use: car-centric development
139	motoring 'enthusiast'
140	parking: costs, cheap
141	two car household

	driving: characteristics
	C20, Q400
142	carsharing: current user
143	carsharing: ex-car sharer
144	carsharing: with family member
145	driving: fuel effct driving
146	driving: high annual mileage
147	driving: high occupancy
148	driving: inefficient
149	driving: long trips
150	driving: low annual mileage
151	driving: low occupancy
152	driving: short trips
153	driving: speeding
154	driving: trip chain
155	other people's car
156	parking: at home
157	parking: park & ride
158	parking: public
159	parking: workplace
160	partner's car is main family car
161	partner is main driver

	PT: inhibitors
	C24, Q458
162	bus: antisocial behaviour
163	bus: deregulation problems
164	bus: exact fare inconvenient
165	bus: stops too often
166	bus: takes circuitous route
167	bus: takes too long
168	bus: uncomfortable
169	buses: too many buses
	complex journey
170	conxn: lack of integration
171	luggage
172	PT: cause sickness
173	PT: crowded
174	PT: deterred by bad experience
175	PT: difficult with luggage
176	PT: difficult with young children
177	PT: fares too complicated
178	PT: overpriced
179	PT: poor image
180	PT: poor rural service
181	PT: stressful
182	PT: takes too long
183	PT: uncomfortable, poor facilities
184	PT: unreliable

	scenario: benefits
	C17, Q440
185	car-club: would consider
186	carpool lane: good idea
187	carsharing: save money
188	carsharing: sees value...
189	carsharing: social benefits
	city bikes: good idea
190	cut driving: could do it
191	home delivery: good idea
192	PCT: advantage
193	PCT: raise awareness
194	ringfencing £: good idea
	road tolls: don't mind
	roadspace reallocn: good idea
195	scenario: positive reaction
196	school bus: good idea
197	smartcard: good idea
198	speed limit: good idea

	scenario: effective
	C11, Q237
199	cut driving: business miles
200	cut driving: commuting
	cut driving: could do it
	fuel £+: reduce mileage
201	fuel £+: switch car
202	fuel £+: switch mode
203	get rid of car
204	ICT: reduce need to travel
205	intervention-led shift
206	PCT: possible beh.change
207	PCT: trade off

	unpowered modes: use
	C7, Q168
208	conxn: walk between
209	cycling: ex-cyclist
210	cycling: off road cycle route
211	cycling: would if I could
212	cyclist: occasional
213	cyclist: regular
214	walking distance

	obligations: work
	C10, Q161
	job: business trips, discretionary
	job: commuting requires car
215	job: corporate culture
216	job: flexible hours
217	job: home working
218	job: irregular / antisocial hours
219	job: regular commuting time / routine
220	job: responsibile for / to others
	job: work requires car
221	job: workload dictates commuting mode

	social groups
	C15, Q233
222	driving: new driver
223	social group: children
224	social group: children (young)
225	social group: cyclists
226	social group: environmentalists
227	social group: families
228	social group: motorists
229	social group: older generation
230	social group: pedestrians
231	social group: poor
232	social group: PT users
233	social group: restricted mobility
234	social group: rich
235	social group: working people
236	social group: younger generation

	motivation
	C19, Q499
237	emissions: aware but not motivated
238	habitual behaviour
239	individual action: important
240	individual action: sceptical
241	lead by example
242	money: is a concern
243	money: not main issue
244	motivation: 'philosophical' outlook
245	motivation: aspiration
246	motivation: efficiency
247	motivation: financial
248	motivation: health
249	motivation: local community
250	motivation: moral / ethical
251	motivation: proenvironmental
252	out of sight / out of mind
253	refuse to change
254	time constrained, busy
255	trendiness, becoming mainstream

	other specific concerns
	C8, Q248
256	emissions: consumption-based
257	emissions: question re car sector
	employment prospects depend on car
258	land use planning
259	other benefits (non-emsns)
260	personal safety
261	personal security
	weather: severe winter

	scenario: issues
	C32, Q430
262	car-club: expensive
263	car-club: inconvenient
264	car-club: limited veh. choice
265	car-club: unfamiliar
266	carpool: problem
267	carsharing: (in)compatible hours
268	carsharing: loss independence
269	carsharing: loss of personal space
270	carsharing: problems
	city bikes: problems
271	fuel £+: priced off the road
272	home delivery: problem
273	PCT: allocation query
274	PCT: beyond my control
275	PCT: favours rich
276	PCT: housing
277	PCT: level of complexity
278	PCT: negative impact on poor
279	PCT: open to abuse
280	PCT: problem
281	PCT: problem, special needs
282	ringfencing: sceptical
	road tolls: dislike
	road tolls: penalise poor
	road tolls: problem
	road tolls: too complicated
	roadspace reallocn: bad idea
283	scenario: negative reaction
284	scenario: sceptical
285	school bus: problem
286	speed limit: too low as it is
287	speed limit: would cause delay

	home location
	C5, Q157
288	job: influence on home location
289	rural location
290	scenario: urban bias
291	station / stop: distant
292	station / stop: nearby

	outlook / engagement
	C44, Q969
293	budgeting
294	cut driving: recognise need, but...
	driving: as a luxury
295	emissions: ranking
296	environmental concern: privileged
297	familiar with the issues
298	fuel £+: easy to envisage
	fuel £+: priced off the road
	fuel £+: reduce mileage
	fuel £+: switch car
	fuel £+: switch mode
299	fuel £+: would absorb
300	fuel price+: prefer over PCT
	get rid of car
	individual action: important
	individual action: sceptical
	intervention-led shift
301	intervention: collective action
302	intervention: conflicting messages
303	intervention: feel deprived
304	intervention: go with the flow
305	intervention: gradual
306	intervention: ICT use
307	intervention: individuals should pay
308	intervention: intrusive
309	intervention: mistrust of govt
310	intervention: necessary
311	intervention: need to see the benefits
312	intervention: negatively affects poor
313	intervention: persuasion
314	intervention: political leadership
315	intervention: private finance
316	intervention: public subsidy
317	intervention: punitive
318	intervention: regulate
319	intervention: resistance
320	intervention: reward good behaviour
321	intervention: technological fix
	intervention: to enable driving
322	intervention: unfair to workers
323	other pro-envtl behaviour
324	pre-planning
325	suggestion
	out of sight / out of mind

	other countries
	C4, Q89
326	driving: in other countries
327	emissions: other countries
328	experienced abroad
	PT: other countries

	reflection
	C5, Q248
329	cultural norm
330	historical transition
331	old travel habit
332	scenario: mixed reaction
333	snapshot

	general
	C4, Q98
334	air travel
335	HGVs
336	ICT: mobile phones
337	increase emsns

APPENDIX 10 – INTERVIEW TOPIC GUIDE

Interviews will comprise three broad sections, although the interview sessions will not necessarily be overtly broken down into discrete parts, as it is hoped that the dialogue will progress naturally.

Questions in the first section relate to the extent to which participants perceive the narrative scenarios are different to their current levels car use. These differences will be explored by discussing the elements of the scenarios that strike participants as most salient, for instance how would changes such as the availability of cheap fuel, free road use and parking and improved public transport impact their current lifestyle.

The second section will focus on participants' sense of how feasible it would be for them to adapt their current lifestyle within the constraints of the scenarios. Here questions will draw out the perceived obstacles and barriers that the scenarios would present to participants. In addition, any perceived benefits of reduced car travel will be drawn out.

The third section investigates the degree to which participants are engaged with the need to reduce emissions from private transport, and will explore participants' level of concern about climate change, and their sense of agency with regard to emissions reduction.

APPENDIX 11 – INTERVIEW KEY THEMES

R01

- Two car household, uses small runabout for 5 mile commute, partner uses more powerful car for 34 mile each way commute
- Occasionally uses PT or cycles, weather and workload dependent.
- Interested in vehicle specifications, efficiency, fuel consumption. Key factors in selecting cars.
- Supportive of speed limit reduction and enforcement, roadspace reprioritisation.
- Strong preference for regulating new car market and improving PT rather than road charging or HOVLs.
- Proenvironmentally motivated to reduce emissions, but does not see PT as a workable option for complex journeys, such as partner's commute - especially for people with inflexible working hours whose presence is required and relied on, PT is too unreliable.
- Recounted numerous incidents of being let down by PT, cancellation of services etc
- Describes cycling in Manchester as 'life in your hands', but does occasionally cycle commute for exercise.
- Suspicious of PCT, not persuaded that it would be to the benefit of poorer groups

R02

- Respondent about to retire in a few months, will drastically cut annual driving distance, removing 13,000 miles+
- During summer, when roads are less congested and job (teaching) workload is lighter, does from time to time use the bus, but finds very early start and need to carry lots of work materials inconvenient.
- Enjoys driving - main annual holiday is driving holiday - and car, speaks positively and acknowledges pride in large, comfortable car (modern efficient diesel).
- Always comes back to time efficiency of travel mode
- Respondent did not think that increasing cost of fuel would force any great change in driving distance for them as money is not such a pressure, but recognised that for many it may. Would not support measures which penalised poorer sections of society.
- Regular user of PT for intercity trips for work trips, although less likely to use if self-funded, sees rail as overpriced and providing poor service.
- Reported willingness to car share (for work trips), and welcomed the social aspects, but noted early start time is generally incompatible with colleagues.

R03

- Respondent recently acquired own vehicle after a long period of non-car mobility
- Uses vehicle purely for SDP, commutes by PT. Most trips are utility or holiday, with above average occupancy
- Has in past extensively used hire cars, open to possibility of car club if they became more widespread and catered to utility vehicle needs better
- Given relatively low mileage, expects to see their own driving distance increase in future, and probably wouldn't be affected by fuel price increase.
- Found parking constraint to be restrictive for the rare but necessarily ca-based trips into town/ city (lift for relatives with restricted mobility, etc)
- PCT or other similar constraint would make it more likely for them to consider using other vehicles appropriate to trip purpose, e.g. hire small car, hire van etc
- Well informed about climate change issues, but sees the main issue with private transport being the health and social problems which arise from passive modes and congestion.
- Does not disregard emissions, but argues that vehicle efficiency improvements could easily be introduced, whereas the health, social problems etc would persist without lifestyle changes.

R04

- Respondent is partly employed by the university, partly self-employed, visiting private tutees around the UK
- Although commuting to university is often done by train, visits to clients (often several in the same day) tend to be difficult to time and combine by PT
- While visits to clients would be classed as business miles, respondent argued that interventions and measures to constrain driving distance would negatively affect their business profitability.
- Suggested measures should be tailored according to journey purpose, and that economically productive trips ought not be constrained
- Partner can but chooses not to drive, tending to use unpowered and PT modes.
- Selected present home location based on access to rail network whilst being in rural environment - careful consideration given to opportunities to non-car mobility.
- Respondent prefers PT for long intercity trips where possible, and walking for local trips with young child
- Numerous references to emissions reduction messages / interventions often being delivered in negative or punitive terms. Respondent argues that people would be more receptive / cooperative if interventions were less punitive or dictatory.
- Respondent indicated that proenvironmental motivations were present, but not prime reason for any decision to drive or not to drive. Would be fitness of mode to journey purpose.

R05

- Respondent has alternated between driving and using train to commute 25 miles from semi-rural location. In last couple of years has reverted to driving
- Has analysed relative cost of season ticket versus use of car and finds season ticket £1k p.a. more expensive, due to small size and good fuel economy of car
- Strongly positive reaction to suggestion of reduced car use - repeatedly refers to preference for not using car if PT cost differential and service provision were better.
- Partner already makes wide use of non-car mobility, walking, cycling
- Parents live in a remote rural location, depend on 4WD for much of year, so argued against blanket ban.
- Expressed concern, as semi-rural dweller, how PCT would affect their personal transport opportunities.
- Bus travel seen as unpleasant, PT means rail.
- Experience of using train service for commuting is of seriously congested, overcrowded trains. Noted health and safety issues, and concerns that current PT lacks capacity for further modal switch from cars.
- Frequently visits family in USA, used to HOVL and road tolls, no problem with their introduction here but argues that they favour people with children, who benefit from higher vehicle occupancy.
- Several suggestions about more flexible vehicle design, and about non-car mobility (horsepower, rickshaws in urban areas).
- Reluctant to see air travel included in PCT as family visits to USA would be penalised.

R06

- Recently switched to driving after many years of commuting by bus, precipitated by parking space being made available at work
- Gives lift to one other former bus passenger, met through socialising with other passengers on bus
- After years enduring antisocial, stressful and uncomfortable conditions on bus, views driving as a luxury - also sees sharing car journey with one passenger as relatively insulated in comparison
- Low annual mileage (c.4000 miles) in small car.
- Reported proenvironmental motivations and cost sensitivity, outweighed by the convenience and relative peace and quiet of car commuting.
- Sceptical about fairness of PCT, referred to differing needs of different social groups (families etc), and also the potential to work-around or abuse the rationing system.
- After lengthy discussion, respondent became more positive about the positive intentions of PCT, but retained scepticism about possibility of misuse, and likelihood of strong resistance from those wealthier, higher emitting groups who would stand to lose.
- Has family members who would be described as 'motoring enthusiasts', for whom PT is anathema, the car representing social status values.

R07

- Respondent immediately stated preference for using PT, especially to commute, to avoid stress of driving on busy, dangerous roads (mentioned concern over personal safety due to speed and carelessness of other drivers)
- Currently takes 2 hours via complex multi stage journey to commute by PT, compared to 25 minutes by car in mornings if travelling before peak rush hour.
- Already made switch from driving for long distance family visit to using train - spoke positively of the experience and plans to continue with PT. Primarily due to price differential between cost of fuel and advance off peak ticket by train.
- Several times mentioned price of fuel already being a concern, which has caused re-examination of family expenditure and new travel modes trialled.
- Also sees current car as being sub-optimally efficient, and once repayment period is over would like to replace with much more fuel economical model.
- Very positive about the prospect of PCT, quickly alighted on the awareness-raising potential of a finite carbon allowance
- Although financial budgeting was main reason for actively constraining driving distance, respondent several times mentioned pro-environmental concerns and other strategies (e.g. looking into solar PV installation).
- Resistant to adding further costs to price of motoring - road tolls etc.

R08

- Lives in rural location, crosses several geographical and regional boundaries to travel to work by motorcycle. PT alternative is complex and time consuming (around 2 hours)
- Aware of the emissions burden from driving, but views it as a trade off for the opportunities for kids to experience more freedom and grow-your-own lifestyle while they're young.
- Repeated preference for PT if a more direct and less time consuming service was available
- Several times mentioned preferred commuting mode would be bicycle, but practicality (time constraint) demands motorised transport.
- Spoke of present lifestyle set up as temporary, albeit likely to persist for a few years.
- Views government initiatives to reduce emissions from all areas, not just behaviour change with citizens, as tinkering at the margins, doesn't have confidence that there's any political appetite for really meaningful intervention
- Receptive to PCT, wondered if it would be possible to build in consumption emissions as their semi-self sufficient lifestyle might help to offset some emissions from the commuting, but regardless stated a willingness to go with it if it meant that meaningful action was taken on emissions reduction.
- Already uses home delivery service
- Rural home location also requires 4WD as main family vehicle, used for high occupancy longer distance trips too
- Has in past car shared with colleagues when commuting from another town

R09

- Respondent car shares daily with partner on 40 mile round trip
- Train service available, but with two passengers driving costs less than two walk on fares.
- Respondent gives very negative account of PT, views overcrowding, antisocial behaviour and loss of private time in car to be unacceptable for price.
- Currently drives performance sports car, at best 28 mpg, would consider swapping for more efficient vehicle under fuel price increase scenario
- Strong objection to road tolls, congestion charging etc, as even with improvements to PT from ringfenced funds, would still want to drive anyway for all the failings of PT above, so sees these measures as punitive
- Receptive to PCT and positive about the handing of control and choice to the end user - saw PCT as a fair system
- Candidly acknowledged that while emissions reduction is imperative, they just didn't feel like it should be them to do it.
- Noted several times the unfairness of measures (VED, fuel tax, road tolls) which would allow the wealthy to continue unabated, while poor people are priced off the roads.
- Argued for phase out of all vehicles but least polluting (e.g. hybrids), as a preferential to trying to affect driving distances.

R10

- Has recently traded in old car for new more fuel efficient, small vehicle, largely in response to increased cost of fuel (but vehicle was due for replacement anyway). Fuel economy was main purchase criteria
- Job originally involved more client visits and less time in Manchester office, now spends more time in office but still needs to use car for client visits.
- Clients are potential employers of graduates - respondent notes that a car is often needed to reach them
- Referred several times to the 'hustle and bustle' of modern life and people feeling that they have to fit so much into limited available time. Would happily see measures that enabled it to slow down.
- Relaxed about using PT, occasionally does so but car is (potentially faster) - however noted that congestion is becoming more and more of a problem and the stop start nature of the commuting journey results in poor fuel economy
- Has on occasion (severe weather, PT strikes etc) co-ordinated with colleagues to car share, happy to do so more, but little reason to make the effort at present.
- Exemplifies aware / concerned but not motivated regarding emissions reduction. Would be content to go with the flow and reduce driving significantly if PT offered a more time efficient option (although it's difficult to see how such an improvement could be made on the service in question: 1h 20m door to door for 30 mile trip - equivalent to typical driving time).
- Money not a particular concern at present and felt the benefits of car use for many trips would mean that they would absorb fuel price increases and continue to use car.

R11

- Bulk of mileage is 7 mile e/w commute and occasional longer trip.
- Occasional bus commuter, but discouraged from more frequent use by notably uncomfortable, cramped travelling conditions
- Recently taken up cycle to work bike loan from employer, plans to cycle more in summer when weather and traffic conditions are favourable
- Would happily default to bus and cycle with better provision for both (proper cycle lanes) and sees that as the role of government.
- Came to driving in late twenties, was previously dismissive of it as an extravagance for someone living and working in same city
- Positive response to PCT - sees it as 'rewarding good behaviour' and intrinsically fair, as it covers rich and poor the same
- Road tolls etc are seen as being unduly complicated and add to the stress of driving - simplicity and all inclusiveness of PCT seen as one of its chief advantages
- Aware and concerned about emissions, but sees the small inconvenient changes they could make as insignificant and not worth the hassle without government assistance to facilitate wider shifts.

R12

- Currently car commutes but has in past for several years used PT to commute - slight change in working hours and timetabling meant that became much less convenient than driving
- Repeatedly acknowledged that having successfully commuted by PT in past could do so in future with minor changes to either working practices or timetabling (plus improvements to travelling conditions)
- Preference for PT rather than car sharing: hassle of co-ordinating with someone else defeats the purpose of the convenience of the car
- Receptive to PCT: buys the rationale but worries that it would not be welcomed by the majority of people
- Sympathetic to environmental aims and emissions reduction, but not convinced that changes at the personal level can have any meaningful impact without systematic changes from the top down (argued that technological improvements could make more of an impact)
- Open to possibility of PT use for longer trips with better information and price differential - already keeps option open and under review for longer trips when able to pre-plan
- Viewed both scenarios as positive, improvements on current situation

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R13

- Involved in running professional sports team, which includes volunteering for lifts to and from fixtures all around the UK. Frequently makes long trips with only a week or two notice, with several other passengers and kit. (already high occupancy)
- Would find ways to reduce day to day mileage (commuting / shopping etc) rather than forego involvement with sports team - family life centres around these activities.
- Has in past used PT to commute; change in work location relative to transport hubs led to switch to car.
- Speaks of experience of PT (primarily bus) use in negative terms - uncomfortable, antisocial behaviour, etc- although journey time is very similar to car commute time.
- Speaks of car driving largely in very positive terms, commute is valued personal time to unwind and escape from the pressures of busy work, family and club life.
- Already adopts as fuel efficient a style as possible, largely in order to stay relaxed and avoid stress. Suggested it may be possible to shift speeding as a cultural norm in the same was a drink driving.
- Sympathetic to environmental goals and actively concerned for future, especially with reference to burden placed on younger generation. One of few respondents to speak about possibility of feeling guilt about the state of the environment and the prodigious consumption of resources. Suggested PCT may be a way of leveraging these latent feelings of guilt by making energy use more conspicuous.
- Was honest about intention to continue driving even despite rising fuel prices or PT service improvements - very mistrustful of government promises about advantages to motorists of c-charge, but happy to pay road tolls for better driving experience and faster journey times.
- Saw 'the car driver' as much put upon social group, with which they identified.
- Voiced a preference for placing cost burden of improving alternatives to car use on general taxation, rather than fuel.

R14

- Uses variety of modes to commute: principally car, but car shares two days a week (on average), occasionally uses PT, and has in recent months started cycling one day per week, considering upping it to twice weekly.
- Self-confessed motoring enthusiast, enjoys driving, has prestige performance car.
- Sympathetic to environmental concerns, but main reasons for using alternative modes are social, financial and health, with environmental benefit as added bonus
- Suspicious of PCT allowing purchase of additional credits - suggesting an upper limit for individuals may be more acceptable
- Indicated that otherwise PCT seems fair in ceding choice and control to the individual, a key concern for this respondent, but went on to note that resentment at any potential constraints on travel behaviour because of the limited time they have to do things.
- Rejected road user charging and congestion charging as additional financial penalties on 'the driver'. Incentives to use other modes should be used to draw people out of their cars, rather than financial sticks to force them.
- Noted (unprompted) that there is little information reaching the public about the connection between the amount of car use and the environmental consequences. Argued in favour of information provision as intervention
- Money not great motivator for reducing driving distance, stated intention to continue for enjoyment and convenience sake.
- Noted the conflicting message presented by energy inefficiencies and visible wastefulness in large organisations
- Noted structural lock ins to driving as experienced by family members who have taken jobs which rely on their being able to access the workplace and clients by car.

R15

- Respondent commutes 23 miles e/w by car from rural hamlet, nearest train 9 miles away, rural bus from nearby town into Manchester, limited hours and drops off in city centre, 2 miles from respondent's office.
- Views (own) driving as a necessary evil and, (more broadly) the ticket out of economically depressed, former industrial areas for many people seeking employment.
- Receptive to most of the measures and interventions in the scenarios, but focussed discussion on the potentially negative impacts on poorer sections of society.
- Suggested that hiking up fuel prices or introducing other taxes or road charges before PT and other alternatives have been revitalised, to allow people alternative options, is unfair and a non-starter in terms of gaining democratic support
- Argued for expansion and subsidy of PT before restrictive measures are introduced.
- Open to car sharing, was unaware of the university's database of potential matches (although the few respondents who have signed up to this noted the almost total lack of uptake)
- Has adopted numerous proenvironmental practices, allotment, no-fly holidays, considering microgeneration. However, stressed that these issues are the preserve of the middle class, and that the reality is different amongst less advantaged sections of society (esp. for domestic heating)
- Also suggested that seeding 'trendiness' and making environmental values aspirational may be one way to shift attitudes and behaviour. Noted the 'grow your own' movement had undergone a similar image change.

R16

- Commutes by car 27 miles e/w from village, currently car shares with family member and drops children off at school on the way
- Noted that this is a snapshot of current car use and travel needs which will change once the youngest child is older and able to make own way to school.
- School, childcare, kids activities figured prominently in weekly car trips.
- Respondent as cycle commuter in youth and regularly leisure cycles with family.
- Despite highest stated annual mileage of any respondent, this is likely to be an overestimate based on travel habits discussed. In fact this respondent has already adopted car sharing and trip chaining practices described in the scenario.
- Comfortable with road tolls, strongly opposed to congestion charging on a need to see the benefits first basis.
- Children increasing environmental awareness of their parents - bring lessons home from school
- Focused several times on health and social disadvantages of city living, hence preferring rural family home. Flipside is not benefiting from decent PT outside city region.

R17

- Car commutes using 4WD, 25 miles e/w from rural location, drops off children at school on way.
- On days when partner can take kids, prefers to use train but limiting factor is availability of parking at small rural station stop.
- Current car choices (partner also has 4WD) is due to winter conditions and remote hilltop home
- Acknowledges that current reliance on car is life-stage specific; once kids are old enough to get the bus to school, that will free up time in the morning to fit around PT.
- Prefers prospect of using PT to carsharing, sees it as probably more inconvenient that using PT. Also suggests that many people will have psychological barriers to sharing their personal space.
- Noted numerous energy efficiency measures implemented in home, micro-generation etc.
- Argued for improvement (more frequent train service at peak times) as key to PT being a more attractive option.
- Currently absorbs fuel price increases and intends to maintain current cars, but ideally switch to PT for bulk of mileage.
- Receptive to PCT, attracted to equity advantages, but concerned that it may end up favouring the wealth without an upper personal limit.

R18

- Respondent commutes once a week 220 mile round trip, 2 miles e/w four days per week
- Noted increasing journey times due to congestion over years, but still rates PT as more time consuming
- Has in past been required to travel for work at third site (i.e. separate from home & Manchester), making car a more convenient option to return to home at end of work
- Acknowledged that having the car in Manchester, or having decide to drive for one specific purpose, then creates opportunities and incentives to make other car trips.
- Saw most of the measures presented in scenarios as being of little benefit for those whose work-home life patterns have been configured on the basis of car availability
- Receptive to car club and city bikes, but not as replacement for own car.
- Resistant to PCT, raised concerns that wealthy would just buy their way out, and also that without grandfathering emissions credits PCT would prevent visiting family abroad.
- Argued against speed reduction suggesting that it would restrict economic productivity and growth - aslo argued against safety rationale for speed limits per se (unprompted)
- Concerned that trying to meet climate change objectives is in conflict with other agendas that people have been encouraged to buy into over decades, whereas action on climate is now asking for immediate overturning of people's lifestyles.

R19

- Daily school run (two different sites) & commute combination is the main reason for using car at them moment, but already looking into other modes as the children get old enough to accompany by bicycle.
- Has taken the first step towards cycling the 6 miles to work, exploring best route and doing a 'practice run'. Similarly has used bus, but found the circuitous route and stop schedule meant it would be quicker to cycle.
- Own family background is one of non-car mobility; is not 'attached' to the car and was quick to state a preference for reducing their own car use, subject to more time efficient PT and reduction in family obligations.
- Describes most day to day driving as stressful, specifically due to congestion, wasted time and aggressive behaviour by other car drivers
- Two car household, partner needs car at disposal for out of hours on call work
- Sceptical about the ability of PCT to affect the behaviour of the rich and famous, who always find a way to work around the system. Indeed main concern was that the very wealthy would drive the price of any surplus credit way beyond the means of ordinary people who may need a few extra. Individual upper limit and strong enforcement (border control) proposed as way to deal with this problem.
- Much less keen on car sharing than PT or unpowered modes, mainly due to hassle factor. Has found that people agreeing to share one-off long distance trips tend not to view it as a commitment (has offered this once and been stood up).

R20

- Respondent drives 13 miles e/w, picks up partner on homeward trip.
- See PT as overpriced, but acknowledged that this is based on a comparison between marginal cost of fuel and walk up price of rail fare, rather than season ticket.
- Currently driving a larger, less efficient car than would ideally like, gifted by family member
- Focussed on perceived cost differential between PT for ad hoc journeys, and the inconvenience of preplanning trips, compared to price of fuel.
- Suggested that PCT would be resisted by older, less technology-aware generation - recommended achieving same ends through increasing price of fuel
- Repeated suggestion that changes and improvements need to be made to PT by government
- Resistant to top-down interventions by government on the basis that officials are not to be trusted and have a poor track record of delivering (both through deceit and incompetence)
- Noted the absence of any coherent, consistent message about transport energy demand reduction, and candid about not feeling any personal need to change

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R21

- Respondent car commutes 110 mile each way once a week.
- Lives in rural village, raised issues of regional disadvantages implicit in many transport infrastructure plans eg high speed rail bring no benefit to such communities
- Sceptical about the achievability of many of the scenario measures within the timeframe, specific concerns about the potential for increasing the capacity of PT and rail freight systems
- Personal safety was noted as a significant reason for preferring not to drive, road accidents being more frequent than rail
- Suggested that as important as many of the transport infrastructure measures would be improving ICT provision, e.g. high speed broadband, for remote communities, to reduce the need to travel
- Referred to several interesting historical precedents for alternative patterns of personal mobility (workplace buses, lower speed limit during first oil crisis)
- Voiced support for fuel tax if properly ringfenced and reinvested in efficient energy
- Suggested PCT has the potential to be more effective in leading to behavioural shifts, but the inclusion of housing and the need to capture the differing energy costs for poor groups make it very difficult to administer fairly.
- Argued that individual action is important, but the role of government is to enable, support and facilitate these choices, which is currently lacking

R22

- Commutes 9 miles e/w by car, largely because of mismatch with bus timetable which means either a very early start or arriving too late.
- Viewed scenarios very positively, embraced the notion of cutting driving, especially commuting, in favour of using PT, assuming provision was increased or job working hours made more flexible.
- Would still need to have car available to household as partner's mobility depends on access to car
- While many trips might be possible without use of car, finds that car becomes the default option when assisting partner
- Finds time penalty associated with making complex or hub and spoke journeys by PT unacceptable
- Strong preference for reducing driving per se by using PT than for car sharing, primarily due to loss of privacy and personal space.
- Supportive of PCT, road charging, etc, arguing that some form of bold intervention is necessary: 'we can't go on like this'.

R23

- Sees driving as most time efficient mode for commuting and most other journey purposes, but open to possibility reducing driving distance and receptive to environmental rationale for doing so.
- Argued for provision of PT as public good, with more public subsidy
- Suggested that a more equitable way to reduce emissions would be to tax distance (mileage), not fuel - tax free allowance
- Concern that increasing tax on fuel may not raise more money and that it is not a fair way of reducing emissions if it prevents ordinary people from travelling.
- Concern that PCT would be open to abuse and extortion by criminal or even just wealthy - proposes a maximum personal limit
- Also concerned that embodied emissions in other areas of consumption, and transport of goods may be more important areas to decarbonise that personal transport.
- Suggested that the poor facilities, level of supervision (of passenger behaviour) and uncomfortable conditions on the one hand, and relatively high incremental price on the other, make PT an unattractive option at present - but also notes that rectifying these problems is a basic question of investment
- Candid about perception of emissions and environmental footprint as being relative to other people. Willing to accept inconvenience to reduce emissions, e.g. car share if possible, but not willing to accept hardship or privation (suffering).

R24

- Currently drives to train station, 5 miles e/w. May change in near future - has made enquiries about possible car sharing from potential new home area, identified people who make the trip but no one willing to enter into an arrangement.
- Experienced cyclist, has experimented with 22 mile door to door commute by bicycle. Would like to make it a regular practice, but finds the outlay on the rail season ticket encourages more train use.
- Welcomed initiatives to make a reduction in driving easier, and supportive of policies that discourage driving in order to meet emissions targets. Follows climate change issues as individual and through job.
- Receptive to PCT, concerned that there would be problems with an equal allocation for people in poor quality housing (additional heating needs) and that it would be difficult for older people to navigate the new fairly hi-tech system - suggested phasing in year by year what is included within the system.
- Willing to make changes on condition that others, especially companies and larger emitting organisations, are seen to be doing the same.
- Has downsized from performance car to more fuel efficient vehicle, also adapted driving style to maximise fuel economy. Largely driven by price of fuel, but underpinned by environmental concerns too.

R25

- Self confessed 'car enthusiast', owns and enjoys driving a kit car
- Recognises need to reduce emissions from driving,
- Has attempted to 'break' own car driving 'habit', getting bus one day a week, but finds the convenience of the car wins out over the uncomfortable and anti-social environment on local buses
- Relaxed about road tolls / charging, accepts them when in other countries, sees them as a potentially necessary source of funding for maintenance of road as a service, rather than to discourage driving.
- By own admission would absorb fuel price increase probably more than most, has sufficient buffer to continue to enjoy driving
- Supportive of PCT in principle, suggested inclusion of consumption emissions would make it even fairer. Commented that the exclusion of PT from the system creates a positive message.
- Generally positive about all measures, although viewed the scenario as 'more stick than carrot', but accepted the rationale for change
- Argued that clearer and more direct information provision would enable people to make better choices.

R26

- Currently drives 8 miles e/w, but has now freed from obligation of dropping off children on way to work, has recently started to use tram / walk more often.
- Still finds the convenience of driving wins out during school holidays when traffic is lighter
- Motivated to reduce emissions from driving and other energy use
- Noted that the gradual increase of fuel prices and the already sunk costs of car ownership makes people resistant to change
- Suggested that giving people context specific information about PT via mobile ICT may enable some of the inconvenience of PT relative to car use to be rebalanced
- Raised the issue of trust with respect to car sharing with people beyond one's immediate family and social circle.
- Saw benefits in PCT, with the proviso that it would only work if alternative low carbon means of transport were already available, especially in view of the non-negotiability of domestic heating and a certain amount of travelling by car for many people.
- Particularly interested in innovative application of ICT to facilitate more efficient, fair and effective means of sharing out the mitigation burden - and ultimately for making life easier for people.

R27

- Strong sense of personal responsibility for emissions
- Hostile to the administrative burden of PCT , stated preference for fuel tax, and strong suspicion that PCT would impose an unwieldy and profit making administrative burden (referred to experience of poorly administered child benefit).
- Argued for PT to be run as a public service, rather than for profit. However, highly mistrustful of government's ability to organise and spend funds to deliver on promised improvements.
- High estimated value of **time** - travel time, work, non-work. Busy family life
- High importance on **financial cost**s
- Complex trip chaining repeatedly mentioned.
- Also noted difference in transport needs between different life stages and demographic groups, interventions would have to allow for this
- Argued for intervention which would target high emitters without penalising ordinary families. Saw PCT as being unable to deliver this.

R28

- Three nursery and primary school age children, drops them off and collects from different sites on way to and from work
- Noted that current reliance on driving to fit in school run and working at university is specific to the current situation, will change as kids are older
- Family uses partner's car for longer distance trips, company car travels more miles. Family trips at high occupancy
- Has experimented with using PT for longer journeys with kids, they prefer it, but found it still requires use of a car, or lift from someone else at destination
- Dislikes driving, but finds it a 'necessity' for family life. Partner's car must always be available at work, so second car is an important back up, mentioned 'in case of emergency'.
- Positive about PCT as fair means to achieve emissions reduction, but concerned about the ability of older people to navigate the system.
- Noted that many proenvironmental practices have moved from the margins to the mainstream (e.g. recycling), and suggested that interventions such as PCT would become more accepted once people got used to them.
- Although money is not the primary concern in selecting mode, would have avoided paying Manchester C-charge had it been taken up, by switching to PT

R29

1. Strong resistance to interventions to reduce driving - suggestion of active protest
2. Argues against unilateral UK action - UK is a small, insignificant country
3. Driving as a social enabler
4. Sees PT as highly unpleasant (socially, weather, walking).
5. Surprising interview, lots of apparent contradiction - despite adopting a highly self-centred position respondent had signed up for bike to work scheme, is vegetarian, expressed considered concerns about personal security.
6. Strong sense of what's 'fair' - quickly identified with PCT scheme
7. Advocates increasing general taxation, income taxation, repeatedly, as opposed to road user charging - vehemently anti-congestion charging
8. Tendency to compartmentalise people into social groups - either by road use (motorists, cyclists), or affluence (the rich, the poor). etc. Conflicted about cyclists!

R30

- Strongly pro-environmental in outlook
- Feelings of guilt at not being able to adopt low carbon transport modes easily, due to restricted access to network from semi-rural home
- Conflicted about flying to distant holiday destinations & family Landrover
- Currently gives son a lift to work - effectively car sharing
- Reported sadness due to accepting that something needs to be done to reduce carbon, but that it will mean a change in a lifestyle to which the respondent had grown accustomed (esp. for foreign holidays).
- Had already swapped 1.8l BMW for 1.2l Fiesta on fuel efficiency grounds.

R31

- Assiduously monitors fuel consumption and expense, knows exactly how many mpg getting, recorded in spreadsheet over years.
- Well informed about emissions and carbon, involved in sustainability group. One of few respondents to be familiar with the idea of PCT.
- Spouse doesn't drive, but pursues highly mobile lifestyle nonetheless using PT.
- Suggested that they could adjust to most of the measures and the top level driving reductions in the scenarios, but was quick to point out that most people would find them unpalatable.

R32

- Ex-salesman, 22 years doing 25k+ miles p.a.
- Car at centre of travel habits entire life.
- Pro-environmentally motivated, aware of issues and willing to engage
- Currently car shares with spouse.
- Have used PT, esp. during winter months, and not averse to further use if financial cost differential with driving changes.
- Holidays in UK. Positive about PCT on fairness grounds
- More likely to change car rather than buy a season ticket.

R34

- Relatively low mileage driver, two car household, other car is main car
- Aware of emissions from driving as an issue, but doesn't feel the need to immediately change.
- For the distances covered, it would not be price of fuel that tipped the balance to PT, it would be congestion.
- Uses PT occasionally, and finds the service workable
- Strong supporter of policies to limit vehicle sales to efficient cars (drives Ford Ka).
- Waste and efficiency key motivators.

R35

- Daily commute of 70 miles round trip, avoids congestion by travelling after the peak rush hours
- Grew up in another country where PT provision is much better, largely as a result of much smaller population placing lower demand on the system
- Sees the UK PT network as being already close to breaking point
- Comfortable with car sharing, would do it to save money, but has been unable to find someone whose hours would be compatible.
- Currently on low income, would prefer PT but cost of season ticket is prohibitive and restricted to the commuting route only, so would still need car for other trips
- Comments on the highly competitive and aspirational culture in Britain.
- Also the culture of the individual having more rights than the group - 'the one who shouts loudest gets their way'.

R36

- Spends a lot of time in London - used to using PT and being car free there
- Sees walking between connections etc as an advantage, seeks opportunities to do so
- Low annual mileage as result
- Has often used bus service to commute, largely positive about the experience
- Main drivers for selecting PT for longer distance trips / holidays would be travelling in a more relaxed way than driving.
- Supportive of PCT in principle, but concerned about the complexity of administration and bringing vulnerable groups into the system.
- Suggestion that a lot of people don't know what PT can offer them, requires familiarity, more exposure.
- Further suggestion that people can probably reduce driving distances more easily than they think - many of the barriers are more perceived than real.

R37

- Has two young children, has already changed hours and cut back working time to accommodate taking to nursery, childcare etc.
- Car commuting is a compromise between time demands of family life (partner walks to work), needing to fit so much into the day, and getting to work on time.
- Low mileage driver, and regular bus user
- Keen to reduce car use and see it reduced in society for many reasons, primarily local air quality, but also carbon emissions
- Strong sense of fairness and ethics in how emissions cuts are achieved - returned several times to building flexibility into policies to ensure that those who were 'doing the best they can' are not unfairly penalised.
- Car as a necessary evil /compromise.
- Several suggestions relating to increasing public subsidy of public transport.

R38

- Regular PT user, commuted from semi-rural village to Manchester for six months by bus and foot.
- Several family members already exemplify non-car mobility, some never having owned a car.
- Other family members lead much higher consumption lifestyle.
- From long experience, respondent found lack of integration and 'joined-up-thinking' in PT provision a constant frustration - noted several reductions in the frequency and times of services which make PT commuting all but impossible.
- Routinely car shares on commute, always with one other, many periods by prior arrangement with two passengers.
- Argued for more flexibility in working hours to facilitate more car sharing.
- Very sceptical about promised new services or proper spending of allocated funds by government (local and central), and produced a catalogue of broken promises. Argues for needing to see the benefits to persuade public to trust political promises again.
- Also obstructed from using PT in a cost-comparative way with driving because of transport authority boundaries, which do not allow crossing on the same travel pass.
- Noted the much higher emissions and more extravagant lifestyles of others contribute far more emissions, wonders what difference small changes in own life would make in the face of that.
- Argued that role of government is to enable people to make changes, either by provision of low emissions vehicles or PT.

R39

- Current PT commuter on busy train service, drives to departure station, car-sharing with partner.
- Commuting journey is complex, numerous modes and stages (car, train, train, bus, walk). Service and facilities provision regarded as poor, has actively lobbied for improvement.
- Has in past driven, but prefers to use train to get the benefit of useful time and avoid dangerous road conditions
- Cost differential between driving and PT may force a switch back to driving if fares continue to increase above inflation

  This would almost triple the respondent’s annual mileage.
- Strong conviction that the level of improvement required to allow any kind of major modal shift will not come about without a change in UK transport policy, which is London and south east centric, to the serious detriment of the regions (esp. the north).
- Proenvironmental motivation leads to efforts to reduce car travel, low annual mileage
- Supportive of most measures and policies discussed, but major concern about all inclusive PCT scheme, which may 'penalise' some for elements such as housing which are beyond their control (and respondent would be affected if housing were included).
- Dependent on having a car at disposal for out of hours on-call work.
- Suggests that in the UK transport spending is blocked by a lack of joined up thinking, for emissions reductions discussed there is more likelihood that European legislation would be able to bring about the necessary changes in transport infrastructure.

R40

- Commutes from Lancashire to university by train, has done for a few years
- Maintains small car as runabout (estimated <1000 miles p.a.), used primarily for family visits and getting to train station in mornings if running late.
- Has in past driven to work when working in an area in which personal security felt more of an issue.
- Tolerates considerable inconvenience (by most people's standards) to avoid driving, but takes philosophical view that at least there's some personal time to read etc, even if train is crowded and uncomfortable.
- Views season ticket as being good value, but not main reason for using train.
- Proenvironmental motivation strong reason for taking train, but also value of ticket, congestion and wasted time driving.
- Partner also a reluctant driver to out of town business park (car-dependent location), used to get a lift for first 6 months, but now drives alone for the convenience of the (ex)lift-giver.
- Sceptical about the ability of train and PT network to cope with the increased demand that major modal shift would place
- Concerns around PCT focused on ability of those people who aren't tech-savvy to engage with the system, and that some people are unable to get to work (or other essential trips) without using a car - penalised for circumstances beyond their control

R41

- Respondent has in last year switched from car commuting 38 mile each way trip (well established habit) to train commuting.
- Winter weather was initial reason, but train soon found to be advantageous: respondent values time to read, and finds new habits (structuring work day, carrying luggage etc) have been easy to adopt & now looks for other opportunities to use PT
- Importantly, found the price of monthly travel pass is less than petrol, and experience of using train satisfactory (uses intercity service)
- Respondent's proenvironmental motivations have also contributed to sticking with PT
- Raised several issues of personal security as an important factor in encouraging PT use, and for individuals in selecting the car over PT
- Has considered changing to very low emissions car, but put off by high initial purchase prices
- Annual driving holiday, sometimes alone, sometimes multiple occupancy
- Supportive of PCT in principle but expressed concerns re including domestic energy use, as alterations to own property would be expensive (in a conservation area).

R42

- Recently moved to rural location, with good road connection to Manchester.
- Has on occasion in winter conditions driven to nearby town and taken train to work. Found journey time more or less comparable with driving, but complex multi-mode trip, much less convenient.
- Acknowledges PT service is workable, but sees no compelling reason to go to the trouble.
- Due to winter conditions in recent years has recently acquired 2X 4WDS, one each for respondent and partner, one of which is partners main commuting vehicle throughout the year (typically 40 miles+ each way).
- Sensitive to parking costs, nearby town charges over £6 for daily parking. Acknowledged workplace parking permit being deducted at source means cost is unnoticed.
- Aware but not sufficiently motivated to change behaviour for proenvironmental reasons, and with two professional incomes, money is not main reason for concern at present.
- Supportive of PCT in principle, but concerns regarding system covering domestic energy use - moved to old converted farmhouse, three other members of household not inclined towards acting proenvironmentally or efficiency.
- Respondent advocates stronger regulation and possibly enforcement to bring about behavioural shift in people in their position.