UK Energy Research Centre

Energy 2050 – WG1 Energy Demand

Lifestyle and Energy Consumption

Working Paper

(subject to peer review)

November 2011

REF: UKERC/WP/ED/2011/001

Dr Jillian Anable, Dr Christian Brand, Dr Nick Eyre, Dr Russell Layberry, Dr Noam Bergman, Dr Neil Strachan, Dr Tina Fawcett and Martino Tran

University of Oxford Environmental Change Institute

University of Aberdeen

The UK Energy Research Centre

The UK Energy Research Centre carries out world-class research into sustainable future energy systems.

It is the hub of UK energy research and the gateway between the UK and the international energy research communities. Our interdisciplinary, whole systems research informs UK policy development and research strategy.

www.ukerc.ac.uk

The Demand Reduction Theme of UKERC

UKERC's Demand Theme core research activities are being undertaken by the Environmental Change Institute at Oxford University, the International Centre for the Environment at Bath University, the Centre for Transport Research at the University of Aberdeen and the Energy Institute at University College London.

www.eci.ox.ac.uk www.abdn.ac.uk/ctr/ http://www.bath.ac.uk/ice/
http://www.ucl.ac.uk/energy/

EXECUTIVE SUMMARY

This report is one of a series of working papers in the UKERC Energy 2050 project series. It investigated the role of pro-environmental lifestyle change for the UK energy system to 2050. We make two assumptions, both of which seem obvious when stated, but are frequently forgotten or ignored in energy futures work. The first is that the behaviour of energy users is not fixed, but rather the outcome of developments in society, and that these are uncertain with the level of uncertainty increasing over time. The second is that any policy framework that seeks to deliver major changes in the energy system, such as an 80% reduction in CO_2 emissions, will be the outcome of a political process in which civil society, i.e. energy users in other roles, will play a key role.

We have used an innovative methodology to combine the strengths of detailed end use models (UK Domestic Carbon Model and UK Transport Carbon Model, both developed at the ECI) and a cost-optimisation model of the whole UK energy system (MARKAL Elastic Demand, developed at UCL).

Our results indicate that energy use in this sort of scenario might be expected to fall in both the household and transport sectors, by approximately 50% in each by 2050. This implies rates of change (energy demand decreases) of just below 2% annually. The key messages are:

- Society and human behaviour change over time, sometimes in unpredictable directions, and therefore there is a wide variety of possible future levels of energy service demand and end use technology choice.
- We have explored a scenario in which social change is strongly influenced by concerns about energy use and its environmental implications, and therefore energy service demand is at a significantly lower level by 2050 than in the 'business as usual' assumptions of other scenarios.
- Social and lifestyle change principally affects energy use in the residential and transport sectors, but has wider implications.
- In the residential sector, the main drivers of energy service demand are internal temperature, consumption of hot water and use of lighting and appliances. In the transport sector, the main factors are mobility itself, the choice of mode and the uptake of more efficient vehicles. The efficiency of energy use is important in both buildings and vehicles.
- In these sectors a combination of energy service demand change and efficiency improvement could reduce energy demand by more than 50% from baseline levels by 2050.
- In both sectors, lifestyle change alone will increase the share of electricity in final demand, but reduce the need for massive electrification to meet tough carbon targets.

- Social and lifestyle change has the potential to reduce national energy use, energy system cost and carbon emissions by 35% and 30% below baseline levels.
- In an energy system constrained to 80% carbon emissions reduction, the main effect of social and lifestyle change is to reduce the costs of delivering a low-carbon energy system, by up to £70 billion.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background to the Energy 2050 project

The UKERC Energy 2050 project aims to show how the UK can move towards a resilient low carbon energy system within the next 40 years. The project focuses on two primary goals of UK energy policy – achieving deep cuts in carbon dioxide (CO_2) emissions by 2050, taking the current 80% reduction goal as a starting point, and developing a “resilient” energy system that ensures consumers’ energy service needs are met reliably. In addition, other policy goals are taken into account, namely managing environmental impacts other than those related to climate change and ensuring that everyone has access to affordable energy services.

The starting point is a set of four variants on a ‘core’ UKERC Energy 2050 scenario. These are used to highlight key policy issues and provide a starting point for different scenarios:

- The core “Reference” (REF) variant assumes that concrete policies and measures in place at the time of the 2007 Energy White Paper continue into the future but that no additional measures are introduced.
- The “Carbon Ambition” (CAM) variant assumes the introduction of a range of policies leading to an 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020.
- The “Resilience” (R) variant takes no account of the carbon reduction goal but assumes additional investment in infrastructure, demand reduction and supply diversity with a view to making the energy system more resilient to external shocks.
- The “Low Carbon Resilient” (LCR) variant combines the low carbon and resilience goals.

A combination of modelling tools is used to develop high-level insights from a systematic comparison of scenarios. The system level models can capture interrelationships and choices across the energy system. The models are used in a “what if” mode to generate insights and quantify discussions. The core energy systems modelling tool is the UK MARKAL Elastic Demand (MED); a technology-rich, multi-time period optimization model (previously used for underpinning analysis for the UK Energy White Paper and Climate Change Bill)

The UKERC Energy 2050 project has focused on cross-disciplinary interactions between the UKERC themes through an iterative methodology. Modelling results relating to the core scenarios have been the focus of the UKERC Research Report UKERC/RR/ESM/2009/001 (Anandarajah et al., 2009), a Synthesis Report (Ekins and Skea, 2009) and a book (Skea, Ekins and Winskel (eds) 2011). The core analysis has been extended through different scenarios using a range of sectoral models to investigate key uncertainties in low and carbon resilient energy futures. The construction, testing and elucidation of scenarios have involved adapting existing research activity in the different UKERC themes, via a process of “soft linking”. These detailed insights from the research themes inform and supplement the models. Working groups – drawn from different themes – have produced various UKERC Research Reports including ‘Technology Acceleration’ and ‘Building a Resilient UK Energy System’[1].

This report is one of a series of working papers and is the output of the Demand Working Group focusing on lifestyle change. It is based on the combined output of the MED model and the sectoral models of energy demand in sectors most likely to be affected by lifestyle change – households and transport. But first, what exactly are lifestyles?

1.2 What are lifestyles?

The notion that people’s ‘lifestyle’ may need to move in more sustainable directions has rapidly become a focus of environmental policy and popular commentary on environmental issues. There is considerable speculation around the possibility of a ‘cultural shift’ affecting the scale and patterns of consumption and behaviour in ways that will lead to a lower impact, less energy intensive and potentially more community oriented society (Defra, 2008; Thogerson, 2005). This transition in the discourse from sustainable ‘consumption’ to sustainable ‘lifestyles’ implies a shift in the salient source of meaning away from consumption towards specific values, rules and social practices which are shared by groups of persons and constitute their ‘way of life’ (Evans and Jackson, 2007).

Yet, despite a widely agreed consensus that societal energy consumption and related emissions are not only influenced by technical efficiency but also by lifestyles and socio-cultural factors, there is a methodological gap between the perceived importance of these factors for energy demand and practice in many quantitative modelling exercises. Modelling studies such as the Japan-UK Low Carbon Societies project (Strachan et al, 2008) have identified improved treatment of behaviour in quantitative analysis as a key priority. Indeed, there is much less consensus as to the character and extent of these influences, particularly when broadened out to include psycho-social factors such as wellbeing, cultural norms and values, and few attempts have been made to operationalise these insights into models of future energy demand.

This report addresses that gap by contrasting techno-economically driven core scenarios with one in which social change is strongly influenced by concerns about energy use, the environment and wellbeing. It takes as its starting point the notion that lifestyles, whilst closely intertwined with consumption, encompass more than economically justifiable preferences and the accumulation of material goods (Reusswig et.al., 2003). Not only are non-price determinants of behaviour recognised, such as values, norms, fashion, identity, trust and knowledge, but non-consumptive elements of behaviour such as patterns of time use, mobility, social networking, expectations and policy acceptance are considered in our characterisation of future patterns of energy service demand.

---

[1] These can be downloaded from the UKERC website at http://www.ukerc.ac.uk/support/tiki-index.php?page=Energy+2050+Overview&structure=Energy+2050+Overview

In addition to consumers, people are also seen as ethical and political actors who are responsible for reflexive and political preferences as well as market choices (Reusswig et al., 2003). Consequently, lifestyles are viewed as more than transient fashions or trends. They encapsulate ethical commitment so that they straddle both notions of individuality and identity on the one hand and community or sociality on the other (Evans and Jackson, 2007). This allows our scenario approach to pay attention to the *interaction* between society and technology (Elzen et al., 2002) and underlines the role that policy can play in working with attitudes, opportunities and impacts to exert a positive influence on the type of society that develops and the nature of the technical system that co-evolves with it.

1.3 Why lifestyle matters for energy use

Energy use in the UK, as in other developed countries, is central to our current way of life. It fuels our manufacturing processes and high levels of mobility, keeps warm (and sometimes cool) our buildings and powers a huge array of electrical appliances from lighting and refrigeration through to the proliferation of modern consumer electronics.

Ultimately, all energy use results from consumption decisions, as it is demand that drives production. So it is theoretically possible to account for all energy use at the point of consumption, as either used directly by consumers or as energy used in production and therefore ‘embedded’ in purchased goods and services. But it is helpful to distinguish between these two categories. In the early stages of industrialization, it was industry that dominated our energy use. But the long term trend is towards an increased share being used in the sectors of the economy where energy is primarily associated with consumption rather than production – in households and transport. These sectors now use 29% and 38% of UK final energy respectively (DECC, 2009a). Increasingly it is direct consumption that drives UK national energy use. That is the focus of this paper.

Personal energy consumption is determined by two factors – the energy services that we demand (for example comfort, mobility and entertainment) and the energy efficiency of the energy conversion devices that provide these services. Lifestyle therefore drives direct energy consumption in different ways.

Most importantly lifestyle influences the type and quantity of energy services we use. Size and scale matter: for example, keeping a large home at a comfortable temperature tends to use more energy than delivering a similar quality of service to a smaller home. And some energy services are intrinsically more energy intensive than others – in particular services that involve heating, cooling or accelerating large amounts of matter have minimum energy requirements determined by the laws of thermodynamics.

Lifestyle is also related to the propensity to use more energy more efficiently. As the environmental impacts of energy use become better known and the ecological limits better understood, different conversion technologies are increasingly associated with lifestyle choices. The ‘social statement’ made by the purchase of a hybrid vehicle is different from that of a 4x4.

Potentially lifestyle may also affect carbon emissions through the carbon intensity of the energy sources we use. Traditionally, the role of individual choice in this factor has been somewhat limited: mains gas, grid electricity and petrol at the pump have been dominant energy carriers, with carbon intensities determined upstream in the energy system. But the commercialization of different transport fuels and small-scale renewables may be expected to alter this and add an extra degree of freedom to the relationship between lifestyle and carbon.

In principle, lifestyle change can affect energy use and carbon emissions in either direction. Greater wealth, higher levels of consumption and new energy services all tend to increase energy use. These trends have more than offset technological improvements in energy efficiency in most countries at most stages of economic development, so that energy consumption has generally risen with increasing affluence (IEA, 2007) and it is quite possible that future energy use in the UK could easily follow such a trend. But it is not inevitable; energy use in the UK has declined modestly in recent years (DECC, 2009a), and this trend is continued in the baseline energy scenarios considered in this book. This paper considers the potential for lifestyle change to amplify and drive stronger reductions in energy use.

1.4 Structure of this report

The next Chapter describes the Energy 2050 'Lifestyle' scenario and its storyline. Chapter 3 then describes the overall methodology of this work before going into more detail in Chapters 4 (residential) and 5 (transport) on how storylines about lifestyle changes are translated into quantifiable modelling language. Chapter 6 then presents the results of using a UK energy system model to assess wider interactions with the energy system including the impact of a national carbon emissions constraint as well as wider economic and energy security implications. Chapter 7 discusses public policy implications before concluding with the key messages arising from this work in Chapter 8.

2 THE ENERGY 2050 LIFESTYLE SCENARIO

2.1 Aims and general approach

By extending the core UKERC 2050 analysis, the following questions were addressed:

- To what extent could lifestyle change contribute to meeting carbon reduction targets?
- To what extent would lifestyle choices reduce the need to employ new supply side technologies?
- What impact would this have on the cost of meeting the UK carbon reduction targets?

The identification of a single scenario as representing 'lifestyle' is, in many ways a misnomer. All scenarios necessarily include lifestyle assumptions even if these are unstated and implicit. In the core UKERC 2050 scenario (all four variants – see section 3) the assumption is explicit – that patterns of lifestyle choices continue to develop along the same trajectory as in the past – i.e. there will be a greater take-up of energy efficiency measures, but people are assumed to balance the initial cost of efficiency measures against on-going energy costs (based on observed income elasticities of demand) with increasing wealth at the projected growth rate. Thus, the evolution of people's lifestyle (i.e. input assumptions about energy service demands (ESDs)) and energy consumer preferences (i.e. the way they respond to prices and available technology) stayed the same.

It can be argued for the low carbon and resilient scenarios, particularly the former, this is not an internally consistent assumption. In practice, the way in which preferences will develop is highly uncertain (e.g. the effect on lifestyles of concern over climate change) and lifestyles are likely to change in many other ways in response to technological developments and other price related and non-price factors. At least in a liberal democracy, where Government is pursuing ambitious carbon emissions, it seems very likely that this is as a result of an explicit democratic mandate and, quite probably, significant social pressure. It therefore seems improbable that personal preferences and behaviour would remain unchanged. However, this assumption does provide a straightforward assumption for a core scenario. In the system economic models it implies that certain key parameters – notably income and price elasticities remain unchanged over time. In the 'bottom up' sectoral models it implies that drivers of energy service demand (building internal temperatures, vehicle km driven, appliance usage) in general continue to develop at the rates experienced in the past at least until some demand saturation level (exogenously determined based on expert judgement) is approached. In practice, some energy service demands are constrained to prevent unlikely outcomes, e.g. internal temperatures delivered by heating systems do not rise to levels exceeding those that would be comfortable, and vehicle occupancies do not fall to below one.

In this lifestyle scenario, however, societal norms and individual preferences are assumed to change and translate into different preferences, patterns of consumption and demands for energy services. In order to investigate lifestyle changes vis-à-vis the core scenario, the following areas were debated and defined as a precursor to developing a more detailed storyline and specific modelling assumptions:

- Drivers of lifestyle change
- The rate of lifestyle change
- The behaviours in the scope of this study.

2.2 The drivers of lifestyle change

History demonstrates that major shifts in societal attitudes and behaviour around perceived collective goods like the environment, national security and multiculturalism do take place (Rajan, 2006). Firstly, however, we need to understand the ways in which positive behaviours and ethical commitments are adopted in the first place as well as how they can be maintained and reinforced over time. Moreover, lifestyle change as a driver of social change is more than a shift in attitudes or behaviours and cannot be measured in single dimensions. In particular, our understanding needs to be informed by a sophisticated appreciation of the ways in which modern lifestyles operate not just at the material level but also at the psychological, social and cultural levels (Jackson, 2005).

What is clear from social psychology is that multiple barriers and drivers all impact on behaviour in combination, but that at a societal level, behaviour change could take place at a sufficiently large scale given the right circumstances (Rajan, 2006). Without repeating that complex discussion here, suffice to say that the most widely-adopted models show many factors, both internal and external, collective and individual, impacting from different directions on an eventual behaviour or collective choice (Anable et al., 2006; Darnton et al., 2006). Many of the factors are non-rational, for instance relating to opportunities or infrastructure, rather than intentional motive. In this way, simple linear ('information deficit') models showing how increased awareness of an issue leads to a reasoned decision and appropriate action, are overturned.

The notion of 'lifestyle' as defined above suggests people can choose to reduce their environmental impacts as part of their 'life project'. Despite this emphasis on consumption and matters of personal or collective choice, consumers are often 'locked-in' to unsustainable patterns of living '*by a combination of perverse incentives, institutional structures, social norms and sheer habit'* (Jackson, 2005). This highlights the interrelationship between consumer behaviour, the structure of the market, technologies and physical infrastructure, institutions and public policy. The implication for policy makers is that policy needs both to help empower consumers to change lifestyles and to loosen some of the external constraints that make changes towards a more sustainable lifestyle difficult (Thogerson 2005).

However, as Darby (2007) points out, the major challenge is that the balance of what is judged to be acceptable or optional (needs or wants) changes with culture, time and in response to technological developments. Individuals will tend to have strong and differing views on what levels of energy services are sufficient, based on their life experiences and on cultural norms. Darby illustrates this with the example of the way in which an abundant, highly predictable supply of electricity has become a ‘need’ in Europe over the last hundred years. Yet, normative judgements on sufficiency, identifying ‘how much is enough’ and intervening in lifestyle choices is an anathema to modern neo-liberal politics of governance (Jackson, 2005; Darby 2007). Identifying the likely impact of lifestyle as a driver of social change, source of social pressure and influence on policy in this context is not easy. Nevertheless, we set out to test the concept of ‘lifestyle’ change to understand the extent to which such shifts could contribute to meet carbon reduction targets and avoid the need to employ new supply side technologies.

2.3 The rate of change

The scenario is designed to be sufficiently distinct from other scenarios to give different outputs, but to remain within the realms of what seems plausible. In the core scenario, (as indeed in reality) there has been little, if any, emphasis on reducing consumption. Reaching an ambitious target means going beyond efficiency, setting some upper limit on the demand for energy services (Darby, 2007). In this lifestyle variant, both demand reduction and accelerated energy efficiency are assumed. Energy service demands will not stay the same. For example, people will travel less as well as use more efficient modes. Thus, lifestyle change includes different consumption patterns and rates of adoption of new technology.

The aim is not to set a utopian vision for future buildings and travel patterns, but to look at what might be reasonable changes to expect in the future. When thinking about alternative futures it is important to maintain a sense of reality and to work within the limits of known technologies and behavioural patterns. Luckily we can build on a large and rich range of solutions in terms of technological and behavioural change opportunities, including considering real examples in space and time, i.e. how much does the behaviour vary currently between places and/or between the past and now? However, it does not mean a continuation of recent trajectories of consumption patterns and behaviour.

Over periods of 40 years, history shows that some social norms and practices do significantly change - behaviours related to smoking, drink driving and seat belts are commonly quoted from the recent past. On the other hand, public attitudes to what is considered ‘normal’ do not change quickly (except under conditions of external shock which we do not seek to describe in this scenario) and many behaviours are constrained by financial pressures, by responsibilities to families and employers, and by the physical and social infrastructures within which communities live.

Nevertheless, behaviour is variable and can change quickly. For example, energy crises show what can be achieved when sudden power shortages impose a ceiling on consumption and perceptions are challenged. Experiences of electricity shortages in Brazil, California, Ontario, Norway show that savings of up to 20% can be achieved and sustained for several months, sometimes with longer lasting impacts as investments in more energy efficient technology and changed behaviour are adopted and maintained (Darby, 2007). Similar evidence exists in the transport sphere. For instance, Cairns et al. (2002) examined over 70 case studies in 11 different studies where road space had been reallocated due to sudden shocks (e.g.

earthquakes) or planned interventions (e.g. pedestrianisation schemes) and found across all case studies, the average traffic reduction in the total local network soon after the change was 22%, with a median of 11% (Cairns et al., 2002). Similarly, we know that the traffic reduction after the London congestion charge was in the order of 15% immediately after its introduction (TfL, 2007), car traffic reduced by 39% on motorways overnight after the 'fuel protests' in the UK in 2000 (Hathaway, 2004), and cycling increased dramatically after the terrorist attacks in London in 2005 (although the trend was already upward).

In judging what rate and scale of change seems plausible we have given most weight to the existing variation in lifestyle observed in societies like our own, i.e. technologically advanced, liberal democracies. Subject to some obvious constraints imposed by age, wealth and location, for example, it seems reasonable to suppose that if a significant fraction of the population (say 5-10%) somewhere in the OECD already behave in a particular way, then it is plausible for this to become a majority behaviour in the UK within a 40-year timeframe. This implies neither incremental nor step changes in behaviour. Indeed, there are increasing suggestions that incremental changes in efficiency and behaviour will not be effective enough to deliver sustainable energy systems on their own in the absence of restrictions in consumption (Darby 2007; WWF, 2008). Instead, this scenario outlines *radical* change leading to relatively fast transformations and new demand trajectories.

Transition theory offers an approach for such long-term radical change, or *paradigm shift* – a systemic shift including infrastructure, institution and paradigms of business and behaviour (Rotmans et al. 2001; Geels 2005b). This shift is needed because the system tends to be *locked in* to patterns of behaviour and trajectories for technological and social development which are hard to change, due to habits, existing competencies, past investment, vested interests, regulation, prevailing norms and worldviews. These lead to system optimisation rather than system innovation, while transitions require organisation-exceeding, qualitative innovations, realised by a variety of participants, which change the structure of the system (Loorbach & Rotmans, 2006). Some research has therefore highlighted *niches* – individual technologies and actors outside or peripheral to the mainstream – as the loci for radical innovation (Geels, 2005a; Rotmans et al., 2001; Smith et al., 2005). These can serve as examples of models of possible alternative behaviour and cultural patterns.

2.4 Which behaviours are in scope?

The primary focus of the scenario is household energy use and personal transport – i.e. the forms of energy most directly controlled by the individual. It considers variations in both:

- in-use behaviour, i.e. use of the existing energy using capital stock, and
- purchase behaviour, i.e. choice of energy using technology.

Consumer behaviour will clearly have an impact on the demand for different services from businesses and changes in attitudes and norms will have implications for corporate behaviour. However, corporate decision-making and business behaviour is beyond scope.

There are clearly other individual lifestyle choices that could be examined. Potentially the most important is fertility and family size, i.e. the primary driver of future population. We have chosen not to investigate this for a number of reasons. It is a complex area that is controversial in a number of ways, most obviously the extent to which public policy can, or should, attempt to influence choice in this area. Any significant changes in population would drive very substantial changes across society, so that the scenario would effectively become a ‘population scenario’ rather than a ‘lifestyle scenario’ in the sense set out above. It will be more helpful to energy research to assess population effects separately.

2.5 Storyline overview

The basic storyline for the scenario begins with steadily changing social attitudes to the environment – with increasing levels of understanding fostered by education (formal and informal) leading to a widely held belief that human activity is beginning to have a serious and deleterious impact on the natural environment in general and the global climate in particular. In most countries of the developed world we are clearly already well into such a change.

The next step, currently not so far advanced and still widely contested, is a broad social consensus that these impacts are strongly related to consumption decisions, so that unlike earlier environmental crises (lead in petrol, acid rain, ozone depletion) there is not a techno-fix solution that Government can mandate and industry can deliver. The polluter is “our consumption” not “their production”. The growing discourse about carbon footprints is evidence of change in this direction, but the process is not as advanced as the consensus about climate science.

The scenario assumes change will continue in broadly the same direction so that by 2020 there is a social consensus in the developed world that consumption cannot continue to grow unchecked. The scenario does not assume complete social harmony or no opposition to change. Nor does it assume a widespread frugality, although ‘alternative lifestyles’ may have a role to play in pushing the boundaries of what is considered socially acceptable. It does however assume majority support for social, political and economic change geared to improving quality of life in ways other than increasing material consumption (at least for the majority in rich countries).

What follows from this is not straightforward [transitions cannot be fully predicted]. In particular the allocation of responsibility to act between Government, business, civil society and the individual is likely to vary from place to place and time to time, depending on a variety of social, cultural, economic and political factors. In practice we are already seeing a confusing mix of initiatives from Governments, business and civil society and, in this scenario, this will continue and intensify. Nevertheless, the overall direction is clear with a progressive increase in mutually reinforcing policies, commercial initiatives and social change.

Starting with opinion leaders (broadly defined) but moving through society, the social norm is for ‘green housing’, ‘healthy eating’ and ‘community living’. Whilst all these notions are continuously reinterpreted, political and business leaders who succeed in delivering them are rewarded, reinforcing the trend.

In a diverse society, opposition remains, but increasingly as malcontentment against perceived ‘green correctness’ and reaction to decline in economic sectors damaged by the direction of change, rather than as a serious alternative political project. The increased frequency and strength of extreme weather events and repeated spikes in fossil fuel prices maintain support for change. Organic horticulture, building renovation, eco-retailing, high-tech cycle repair and community development become mainstream professions with influential support so that changes become locked in to social structures.

Transport proves the most difficult socio-technical system to change as the ‘globally aware’ generation driving the change retains a desire for high mobility. Wholesale change to land transport technology and infrastructure after 2025 address some of the problem, and high quality video-conferencing replaces the long distance business meeting for a new generation of professionals. ‘Carbon guilt’ becomes focussed on aviation for leisure that forms an increasing fraction of personal emissions. Overall, car dependence, speed and mobility gives way to a greater emphasis on active modes, quality of the journey experience and accessibility.

Table 1 provides an overview of the storyline.

Table 1: Lifestyle scenario storyline overview

	to 2020	to 2050	POLICY
GENERAL	Social values are changing but not rapidly; Acceptance for lifestyle restrictions is growing but voluntary change confined to minority groups; Local communities are increasingly engaged in sustainable use of resources; Quality of life and wellbeing are coming to the fore e.g. quality of life is major attractor for companies to invest in regions; Changing consumption values, early adopters and new technology are driving change; Energy efficiency improvement is still a stronger driver than reduction in demand for energy services.	Lifestyle begins to replace consumption for social meaning; Change begins to happen voluntarily; Voluntary movements such as organic food and local living go from minority to majority by 2030; Informed citizens play an important role in new governance structures; Social capital is high; Take-up of technology is rapid due to carbon constraints; Pressure is put on Government to act; Demand reduction complements efficiency gains	Government leadership by example and policy change is a key factor in wider change. There is a synergy with social change. Acceptance of policies that involve 'lifestyle restrictions' grows. Policy focus moves from limited carbon pricing and regulation for technical efficiency towards a mix of support for green technical and social developments, more policies to cap emissions and regulation of environmentally damaging behaviours.
HOMES	Large programmes complete the installation of basic energy efficiency measures and begin more difficult measures in the housing stock. Home labelling, smart meters, community projects and environmental awareness gradually change attitudes and behaviour to energy use in the home. Adoption of radical lifestyle change and innovative technologies limited to minority groups..	Conspicuous consumption in the home becomes socially unacceptable. Community based organisations, social housing providers and local small businesses develop successful models of low energy retrofit and living. High levels of investment in home improvement continue and are redirected towards sustainable goals. New technologies consistent with these patterns are adopted rapidly but not uncritically	Social housing providers, local authority programmes and owner occupier actions are supported by incentives, training and regulatory policy. Energy prices rise steadily, driven by moves to renewable sources an carbon pricing policies, with policies focussing on support for individual and community action rather than energy companies, universal labelling and product regulation are introduced with strong majority support.
MOBILITY AND TRANSPORT	Car dependence shows signs of a downward trend by 2010; Large cars and high road speeds and single occupancy car trips for some purposes are starting to become socially unacceptable; International air travel is slowly replaced by more domestic surface travel,	Accessibility, not mobility is the prevailing ethos; Local and social networks grow; Quality and reliability overtakes speed as priorities; Communities re-evaluate the role of the car – only electric vehicles are allowed in town centres; A new spatial order with compact	Increasing acceptance of restrictive policies in the context of improved local infrastructure. Pricing is a key element to enhance economic rationality in decision making and to achieve behavioural change. All forms of road space (including in use and for

	and some longer distance domestic travel is often substituted by walking and cycling near to home; A trend towards smaller cars and second car ownership is replaced by membership of car clubs and more use of hire cars; ICT starts to pervade all travel choices -modes, destinations, routes, times and driving style.	cities, mixed use development and self contained regions, Rural populations are maintained by developing services and infrastructure (e.g. high speed broadband and demand responsive services); ICT alters destination choice, driving style, paying for travel, including in the freight through telematics, in-car instrumentation, intelligent speed adaptation, intelligent highways, video conferencing, smartcards, e-commerce); Air travel is regarded as a luxury.	parking) will be priced (either by road user or emissions charging). Restrictions include speed enforcement and the general phasing out of petrol vehicles in town/ city centres. Generally, however, the policy environment is one of push and pull' as fiscal and regulatory sticks are combined with the carrot of infrastructure investment (e.g. in car clubs, public transport, cycle infrastructure, railway capacity).

3 METHODOLOGY – QUANTIFYING LIFESTYLE

3.1 The challenge of quantifying lifestyle

Lifestyle, as defined above, is a qualitative concept. In contrast, the role of energy use in the energy system is only meaningful if quantified, yet, for the reasons set out above, it is a function of lifestyle. To quantify energy use we need to use metrics of the key energy using behaviours (service demands and technologies) that result from a given lifestyle, e.g. room temperatures, kilometers travelled and conversion technologies used. Both the energy service demands and conversion efficiencies are, by definition, quantifiable.

In practice, we cannot define scenarios for every energy service demand and technology. We choose to focus on those that are quantitatively important for energy use, either now or potentially in the period to 2050. Both the simplifying assumptions made and the plausible range in parameters inevitably introduce uncertainties. These are particularly significant for the end of the period to 2050, by which time significant social, cultural and technical change is expected. However these uncertainties apply to all scenarios, not just those that consider pro-environment behaviour change. All the scenarios set out in this book and elsewhere implicitly use assumptions about future behaviour change, even where these are hidden or modelled very simplistically, e.g. as an extrapolation of future trends. All that is conceptually distinct about the pro-environmental scenario set out in this chapter is that the implications for consumer energy use are explicit.

Modelling the energy implications of lifestyle change involves not only detailed assumptions about both the demand for energy services and the choice of energy using technology, but also how these interact with other decisions relating to the energy system. For example, if car buyers purchase more electric vehicles, this will increase demand for electricity and, other things being equal, lead to more power station construction. However, the choice of new power station is not made by the car buyer, and so, as well as describing future consumer behaviour in some detail, we need to model the implications for the whole energy system.

We have addressed this challenge by using three models with different capabilities, as follows:

- the UK Domestic Carbon Model (UKDCM) (Palmer, 2006).
- the UK Transport Carbon Model (UKTCM) (Brand, 2010a; Brand, 2010b and Brand et al, 2010).
- the MARKAL energy system model (Strachan et al, 2008, Kannan et al., 2009, Strachan and Kannan, 2008).

The use of these models is described in more detail below.

3.2 Quantifying residential energy demand

3.2.1 UK Domestic Carbon Model

This is a model of energy use in the UK housing stock. It contains many categories of residential buildings, each category representing a number of real world dwellings in the country in the model base year of 1996. For each building category, there is data about the building form and fabric and other properties related to energy use (windows, walls, lofts, air change rates and internal temperatures). The majority of the information was taken from the English House Condition Survey (EHCS) 1996 which contains structural information for almost 30,000 representative dwellings (DETR, 2000). The 1996 EHCS contained an energy sub-module which later surveys have lacked.

For each building category, the model calculates the energy demand placed on the space heating system in each month to keep the required mean internal temperature, assuming the mean monthly UK external temperature for the period 1970-2000. This is done by calculation of energy flows out of the building, from the information set described above on building fabric areas, U-values and air change rates, using the same approach as the BREDEM-8 model (Henderson and Shorrock, 1986). The calculations take account of incidental gains from cooking, human metabolism, solar gain (through windows) and waste heat from hot water, lights and appliances. In common with most similar models for the UK, there is no explicit modelling of space cooling, as this is (at least currently) a very small component of demand.

UKDCM can be used to calculate the final demand for space heating and water heating over the stock, using inputs on the type and efficiency of heating systems, including gas boilers, electric heating, solar thermal and solid fuels, and in future years such technologies as CHP (Stirling engine, fuel cell, district heating), heat pumps and biomass heating.

The model allows building electricity demands to be offset by on-site generation (from CHP, micro-wind and solar PV). The calculations result in monthly fuel demands (gas, electricity, coal/oil, biomass) from the UK housing stock. For each year, the housing stock is updated (new build, demolition and retrofits) and the heating system type, demand for hot water, demand for lights and appliances and internal temperatures may also be varied annually. The result, when aggregated, is the end use demand (for space heating, cooking, lights and appliances and hot water) and the fuel demand (gas, electricity, coal, oil and biomass) of the UK housing stock on a yearly basis from 1996 to 2050. From these data, carbon emissions due to UK household energy use in each year are calculated. The model is described in more detail in Palmer et al. (2006).

Scenarios can be constructed for alternative rates of house-building, demolition, fabric improvements, microgeneration installation and efficiencies, improved efficiency in lights and appliances, as well as changes in internal temperature, hot water use and other energy using behaviours. The scenarios can explore the potential for energy use and carbon emissions in the period to 2050, including the impact of changes in external mean temperatures. For this research, UKDCM was used to specify the energy service demands for space and water heating, with MARKAL (see below) then used for technology choice. For other energy end uses, UKDCM was used to specify the final energy demand. In all cases, MARKAL readjusts demand levels to allow for responses to price changes.

3.3 Quantifying mobility energy demand

The quantification of mobility energy demands for these scenarios involves:

1. Storyline development and bottom up spreadsheet modelling to develop an alternative set of transport energy service demands.
2. Sectoral modelling using the UK Transport Carbon Model (UKTCM) for vehicle ownership, vehicle technology choice (size, performance, preference, market potentials) and vehicle use (in-use fuel consumption).
3. UKTCM outputs of fuel consumption and vehicle fleet evolution by technology were then translated into MED inputs, through specification of technical energy efficiency, and technology deployment constraints and bounds.

3.3.1 Storyline development and spreadsheet modelling

Transport energy demand is a function of transport mode, technology and fuel choice, total distance travelled, driving style and vehicle occupancy. Distance travelled is itself a function of land use patterns, destination, route choice and trip frequency. Most travel behaviour modelling and forecasting is based on principles of utility maximisation of discrete choices and on the principle that travel-time budgets are fixed (Metz, 2002). However, based on evidence relating to actual travel choices, the lifestyle variant scenarios modelled here explored a world in which social change is strongly influenced by concerns relating to health, quality of life, energy use and environmental implications. As such, non-price driven behaviour, which has already been found to play a significant role in transport choices (Anable, 2005; Steg 2004; Turrentine and Kurani, 2007) becomes a dominant driver of energy service demands from transport.

The ‘lifestyle’ consumer is more aware of the whole cost of travel and the energy and emissions implications of travel choices and is sensitive to the rapid normative shifts which alter the bounds of socially acceptable behaviour. Consequently, the ‘Lifestyle’ variant scenarios assumed the focus would shift away from mobility towards accessibility. In other words, the quality of the journey experience rather than the quantity and speed of travel would become more important. Social norms elevate active modes and low-carbon vehicles in status and demote large cars, single-occupancy car travel, speeding and air travel.

The consequences for travel patterns of these shifts were first analysed using a spreadsheet model which took as its starting point the figures for current individual travel patterns based on the UK National Travel Survey (DfT, 2008a). Figures for each journey purpose (commuting, travel in the course of work, shopping, education, local leisure, distance leisure and other) in terms of average number of trips, average distance (together producing average journey length), mode share and average occupancy were altered based on an evidence review relating to the impact of transport policies and current variation in travel patterns within and outside the UK.

3.3.2 Sectoral modelling using the UK Transport Carbon Model

The UK Transport Carbon Model (UKTCM) is a strategic transport-energy-environment simulation model designed to model a wide range of policies and policy ‘packages’ (or ‘bundles’) including demand management policies, measures affecting vehicle ownership and use, fiscal and pricing policies, eco-driving programmes, fuel obligations, speed enforcement and targeted technology investment incentives. It provides annual projections of transport supply and demand, and calculates the corresponding energy use, life cycle emissions and environmental impacts year-by-year up to 2050. It simulates passenger and freight transport across all transport modes, built around exogenous scenarios of socio-economic and political developments. It integrates simulation and forecasting models of elastic demand, vehicle ownership, technology choice (using a discrete choice modelling framework), stock turnover, energy use and emissions, lifecycle inventory and impacts, and valuation of external costs.

The UKTCM is complimentary to detailed transport network models and energy system models. The exercise presented here shows the potential to link the model with Markal or system wide models. UKTCM is neither a forecasting nor a cost optimisation model. However, it can be argued that any long term (>2020) forecasting is inappropriate given the uncertainties involved. Also, cost is not the only factor in modelling demand and supply, particularly for private vehicle ownership and use. Although lacking the infrastructure detail of a transport network model, the UKTCM has the ability to endogenously model network capacity constraints for road networks via congestion/speed profiles.

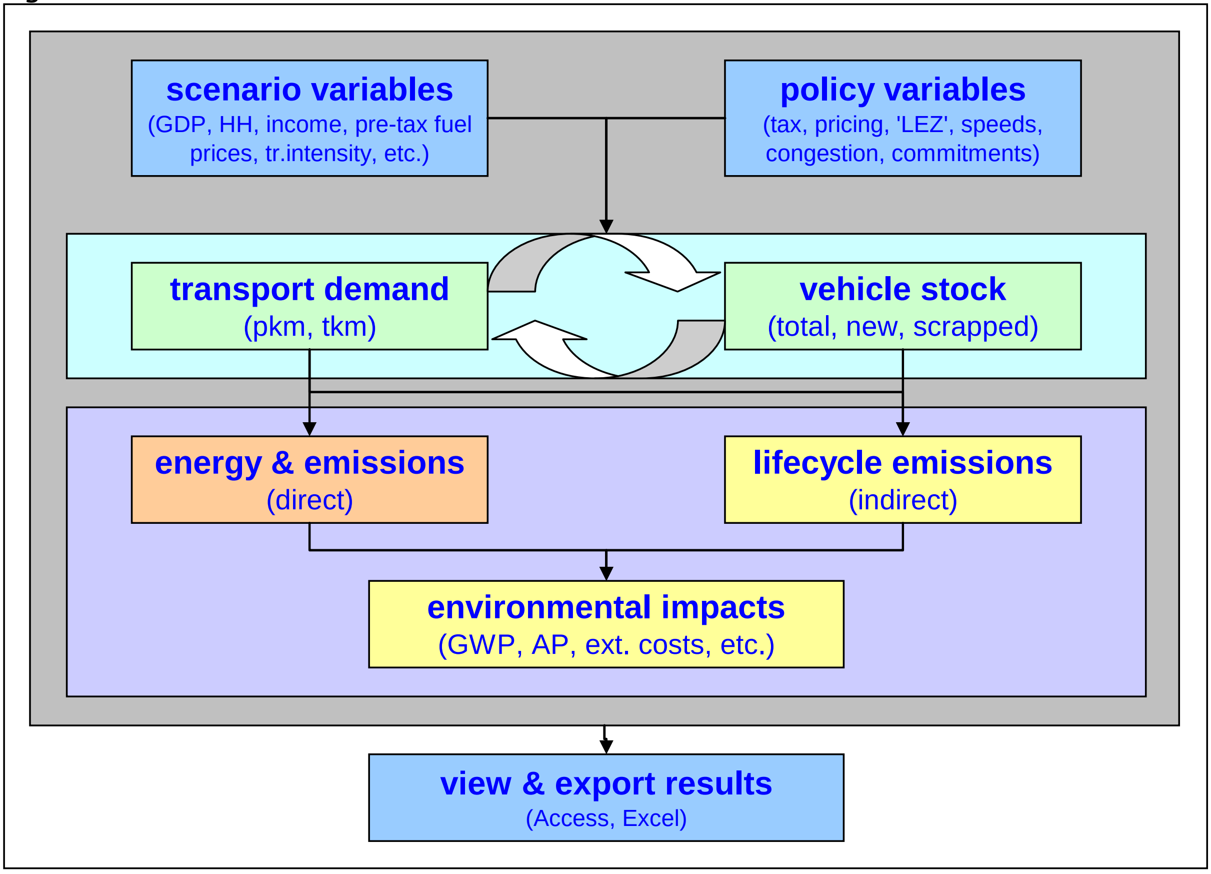
An overview of the model is shown in Figure 1, and briefly described below:

- The exogenously defined scenarios introduce wider contextual factors (such as projections of GDP, energy resource prices, population) and consideration of uncertainty into the analysis of transport policy and technology take-up.[2]
- The policy module sets up policy options that are endogenously modelled in UKTCM, including the above mentioned policies.
- The demand module calculates the overall level of transport activity and modal shares for passenger and freight movements (in passenger- or tonne-km).
- The vehicle stock module tracks the changes in the vehicle stock brought about through new vehicles, potentially using new or improved propulsion technologies, entering the stock to replace older vehicles. The model currently includes definitions of more than 600 vehicle technologies (such as passenger car, medium, gasoline, hybrid electric, 2005-2009 vintage). The outputs of the vehicle stock module are the disaggregated vehicle kilometres and number of vehicles for historic (1995-2007, for calibration and validation) and future years (2008-2050).
- The vehicle energy and emissions module takes data from the stock module to calculate the direct (tailpipe, or source) emissions and energy consumption due to the different vehicle technologies that comprise the vehicle fleet. The module produces information on direct emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_X), sulphur dioxide (SO_2), hydrocarbons (HC) and particulate matter (PM).
- The lifecycle emissions module then calculates the energy consumption and pollutant emissions due to the manufacture, maintenance and disposal of vehicles, as well as infrastructure contributions (e.g. the introduction of high speed rail requires a network of high-speed rail tracks, with substantial material demands and associated embedded energy use and emissions). It also calculates energy use and emissions over the fuel production cycles for the different fuels used by different vehicle technologies.
- Finally, the environmental impacts module takes the data on overall levels of emissions and uses them to provide a series of ‘impact indicators’, such as global warming potential and human toxicological classification, as well as monetary valuation of the damage associated with such emissions levels (external costs).
- All results are disaggregated by year, mode, vehicle type, fuel type, journey segment type (e.g. urban, rural, intercity rail, short haul air) and vehicle technology and can be viewed via the graphical user interface (MS Access) or exported to analysis packages such as MS Excel.

---

[2] When talking about exogenous developments, we mean factors that are external relative to the UK transport system but nevertheless salient to its evolution, and specifically to the deployment of transport technologies.

Figure 1 Overview of the UKTCM



Further details are included in Appendix A. An introduction to the model has been published in Brand et al. (2010). More technical details can be obtained from the Reference Guide (Brand, 2010a) and User Guide (Brand, 2010b), published online by the UK Energy Research Centre.

3.4 Markal Elastic Demand

Outputs from UKDCM and UKTCM were translated into Markal outputs. MARKAL is a widely applied technology-rich, multi-time period optimisation model (Loulou et al, 2004). It portrays the entire energy system from imports and national production of fuel resources, through fuel processing and supply, explicit representation of infrastructures, conversion of fuels to secondary energy carriers (including electricity, heat and hydrogen), to end-use technologies and energy service demands of the entire economy. As a perfect foresight partial equilibrium optimization model, MARKAL in its elastic demand mode (MED) minimizes the sum of producer and consumer surplus – as a metric of social welfare – by considering the investment and operation levels of all the interconnected system elements and well as resultant demand changes. The inclusion of a range of policies and physical constraints, the implementation of all taxes and subsidies, and calibration of the model to base-year capital stocks and flows of energy, enables the evolution of the energy system under different scenarios to be plausibly represented.

3.4.1 Modelling the lifestyle scenarios in MED

Using outputs from UKDCM and UKTCM and MED, the ‘lifestyle scenario’, was modelled with two variants: one (denoted LS-REF) in which carbon emissions are not constrained, and another (denoted LS-LC) in which carbon emissions from the whole energy system are constrained to fall by 80% relative to 1990 levels by 2050. These two lifestyle variants have been contrasted with the corresponding core UKERC Energy 2050 scenarios (REF and LC). The relationship between the four scenarios is shown in **Error! Reference source not found.** and the core scenarios are described in Table 3.

Table 2 The Lifestyle scenarios related to the Core scenarios

		System wide carbon constraint in 2050	
		None	– 80%
Social/lifestyle assumption	Business as usual	REF	LC
	‘Lifestyle’	LS REF	LS LC

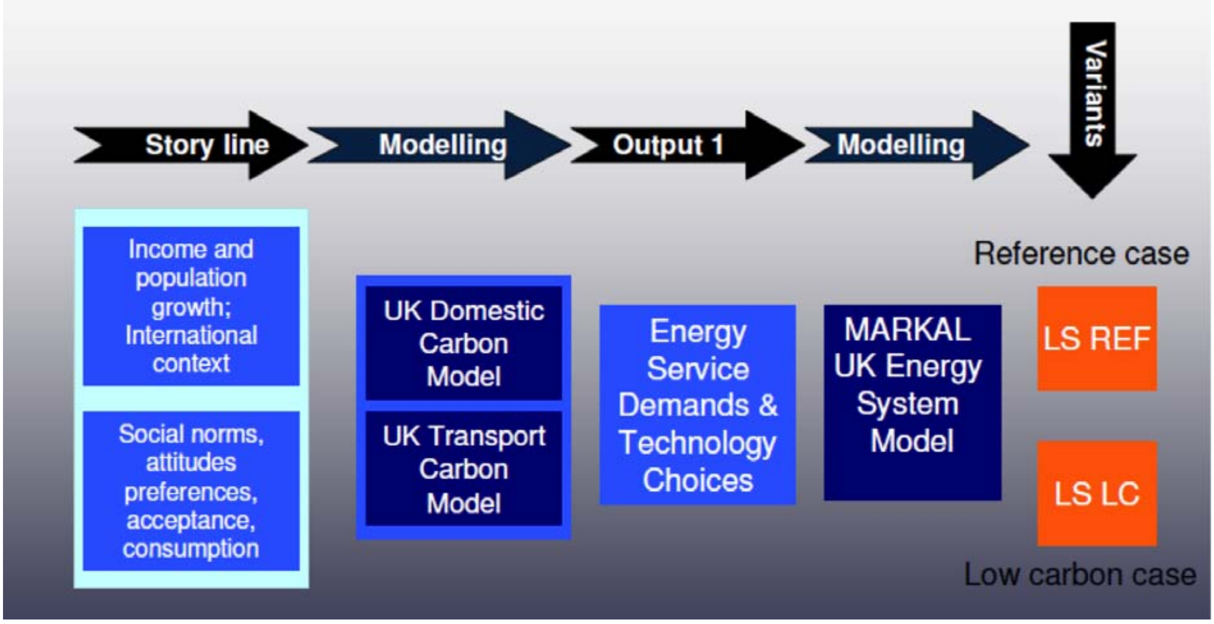
Table 3 Summary of the four contrasting scenarios runs using MED

	Core Energy 2050 Scenarios		Lifestyle Variants of the Core Energy 2050 Scenarios	
	REF	**Low Carbon REF (LC)**	**Lifestyle REF (LS REF)**	**Lifestyle Low Carbon (LS LC)**
Key assumptions/ method	UK Government projections + MED provides a baseline from which to assess the actions and costs associated with achieving policy goals. Concrete policies and measures in place in the UK in 2007 continue into the future but no additional measures are introduced.	REF + carbon constraint leading to an 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020 and linear interpolation in between.	Shifts in societal preferences, activities and associated policies modelled using bottom-up spreadsheet modelling and UKTCM and UKTCM to generate an alternative set of energy service demands, technology uptake, on-road fuel efficiencies etc. as direct inputs to MED. MED was then run without a carbon constraint akin to the core REF scenario.	LS REF + carbon constraint leading to an 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020 and linear interpolation in between.
GDP and population growth	Historic long-term average GDP growth rate for the UK of 2.0% continues to 2050; projections of population growth were taken from UK Government sources.			
Lifestyle assumptions	Lifestyle choices continue to develop along the same trajectory as in the past – i.e. there will be a greater take-up of energy efficiency measures, but people are assumed to balance the initial cost of efficiency measures against on-going energy costs (based on observed income elasticities of demand) with increasing wealth at the projected growth rate.		Lifestyle choices are strongly influenced by concerns about energy use, the environment and wellbeing. Not only are non-price determinants of behaviour recognised, such as values, norms, fashion, identity, trust and knowledge, but non-consumptive elements of behaviour such as patterns of time use, mobility, social networking, expectations and policy acceptance are considered. Policy shifts will serve to empower consumers to change lifestyles and to loosen some of the external constraints that make changes towards more sustainable travel patterns difficult.	
Demand elasticities	MED demand elasticities remain unchanged over time to reflect the fact that energy consumer preferences (i.e. the way they respond to prices and available technology) stay the same.		The derived ‘lifestyle’ demand projections imply gradually lower elasticities of demand as incomes and population continue to grow. In order to avoid double counting the transport and residential	

		energy demand elasticities in the Lifestyle MED runs were set to zero (while agriculture, service and industry demand elasticities were untouched).

The use and interaction of the different models is set out in Figure 2**Error! Reference source not found.**. In essence, we have used the detailed sectoral models (UKTCM and UKDCM) to model the energy service demands and details of some end use technologies, and the UK energy system model (MARKAL) to model wider interactions with the energy system including the impact of a national carbon emissions constraint. More details on the assumptions in the UKDCM and UKTCM models and how energy service demands and technology link into an energy system framework are provided below, with the full range of key energy system assumptions for these runs given in Anandarajah et al. (2009).

Figure 2 Outline of the modelling process



The influences, recent trends and storyline development for each of the residential sector and the transport sector will now be described in detail in section 4.

4 LIFESTYLE CHANGE AT HOME

4.1 Influences on residential energy demand

Residential energy demand includes all of the energy services that households require within the premises of their home. The most important historically has been thermal comfort provided by space heating, which now uses 58% of household energy (Utley and Shorrock, 2008). This is followed by two other heating services: water heating (largely for personal hygiene) and for cooking food. These remain the main uses for fuel (as opposed to electricity). The key drivers are the level of service required and the efficiency with which it is provided.

For space heating, energy service demand is driven by heated floor area and internal temperature. Energy efficiency is determined by both heating device efficiency, but also very importantly by the thermal properties of the home (external surface area, insulation and air-tightness), which vary by large factors across the building stock. In most cases, water heating is provided by the same device – a gas boiler in 80% of UK homes (Utley and Shorrock, 2008), and therefore water heating efficiency depends on the energy efficiency of the boiler and the water use efficiency of the device.

The development of electricity grids and their extension to give nearly universal coverage by the mid 20th century provided the stimulus for electrically provided services. Although electricity still provides only a small share of final household energy (22%), its share in both costs and emissions is much larger. Only 10% of homes rely on electricity as the main heating fuel, partly because use of direct resistance heating is inefficient (due to power station losses) and expensive. There has been a larger shift in cooking.

The predominant uses of electricity are for other services provided by lighting and electrical appliances. Traditionally appliances have been segmented into ‘cold appliances’ (refrigerators and freezers), ‘wet appliances’ (washing machines, dryers and dishwashers) and ‘brown appliances’ (radios, televisions and other entertainment) with a more diverse group of other ‘minor appliances’ e.g. irons, vacuum cleaners. In all cases, total electricity use is essentially determined by the product of appliance numbers, running hours and specific energy consumption.

In recent years, the use of electronic appliances has grown and diversified. As with other appliances, key drivers of electricity use include efficiency and the number of appliances. For many electronic devices there is the option of ‘standby’. Although standby power demand is relatively small, very long running hours in this mode can result in standby energy consumption forming a significant fraction of energy use in such devices.

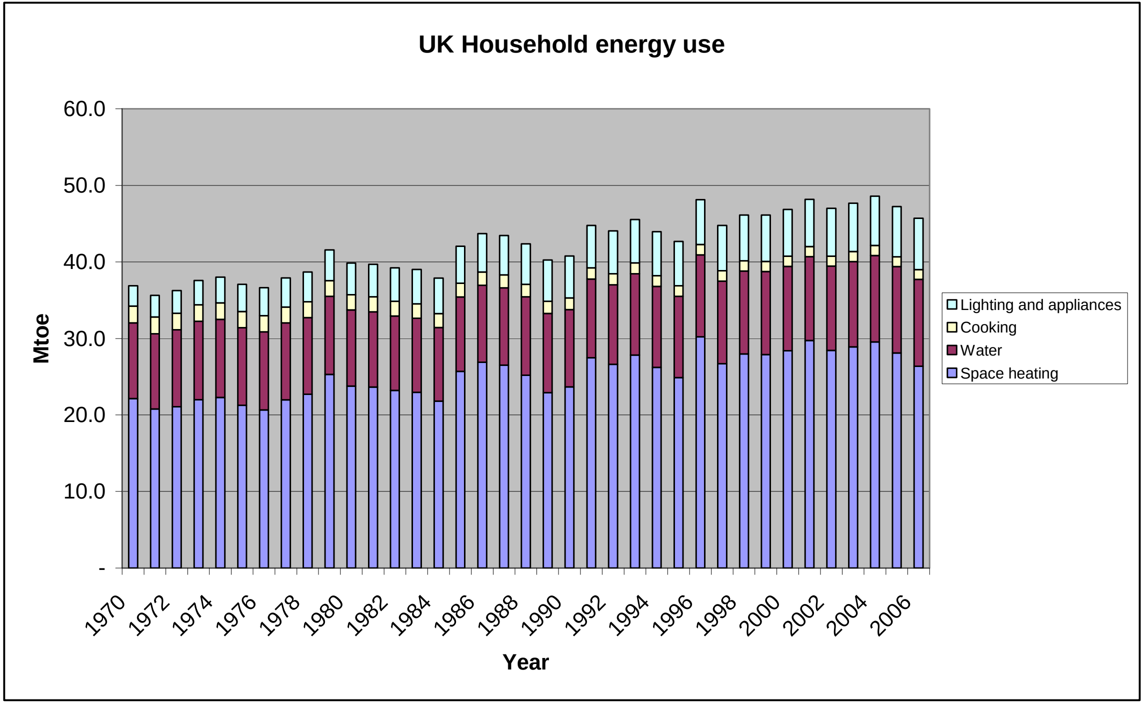
4.2 Recent trends in residential energy demand in the UK

The trend in household energy use from 1970 to 2007 is shown in Figure 3. For most of the period, there was a trend of rising energy use at ~1% annually. There is significant interannual variability due primarily to weather, but this is adjusted in **Error! Reference source not found.** to show the long term trend. This rate is broadly similar to the rate of increase in household numbers, i.e. annual energy use per household has been broadly constant over the period. This is due to the combination of different counteracting drivers. In general, the level of energy services (internal temperature, hot water volume, lighting levels etc.) has increased, but the efficiency with which these are provided has risen.

Figure 3 also shows that space heating remains the dominant component in household energy use, even though its relative importance in the most recent years has fallen. The rise in space heating demand is driven by increasing internal temperatures that masks the strong opposing effect of major improvements in home insulation and heating system efficiency, without which space heating energy use would have doubled since 1970 (Utley and Shorrock, 2008). Space heating energy use has declined substantially since 2004, over a period in which energy prices have risen sharply and household energy efficiency programmes have increased in scale substantially.

Demand in other end uses has risen faster over recent decades, with the exception of cooking where it has changed very little. Hot water use has increased faster than heating system efficiency, leading to modest growth in energy use.

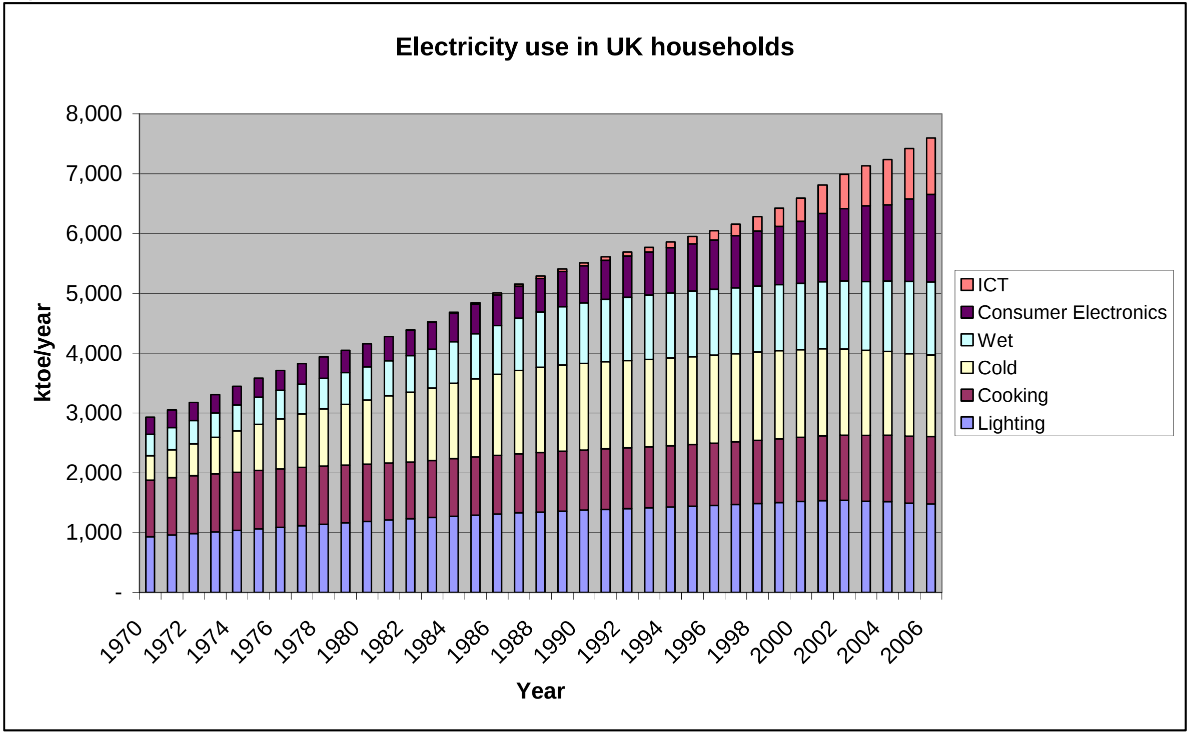
Figure 3 UK household energy use



Based on DECC, 2009a

Energy use for lighting and appliances (almost exclusively electricity) has risen fastest of all (Figure 3). In 1970, electricity use was dominated by lighting and cooking. In these end uses demand for electricity has only risen slowly. In cooking this has been due entirely to electricity substituting for gas (DECC, 2009b). In lighting, there has been significant growth in the number of fittings, but this has been largely offset by improved efficiency, especially with use of compact fluorescent lamp technology which has reduced lighting electricity demand since 2002 – a trend which is expected to continue and intensify with the phase out of incandescent bulbs, except in specialist applications.

Figure 4: Electricity use in UK households



Based on DECC, 2009a

Increased demand for electricity in households has been driven much more strongly by the wider use of appliances delivering new energy services. For each new energy service demand, there is a tendency for energy demand to rise quickly as the market develops, then stabilise as it saturates and even begin to fall as appliance efficiency improvements overtake increased use.

There was growth in energy use in cold appliances (predominantly through the introduction of freezers) in the 1970s and 1980s, although this has now stabilized and fallen slightly in the last decade. Energy use in wet appliances is still rising slowly, primarily due to rising use of dishwashers. Since 1990, demand growth has been driven primarily by consumer electronics, joined in the last decade by home information and communications technologies, ICT (primarily home computing). Together they have grown from using only 11% of household electricity to 32% in just two decades (DECC, 2009b).

4.3 Future trends in a lower energy lifestyle: approach and storyline for residential homes

The trends set out above and illustrated in **Error! Reference source not found.** show that household energy demand has fallen rapidly in recent years. It is clear that most of the main energy service demands are rising only slowly (if at all) and that efficiency improvement is more than offsetting these.

However, it would be unwise to project this trend uncritically. Rising environmental awareness and expanded energy efficiency programmes have been major contributors to the change, and these may well continue. But there has also been an impact from a very sharp rise in energy prices of between 50% and 100% for the main household fuels, which is a trend that is unlikely to continue, certainly at this rate.

The key changes that affect residential energy use in the Lifestyle scenario are as follows. The scenario assumes increasing use of low energy technologies and that this continues to be accompanied by stabilizing and/or declining levels of energy service demands through to 2050. This is driven by a combination of increasing energy awareness, modestly higher prices and improved real time information. These increasingly allow more pro-environmental attitudes to be reflected in behaviour. Social norms increasingly emphasise environmental performance and this is reflected in market values, as building and product labeling make reliable information available. The same factors make conspicuous consumption of energy socially unacceptable.

Insulation of the building stock to a high standard becomes a social expectation. Government and energy company programmes allow the basic insulation measures to reach close to saturation levels by 2020. Adoption if more expensive and difficult measures is slower, but ‘pay as you save’ mechanisms increasingly support very high efficiency retrofits. Refurbishment to passive-house standard is adopted progressively, initially through niche ‘able to pay’ markets and low-income programmes in areas of multiple deprivation in cities and then to rural solid-walled properties. After 2020, the norms for energy performance effectively require high quality retrofits as properties are sold. The large existing sector of SME building tradespeople who do most of the repair and maintenance of residential properties gradually develop new knowledge and skills required to undertake this work.

Smart meters are deployed rapidly after 2010, and universally by 2020, with rapid improvements in future generations of technology to provide information on energy use by individual devices, in real time. These provide comparisons with historical data for the houses and similar households accessed in a variety of ways to suit consumer preferences, including dedicated displays, TV, SMS and internet, as well as with warnings of non-standard use patterns.

Over-heating of buildings becomes socially unacceptable. Initial pressures focus on office buildings, but the same factors then affect the residential sector, so that the long-term trend in rising internal temperatures ends before 2010 and they decline modestly back to levels experienced in well heated homes in the 1990s. Hot-water use also declines, partly reflecting greater awareness, especially as the use of solar water heating increases, but also as water conserving and lower temperature washing technologies are introduced. Levels fall to those already found in many other European countries.

The dominance of gas and oil boilers continues for some years. However, new low- and zero carbon heating systems enter the market after 2010 and take a large market share around 2020. In densely populated urban centres, district heating schemes using CHP (some of it waste and biomass fired) become common, initially for new developments driven by building regulation requirements, but then also in retrofit schemes centred on commercial developments. In the bulk of the housing stock there is strong competition between gas-fired micro-CHP fuel cell systems and electrically powered heat pumps (largely new designs of air source heat pumps). As electricity production is decarbonised, the economic and environmental balance swings in favour of heat pumps. Biomass boilers also play a significant role in larger properties of the gas grid. Building regulations prevent the use of direct electric heating after 2030.

The phase out of incandescent lighting in 2011 is successful, with a wide range of solid-state lighting systems rapidly gaining mass consumer markets as efficiencies rise and costs fall. There are some initial trends to proliferation of lighting locations and uses. However, as conspicuous consumption becomes less socially acceptable, the emphasis tends towards design quality for good performance without frivolous use.

Cold appliance labels and standards are rapidly improved at an EU level in the years after 2010 and focus on consumption rather than efficiency. This prevents markets for US size appliances developing. Typical appliance efficiencies continue to improve up to 2050, especially in cold appliances through the use of advanced insulation and in consumer electronics through continued improvement in processing speed. Every home is internet connected before 2020, as part of changes to mobility, but growth in electricity use for home computing ends, as remote processing of data with low-power clients for home access is introduced. The 1 Watt initiative for standby is widely implemented globally. With increased use of ‘all off’ switching for unoccupied property and automatic low-power modes, standby electricity use decreases.

The period 2010 to 2020 sees the continued development of a niche market for air conditioning as the frequency of warm summers increases. However, tough standards for new homes prevent its use in this sector and stimulate experimentation with and then wider use of passive and low-tech approaches already familiar in the vernacular architecture of other parts of Europe, e.g. shading, shutters and ceiling fans. These practices are then reflected in retrofit designs. The use of air conditioning in housing is limited to some reversible air source heat pumps in peak summer conditions and never becomes the norm.

Social reaction to conspicuous consumption also prevents any significant growth in markets for new high energy devices such as patio heaters, hot tubs and large plasma screens, initially through peer pressure which is reflected in CSR policies of major retailers and regulation.

Initial market growth in micro-renewables is highly dependent on the core of committed green energy innovators. Starting with some key influential groups and influenced by zero carbon new-home trends and more generous incentives, microgeneration becomes increasingly popular – first solar water heating, then photovoltaics and micro wind in specific locations as technology performance improves.

4.4 Modelling low energy lifestyle: approach and assumptions

The lifestyle changes described qualitatively above were modelled as follows in the LS REF and LS LC scenarios. Many of the assumptions reflect analysis undertaken previously in a low-carbon scenario for the Royal Commission on Environmental Pollution (Palmer et al., 2006). However, the specific assumptions of the lifestyle scenario imply a much greater emphasis on behaviour change, notably lower internal temperature and less hot-water use. They also imply less reliance on command and control policymaking, notably in this case housing demolition. In addition, we have updated assumptions to reflect more recent information, for example by using a higher potential for heat pumps and lower potentials for district heating and microwind turbines. The key modelling assumptions are set out below.

Average internal temperatures in homes peak at 20C in 2010, then fall back at 0.2C/year to 17C in 2025 and stabilise there. The implication of falls in gas use in homes since 2004 (at greater rates than energy efficiency improvement) is that such a change may have already begun. It should be noted that the temperatures quoted above are mean internal temperatures, as this is the input data required in our modelling. In this context, it should be emphasised that comfort and energy service demand are different. A reduction in the mean demand temperatures inside a house can be achieved without loss of comfort by not heating unused rooms, not heating the house when it is unoccupied and/or wearing warmer clothes in the house. None of these can be assumed to involve a loss of comfort, but rather a lifestyle choice. So 17C is the assumed average temperature in the whole housing stock during the heating season; a significantly higher level could be achieved in occupied rooms in occupied houses during the daytime. Moreover, temperatures vary quite considerably between different homes, so that average temperatures can be reduced without reducing temperatures in homes that are already cold. Better control systems, smart meters and increased energy awareness could play a significant role in this process.

Housing demolition rates remains at a relatively low rate of 17,000 per year, reflecting a desire to maintain existing neighbourhoods and reuse existing capital assets. This, of course, has implications for renovation policy – the vast majority of homes will need to be renovated to high energy performance levels rather than demolished, but this would still be the case even with significantly higher demolition rates.

New build rates are assumed to rise, broadly in line with Government targets to reach a peak of 255,000 per year in 2016 and stabilises at 120,000 per year. The energy performance standard of new homes is already significantly better than the stock average, it has been improved in successive alterations to the Building Regulations and this process is expected to continue. In England, the Government has targeted ‘zero carbon’ new build from 2016. This is universally acknowledged as extremely ambitious, especially to deliver in practice as opposed to in design. We have therefore assumed a still ambitious, but probably more realisable outcome.

We assume that energy demand for air conditioning remains negligible (in homes). This remains a controversial assumption, given existing trends and the potential for significant rises in summer temperature by 2050 (Defra, 2009). Our assumption is that, in the lifestyle scenario, a shift to air conditioning is seen as socially undesirable and that the rate of change of summer temperatures is likely to be sufficiently slow to alter this. We assume that renovation practice increasingly adopts the vernacular architecture of warmer climates, e.g. shading and shutters. Growth in use of air source heat pumps (ASHP) may aid the adoption of air conditioning – as ASHP operated in a reverse modes are air conditioners. However, the evidence indicates that even a significant increase in uptake of air conditioning in the residential sector has a rather small impact on energy demand under conditions projected for the UK and the rest of Northern Europe (Henderson, 2005; Jochem, 2009).

Hot-water use is assumed to fall linearly by 1.25% annually from 2010 to 2050. Recent trends having modestly upwards, with increasing washing (personal and clothes) more than compensating for the increased use of showers as opposed to baths. Future trends are difficult to predict. However, it is clear that much hot water is used wastefully (taps left running etc) and that there is scope for modest technological change (low flow showers and lower temperature washing) to have further impact. Longer term technical change may produce yet further opportunities. The impact of water shortages in the driest and most densely populated areas of the UK may give further impetus to these in the medium term. Energy use in water heating in the UK is very high, even by developed country standards, being higher than that in the USA and double the level of France and Germany (IEA, 2007). Our assumption is therefore that hot water use declines to continental European levels by 2050.

We assume that there is continued uptake of basic energy efficiency measures – cavity wall insulation and loft insulation. We assume full penetration of cavity wall insulation by 2020 and loft top up to high standards by 2040. These are well within what can be delivered within existing policy approaches, notably via energy supplier and fuel poverty programmes.

Increased use of other insulation technologies (external and internal wall insulation and floor insulation) has currently been found to be more problematic, as they are more expensive, intrusive and disruptive, unless undertaken within the context of major refurbishment. Internal wall insulation has potentially negative consequences for summer overheating by reducing building thermal mass. And in the lifestyle scenario, we expect that there will be conflicting pressures relating to external wall insulation – environmental pressures for adoption, but urban townscape conservation pressures to resist. We have therefore made rather conservative assumptions that adoption is far from complete even by 2050 with rates of 35% for solid wall insulation and 37% for external cladding of cavity walls. We assume that materials improvement continues so that, where used, retrofit wall insulation delivers U-values of 0.25 W/m^2/K. We assume lower rates of floor insulation, 0.5% of the stock annually.

We assume that window replacement continues with a 30 year lifecycle and that the more extreme heritage protection arguments to retain poorly performing windows are overcome as new designs combine high levels of thermal performance with good aesthetics. We further assume that window performance improves rapidly to 0.8 $W/m^2/K$, reflecting existing Northern European practice.

Conventional heating systems, i.e. solid-fuel, gas and oil boilers and direct electric heating, are challenged in the market new, more efficient alternatives – district CHP, micro-CHP, electric heat pumps and biomass boilers, all of which are already technically proven but only niche market products in the UK. Our specific modelling assumptions for the different technologies are as follows. District CHP take up reaches between 10% and 25% of homes by 2050, reflecting it very probable suitability in high density urban areas, but likely unsuitability in suburban and rural housing. We assume that both micro-CHP and electric heat pump take-up reaches between 10% and 60% of homes by 2050, with the technologies in competition in the largest part of the UK residential market – semi-detached and detached homes. We assume that single-dwelling biomass take-up is limited to a maximum of 20%, due to constraints on storage of wood fuel in urban areas. These assumptions are deliberately conservative, as there is probably scope for using building regulations to eliminate conventional heating completely once a full range of commercially proven alternatives for all housing types is demonstrated.

Solar thermal hot water is the best developed 'new technology' with approximately 100,000 installations already in the UK. In the Lifestyle scenario installation rates increase rapidly driven by positive social attitudes, increased personal wealth and public policy incentives. We assume that average installation rates are ~400,000 annually so that 50% of dwellings are reached by 2050. Solar heating can provide up to 70% of hot water, but there is evidence that actual performance is much lower than this in practice. So we make a conservative assumption that solar heating providing 25% of domestic hot water by 2050.

Electricity generating micro-renewables have to date made much less impact on the UK market, with only a few thousand installations. However, there are very large proposed changes to the public policy framework through feed-in tariffs. Future trends are therefore very difficult to predict. Photovoltaic (PV) panels are high cost, but these are expected to continue to fall and the technology is applicable on any home with a south-facing roof space. Microwind turbines have lower costs but are only viable of roofs with relatively high wind speeds, and therefore have lower applicability. We assume that solar PV panels are installed on 15 % of dwellings (approximately 4.5 million) by 2050 and that microwind turbines are installed on 5 % (approximately 1.5 million) of dwellings by 2050. Given the recent proposed policy support through very significant feed-in tariffs (DECC, 2009b), these are quite conservative assumptions.

In the Lifestyle scenario, increased wealth is no longer associated with consumerism and therefore the trend towards an ever increasing list of electrically powered gadgets comes to an end. However, this is not a 'hair shirt' scenario, so the trend is not strongly reversed either. In sectors where demand is already close to saturation, energy efficiency improvements allow energy demand to fall. This is most strongly observed for lighting with the elimination of 19th century incandescent technologies, replaced first by fluorescents and then solid state (light emitting diode, LED) technologies. The same trend, although less marked is seen in cold and wet appliances.

The recent growth in consumer electronics and ICT use continues until about 2020, by which time personal entertainment, communication and computing markets are fully saturated. There follows a modest decline in energy use as efficiency improves and there is some consolidation of end uses.

Products which are considered energy-profligate and non-essential (such as gas burning patio heaters, hot tubs and large screen TVs) become socially unacceptable. Pressure on leading retailers (already observed for patio heaters) makes them withdraw these products from mainstream markets. New large energy using consumer markets therefore do not emerge.

4.4.1 Residential energy system modelling in MED

A comparison of UK MARKAL with UK building stock models is given in Kannan and Strachan (2009). UK MARKAL and UKDCM have very different strengths. UKDCM provides a very detailed simulation of the types and fabrics of the housing stock. It contains information on costs of individual technologies that allows calculation of the costs of different investment scenarios and, if fuel prices are added exogenously, their cost effectiveness. It is a simulation model and therefore technology choices are not determined by economic criteria (such as least-cost optimisation); these are exogenous inputs relying on modeller judgment. MARKAL has a much less detailed description of the housing stock and its technologies. Fuel prices are calculated in other modules of the model and, with technology costs (and where included shadow prices, e.g. for carbon), determine the choice of technology by economic optimisation, subject to any external constraints imposed by the modeller at either the household sector or whole system level.

Investments in the housing stock are difficult to describe using rational actor economic models (Sanstad and Howarth, 1994, OXERA, 2006). If MARKAL is used, it needs to be heavily constrained which reduces the benefits of its economic insights. In this project we have therefore chosen to use explicit modeller judgement and UKDCM for most housing related variables. The exception is that we have used MARKAL to model the choice of heating system to 2050. This is because we expect this choice to depend not only on the characteristics of the technologies and the people and buildings they serve, but also upon the development of the wider energy system, in particular the use of electricity and biomass in other sectors, relative fuel prices and the carbon content of electricity. Use of electricity or gas for heating in carbon-constrained scenarios is particularly sensitive to these factors and extremely important in relation to the wider energy system. However, none of these factors will affect so strongly investments in building fabric, energy efficiency measures or appliance choice, which we therefore have modelled with the higher resolution available in UKDCM.

5 LIFESTYLE CHANGE IN MOBILITY AND TRANSPORT

5.1 Influences on mobility and transport

Energy demand, whether for private or commercial transport purposes, is essentially the product of four factors:

1. the demand for movement (distance), itself derived from the need to access facilities, services and goods and determined by land use patterns, trip frequency and route choice;
2. the mode of transport used to meet that demand;
3. the technical efficiency of vehicles used to power the vehicles; and
4. the operational efficiency with which vehicles are used (e.g. how they are driven and how much of their carrying capacity is used).

Each of these areas in turn is influenced by a wide range of factors that help explain transport emissions trends to date. For instance, the UK Department for Transport makes use of its National Transport Model (NTM) to forecast future levels of traffic. It notes that "key drivers of traffic growth in the NTM are changes in income, population, employment, and travel costs" (DfT, 2008a). Current mid-range forecasts are that traffic will be 31% higher in 2025 and car ownership 33% higher per capita than in 2003.

Traditionally, transport activity, economic activity and transport energy demand have been strongly correlated (Banister and Stead, 2002). As incomes grow, the demand for goods and services increases, as does the demand for travel. These trends can be influenced by individual preferences as well as social and cultural norms that have an impact on journey purposes (e.g. more travel for leisure), journey lengths and modes used – we travel further and faster, choosing to purchase vehicles with greater power and additional features, thus increasing vehicle weight and off-setting efficiency gains (Sorrell, 2007). The type of land use that accompanies economic growth is also important. The trend towards centralisation of service, distribution and retail provision often at edge of town developments, together with less dense housing provision, have all contributed towards increasing demand for transport.

The last fifty years have also seen some dramatic changes to the socio-demographic structure of Great Britain with associated impacts on travel patterns. Whilst the number of households has increased by almost 8 million since 1961, average household size has declined from 3.1 to 2.4 over the same period (Jeffries, 2005). The UK's demographic structure is expected to change significantly in future, in particular through an increasingly ageing population. This could lead to an increase in future transport energy demand as, unlike past generations, these older cohorts may have higher incomes, will have grown up being dependent on the car and may have a higher propensity to travel by air. For example, of those aged over 70, over half hold a driving licence (51%) compared to only 15% in 1975/6 (DfT, 2008b). Also, as a proportion of the adult population, over 65s are set to increase by 21% and 53% respectively so that by 2020 they will make up 19% of the adult population and 23% by 2050. Older people are driving later on in life and more miles than ever before (Tomassini, 2004).

There has also been a marked increase in the number of women in the workplace, and 63% of women now hold a full driving licence, up from 29% in 1975/6 (DfT, 2008b). Overall, however, driving licence holding has stabilized at around 70% of adults since 2000, in part due to a slow down in driving licence uptake by younger people.

However, while only three out of ten households in Great Britain in 1961 had a car, by 2004, one in four households did not have a car, whilst almost one in three had two or more (DfT, 2008b). This, in turn, has been driven by a reduction in real terms in the overall costs of motoring in the last 20 years (Green Fiscal Commission, 2009). In addition, over this period increases in public transport fares above the rate of inflation have made travel by car relatively cheaper.

Similar drivers support the future forecast growth in aviation (Pearce, 2008). Since deregulation of the airline industry in 1996, the development of the low cost aviation sector has introduced low and unrestricted fares and has opened up the range of destinations and airports available. There is some debate as to whether the growing affordability of air travel has led to an increase in the overall passenger growth rate or whether it may well have happened anyway, particularly due to income growth. Since 1996, annual growth rates have averaged around 5-6%, which represent strong growth but are similar to the rates experienced prior to deregulation (Dargay et al., 2006). What is clear, is that most of the current air passenger demand is for leisure purposes and the availability of low cost flights has not in fact significantly altered the type of people who are flying (Dargay et al., 2006; CAA, 2006). The growth is comprised of existing passengers flying more than in the past, particularly those from middle and higher income bands travelling short-haul.

5.2 Recent trends in mobility and transport

It is questionable how certain we can be that historical relationships between travel, income, demographic composition and employment will hold true in future decades. For instance, Bayliss et al. (2008) identify that actual traffic levels (up to 2006) have been well below the mid-range forecasts provided by both the 1989 and 1997 National Road Traffic Forecasts. It would appear that traffic growth is already decoupling from economic growth. Since the mid 1990s, the rate of growth in both passenger and goods transport has halved even though economic growth has been 50% higher (DfT, 2008b). Between 1996 and 2006 car travel increased by only 11% compared with a 34% increase during the previous decade. By contrast, travel by all other passenger modes increased by 34% (mostly rail) compared with a decline of 4.5% previously. The long-term decline in walking and bus use has been stemmed, but not reversed and there has been no overall increase in cycling levels. As a result the share of private trips by car has fallen over the last decade (from 94% to 92%) – an unprecedented occurrence (Headicar, 2009). Some of the key changes in UK transport system between 1998 and 2008 are summarised in **Error! Reference source not found.**.

Table 4 Changes in UK Transport System 1998-2008

Indicator	Units	1998	2008	Change	Comment
Car Traffic	Bn veh-km	370.6	404.1[a]	🟥 ↑	But rate of growth slowed.
LGV and HGV traffic	Bn veh-km	78.5	97.6[a]	🟥 ↑	Main growth in LGV class
Local Bus (exc. London)	Millions	3149	3074	🟨 ~	Boosted by concessionary fares
Local Bus (London)	Millions	1281	2090	🟩 ↑	Frequency, fares and congestion charge
Rail Journeys	Bn-pass-km	34.7	46.2	🟩 ↑	Growth not forecast at privatisation
Walking	Trips/person[b]	292	245	🟥 ↓	Av. trip distance approx. constant
Cycling	Trips/person[b]	18	14	🟥 ↓	Stabilised with some increases
CO_2 emissions road	$MtCO_2$	116.0	121.6[a]	🟥 ↑	HGVs and vans (cars stable)
CO_2 emissions non-road	$MtCO_2$	7.3	9.7[a]	🟥 ↑	Excludes international aviation
Air Quality	Authorities with AQMA	?	235	🟨 ~	Reductions in toxic emissions but traffic based exceedences remain
Killed & Seriously Injured	000s	44.2	28.6	🟩 ↓	Continued success of road safety strategy
All casualties	000s	325.2	230.9	🟩 ↓	
Condition of road network	Defects[c]	-	-	🟩 ↓	Strongly related to investment levels
Motor Vehicles Licensed	Million	27.0	34.0	🟥 ↑	Utilisation rate dropped
Cars under 1200cc	%	18.2	11.6	🟥 ↓	Upsizing of purchases offsets some of efficiency gains
Cars over 2000cc	%	8.5	13.7	🟥 ↑	
Rail Costs (05/06 prices)	£Bn	7	12	🟥 ↑	
Rail farebox proportion	%	65	49	🟥 ↓	Difficult to sustain
Bus Subsidy[d] (07prices)	£M	812	1994	🟥 ↑	Pressure grows as car use rises
Income VED	£Bn	4.5	5.2	↑	
Income Fuel Duty	£Bn	19	23.2	↑	

[a] figures are last confirmed figures from 2007

[b] figures are changes 1995-97 to 2005

[c] changes in measurement approaches make summarising difficult but this applies across all road categories

[d] Concessionary fare support and local subsidy only

Source: Marsden et al., 2010

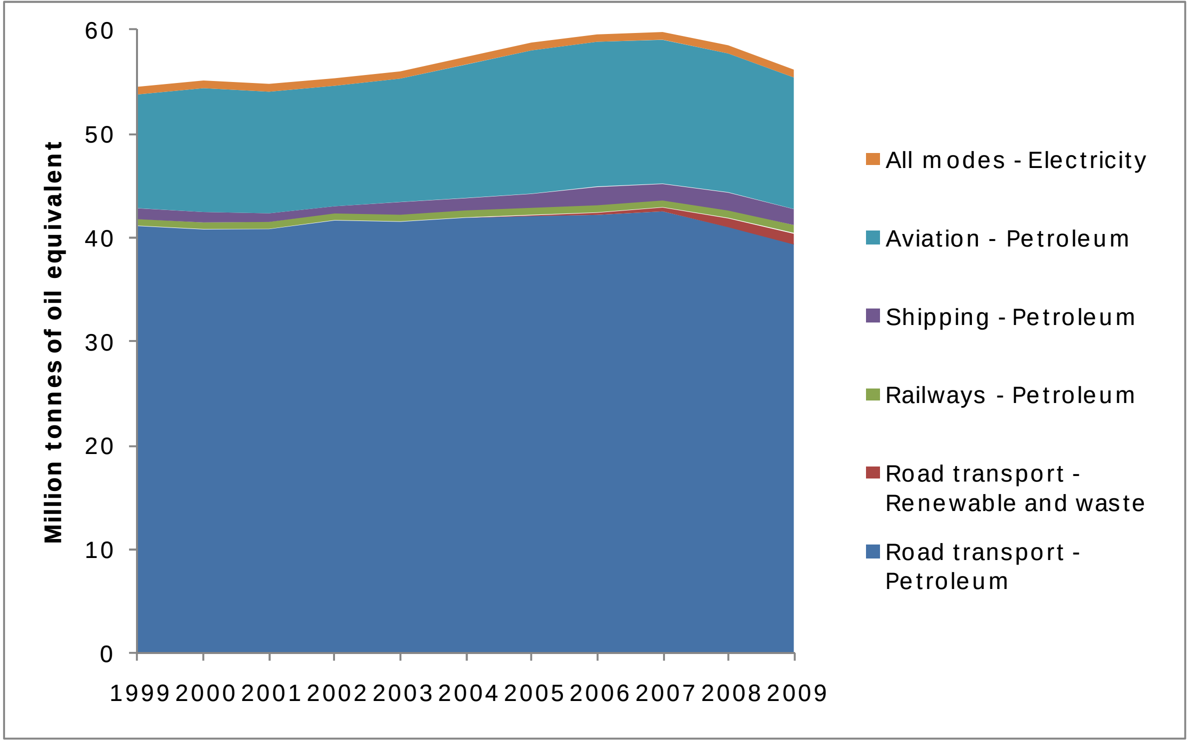
Data from the National Travel Survey shows that the total distance travelled per person (by all modes) has levelled off since 1999. In the two decades prior to this, the large increase in overall distance travelled was primarily a function of increased trip length rather than additional trips. Over the last decade, average trip lengths by car have continued to increase but the number of trips made has fallen resulting in only a slight increase in distance travelled overall. Yet, car ownership has continued to increase quite steeply over the last decade which makes the levelling off in car use all the more notable. As a result, the use made of individual cars has fallen – the annual mileage per car fell by 10% during the last decade after increases over several decades previously. There is further evidence that car dependency has shifted: "The evidence suggests that our attitudes have only really started to change in the last few years. Two years ago, the number of motorists saying they'd find it difficult to adjust their lifestyle to not having a car stood at 87%; in 2007 it fell to 81% and this year it's down to 73%. Which means the one in six motorists who, just two years ago, said they'd find it very difficult to adjust no longer say that. The tipping point was 2004, when the number of motorists saying they'd use their car less if public transport was better passed 50% for the first time." RAC (2008)

Some believe it may not be a coincidence that decoupling began to coincide with introduction of the internet in the early 1990s (Lyons et al., 2008). The information age is unfolding around us far more rapidly than the motor age did before it. In 1998 only 9% of households had access to the Internet. By 2007 this had increased to 61%, with 52% having broadband access (Marsden et al., 2010). We have passed the point where there are more mobile phones than people in the UK. In the early 1990s, commentators had said "there is no natural way for grocery teleshopping to evolve alongside superstore retailing" (Hepworth and Ducatel, 1992) and yet today online grocery shopping is very much making its presence felt with over 20 million people shopping online in 2005 and Internet sales representing 10% of the value of all sales of UK non financial sector businesses in 2008 (OFT, 2007; ONS, 2009).

Together, these trends have led to speculation that ICT will continue to weaken the temporal and spatial fixity of participation in activities and, since much if not all travel is derived from such participation, it follows that ICTs will impact on the demand for mobility. ICTs can impact upon travel by substituting for trips, stimulating more trips and enriching the experience of travel itself through travel time use (Lyons et al., 2008). The more radical changes are likely to take place through changes in work patterns. The impacts of teleworking are known to be complex, but potentially important. Currently, 3% of workers say they always work at home but an additional 15% occasionally work from home or say it would be possible for them to do so (DfT, 2007). This latter group are working at home more often and, in the future, the composition of the labour market may change to facilitate more home-working. ICTs allow us to do things differently. What is uncertain is how such opportunity permeates into society and everyday social practices to redefine norms of behaviour. The question for policymakers is whether they should be inactive, reactive or proactive in policy response.

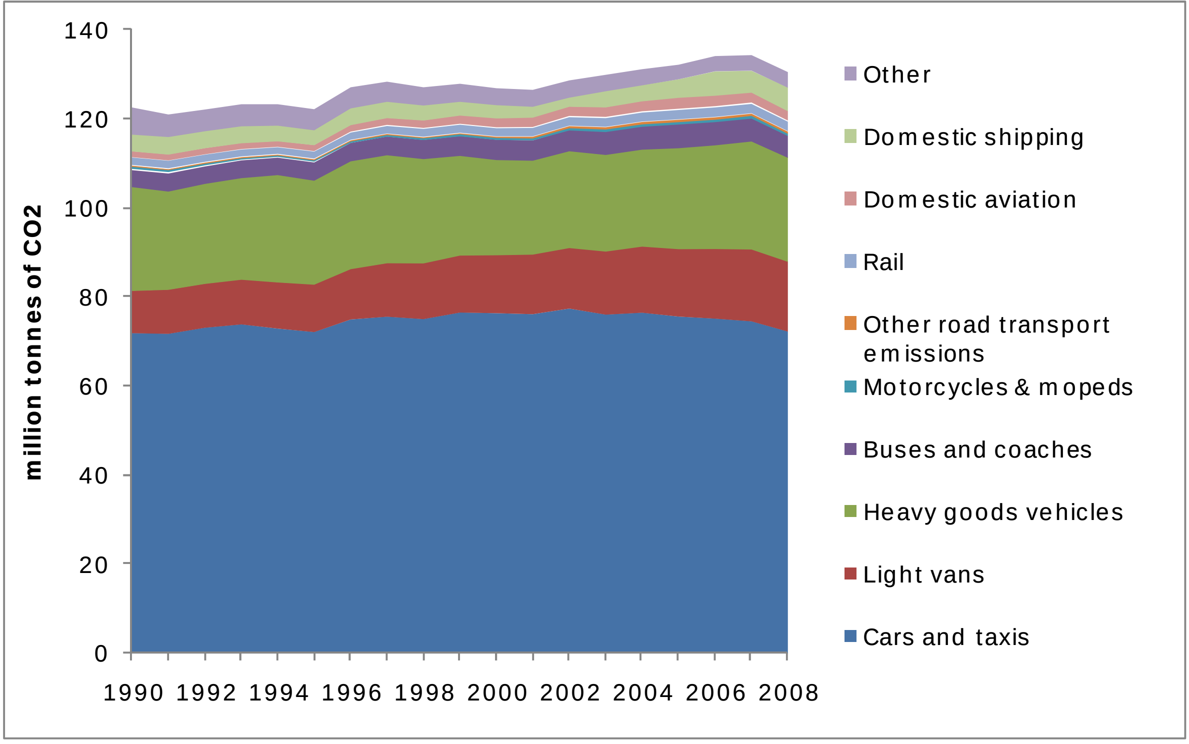
Despite the relative decoupling of car travel to income, improvements to vehicle efficiency up to 2008 have only resulted in a stabilization in energy demand from personal car travel (Figure 5). Since then, the biggest impact on energy use has been the economic crisis and subsequent recession. Improvements in engine efficiency during this period have been essentially negated by the increased traffic levels and uptake of more powerful vehicles. There is some evidence, however, that car buying habits in the UK may be changing as in 2009, for the first time, more small cars were sold than larger models and the annual rate of improvement of average new car CO_2 emissions was the best on record at 4.2% in 2008 (SMMT, 2009). At the same time, the membership of car clubs, albeit still small at 100, 000 people in the UK, is doubling year on year (Carplus, 2009).

Figure 5: Energy consumption by transport mode and energy source, UK



Source: DfT, 2010

Figure 6: CO_2 emissions (at source) from UK domestic transport, by mode of transport



Source: DfT, 2010

This trend in energy use is mirrored in the historic CO_2 emissions trend, shown in Figure 6. Before the recession CO_2 emissions from cars were nearly constant, while the main increase in domestic emissions was from the increased use of light vans.

5.3 Future trends in a lower energy lifestyle: approach and storyline for transport

Given the apparent breakdown in traditional relationships between income growth and travel demand, how far might this trend go? For instance, what impact might continuing volatility in the oil market have on lifestyle choices? Will future generations cease to see congestion increases and carbon reduction as the major economic drain that it is conceptualised as today (Goodwin and Lyons, 2009)?

Based on the literature on socio-technical transitions, socio-psychological models of behaviour change and evidence relating to actual travel choices in response to policy interventions as well as, the Lifestyle variant explored a world in which travel behaviour is strongly influenced by concerns relating to health, quality of life, energy use and environmental implications. As such, non-price driven behaviour, which has already been found to play a significant role in transport choices (Anable, 2005; Steg 2004; Turrentine and Kurani, 2007) was deemed to be a dominant driver of energy service demand from transport.

Making assumptions in this way, albeit based on uncertain evidence, is akin to the treatment of the technical potential of various solutions relating to vehicle technologies and fuels which, as discussed, normally comprise the bulk of the future developments in transport energy scenario modelling exercises, despite also being highly uncertain. In judging what rate and scale of change seems plausible we have given most weight to the existing variation in lifestyle observed in societies like our own, i.e. technologically advanced, liberal democracies. Subject to some obvious constraints imposed by age, wealth and location, for example, it seems reasonable to suppose that if a significant fraction of the population (say 5-10%) somewhere in the OECD already behave in a particular way, then it is plausible for this to become a majority behaviour in the UK within the timeframe to 2050. This implies neither incremental nor step changes in behaviour. There are increasing suggestions that incremental changes in efficiency and behaviour will not be effective enough to deliver sustainable energy systems on their own in the absence of restrictions in consumption (Darby 2007; Crompton, 2008). In addition to incremental change, there is considerable interest in the possibility of a 'cultural shift' affecting people's lifestyles (Elzen et al., 2002; Evans and Jackson, 2007; Koehler, 2009; Crompton, 2008). Consequently, this Lifestyle variant outlines radical change leading to relatively fast transformations and new demand trajectories.

In the Lifestyle variant, travellers are more aware of the whole cost of travel and the energy and emissions implications of travel choices and are sensitive to the rapid normative shifts which alter the bounds of socially acceptable behaviour. Consequently, the variant assumed the focus would shift away from mobility towards accessibility. In other words, the quality of the journey experience rather than the quantity and speed of travel would become more important. Social norms elevate active modes and low-carbon vehicles in status and demote large cars, single-occupancy car travel, speeding and air travel.

Efficient, low-energy and zero energy (non-motorised) transport systems will replace current petrol and diesel car-based systems. The increased uptake of slower, active modes reduces average distances travelled as distance horizons change. Localism means people work, shop and relax closer to home and long- distance travel will move from fast modes (primarily air and the car) to slow- speed modes covering shorter distances overall (local rail and walking and cycling). The novelty of air travel wanes as not only does it become socially unacceptable to fly short distances, airport capacity constraints mean it becomes less convenient. Weekends abroad are replaced by more domestic leisure travel but this is increasingly carried out by low-carbon hired vehicles, rail and luxury coach and walking and cycling trips closer to home. It also becomes socially unacceptable to drive children to school. However, capacity constraints limit the pace of change so that mode shift to buses and rail will be moderated. New models of car ownership are embraced. This includes car clubs[3] and the tendency to own smaller vehicles for every day family use and to hire vehicles for longer distance travel. These are niche markets in which new technology is fostered. Lower car ownership is correlated with lower car use.

---

[3] In the UK, Car clubs are 'pay as you go' car hire schemes known as 'Car sharing' in many other European Countries.

The new modes, in turn, will result in a new spatial order towards compact cities, mixed land uses and self contained cities and regions. Some services return to rural areas, but it becomes more common to carry out personal business by internet. Small-scale technology facilitates relatively rapid behavioural change. Information and Communication Technology (ICT: telematics, in-car instrumentation, video conferencing, smartcards, e-commerce) makes cost and energy use transparent to users and changes everything from destination choice, car choice, driving style and paying for travel, including in the freight sector. A more radical change takes place through changes in work patterns and business travel. The impacts of teleworking and video conferencing are known to be complex, but potentially important (Gross et al., 2009). Teleworking particularly affects the longer commute trips and thus has a disproportionately large impact on average trip lengths. Increased internet shopping and restrictions on heavy goods vehicles, particularly in town centres, increases the use of vans. There is some shift towards rail freight.

There is increasing acceptance of restrictive policies in the context of more choice for local travel as the alternatives are improved. These restrictions include the general phasing out of petrol/diesel vehicles in town/city centres through low emission zones, increased parking charges and strict speed enforcement. Generally, however, the policy environment is one of ‘push and pull’ as fiscal and regulatory sticks are combined with the carrot of infrastructure investment (e.g. in car clubs, public transport, cycle infrastructure, railway capacity). Combined with the shifts towards active modes and different models of car ownership, this amounts to significant lifestyle shift.

Some present benefits of private travel would be lost, such as privacy and the psychological benefits of driving and flying abroad. However, the changes would bring its own benefits (Moriarty and Honnery, 2008). Active travel modes would become safer and less stressful, and their more widespread use would enhance both health and fitness levels (Woodcock et al, 2007). Fewer vehicle traffic casualties would result and, if allowable speeds for remaining road vehicles were greatly reduced, so would injury severity in any remaining collisions. The changes would also lead to a reduction in air and noise pollution, and in community severance from heavily trafficked roads. Urban land currently used for car-parking, and some road space, could be freed up for other uses. The new system would be more equitable, since it would not only be cheaper than a car-based system, but also would not limit access for those without a driving licence, as is presently the case (Moriarty and Honnery, 2008).

Much of the creativity and change needed for large travel reductions would come from individual households modifying their daily travel patterns in unique ways to adjust optimally to the new constraints. Based on current travel patterns and the evidence in the UK and elsewhere on the scale of voluntary travel behaviour change achieved through ‘smarter choice’ measures, much of this can be done quickly (Cairns et al., 2004). For instance, 25% of car trips in the UK are less than 2 miles, 50% less than 5 miles (NTS); average car occupancy for commuting trips is 1.2 people; 24% of households already live without a car. Recent intensive implementation of measures such as individualised marketing to households, travel planning, awareness campaigns and cycle infrastructure improvements in three demonstration towns in the UK has illustrated the scale of change to be achieved when such measures are 'mainstreamed'. Not only did the baseline research carried out in the three towns (Peterborough, Darlington and Worcester) conclude that 32% of car trips undertaken by local households had an alternative available and were not restricted by other constraints, monitoring after two years of implementation showed car driver trips had reduced up to 11%, cycling had increased up to 60%, walking 13% and public transport 11% across the whole of the towns (i.e. taking into account target and non-target areas) (ref). Similar 'quick wins' exist with respect to car purchasing behaviour where there is an average of 25% different between the highest and lowest emitting car in any of nine vehicles classes in the UK market, suggesting that, even without downsizing, significant savings can come from consumer choices over the next decade (King, 2008). Similarly, just over half of cars are driven over the 70mph speed limit on UK motorways and dual carriageways, 18% above 80 mph where there is a large fuel penalty (Anable et al., 2006). For all these changes, ICT will help to both reduce the need to travel by supplementing it with 'virtual' opportunities and will inform travel choices by making options, fuel use, costs and emissions transparent in real time.

So, how would such a shift to sustainable transport be realised? Despite the non-price influences on demand discussed above, we know transport demand can in principle be reduced dramatically by applying sufficiently high road user charges, fuel taxes and taxes on car ownership (refs). However, a more equitable approach could include government policies such as much lower maximum road speeds, a removal of (petrol/ diesel driven) cars and greater parking restrictions in urban centres, an end to road building and widening, provision of extra public transport services and infrastructure for non-motorised modes and incentives to use these modes.

There will be more flexibility in local public transport provision (demand responsive buses, bus companies becoming 'travel providers' thus also offering car hire for at least part of the journey). Generally there will be improved integration of public transport, semi-public transport (taxis etc), car rental, car sharing and car pooling with the help of integrated information, booking and payment systems (Vibat). For instance, technological innovation allows for the introduction of a national travel card to allow payment and stored value for all travel related purchases. This will be loaded with credits for certain user groups such as the elderly and the unemployed etc. This may take the form of a smart card incorporated within a mobile phone (or personal communicator), that can be used for all forms of communication and information service and will include real time information on travel services and facilities (Hickman and Banister, 2007). It will include car club and car rental facilities. This will also have an advisory function in that it will suggest alternative travel options. The transition to these flexible systems which blur the boundaries of private and public transport and are increasingly dependent on communications technology are a perfect example of a 'new functionality' described by Geels (2005). As communications and transport technologies become positively reinforcing and aligned with social visions and values, a 'system innovation' with regard to the status and usage of (flexible) public transport networks will occur.

Such policies would be combined with regulatory and fiscal policies to encourage market transformation of the vehicle market and accelerate the uptake of low carbon vehicles. Nevertheless, given the potential for rebound as efficiency gains lead to cheaper unit costs of travel, total motoring costs must outpace efficiency gains in order for real carbon cuts to be achieved. The evidence on the potential for these policies to change behaviour has recently been reviewed within UKERC (Gross et al, 2009; UKERC, 2009).

5.4 Modelling lifestyle mobility energy demand

5.4.1 Spreadsheet modelling of future travel patterns

The consequences for travel patterns of these shifts were first analysed using a spreadsheet model which took as its starting point the figures for individual travel patterns in 2007 based on the UK National Travel Survey (DfT, 2008). Figures for each journey purpose (commuting, travel in the course of work, shopping, education, local leisure, distance leisure and other) in terms of average number of trips, average distance (together producing average journey length), mode share and average occupancy were altered based on an evidence review relating to the impact of transport policies and current variation in travel patterns within and outside the UK.

The underlying principle of the derived projections of 'lifestyle' travel patterns is that they should be internally consistent and plausible. The method of how they were derived implies that they do not present a forecast using an econometric transport demand model, or a 4-stage transport demand network model. Specifically, the lifestyle projections of travel demand are not the result of changes in income or price elasticities of demand, GDP or population growth. The derived 'Lifestyle' travel demand projections actually imply gradually lower income (and population) elasticities of demand as incomes and population continue to grow in all four scenarios considered in this paper (see Table 1). Notably, in order to avoid double counting once these projections were eventually fed into MED, the transport demand elasticities in the Lifestyle MED runs were set to zero.

5.4.1.1 Average distance travelled

The proportion of travel carried out for certain journey purposes will not stay the same. Partly as a result of the ageing population and partly due to the increase in domestic leisure travel, work, business and school journeys will fall as a proportion of total travel. Each journey purpose will be subject to slightly different pressures (including social pressures) and policy targets.

The 2007 National Travel Survey statistics were used as the starting point for the assumptions regarding number of trips and average trip distance in future years (DfT, 2008). Figures for 2007 can be seen in Table 6 Calculations for average number of trips and trip distances per person for each journey purpose below. For each journey purpose, average number of trips and trip lengths were adjusted upwards or downwards for the years 2020 and 2050 on the basis of the following assumptions:

- Impacts of an ageing population: As a proportion of the adult population, over 65s are set to increase by 21% and 53% respectively by 2020 and 2050;
- Impacts on travel behaviour from a range of hard and soft transport measures based on evidence of best practice in the literature.

The main assumptions are outlined in **Error! Reference source not found.**:

Table 5 Assumptions regarding trips and trip distances for each journey purpose

Journey purpose	Assumptions	
	No of trips	Average trip length
Commute	Assuming the retirement age stays the same, the average number of work trips per adult will reduce due to ageing population. The proportion of those in work who are teleworking increases due to tax incentives, travel plans, broadband-roll-out, and road user and parking charges.	Teleworking abstracts more of the longer commute trips and therefore has a disproportionately large impact on average trip lengths. The proximity principle assumes there is movement towards living closer to work places. NB: The potential effect on home energy use has been excluded due to lack of credible evidence.
Business	Evidence concludes tele/ video conferencing could reduce business trips by 18% after 10 years (Cairns et al., 2004). This was extrapolated to reach 30% maximum reduction in trips on the basis there are many business trips which cannot and will not be avoided.	There is no obvious reason why the average distance of the majority business trips remaining should change. However we assume a disproportionate number of longest trips are substituted by tele/video conferencing encouraged by better facilities, higher travel costs and the drive to corporate social responsibility.
Shopping	Those aged 65+ make 46% more trips for food shopping. Food shopping accounts for around half shopping trips (= 23% extra) (Solomon and Titheridge, 2006). Cairns et al., (2004) suggest home shopping could reduce vehicle mileage for shopping by 4% after 10 years. Here we assume 5% fewer trips by 2020 and 20% by 2050. However, this will also increase van use but will be facilitated by co-ordinated distribution.	A shift towards more local shopping patterns is assumed due to more elderly who tend to shop locally, the introduction of parking charges in all public spaces and the move towards use of walking and cycling which increases frequency but reduces ave. trip distance. Restriction of cars in urban areas means shorter, local journeys become more attractive.
Leisure - local	The retired make more leisure trips as a proportion of their total but fewer in absolute terms due to income and mobility factors and fewer trips for sport and visiting friends and family. However, this may change in the future. We assume there is no impact on balance due to the ageing but there is a general shift in all age groups towards more frequent local leisure at the expense of longer trips due to social pressure to reduce flying, the general	Although there is a shift towards walking and cycling and some bus and train use around the local area, this does not reduce the average length of local leisure trips. With leisure, it is mainly modes that change, not the number or length of trips.

Journey purpose	Assumptions	
	No of trips	Average trip length
	increasing cost of motoring, and the general move to low carbon modes.	
Leisure – distance	Retired people initially tend to make more trips, but as they become older and disabilities intervene, trip making tails off. Fewer people travelling abroad means more domestic holidays – however, the increase in weekends away will be balanced by fewer distance day trips (due to affordability as price of travel increases) with people using their local area more instead.	There are fewer day trips and more people cycling and walking from home but some longer holiday trips (weekends away) to replace travel abroad – means that on balance average distance stays the same.
School	An older person makes very few work or education trips – just 24 trips per person per annum on average, less than 3% of their total annual trips. There is no other reason why the number of trips to school should reduce.	School selection policy is revised to insist that 'local schools' are chosen so average trip lengths fall.
Other	On average those 65+ make 33% more trips than the UK average person makes in a year for non food shopping and personal business purposes (e.g. almost twice the number of trips for medical purposes). However, it will increasingly be the norm to access many services such as banking and even medical care on-line.	Re-introduction of local clinics, post office/ banking services etc especially in rural areas. Restriction of cars in urban areas means that shorter, local journeys become more attractive.

Table 6 Calculations for average number of trips and trip distances per person for each journey purpose

	Year	No. Trips# (pppa)	Ave. Trip Length (km pppa)	Total ave. distance (km pppa)
Commuting	2007*	160	13.6	2168
	2020	137	12.9	1767
	2050	119	10.0	1199
Business	2007	35~	33.3	1167
	2020	30	32.3	983
	2050	21	28.3	604
Shopping	2007	219	6.8	1490
	2020	224	6.5	1450
	2050	209	5.4	1140
Leisure – local	2007	117	11.2	1308
	2020	120	11.2	1348
	2050	128	11.2	1439
Leisure – distance	2007	154	20.7	3203
	2020	154	20.7	3203
	2050	154	20.7	3203
School	2007	106	4.6	492
	2020	101	4.5	454
	2050	93	3.7	346
Other	2007	247	6.7	1648
	2020	244	6.3	1544
	2050	206	5.3	1098
Total	2007	1038	11.1	11477
	2020	1011	10.6	10750
	2050	932	9.7	9029

Only includes surface passenger modes (i.e. not air trips)

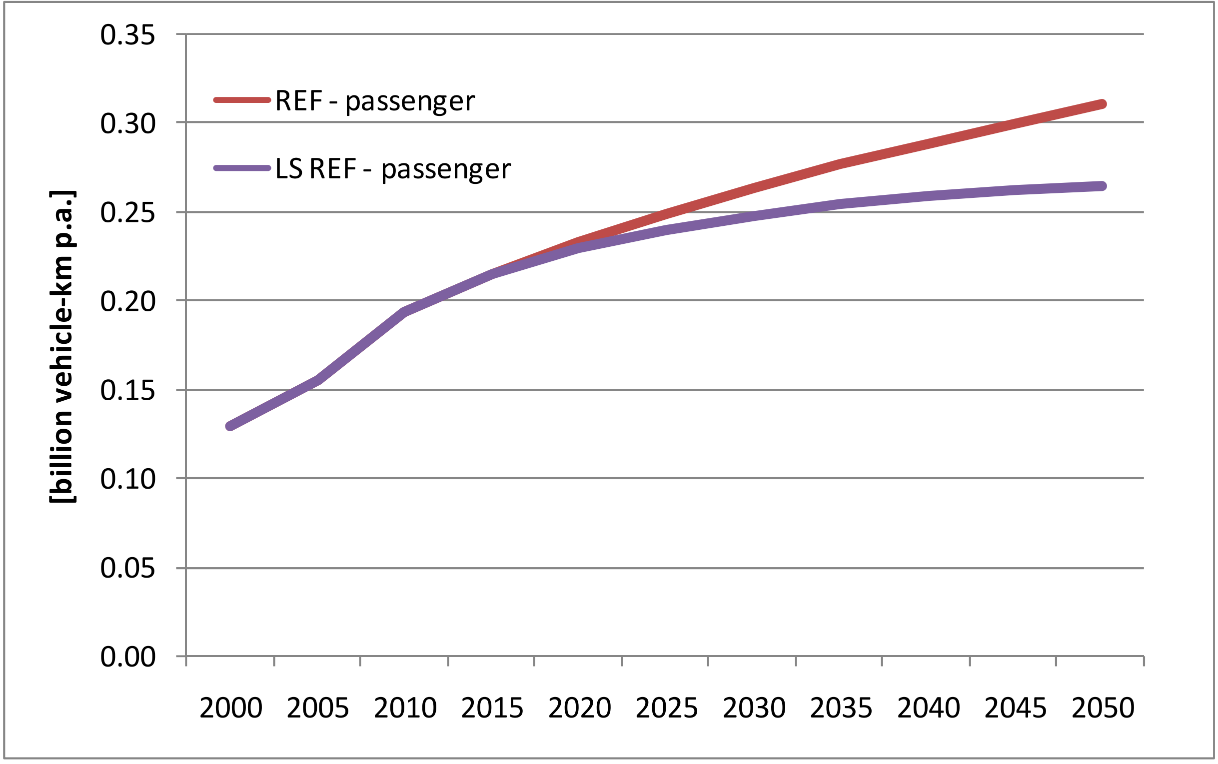
* 2007 figures are based on TSGB, Table 1.4 (DfT, 2008b) and converted into kilometres (1 mile = 1.607km)

~ Based on Focus on Personal Travel Table 3.1 – gives trips and distance per person per year broken down by commute and business for 2002/03

In summary, therefore, total distance travelled by surface passenger modes reduces by 6% by 2020 and by 21% by 2050 in this scenario. This is predominantly due to significant alterations in work and business practices as trips and trip lengths are reduced through substitution of longer trips by tele and video-conferencing and a smaller population of working age. The number of leisure trips increases overall, but many longer trips are gradually replaced by trips closer to home, as is the case with shopping and personal business trips which are also reduced by more home deliveries. Overall, travel horizons are reduced as travel becomes more expensive and the use of the car is restrained through road space reallocation, parking and user charges and a removal from urban centres.

Some assumptions were also made regarding domestic air travel and surface freight movements. With regard to air travel, growth in domestic flights are assumed to slow and eventually saturate due to cost disincentives as the price of flying is increased and due to competition from rail and a growing unacceptability of flying short distances. Flying becomes a luxury and becomes increasingly uncompetitive on the basis of time and cost for most domestic routes as the price increases and rail is improved. Average load factors are assumed to stay unchanged compared to the REF scenario. As a result, any changes in passenger-km translate directly into vehicle-km, as shown in Figure 7: Demand for domestic air travel by mode and scenario.

Figure 7: Demand for domestic air travel by mode and scenario



With regard to light van traffic, van ownership and use continues to increase pretty much as it did in the decade prior to 2007, growing by 138% by 2050 over the 2005 levels. The move towards a service economy and more teleshopping fuel this trend. As van technology improves and their cost of ownership and use declines, this further encourages their use. Town and city centres increasingly ban heavy goods vehicles but allow electric vans and local traffic regulations will give priority to professional home delivery and coordinated urban distribution with clean vehicles. As a result, the overall distance travelled by vans will *increase* by 5% by 2050 in this scenario when compared to the reference scenario.

With regard to heavy goods vehicles, we assume in this scenario that their use is still set to grow (by 36% between 2005 and 2050) but as a result of increased load factors, overall distance travelled by these vehicles will fall by 3% (2020) and 12% (2050) when compared to the reference scenario. Changes in consumer demands (including through origin/ carbon labelling and the substitution of products with services) may lead to reductions in freight movements, but the greatest savings will come from more efficient logistics. The ‘lorry intensity' of the UK economy (the ratio of lorry-kms to GDP) declined by almost 20% between 1990 and 2004, partly as a result of companies using vehicle capacity more efficiently (Mackinnon, 2007). There, nevertheless, remains considerable potential for improving 'vehicle fill'. Companies can adopt a range of vehicle utilization measures which would lead to reduced lorry-kms and CO_2 emissions. In some cases this will require changes to current business practice utilising integrated logistic services pertaining to several steps of production and distribution and based on complex information systems. These changes will require policy support for the development of technologies and standards for automatic flexible freight handling and tracing together with the introduction of CO_2 related taxes for freight vehicles to effectively raise road transport costs and the implementation of consolidation centres (Hickman and Banister, 2007). These changes will together mean the growth in heavy freight will be substantially reduced, particularly by road. Rail and waterborne freight play a bigger role, mainly due to mode shift from roads (discussed next).

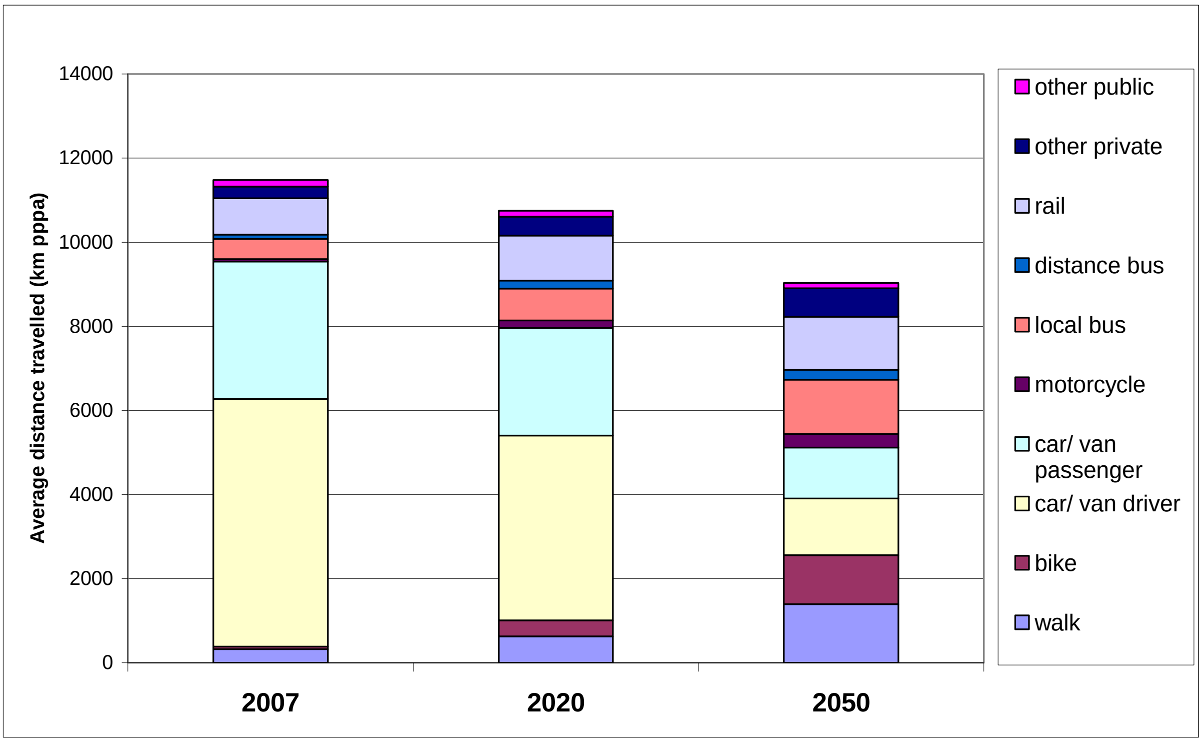
5.4.1.2 Mode shift

Mode shift was calculated by once again starting with figures from UK national travel statistics for 2007 (DfT, 2008) and, on the basis of evidence based assumptions about demographic, normative and policy related changes in **Error! Reference source not found.**, proportions of distance travelled in different mileage bands were reallocated to different modes for 2020 and 2050. The results of this process can be seen in **Error! Reference source not found.**and Figure 8.

Table 7 Distances travelled (km) by each mode in each year and (%)

	Distance per year (km pppa)			Proportion of distance		
	2007	2020	2050	2007	2020	2050
walk	323	634	1,396	2.8%	5.9%	15.5%
bike	63	377	1,160	0.5%	3.5%	12.8%
car/ van driver	5,890	4,391	1,350	51.3%	40.9%	15.0%
car/ van passenger	3,271	2,556	1,211	28.5%	23.8%	13.4%
motorcycle	55	185	326	0.5%	1.7%	3.6%
local bus	477	757	1,289	4.2%	7.0%	14.3%
distance bus	101	188	237	0.9%	1.8%	2.6%
rail	870	1,068	1,257	7.6%	9.9%	13.9%
other private	273	448	681	2.4%	4.2%	7.5%
other public	155	145	122	1.3%	1.3%	1.3%
Total	11,477	10,750	9,029	100	100	100

Figure 8: Mode split in 2007, 2020 and 2050



From this it is apparent that our scenario assumes people become progressively more 'multi-modal' by the end of the period using the most appropriate, efficient and cost effective mode for each journey undertaken. In 2020, the car is still used for the majority of distance travelled as a driver or passenger (67%), but this drops to 28% by 2050. This translates into a reduction of 70% in distance carried out as a car driver in privately owned vehicles. However, 'other private', (which includes taxis, hire cars and car club cars) increases from 2.4% of distance in 2007, to 7.5% so that, combined with being a car passenger, 36% of all distance is still undertaken by car in 2050. The motorbike experiences a considerable renaissance, growing in share from just 0.5% in 2007 to 3.6% in 2050. At the same time, cycling goes from accounting for less than 1% to almost 13% of distance travelled. This surpasses levels seen today in countries regarded as demonstrating best practice in this area: in 2006 an average Dutch person cycled 850km per year, corresponding to around 8% of total distance travelled (SWOV, 2006). We have chosen to push this further in 40 years time on the basis that the Dutch have achieved this level so far without comprehensively restricting cars from urban centres and increasing the cost of motoring which this lifestyle scenario entails. If cycling and walking are added together, 'slow modes' account for 28% of travel in 2050. Implicit in the assumptions made here is the fact that cars are increasingly banned or priced out of city/ town centres.

Another notable difference is the doubling of mode share of local bus use. The latter includes bus rapid transit systems, park and ride and demand responsive modes, particularly in rural areas. Most urban bus service use electric vehicles. 'Other public transport' could include light rail and underground systems, but nothing has been assumed to happen with this mode. Also, any shift to rail has been within existing capacity, albeit significantly upgraded (e.g. double-decker trains where possible), and no high speed rail is assumed on the basis that this is deemed to be too energy intensive in this carbon conscious future (Givoni et al., 2009). Together, bus and rail add up to 32% of distance in 2050, slightly more than double the 2007 share of 14%.

The **combined effects** of the above changes in **distance travelled** (5.4.1.1) and **mode shift** (5.4.1.2) can be seen in Figure 9 (passenger) and Figure 10Figure 10 (freight), comparing transport demand for the REF and LS REF scenarios for the years 2007, 2020 and 2050.

Figure 9: Demand for passenger transport (in passenger-km)

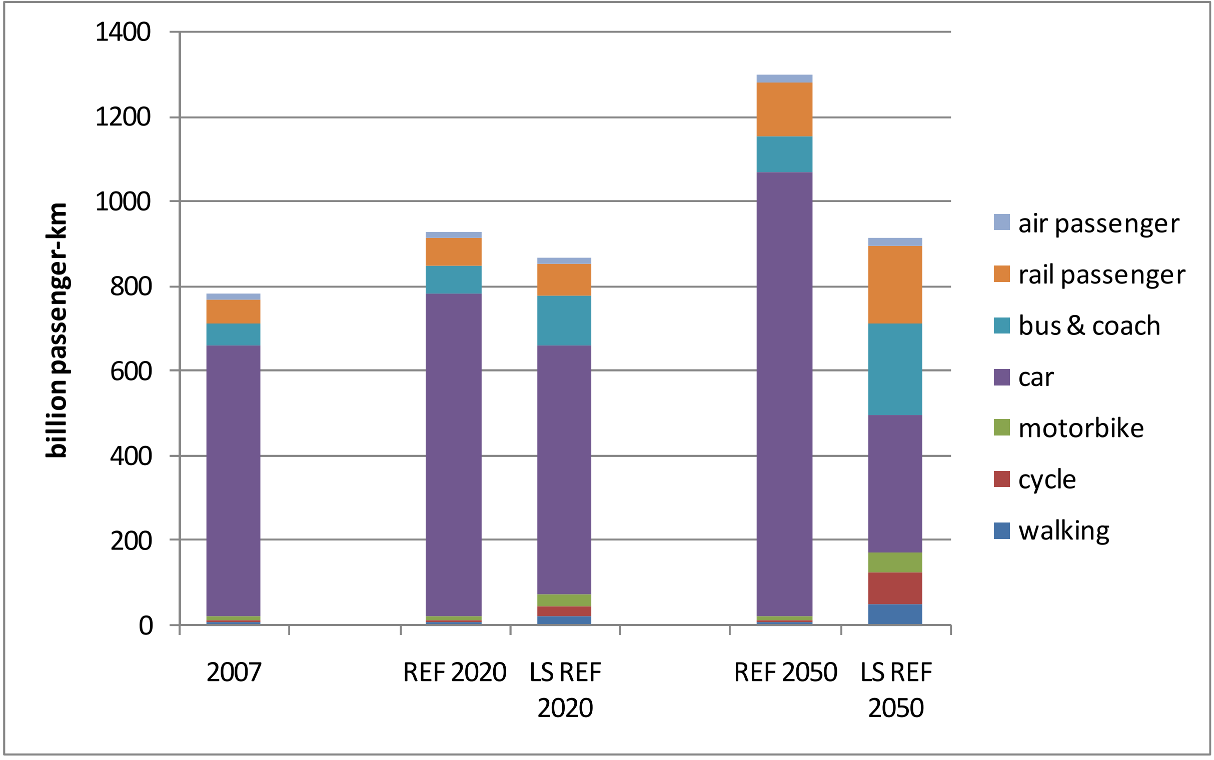
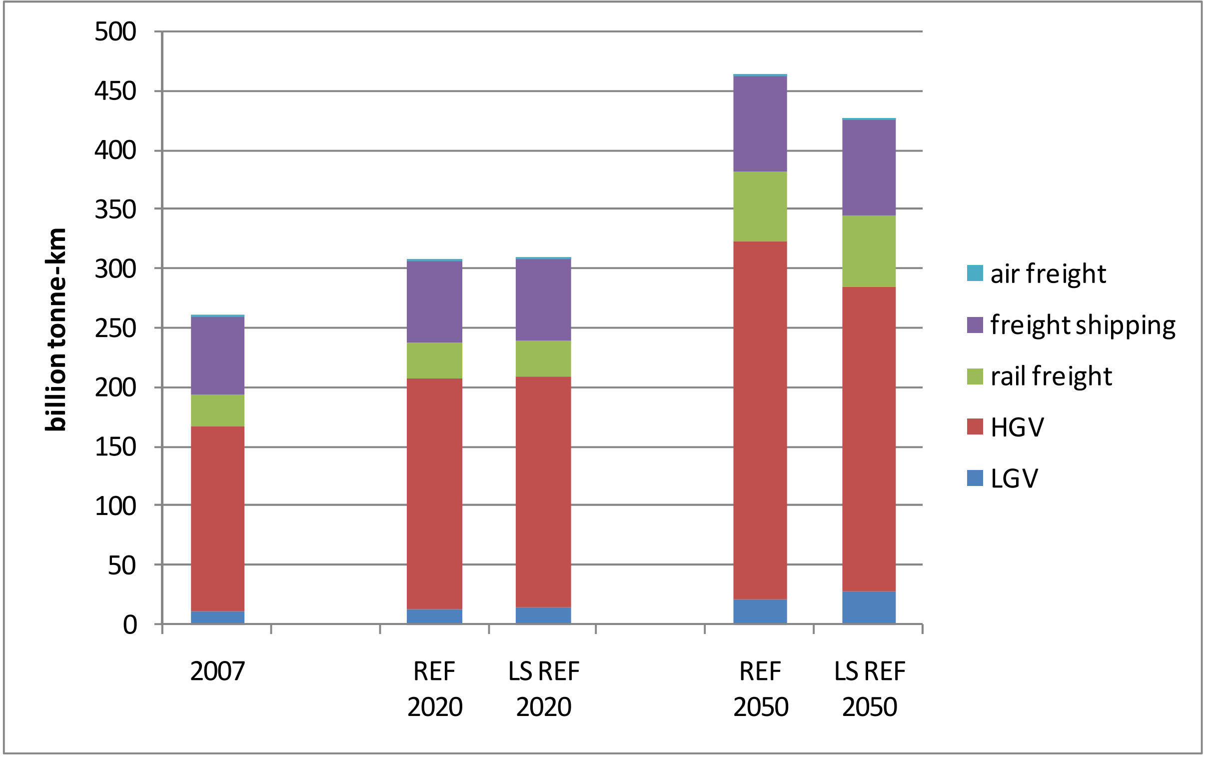


Figure 10: Demand for freight transport (in tonne-km)



5.4.1.3 Vehicle occupancy

There is much debate about the potential to increase efficiency of car use (and thus per passenger carbon emissions) by improving the occupancy rates of vehicles, particularly through the use of communication systems to permit drivers to match their journeys with others to increase levels of car sharing. Initially this would be work based, but it can be expanded to cover other activities (such as shopping and sports).

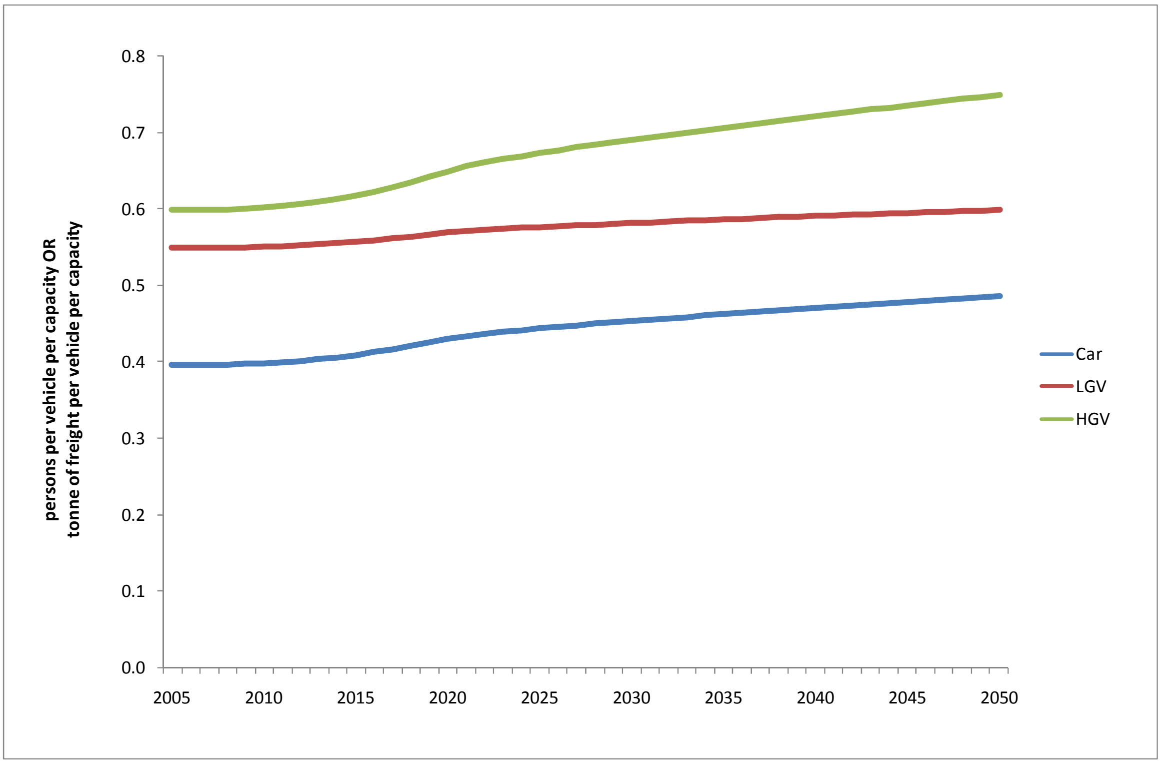
Table 8 demonstrates our thinking on the scope to improve this aspect of travel behaviour, once again based on the evidence – this time pertaining to car occupancy and car sharing initiatives. Our analysis concludes there is much scope for improving the utilisation of cars during both the commute and the journey to school, but less scope for other journey purposes. Whilst the reduction in short shopping journeys may lead to longer, ‘family’ shopping trips and a higher occupancy, leisure journeys by car already tend to be carried out with more than one member of the family. Overall, therefore, we calculate a 9% (2020) and 23% (2050) improvement in overall car occupancy. Similarly, load factors increase for HGV (higher rate than cars) and LGV (lower rate) (Figure 11).

Table 8 Car occupancy for each journey purpose 2007, 2020 and 2050 and assumptions made

	2007	2020	2050	Assumptions
Commute	1.2	1.6	1.9	Increased car sharing, HOV lanes, employer incentives plus reduction in short, SOV trips. It becomes socially unacceptable to drive the car alone to work
Business	1.2	1.3	1.4	This may creep up slowly as the shortest business trips are transferred to other modes. However, not much scope for change.
Shopping	1.7	1.9	2.1	Short trips with only one person in the car are reduced thus increasing the average occupancy.
Leisure – local	1.7	1.7	1.7	Car occupancy is already quite high for short leisure trips and thus not much scope to change.
Leisure – distance	2.0	2.0	2.0	Car occupancy already high and not much scope for change
School	2.0	2.2	2.5	Much scope for change here as access to schools by car is restricted, short journeys are switched to alternative modes. It becomes socially unacceptable to drive kids to school.
Other	2.0	2.0	2.0	There may be little scope to change the car occupancy of these disparate journeys.
*Total**	1.58	1.72	1.94	This equates to a 23% improvement between 2007 and 2050

* Weighted by car miles conducted for each journey purpose

Figure 11: Lifestyle projections of specific load factors for cars, LGV and HGV in the lifestyle scenario



Load factors were also calculated for LGV and HGV on the basis of assumptions about utilisation of vehicles. While load factors stayed constant at the 2007 level, we assumed they change over time in the lifestyle scenario (**Error! Reference source not found.**). By raising vehicle load factors it is possible to reduce the amount of commercial vehicle traffic (measured in vehicle kms) required to move a given quantity of freight (measured in tonne-kms). There is a corresponding reduction in energy consumption and CO_2 emissions. In addition to reducing these externalities, improved loading also increases the efficiency of delivery operations. This measure therefore has the advantage of yielding economic as well as environmental benefits and, in most cases, being self-financing (MacKinnon, 2007).

Table 9 Load factors for LGV and HGV in the lifestyle scenarios

	Load factors			
	2007	2020	2050	Assumptions
HGV	60.0%	65.0%	75.0%	The average weight-based utilisation of lorries on laden trips has declined from 62% in 1997 to 57% in 2003 (Mackinnon, 2007). Following analysis from Mackinnon, it was assumed that, by raising vehicle load factors it is possible to reduce the amount of commercial vehicle traffic (measured in vehicle kms) required to move a given quantity of freight (measured in tonne-kms). Improved loading also increases the efficiency of delivery operations. This measure therefore has the advantage of yielding economic as well as environmental benefits and, in most cases, being self-financing. The use of telematics, however, can help fleet managers to organize backhauls across congested road networks.
LGV	55%	57%	60%	The current load factor for LGVs is smaller as the HGV load factor is optimised as far as possible by fleet managers and empty running is greater (AEA Technology 2005). As only approximately 35% of van traffic can be classified as 'freight' (Mackinnon, 2007), it is assumed there is less opportunity for load consolidation.

5.4.2 Transport sector modelling in UKTCM

The set of 'Lifestyle' transport energy serviced demands developed above was entered into UKTCM as exogenous transport demands. In addition, lower multiple car ownership was simulated by lowering the car ownership saturation levels for households owning 2 or more cars.

By 2020 no 'large cars' (above a certain engine size and gross vehicle weight) are being sold. The changes in social norms, consumer preferences, improved performance and market presence of low carbon road vehicles (essentially efficient Hybrid Electric Vehicles (HEV), Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV)) were modelled by assuming low carbon road vehicles have gradually increasing consumer preferences, performance and market availability up to the point where they are comparable (or even better) than their conventional counterparts of a certain reference technology (e.g. medium size gasoline internal combustion engine car of vintage 2015-2019). The scale and timing of these changes have been modelled on the assumptions behind the high- to extreme-range technology scenarios of the recent scoping exercise commissioned by UK Government Departments (BERR & DfT, 2008), and further informed by low carbon transport scenario work such as reported in Hickman and Banister (2007). Within the UKTCM discrete choice modelling framework, equal preference implies equality in perceived market potentials (availability of infrastructure), perceived risk (fuel type, 'proven' vs. 'new' technology) and performance (range, speed, acceleration, etc.).

No changes in investment and fixed Operation and Management (O&M) costs were assumed, as consumers of tomorrow choose to buy greener vehicles not on the basis of reduced purchase prices but on the basis of changed preferences for and perceived risk of a low carbon vehicle.

Finally, the on-road fuel efficiency programme and general adherence to speed limits was modelled by assuming an alternative set of speed profiles for motorways and dual carriageways, with direct effects on on-road fuel consumption.

In sum, the following changes were made to the UKTCM 'reference' scenario (also called REF in order to be consistent) in the UKTCM 'lifestyle' scenario (LS REF):

- Vehicle technology choice: private, fleet and commercial buyers prefer lower and zero carbon vehicles;
- Downsizing cars;
- Implementation of a nationwide on-road fuel efficiency programme;
- Lower levels of household car ownership in urban areas.

These changes are described in more detail as follows.

5.4.2.1 Vehicle technology choice

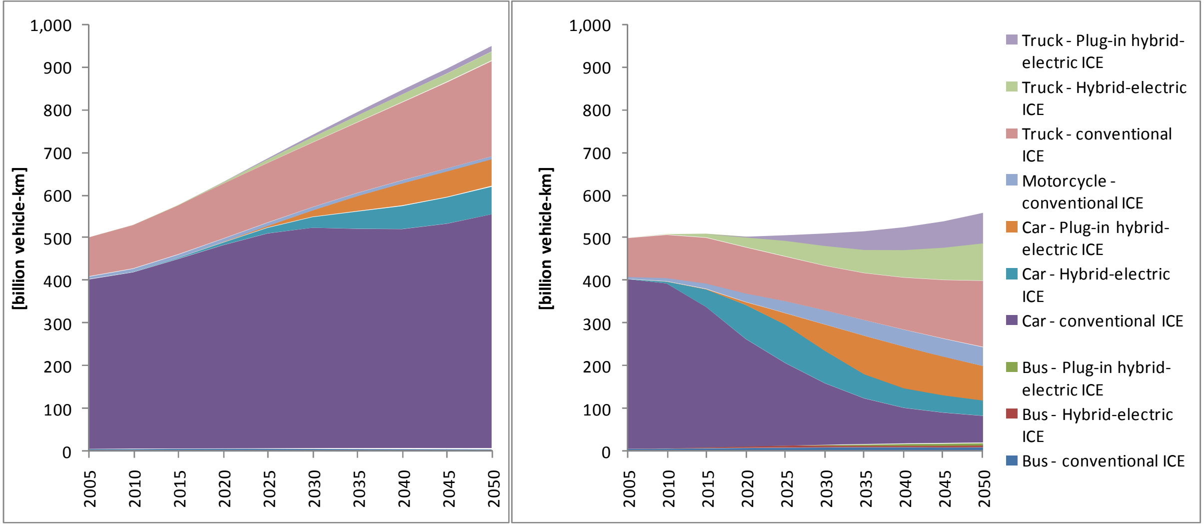
With respect to car choice, the higher uptake of low carbon vehicles has been modelled in UKTCM by assuming more favourable preference and performance parameters than in the reference (REF) case for Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV) and Plug-in Hybrid Electric Vehicles (PHEV). The scale and timing of these changes have been modelled on the high to extreme technology scenarios of the recent scoping exercise commissioned by BERR & DfT (2008) and other scenario work such as reported in Hickman and Banister (2007). This entails:

- Ultra efficient ICE and HEV vehicles will be the main focus in the short term (<2020);
- BEV fulfil market niche roles in the medium term, especially electric buses, cars and vans in urban areas (approximately 2015-2030);
- PHEV dominate vehicle sales in the medium to long term (from 2025), coupled with a decarbonised electricity supply system.

The scenarios were reproduced in UKTCM by assuming that, at equal lifetime costs, consumers show *equal preference* for conventional and EV/HEV/PHEV vehicles and, in some cases, prefer the latter by a ratio of 2-to-1. As described earlier, equal preference implies equality in perceived market potentials (availability of infrastructure), perceived risk (fuel type, 'proven' vs. 'new' technology) and performance (range, speed, acceleration, etc.). No changes in investment and O&M costs were assumed, as consumers of tomorrow choose to buy greener vehicles not on the basis of reduced purchase prices but on the basis of changed preferences for and perceived risk of a low-carbon vehicle.

The results of modelling technology preference can be seen in the road vehicle traffic in the reference (REF, on the left) and lifestyle (LS REF, on the right) scenarios shown in Figure 12. In LS REF, total road vehicle-km stay about constant at the current levels (while they nearly double in the REF scenario), and conventional ICE technology is gradually replaced by HEV and PHEV technology. While in 2007 more than 99% of new cars are conventional ICE vehicles, the LS REF scenario suggests that by 2020 28% of new cars will be ultra-efficient HEV, 16% small BEV, and 8% PHEV. By 2050, nearly half (46%) of new cars will be PHEV, 18% HEV and 9% small BEV.

Figure 12: Road traffic by vehicle type and propulsion technology (REF on the left, LS REF on the right)

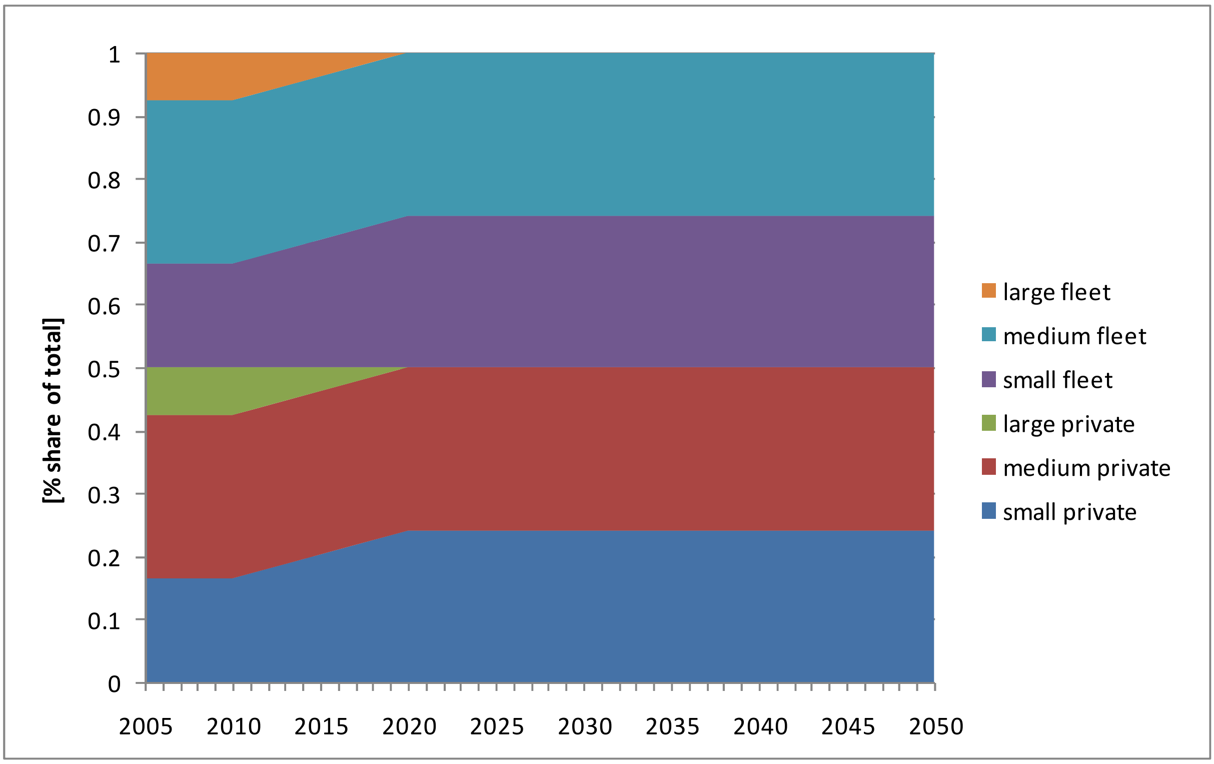


Note: Although not shown separately, electric vehicle-km (mainly cars and motorcycles) in the REF scenario peak around 2035 at 19 billion km (2.5% of the total), while in the LS REF scenario they peak slightly earlier (around 2030) at 52 billion km, or 10% of the total.

5.4.2.2 Downsizing cars

Car buyers – whether private, fleet or business – choose smaller cars instead of larger ones. This is simulated in UKTCM by phasing out the sale of new large cars (engine size >2.0 litres) by 2020 – starting in 2010, with linear interpolation between 2010 and 2020. The assumptions on new car sales by size and ownership type are shown in Figure 13 for the LS REF scenario.

Figure 13: New car sales by size (small/medium/large) and ownership type (private/fleet), LS REF scenario



5.4.2.3 <u>On road fuel consumption – eco-driving and speed enforcement</u>

Eco-driving reduces fuel consumption through more efficient driving style, reducing speeds, proper engine maintenance, maintaining optimal tyre pressure, and reducing unnecessary loads. Policy measures can include information campaigns and encouraging or requiring driver training[4]. The evidence related to eco-driving is very clearly linked to CO_2 emissions and quantifies both potential savings and cost-effectiveness (Gross et al., 2009). Potential savings appear to be significant and costs low, with the biggest obstacles being securing driver participation and ensuring that efficient driving habits are sustained over time. This suggests that if the potential benefits of more efficient driving styles are to be secured, an ongoing programme of training, and reinforcement through advertising and other awareness raising mechanisms is likely to be needed.

In this scenario, the high cost of motoring and the social pressure to improve driving standards for both safety and environmental reasons, mean that efficiency, quality and reliability overtake speed as the priority for travel. Ecodriving is reinforced with strict speed enforcement, high penalties and tax incentives for in car instrumentation such as speed limiters, fuel economy meters, tyre pressure indicators.

Initial calculations were made by estimating how many drivers in any given year would be practicing ecodriving and what proportion of their miles would be affected at what level of

---

[4] Recent examples include the current UK Government 'Act on CO_2' campaign, and the inclusion of an 'Eco-safe driving' element into the UK driving test.

efficiency improvement. In any given year, new drivers will start to practice these techniques, and for others the effectiveness will begin to 'trail off', although it is assumed that the behaviour is reinforced by repeat training programmes and campaigns so that it becomes more or less habitual. Even for those who are practicing it, not every mile they drive will be affected. For those miles affected, an 8% efficiency improvement is assumed. This is at the lower end of the evidence base (Gross et al., 2009). Business uptake of eco-driving is expected to be quicker as it is easier to integrate training programmes and instrumentation. This is a false divide in reality as business drivers are also private drivers, but the reinforcing messages about economical use of fuel when driving for business are assumed greater. Speeding becomes socially unacceptable as it is seen as wasteful. Speed limit enforcement and in-car instrumentation is assumed to be introduced to augment the behaviour change from about 2015.

Ecodriving will also be practiced by LGV (vans) and HGV (trucks) drivers. Penetration through van fleet is expected to mirror that of car business travel. Penetration through the truck fleet is the same as for vans. However, the savings per mile are lower (4%) as these vehicles are already speed limited.

In each case, a certain proportion of distance travelled is assumed to already be benefiting by drivers practicing ecodriving techniques at the beginning of the period (4% in each case). Also, in each case (for cars, vans and trucks) the savings only apply to petrol/diesel vehicles. The potential to save fuel and emissions for alternative propulsion vehicles such as electric and plug-in hybrid electric vehicles is lower, as the propulsion system is already technically optimised, leaving less room for improvement by the driver (Gross et al., 2009).

Table 10 On-road fuel efficiency improvements from ecodriving

	Vehicle distance (km) affected		
	2007	2020	2050
Cars (8% more efficient per km)	4%	46%	62%
Vans (8% more efficient per km)	4%	50%	70%
Trucks (4% more efficient per km)	4%	50%	70%

These assumptions were then combined to derive a time series of aggregate fuel consumption for the car, van and truck fleets. This was then transferred to the UKTCM by scaling the vehicle emissions factors used. For cars, for example, the miles affected reaches 62% by about 2025, times 8% saving in fuel consumption gives 5% in fuel consumption savings, or a scaling factor of 0.95 for fuel consumption and CO_2. This is shown for cars in Figure 14Figure 14, and for vans and trucks in Figure 15.

Figure 14: On-road fuel efficiency of cars – assumptions made in the lifestyle scenario (LS REF)

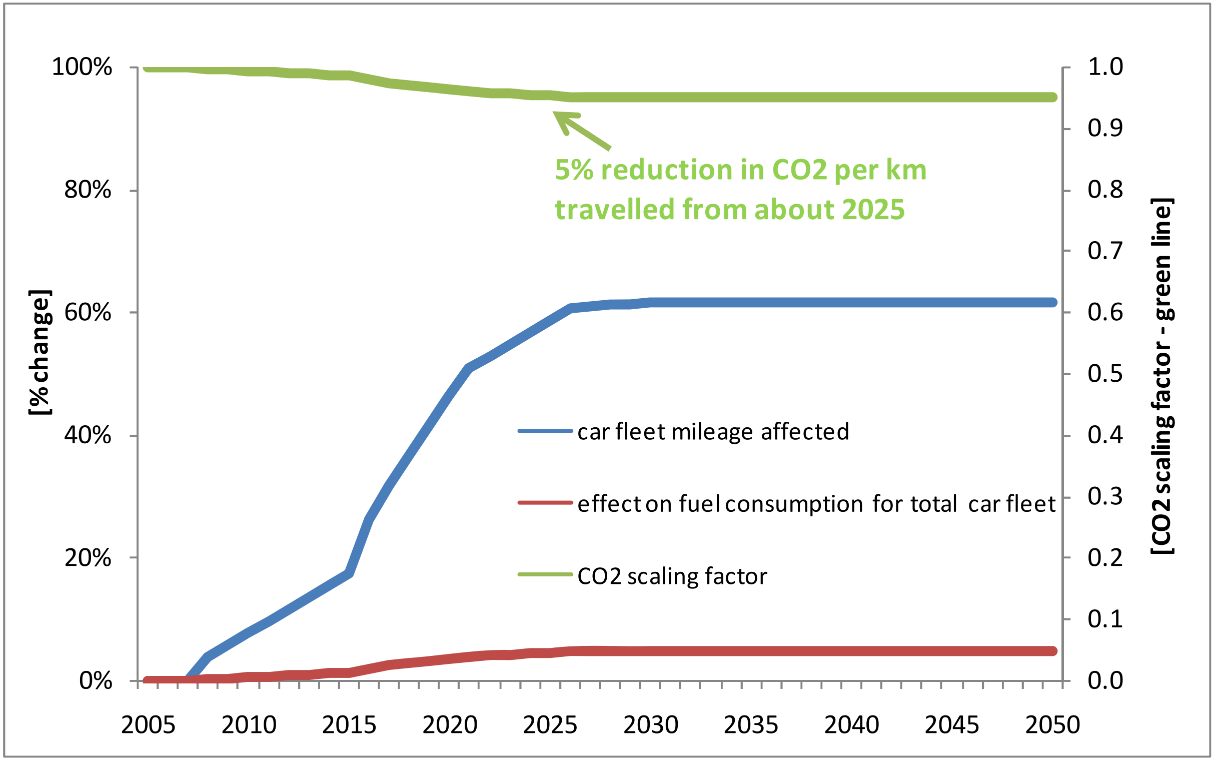
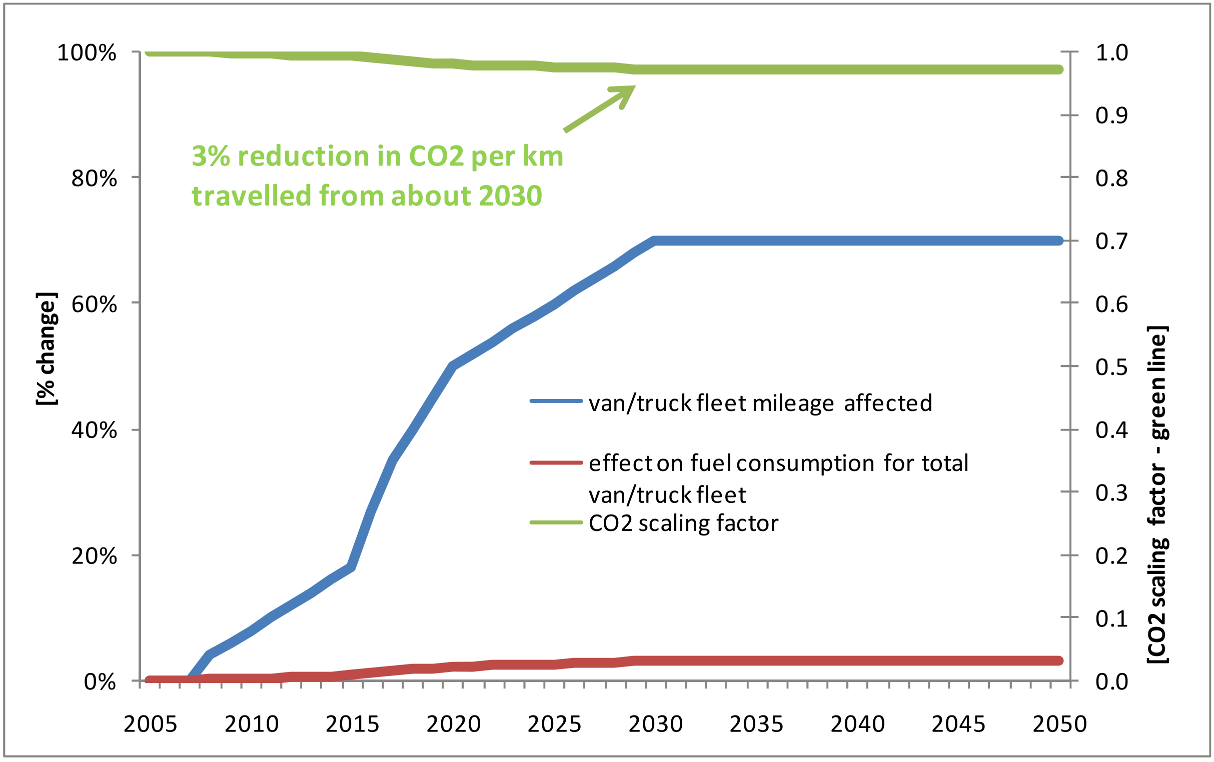


Figure 15: On-road fuel efficiency of vans and trucks – assumptions made in the lifestyle scenario (LS REF)



5.4.2.4 Car ownership

The tendency towards less overall car use and the increased membership of car clubs for use of a variety of types of cars for longer distance journeys is modelled endogenously in UKTCM by assuming significantly lower levels of maximum car ownership per household in urban and non-urban areas – about half of the REF scenario value for households owning 'at least 2 cars' and 'at least 3 cars'. The UKTCM REF case levels are based on assumptions contained in the DfT's National Transport Model, which in turn are close to the sort of levels we see in the US or, closer to home, Italy. By lowering the maximum levels for second, third or more cars per household we basically limit overall car ownership levels for multiple household car ownership.

The modelling shows that the lower trajectory for car ownership levels in the LS REF scenario lags behind the one for car-km. This makes sense as first households use existing cars less, followed by the decision to purchase fewer vehicles as they are not needed anymore.

5.4.2.5 Note on fiscal policy

Although road transport fuel taxation needs to be updated in the current MED model, the current dataset is appropriate for the Energy 2050 exercise. Taxation is generally regarded as a key driver for changing demand, and should ideally be modelled endogenously in the lifestyle scenarios. However, the revised lifestyle mobility demands derived above already include demand changes as a result of lifestyle changes brought about by changes in perceptions, preferences and pricing mechanisms. So in order to avoid double counting taxation levels are kept unchanged from the core scenarios.

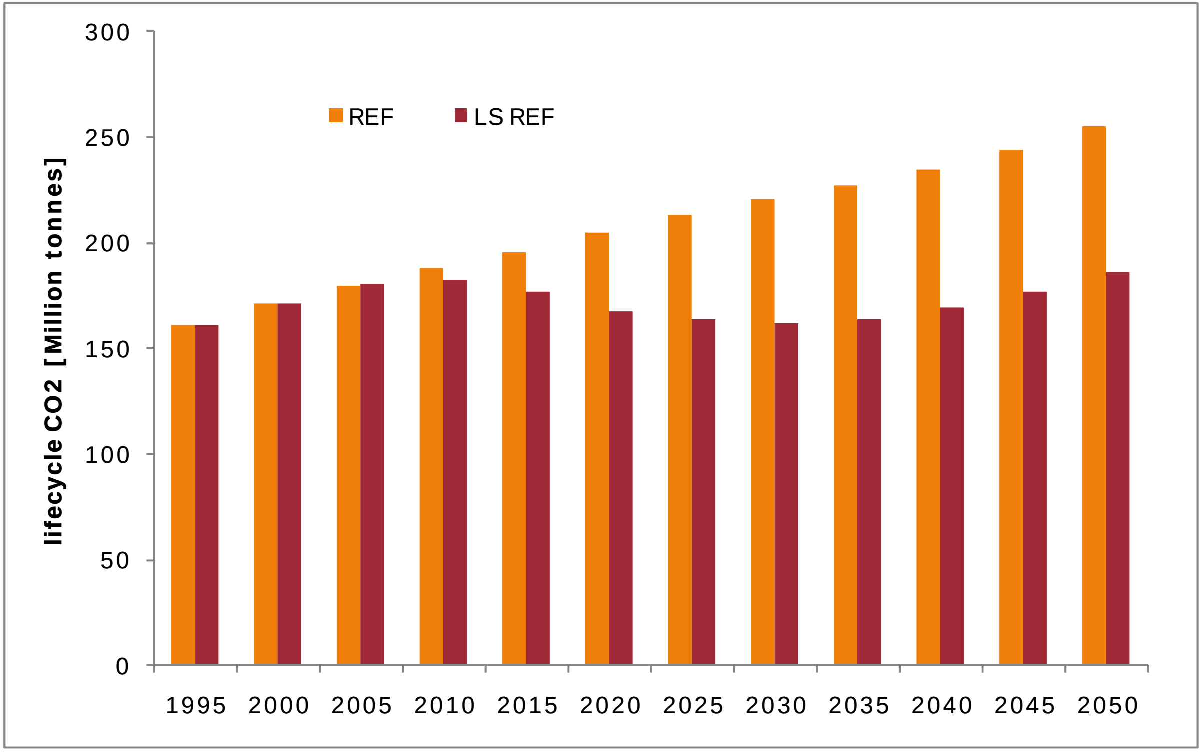
5.4.2.6 Summary of intermediate modelling results

Modelling of lifestyle changes led to a 74% reduction in distance travelled by car by 2050. The use of all other surface transport modes increases, apart from a 12% fall in distance travelled by trucks. The reduction in car travel comes about as a result of significant mode shifts, particularly to bus travel towards the latter half of the period (184% increase in vehicle kilometres) and cycling and walking. The take-up of cycling as a mode of transport reaches the same level in terms of mode split by 2050 as is the norm in the Netherlands today (40% of all trips). Mode shift is combined with destination shifting as trips are either totally abstracted from the system through virtual travel or shorter as a result of localisation.

Lifestyle changes imply that 10% of the UK car parc will be able to connect to the grid by 2020 and 26% of road transport energy demand is met by plug-in electric hybrids (PHEV) by 2050. There is no change compared to the reference case (REF) in the short term, as the numbers remain constrained by the lack of vehicle and infrastructure availability. Car owners downsize and drivers respond to the on-road fuel efficiency programme and speed limit enforcement as the car fleet alone uses 5-6% (2020) and 11-12% (2050) less energy per km driven. For road freight, the lifestyle scenario implies that nearly half of the UK van and HGV fleets will be able to connect to the grid by 2030.

Overall, the lifestyle scenario results in a 26% and 58% reduction in transport CO_2 emissions (at source) by 2020 and 2050 from baseline levels. UKTCM can further model total lifecycle emissions, which are outside the remit of the overarching MED modelling framework. However, for illustration purposes the projected lifecycle CO_2 emissions from transport are shown in Figure 16Figure 16, suggesting 18% and 27% lower emissions in the lifestyle case (LS REF) than baseline (REF) by 2020 and 2050 respectively. Importantly, emissions in 2050 are projected to be back to the levels in 2010 – yet arguably what we need is a significant drop of emissions levels by then.

Figure 16: Scenario comparison of total lifecycle emissions of CO_2 (UKTCM REF, UKTCM LS REF)



5.4.3 Transport energy system modelling in MED

UKTCM outputs (specific fuel consumption, vehicle fleet evolution by vehicle technology) were translated and aggregated into MED inputs (technical energy efficiency, technology deployment constraints and bounds). The general shift in consumer preference was further modelled in MED by assuming lower 'hurdle rates' (discount rate for capital expenditure) for energy-efficient and low-carbon vehicles such as PHEV cars (12.5% instead of 15%, from 2020) and BEV motorcycles (15% instead of 25%, from 2015). The MED results suggest, however, that electric vehicles were not taken up more than 'prescribed' by the UKTCM modelling outputs (= MED inputs as bounds and constraints).

As detailed in section 3, four contrasting MED scenarios were developed and compared – two core Energy 2050 scenarios and two Lifestyle 'variants'. The resulting impacts of these scenarios on the energy system will now be documented.

6 LIFESTYLE CHANGE AND THE ENERGY SYSTEM

As described in Sections 4 and 5 above we have modelled two Lifestyle scenarios (LS REF and LS LC) as variants of the Core scenarios REF and LC. Both LS REF and LS LC include similar lifestyle changes; the difference is the inclusion of a 80% carbon constraint in LS LC. The commentary below largely focuses on the difference between REF and LS REF; and between LC and LS LC.

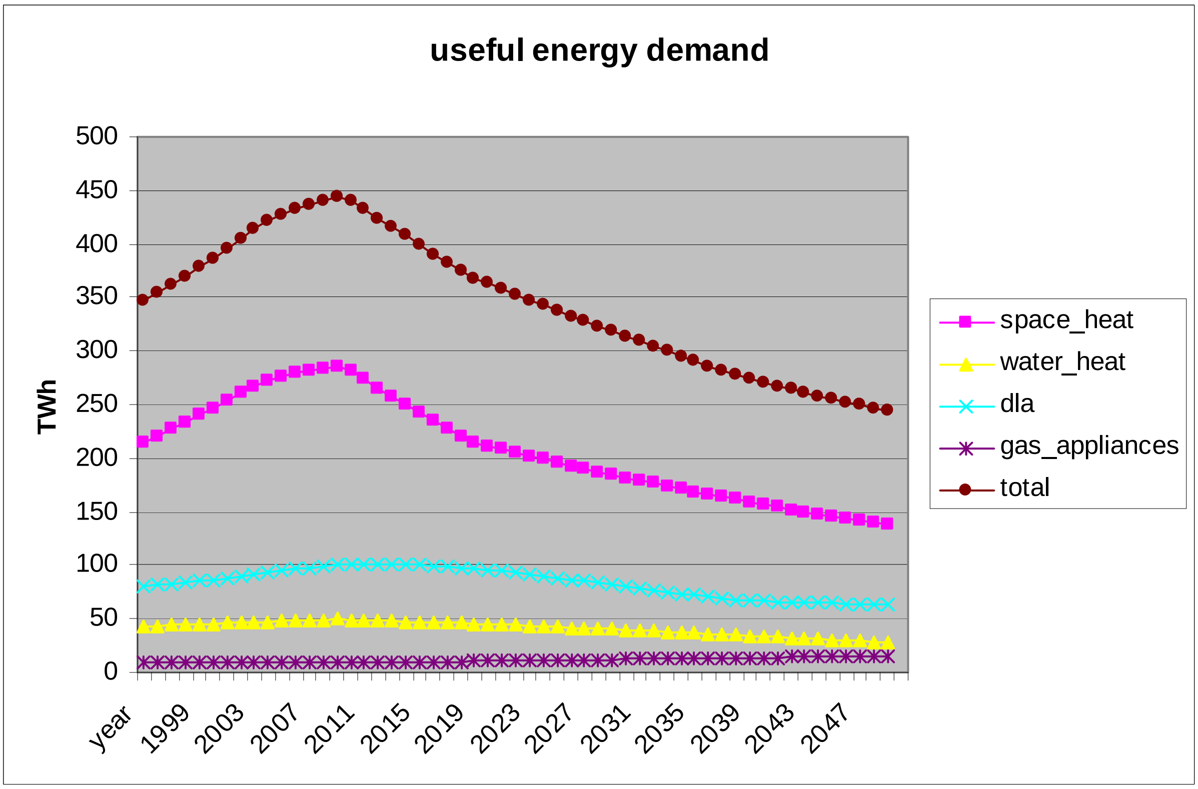
Scenario terminology:
REF – Core no carbon constraint
LC – Core with -80% constraint
LS REF – Lifestyle no carbon constraint
LS LC – Lifestyle with -80% constraint

Base – referring to the base year 2000

6.1 Energy use in the residential sector

For the reasons set out in Chapter 4 above, space heating is currently the dominant energy demand in UK homes, and is likely to remain so in the period up to 2050. However, the combined effects of substantial improvements in building fabric (wall, roof and floor insulation), the widespread use of advanced glazing systems and modestly lower internal temperatures have a significant effect on the demand for space heating. Figure 17 shows the trend to 2050 for space heating useful energy demand, i.e. the heat *output* from the central heating system. The recent (post-2004) trend of a decline in useful energy demand continues, so that energy demand falls by approximately 50% in LS REF compared to REF (and compared to current use).

Figure 17: Household energy demand in the LS REF scenario

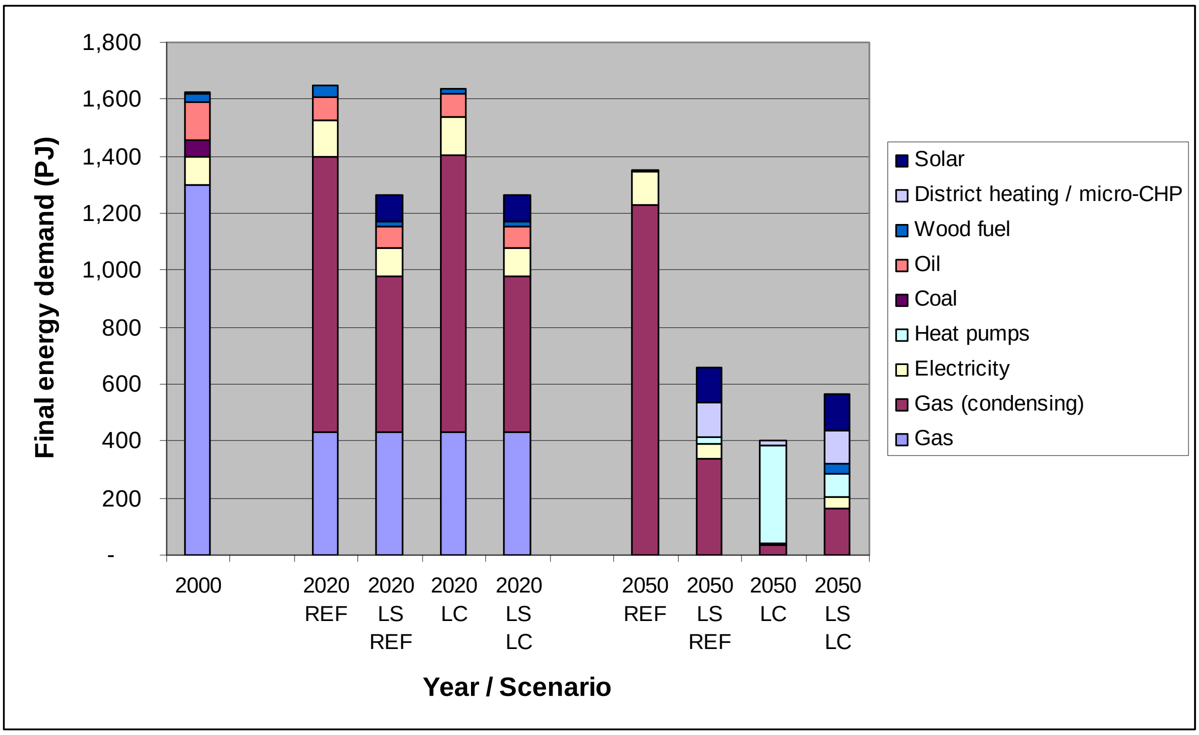


space_heat = space heating; water_heat = water heating; dla = domestic lights and appliances

The demand for energy for providing hot water follows a broadly similar pattern, driven by the reduced demand for hot water described in Chapter 4.

The dominant heating technologies also change radically (Figure 18). In the period to 2020, the major change is the continued penetration of condensing gas boiler, replacing older, less efficient non-condensing technology as each boiler reaches the end of its natural life. Later, the current predominance of the gas boiler begins to be challenged by several alternatives - biomass, CHP at various scales and heat pumps. Heat pumps (ground source and air source) take a significant share, but gas-fired-technologies (district heating, in urban centres and mixed use developments, and fuel cell micro-CHP in smaller suburban properties) also develop and retain a bigger share. This remains the case even in LS LC when national CO_2 emissions are reduced by 80%, although heat pumps and wood have bigger markets in this case.

Figure 18: Residential heating by fuel type, different scenarios

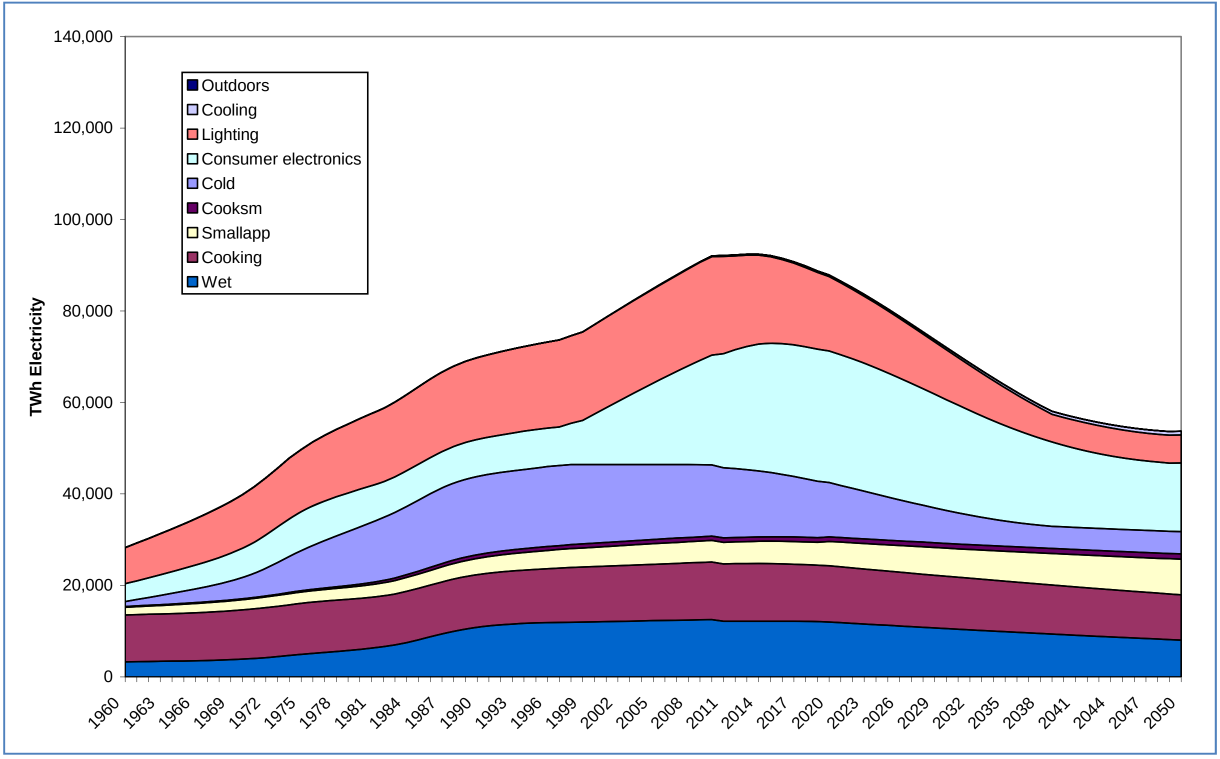


The higher efficiency of the new technologies, in particular heat pumps, results in final energy demand falling more rapidly than useful energy demand. By 2050, final energy demand for heating is only 41% (in LS REF) and 35% (in LS LC) of the year 2000 demand. However, it should be noted that the much larger role of heat pumps in the LC scenario leads to an even lower final energy demand. Although there is far less behavioural change than in LS LC, the tough carbon target leads to an almost complete switch to heat pumps (powered by zero carbon electricity) in the carbon constrained scenarios with higher overall energy demand like LC. In the Lifestyle scenarios, such wholesale switching of heating technology over a relatively short period is not required. A more diverse, and arguably more plausible, balanced of different technologies is retained.

Solar water heating becomes an accepted part of the built environment after 2010 in LS scenarios, providing 50% of water heating demand by 2050.

The trends in electricity use for lighting and appliances are shown in Figure 19Figure 19. The decline of traditional incandescent lighting accelerates in the period up to and after the voluntary phase out. They are initially mainly replaced by compact fluorescent lamps (CFLs), but low-cost Light Emitting Diodes (LEDs) rapidly enter the market after 2010 in LS scenarios and become the norm by 2020. With increased levels of illumination, lighting energy use still falls by 70% by 2050.

Figure 19: Electricity use in lights and appliances in the Lifestyle scenario



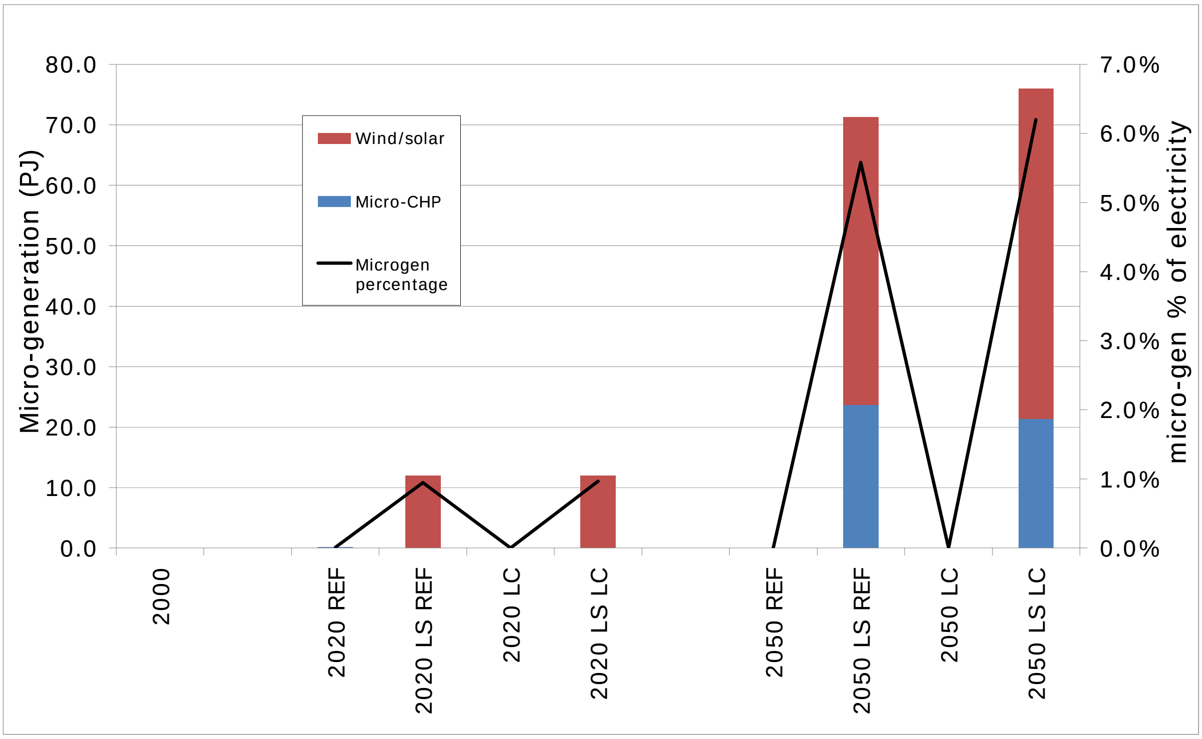
Trends in appliance electricity use prove more difficult to reverse, reflecting the continuation of history trends in increased appliance ownership described in Section 4. However, by 2020, continuing improvements in energy efficiency, the saturation of the most intensive uses and the absence of important new sources of demand combine to begin the trend of increasing use. This effect can only be fully understood by considering the different trends for different appliance groups. For cold appliances (refrigerators and freezers), little growth in ownership is expected. In the Lifestyle scenario we assume that deployment of existing efficient technologies increases rapidly and the use of new technology (vacuum panel insulation) after 2020 allows major reductions in energy use. Similar patterns are expected for wet appliances and cooking, although the efficiency improvements are less pronounced. The trend for consumer electronics (here including ICT) is different reflecting the different level of product saturation. Increased ownership drives increased electricity use until 2020, after which time the improved efficiency options already technically possible (particularly power management and screen efficiency) reduce demand modestly.

In LS scenarios, energy demand for lights and appliances falls at a rate averaging 1.5% annually from 2020 to 2050. The main technical contributions are from LEDs, more efficient consumer electronics and vacuum panel refrigeration (Hinnells et al, 2007).

Electricity-generating micro-renewables remain expensive in the early part of the period under consideration. However, changing attitudes and allow markets to grow even under these conditions, but only slowly until 2020 (Figure 20). After 2020 costs (particularly of PV) fall, a viable installation industry has developed and the technical potential is better understood. Using the assumptions set out in Chapter 4 – i.e. market penetration of 4.5

million homes for PV and 1.5 million homes for wind by 2050 – electricity output reaches about 13 TWh/year.

Figure 20: Residential microgeneration in different scenarios



6.2 Energy use in the transport sector

The higher uptake of lower and zero carbon vehicles combined with mode shifts and significant alterations to work, shopping and leisure travel patterns result in final energy demand being halved from this sector by 2050 compared to unconstrained reference case (REF). In addition to total fuel demand, the main differences between the unconstrained lifestyle scenario and the unconstrained reference case with respect to transport energy demand is the degree to which electric vehicles and biofuels enter the market in the two scenarios.

6.2.1 Demand for transport fuel

As a result of demand reduction, fuel switching and efficiency gains in the unconstrained Lifestyle scenario (LS REF), total fuel demand reduces by 23% by 2020 and by 43% by 2050 compared to the 2000 base. This contrasts to an *increase* of 15% in the Energy 2050 reference case (REF) in 2050.

Table 11 Transport fuel demand by transport fuel – comparison with 2000 Basegives comparable figures for each transport fuel, demonstrating that the demand for conventional fuels (petrol + diesel) decreases by 57% by the year 2050 in the unconstrained lifestyle scenario (LS REF) and by 87% when constrained (LS LC). However, in all scenarios, conventional fuel still dominates use in 2020, never falling below 89% of total demand.

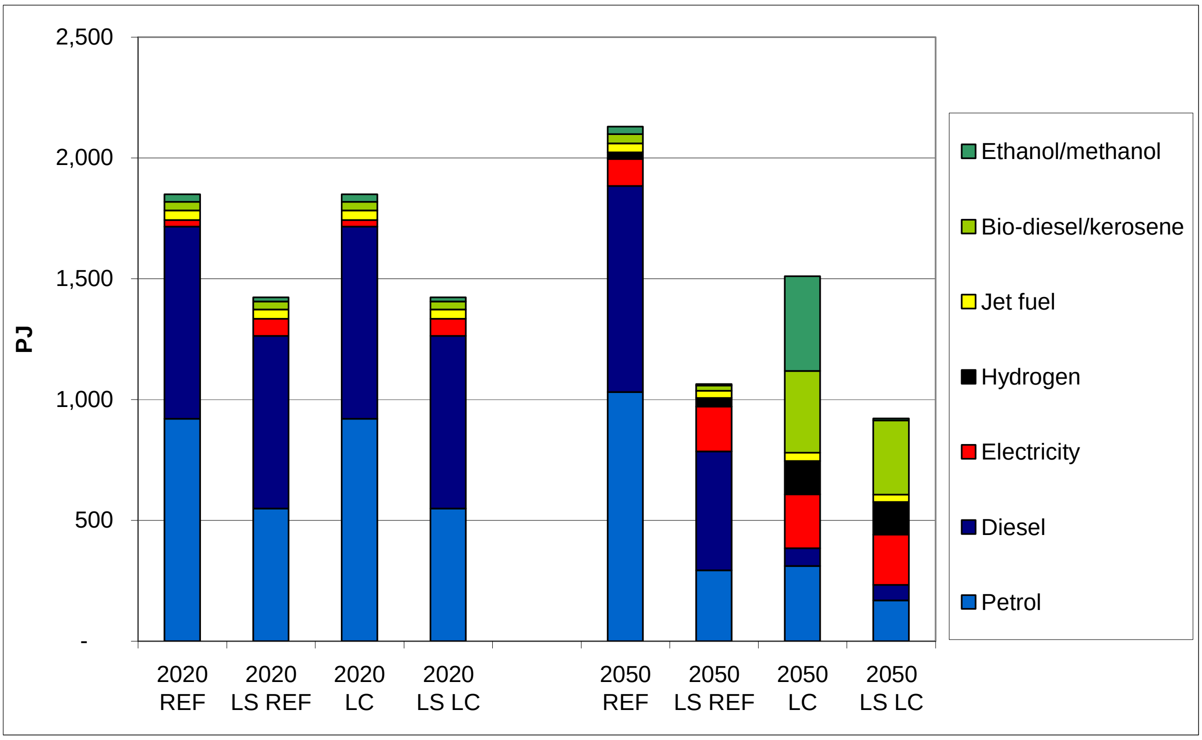
Table 11 Transport fuel demand by transport fuel – comparison with 2000 Base

	By 2020					By 2050			
	REF	LS REF	LCC	LS LC		REF	LS REF	LCC	LS LC
% compared to 2000 base	%	%	%	%		%	%	%	%
Petrol	5.6	-37.1	5.6	-37.1		18.2	-66.4	-64.3	-80.5
Diesel	-14.8	-23.3	-14.8	-23.3		-8.5	-47.3	-92.1	-93.1
P+ D combined	*-4.9*	*-30.0*	*-5.0*	*-30.0*		*4.4*	*-56.5*	*-78.6*	*-87.0*
Electricity	38.0	253.3	37.9	253.3		462.9	838.6	1022	941.8
Jet fuel	30.7	28.8	30.7	28.8		22.0	2.9	12.4	2.9
	PJ	PJ	PJ	PJ		PJ	PJ	PJ	PJ
Hydrogen						26	34	138	135
Bio-diesel/ bio-kerosene	36	33	36	32		39	22	338	307
Ethanol/ methanol	31	17	31	17		32	5	393	8
Total	-0.3%	-23%	-0.3%	-23%		15%	-43%	-19%	-50%

By comparison, electricity demand grows steeply, particularly in the second half of the period, accounting for 18% of total fuel demand in the unconstrained lifestyle scenarios by 2050 (Figure 21Figure 21). This demand is 67% higher than in the unconstrained reference case where HEVs and BEVs have zero market share, even by 2050, although there is some increase in electricity use later in the period from rail, some battery operated buses and plug-in vans. In the constrained reference case, however, the uptake of PHEVs is very high.

Biofuels and hydrogen only play a major role in the carbon constrained cases. For biofuels, this is a result of (a) the assumption in MED that biofuels have zero net CO_2 emissions and (b) the availability of unconstrained blending or supply of second generation biodiesel, while in the reference cases (REF and LS REF) demands *decrease* in line with petrol and diesel demands. A high-level blend of bioethanol and petrol (E85) used in flex-fuel road vehicles only appears in the core constrained case (LC) where it accounts for 26% of total fuel demand. In the related lifestyle scenario, lower demand and greater preference for efficient vehicles means that biodiesel hybrids are preferred over their bioethanol counterparts.

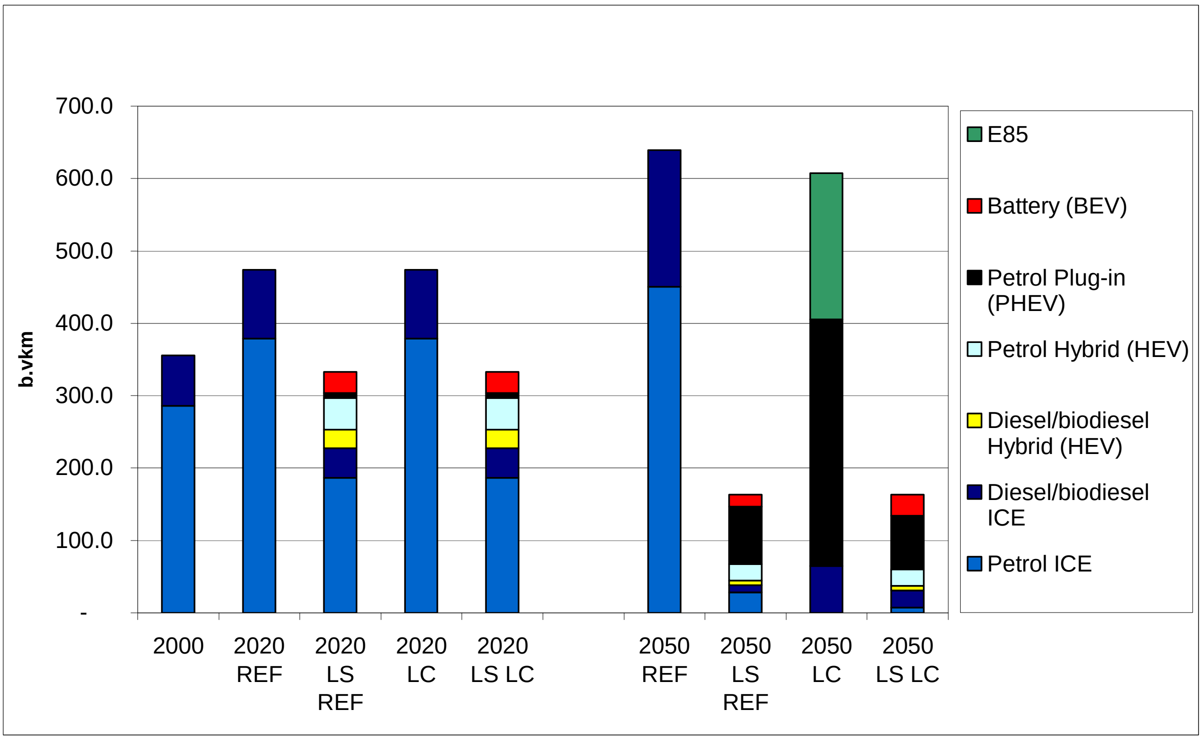
Figure 21: Transport fuel demand by transport fuel in each scenario in 2020 and 2050, in PJ



6.2.2 Transport fuel demand by vehicle type

In the lifestyle reference (LS REF) case, by 2020 market shares (in terms of vehicle km, not energy use) for hybrid electric (HEV) cars and battery electric (BEV) reach 21% and 9% respectively, compared to zero penetration in the REF and carbon ambition (LC) cases (Figure 22). From 2020 petrol plug-in hybrid electric (PHEV) cars become more popular, reaching market shares in 2050 of nearly 50%. In total, HEV, BEV and PHEV cars have a 77% market share in 2050 albeit of a significantly smaller market overall (car use is 74% less than in the REF case). Bio-ethanol flex-fuel (E85) cars only appear in the constrained reference case in the longer term. Diesel PHEVs, hydrogen and methanol fuel cell cars do not appear in any of the scenarios.

Figure 22: Car vehicle type by distance driven in different scenarios and years



The freight sector also sees more efficient and electric vehicles, in particular PHEV vans (60% of the van share of vehicle-km in 2050 compared to 42% in the unconstrained REF case). For heavy goods vehicles, conventional diesels are phased out completely by 2020 and replaced by hybrid diesels. Hydrogen trucks only appear in the constrained scenarios.

By 2020, battery powered buses are beginning to appear and their use increases to 50% of bus kilometres driven by 2050. Altogether, taking cars (PHEV and BEV), vans (PHEV and BEV) and buses (BEV) together, a third of road transport *energy* demand is met by plug-in electric vehicle technology in 2050. Use of electrified rail also increases by over 200% over present use by 2050 and hydrogen powers a third of rail energy demand by then.

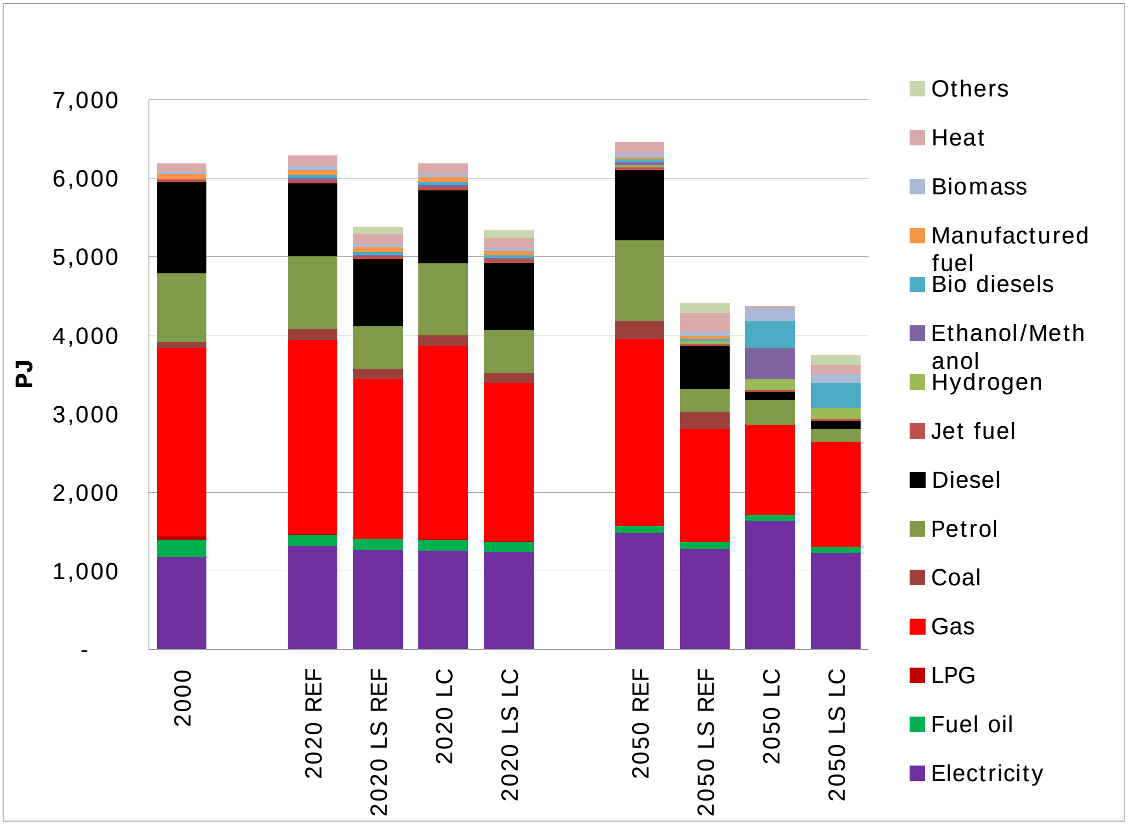
6.3 Implications for the wider energy system

The most significant impact of lifestyle change on the wider energy system, compared to the core scenarios, is due to reductions in the overall demand for final energy, particularly for gas in households and oil derived fuels in transport (Figure 23). Total final energy demand is 15% lower than the REF scenario by 2020 and 30% by 2050, with beneficial effects for energy system costs, carbon emissions and energy import requirements. Lifestyle change alone (without a carbon constraint) has a similar effect on total final energy demand to an 80% carbon constraint with no lifestyle change.

The effects are most strong for the fuels where import dependence is most likely. In LS REF scenario, by 2050, gas use is 34% lower and oil use 54% lower than in REF. The implications for energy security are therefore very substantial. This compares interestingly to findings reported elsewhere that explicit concerns about energy security would lead to greater attention to reducing demand (Skea et al, 2009), i.e. the same correlation but with opposite causality. The implications of concerns about a combination of climate change and energy security merit further research.

Carbon emissions being reduced by 30% in LS REF compared to REF (see Section 6.4 below). This allows radical carbon reductions, such as 80%, with fewer changes to the energy system. This is apparent in Figure 23 from the much smaller changes in fuel use and fuel mix between LS REF and LS LC in 2050, than between REF and LC. This has important implications for climate mitigation policy. A scenario that involves voluntary lifestyle change will place much less pressure on policy to require rapid (and potentially disruptive) technical change, including technologies at the point of energy use. The assumption that encouraging lifestyle change presents more problematic issues for policy makers than a "top down" technical solution is therefore not necessarily correct.

Figure 23: Final energy demand by fuel in different scenarios for different years



Final demand for electricity is reduced by less than other fuels, only 14% in LS REF compared to REF in 2050. This is because, although lifestyle change involves reductions in demand and improvements in efficiency of electricity use, it also includes some fuel switching to electric technologies, notably plug-in hybrid vehicles and electric heat pumps. In carbon-constrained scenarios, the reduction from the reference to lifestyle case is bigger (25% reduction from LC to LS LC) as the LC includes more electrification (to zero carbon electricity) to achieve tough carbon targets primarily through high carbon prices. In contrast LS LC shows a much lower rate of growth than LC in construction of centralised zero carbon electricity technologies – CCS, nuclear and wind (see Figure 27 below).

Final energy demand by sector is shown in The implications for primary energy demand are set out in Figure 25. The key implications of lifestyle change are the much lower demand for oil and gas already identified. In the carbon constrained scenarios, the Lifestyle scenario (LS LC) implies the development of significant biofuel and nuclear sectors by 2050, but much smaller than in the equivalent REF scenario. This is discussed further below.

Figure 24. The LS scenarios differ from the REF equivalents only in the household and transport sectors for all of the reasons set out above. There are no similar effects in agriculture, services or industry. This is simply a function of our modelling assumptions. It is quite likely that changes in personal consumption in households and personal transport will have implications for other sectors, but we not attempted to model these in this research.

The implications for primary energy demand are set out in Figure 25. The key implications of lifestyle change are the much lower demand for oil and gas already identified. In the carbon constrained scenarios, the Lifestyle scenario (LS LC) implies the development of significant biofuel and nuclear sectors by 2050, but much smaller than in the equivalent REF scenario. This is discussed further below.

Figure 24: Final Energy Demand by Sector

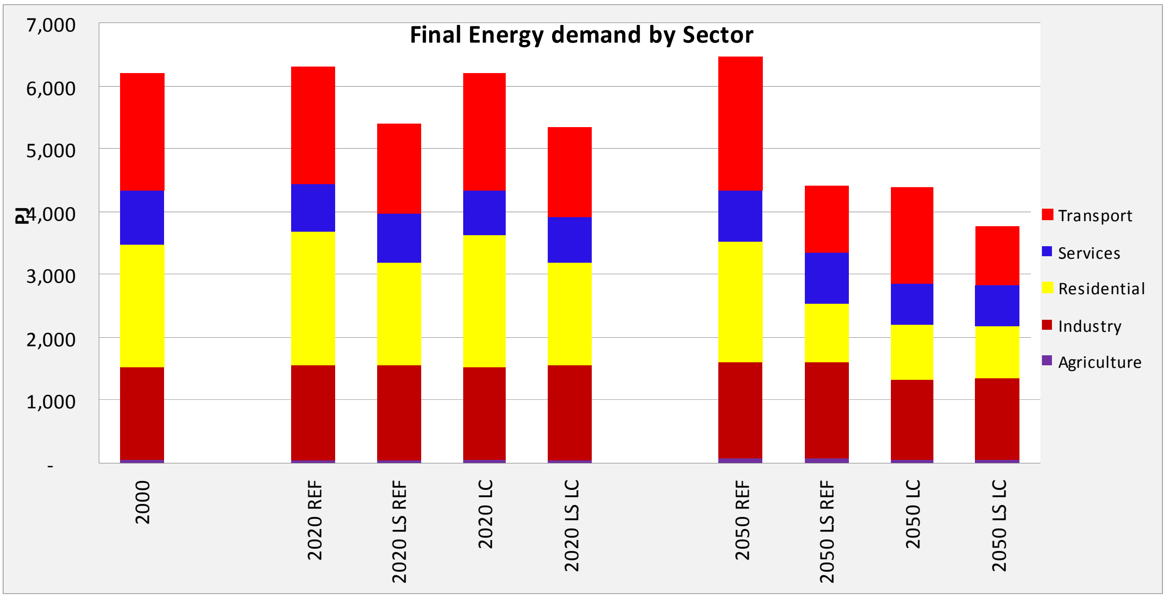
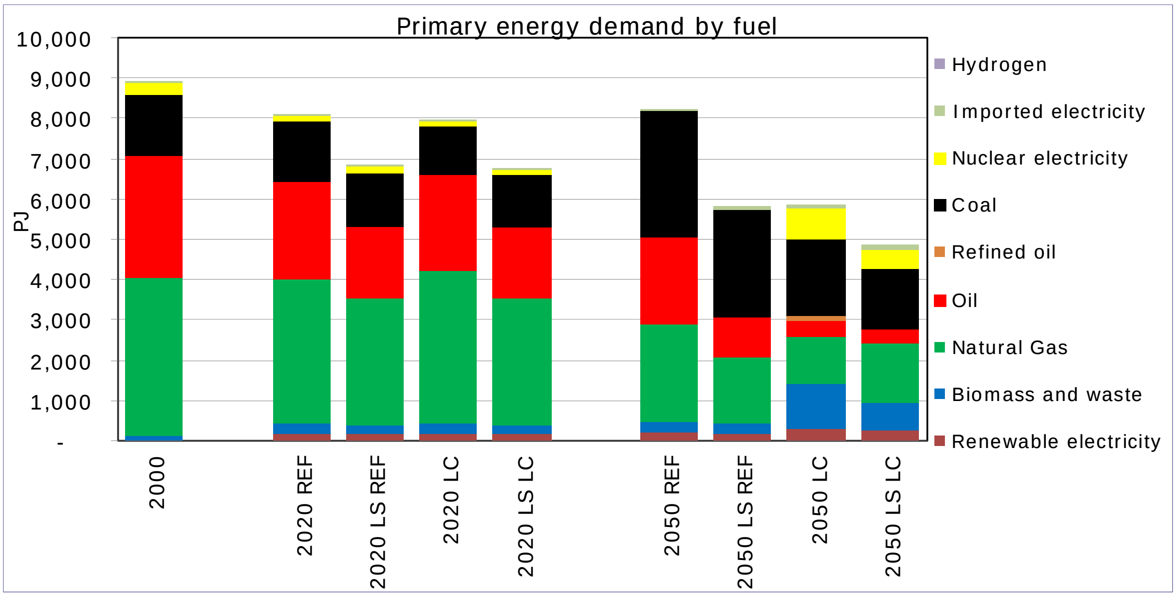
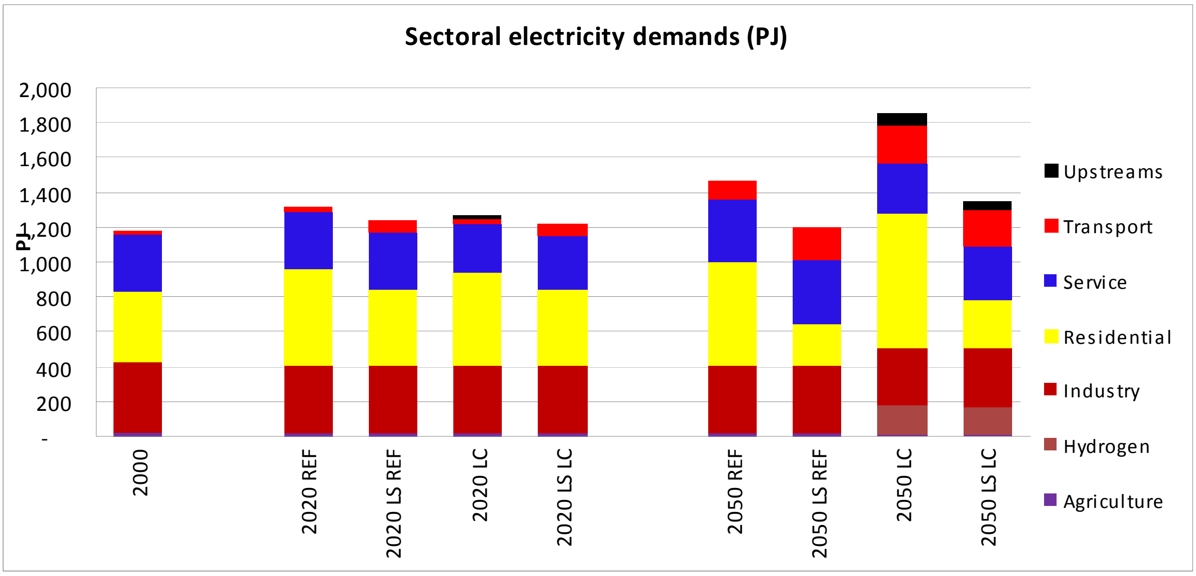


Figure 25: Primary Energy Demand



Electricity demand by sector is presented in Figure 26. The scenario differences are relatively modest by 2020, but very large by 2050.

Figure 26: Electricity demand by sector



The scenario variations are most pronounced in the residential sector. In the reference scenarios, the demand growth is significant, especially in the LC scenario where high carbon prices force a dramatic shift to heat pump technology, so that household electricity demand is almost double the year 200 level. In contrast in the LS scenarios, demand reduction and energy efficiency improvement are much more significant and reduce electricity demand by 30-40%. The use of heat pumps in the LS LC scenario does not outweigh this effect.

The transport sector is projected to have significant growth in electricity demand in all scenarios by 2050. In the LS scenarios there is already an impact by 2020 as electric vehicles establish significant niche markets earlier. By 2050, the effect is very large, particularly in the carbon constrained scenarios where electricity is also used to produce hydrogen for transport. Despite more switching to electric vehicles proportionately in LS LC, the use of electricity is higher in LC, as the total energy use in transport is much greater.

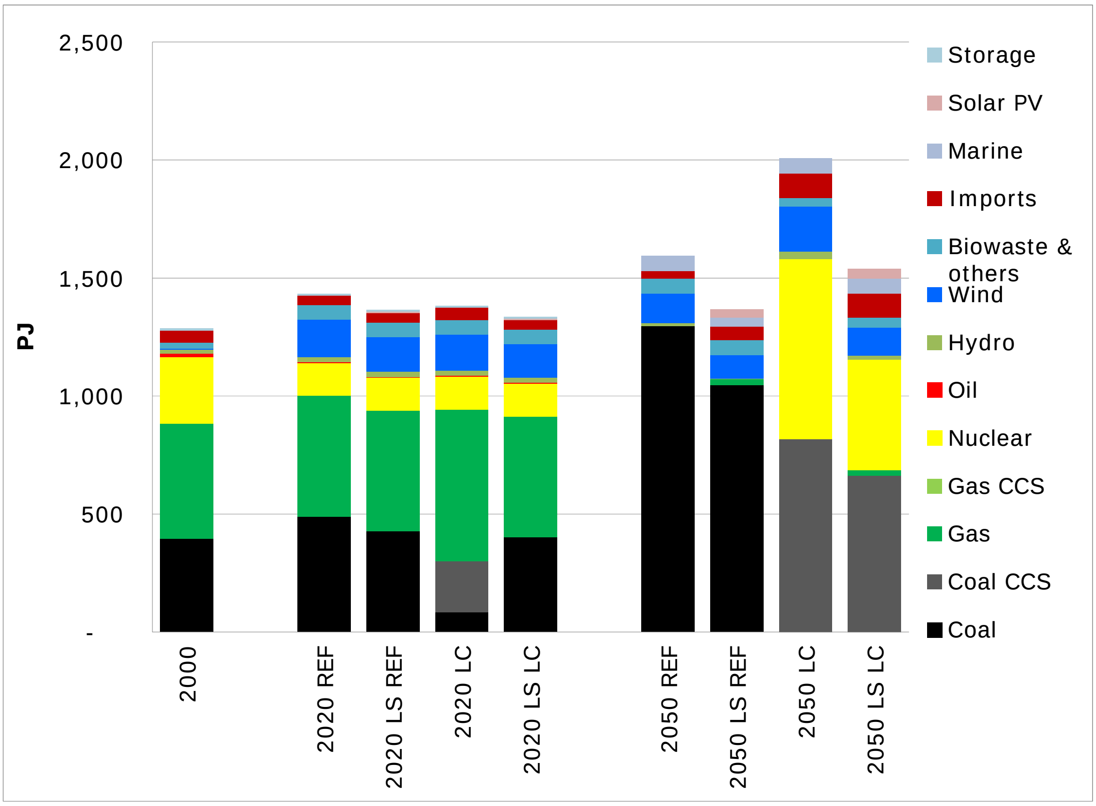
Total demand on the grid is broadly unchanged from year 2000 levels in 2050 in LS REF compared to a rise of 25% in REF. The effect is more significant in the LC scenarios due to increased use of decarbonised electricity. Lifestyle change limits the increase in demand in LS LC to 15% from year 2000 levels; but this compares to a 57% rise in LC.

The combined effects of changes in demand in households and transport have potential implications for the low voltage electricity grid. It is assumed that all electricity to households will continue to be delivered through this network and electricity for recharging vehicles will be delivered through the same system if these are charged at home. Electricity generated within homes, microgeneration, will reduce this demand on the LV grid. The sum of electricity demand in households and transport, less the contribution of microgeneration is therefore potentially the key indicator of low voltage power demand. The projected changes from year 2000 levels by 2050 are negligible (less than 5%) in the LS scenarios with increased transport demand offset by reduced household demand and microgeneration. In contrast, the changes in the other scenarios are a 57% increase in REF and 174% increase in LC. The latter figure is particularly worthy of comment – the combination of heat pumps and electric vehicles, with little offsetting contribution form microgeneration of reduced demand may well prove problematic. It certainly implies the need to consider very widespread upgrading of the low voltage grid. The costs and feasibility of such a change do not seem to have been factored into most assessments of “supply side solution” scenarios to climate mitigation such as LC.

The electricity from increased use of electric vehicles is generally assumed to come mainly from night charging. This potentially allows the PHEV fleet to act as a load levelling opportunity for the electricity system, enabling base load centralised generation plants to run better (and cheaper), although more detailed assessments of diurnal load variation require models not used in this research.

The implications for electricity generation mix are shown in Figure 27 and depend heavily on the assumptions about the relative costs of different power generation options in the MARKAL model. These are discussed more fully elsewhere (e.g. Ekins, 2009). The point worthy of attention here is that both carbon constrained scenario imply very substantial investment in zero carbon electricity by 2050, exacerbated by increased demand for power to substitute for fossil fuels. Carbon capture and storage (CCS), nuclear and wind all supply very large amounts of power. The LC scenario is particularly extreme in this regard with electricity generation rising from 360 TWh/year currently to 560 TWh in 2050.

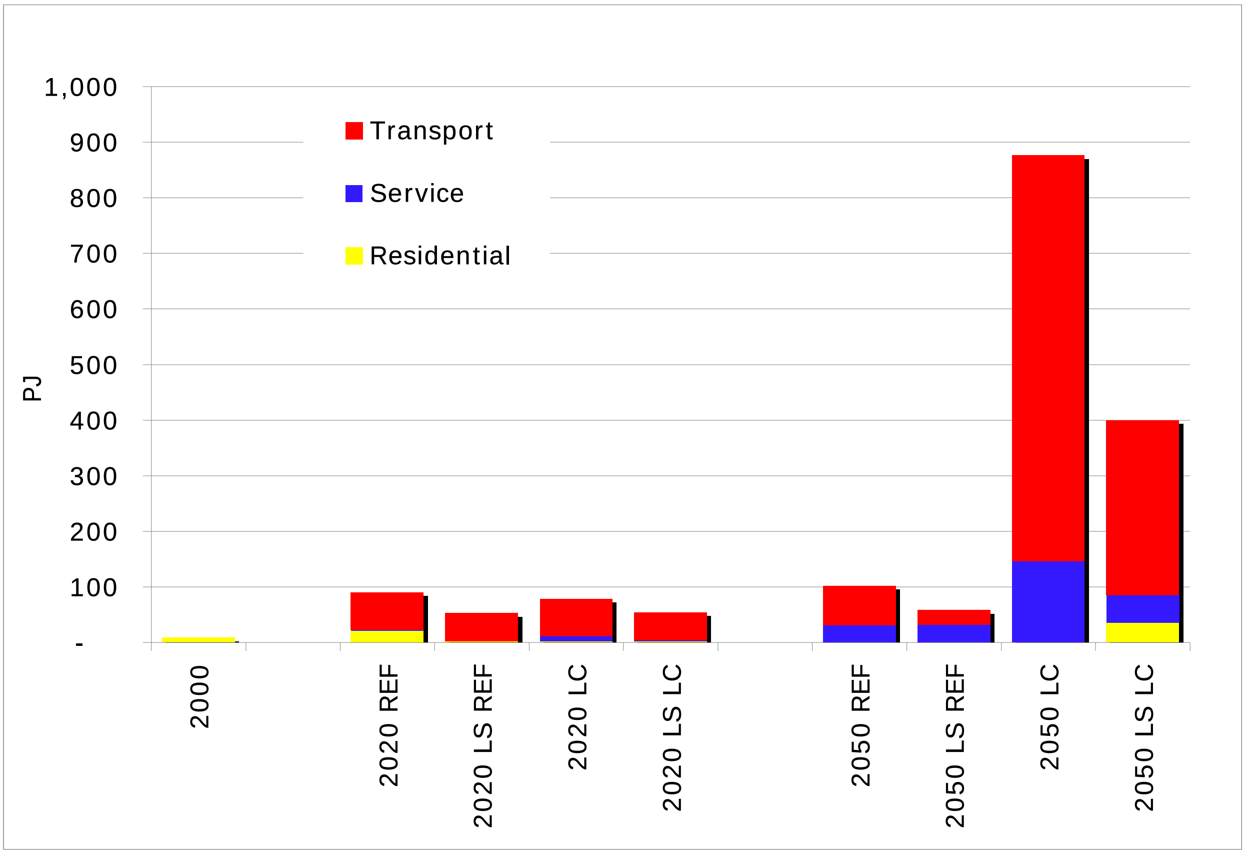
Figure 27: Electricity generation mix in different scenarios for different years



The implications for use of biofuels in different sectors are shown in Figure 28. In all cases it is projected that the transport sector is the dominant user of biofuels, but the scale of use is very variable across the different scenarios. Up to 2020 use of transport biofuels is driven by existing regulatory requirements. The same effect largely determines biofuel use in the scenarios that are not carbon constrained in 2050, reflecting the higher costs of biofuels than alternatives. Both of the carbon constrained scenarios have a much higher dependence on transport biofuels, but this is particularly pronounced for the LC scenario in which use rises to 340 PJ of biodiesel and 390 PJ of bioethanol annually by 2050. Once again it is the LC scenario (low carbon, with limited lifestyle change) that requires the most challenging changes for the energy system.

The much reduced dependence on oil in LS LC is due to a combination of reduced demand, modal switch, improved efficiency and increased use of electricity. This also results use of biofuels at only half the level of LC.

Figure 28: Demand for bioenergy in different scenarios for different years

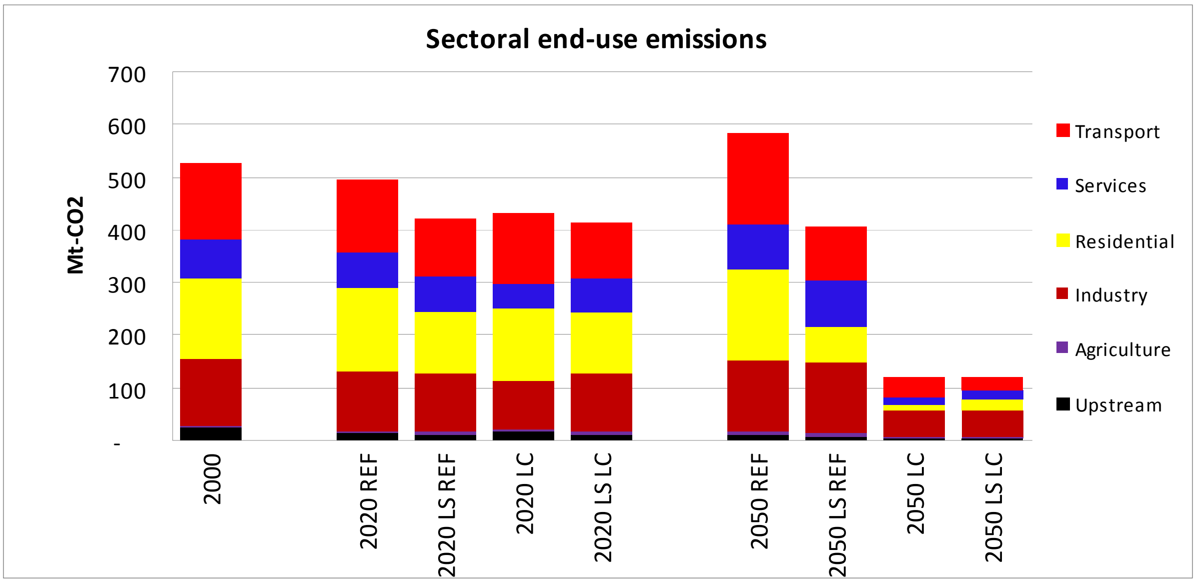


6.4 Progress towards carbon reduction targets

The Lifestyle scenarios have significant implications for carbon emissions, see Figure 29. In the scenarios without carbon constraints, changes of lifestyle result in significant changes in carbon emissions. These are 15% lower in 2020 and 30% lower in 2050 in LS REF compared to REF. In other words lifestyle change alone can contribute a significant fraction, but not all, of the UK target for 2050.

In scenarios where we model an imposed constraint of an 80% reduction on carbon emissions in 2050, both scenarios reach that target exactly, as expected. In these cases the differences between the scenarios are reflected more in the costs of reaching that target, as discussed in the next section.

Figure 29: Carbon Emissions by Scenario

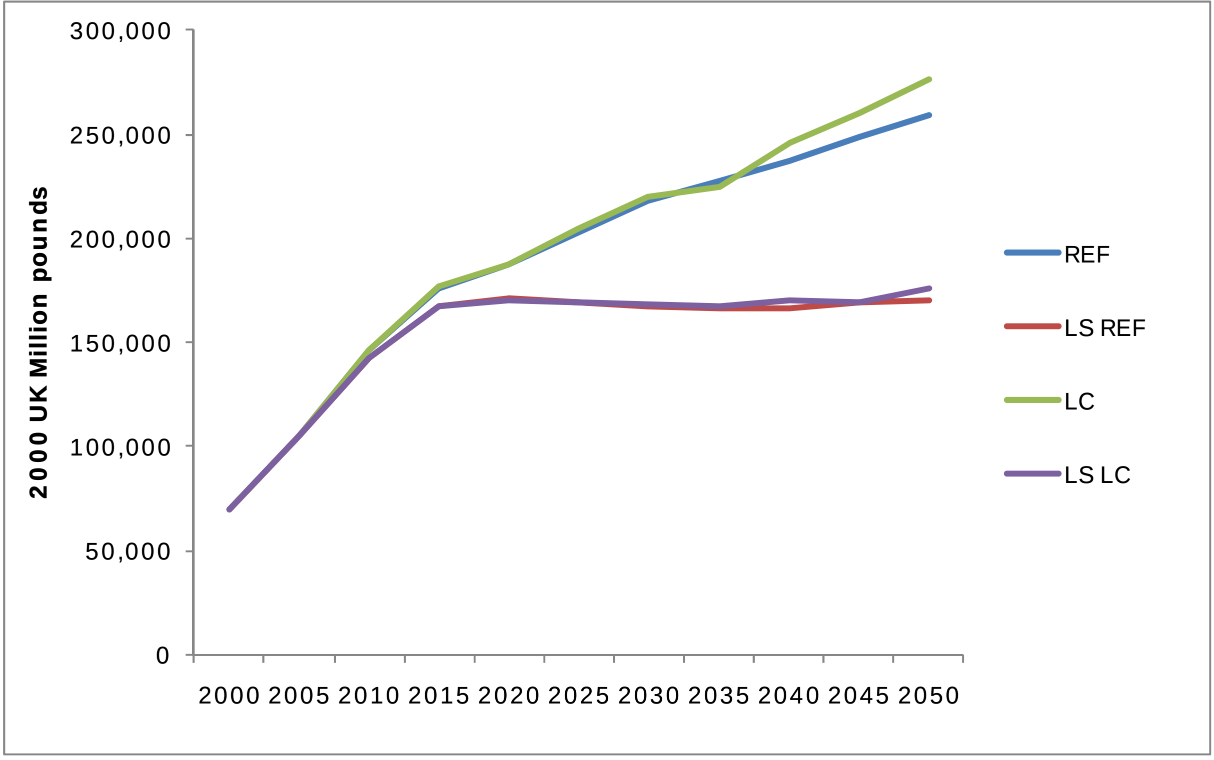


6.5 Economic implications

The standard economic technique to make economic comparisons between scenarios is to measure the 'social welfare', defined to be the aggregate of producer and consumer surpluses. Such comparisons assume a given set of consumer preferences, i.e. the same willingness to pay for energy services in the scenarios under comparison. This is not the case when comparing the Lifestyle and Reference scenarios – consumer preferences differ very explicitly because of different lifestyles and not solely price signals – and therefore a welfare comparison cannot be made.

What can be meaningfully compared are the costs of the energy systems implied by different scenarios. Total energy system costs are £16 billion lower in 2020 and £89 billion lower in 2050 in the Lifestyle scenario (LS REF) compared to the Reference scenario (REF), as shown in Figure 30. (These numbers rise to £17 billion and £94 billion respectively in the carbon-constrained scenarios, LS LC vs. LC). This is primarily driven by the much smaller size of the energy system. Another relevant metric is the incremental cost of delivering a low-carbon system in 2050 – this falls from £17 billion for a Reference scenario to £12 billion in a Lifestyle scenario. In other words, due to a much smaller energy supply system in the Lifestyle scenario, the incremental costs of a low-carbon energy system are lower.

Figure 30: Total MED energy system costs (in £ billion)

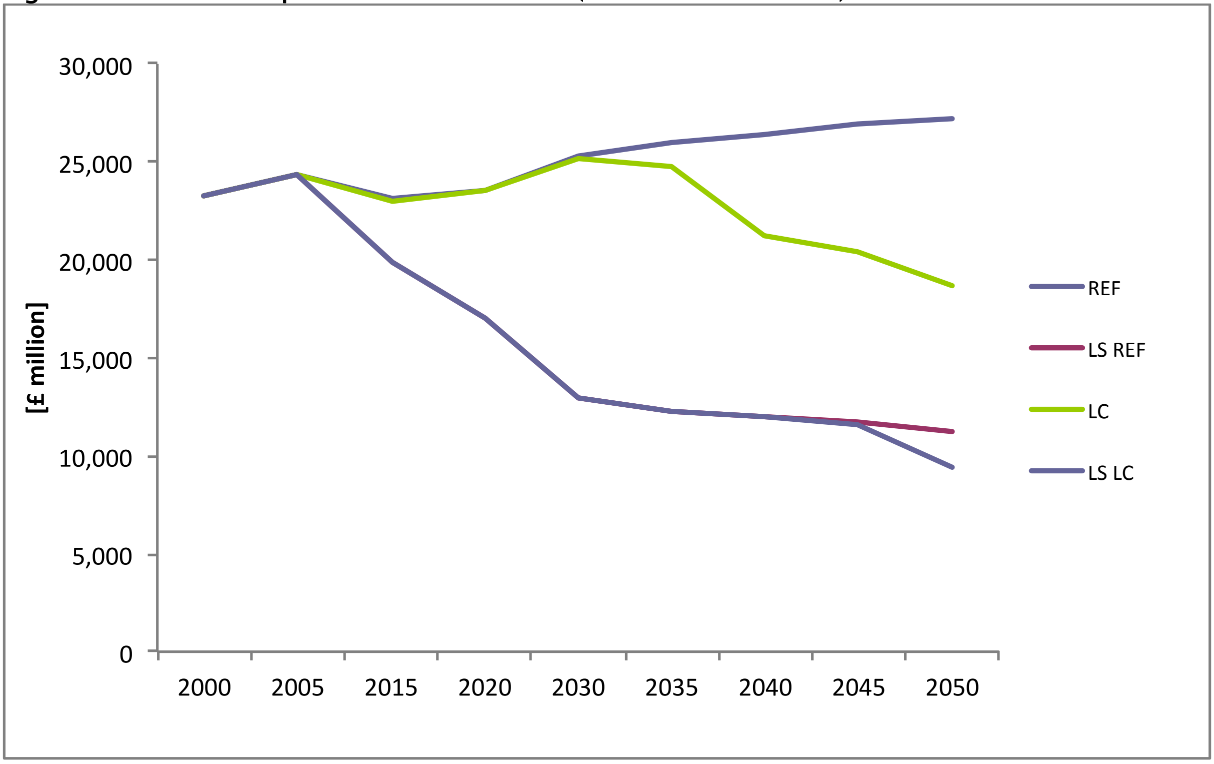


These figures need to be subject to the caveat that our cost modelling approach excludes some the costs of some (but not all) demand side investments. For the household sector, the additional cost of insulation measures in the Lifestyle scenarios compared to the REF cases is £20 billion over the whole period to 2050 (while the above energy system costs are annual figures) and approximately £0.35 billion in 2050, i.e. a negligible correction to the data shown in Figure 30. The difference in transport sector costs is difficult to estimate – they would consist of a combination of increased investment in public transport systems and reduced expenditure on road construction and maintenance. These have not been explicitly modelled, but almost certainly are lower in the LS scenarios due to reduced travel. We expect that they would represent a small correction on the data shown in Figure 31, but further research is required to confirm that. The estimate that the lifestyle scenario energy system costs in 2050 are at least £90 billion lower than the reference comparators is therefore robust.

Although these are not GDP costs (as this depends on the impact of changes in investment, consumption and the balance of trade), as a context, UK GDP was £1.46 trillion in 2008 and, with an assumed average 2% annual growth rate, is projected to be £3.3 trillion in 2050. The energy system costs are estimated to be 8% of GDP in the Reference scenarios, but only ~5% in the Lifestyle scenarios, similar to the current level. In other words, the energy system takes a rising share of GDP in the Reference scenarios, but can be held at current levels by lifestyle changes. In either case, the incremental cost of achieving a 80% carbon emissions reduction target is modest (and certainly consistent with a lower bound of around 1% as in the Stern Review (Stern, 2006) – with the lifestyle scenario costing around 50% less than the reference CO_2 constrained case.

The reduced demand for transport fuels as set out above implies a reduction in fuel tax revenues. Assuming taxation levels do not change over the modelling period, total road fuel tax revenues in 2050 are around £27 billion in the Reference scenario (REF), and only £11 billion in the Lifestyle scenario (LS REF) – i.e. a 59% reduction.

Figure 31: Road transport fuel tax revenues (as modelled in MED)



The marginal cost of carbon abatement in 2050 in the carbon-constrained scenarios falls from £169/tCO_2 in the Reference scenario (LC) to £163/tCO_2 in the Lifestyle scenario (LS LC) (see Figure 32 on the right). This rather modest change shows that although less overall reductions are required, at the margin some rather expensive decarbonisation options (of marginal costs greater than £100/tCO_2) are still required to achieve 80% carbon emissions reductions. Figure 33 further shows that expensive decarbonisation options are required for the Lifestyle scenario (LS LC) only at the end of the modelling period, while significantly earlier (from 2030) in the Reference scenario (LC).

Figure 32: Total CO_2 emissions and marginal cost of CO_2 (2020 in columns 2 to 5, and 2050 in columns 6 to 9)

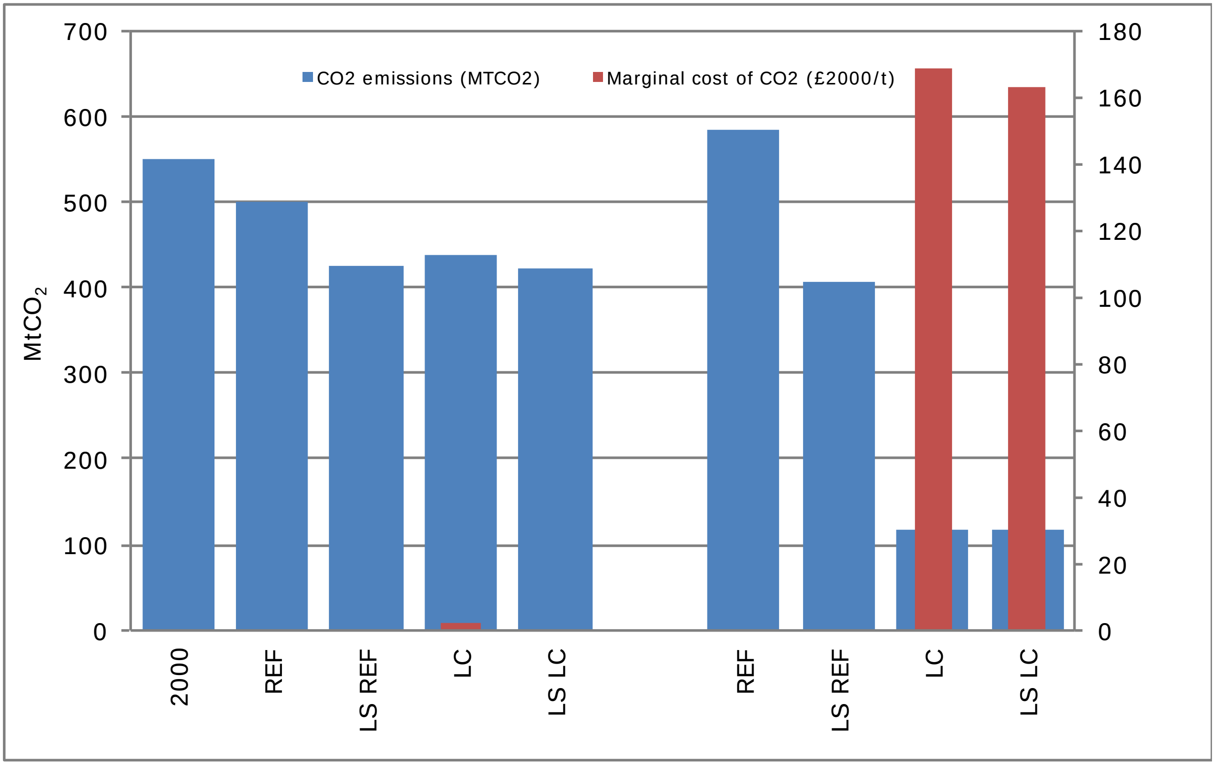
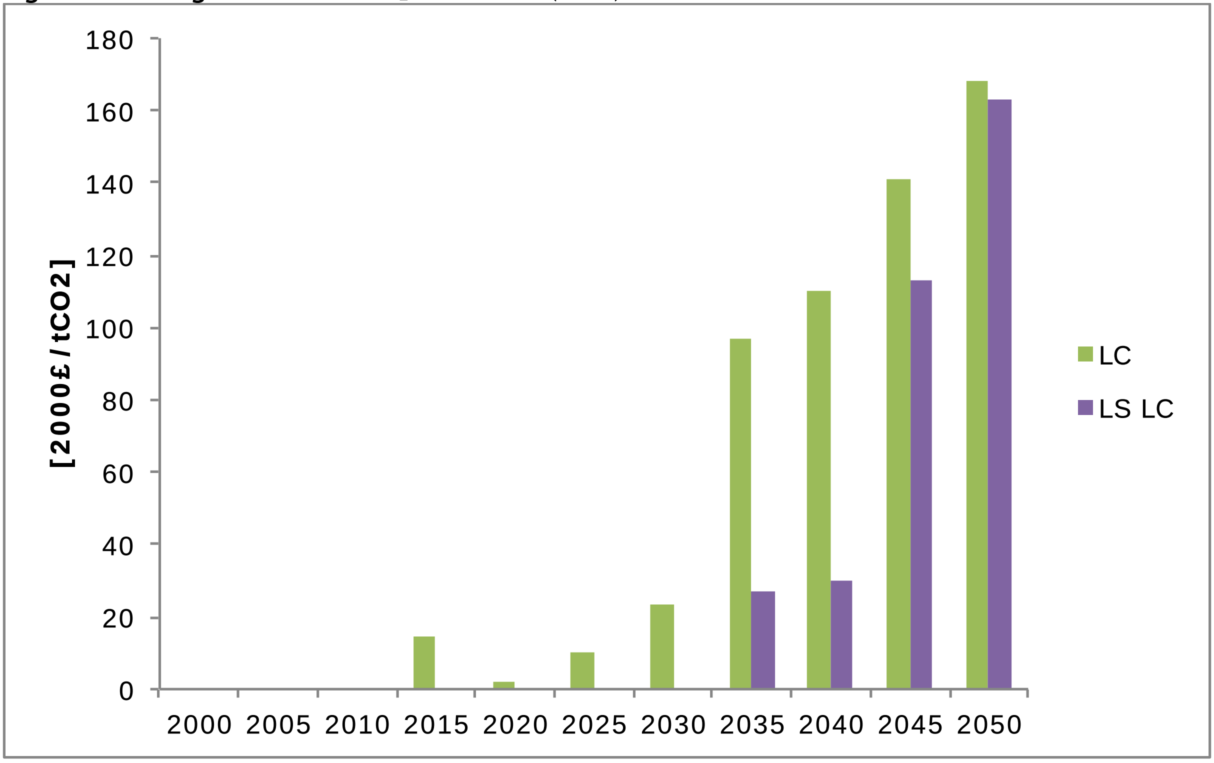


Figure 33: Marginal cost of CO_2 over time (MED)



The reduced costs of the energy system in a Lifestyle scenario would be reflected in increased economic activity elsewhere in the economy, if overall economic activity (GDP) is to be the same (which is our assumption). Our models for this work are confined to analysis of the energy system, and therefore do not provide insights into the wider macroeconomic implications of this reduction in size of the energy sector.

6.6 Implications for energy security

The largest implications for energy security in the UK of the Lifestyle scenario flow directly from the earlier and larger reductions in primary energy demand set out above. The effects are also strongest for the fuels where import dependence is potentially most problematic – oil and gas. In both cases, the UK has become a net importer in recent years, and there are expectations, within the period of time addressed in this work, of reliance on sources from areas with significant geopolitical risks – Russia and West Asia for natural gas, and the Middle East for oil. For oil, there are also geological and economic concerns about resource availability after 2020 (Sorrell et al., 2009).

In most 'resilience' scenarios the reductions in energy demand are driven explicitly by the goal of reducing reliance on imported oil and gas via reductions in energy intensity; in Lifestyle scenarios the reduction is achieved primarily through pro-environmental behaviour, but achieves the same end of reducing use of oil and gas.

Energy security concerns do not relate solely to availability of imported oil and gas. Indeed, historically, most disruptions to continuity of energy supplies in the UK have other causes. Lifestyle scenarios should be advantageous with respect to availability of other fuel sources, whether imported or not. These include nuclear fuel and biofuels. They are also less sensitive to failures in new supply side technology, including nuclear accidents, breaches of carbon dioxide transportation and storage systems, and systemic failures in offshore renewables and transmission. Finally an easing in the requirement for new energy infrastructure, especially low voltage distribution, will assist in ensuring reliability.

However, Lifestyle scenarios do not remove energy security concerns. Like all low- carbon scenarios they imply some increased electrification, with heating and transport systems highly dependent on electricity supply continuity. The greater decentralization of electricity supplies in a Lifestyle scenario has complex implications here. It potentially allows operation of local grids in an 'islanded mode' in the event of wider system problems. On the other hand, it also implies increased dependence on highly decentralized generation, requiring a new 'active management' approach to distribution grids with new risks as well as new benefits (Woodman and Baker, 2008).

7 POLICY IMPLICATIONS

7.1 Lifestyle and policy interaction

The critical role of behaviour change in carbon emissions reduction policy is already established. The Stern Review identified a trio of types of intervention required to deliver a low carbon economy – pricing of carbon, low carbon technical innovation and behavioural change (Stern, 2006). Economic and technological analysis are insufficient to inform this third pillar, as neither seeks to explain changes in human behaviour due to factors other than technological change, prices or incomes. Analysis of policies to change behaviour needs to draw on a wider range of disciplinary traditions, including psychology and social sciences (e.g. Stern and Aronson, 1984, Lutzenhiser, 1993).

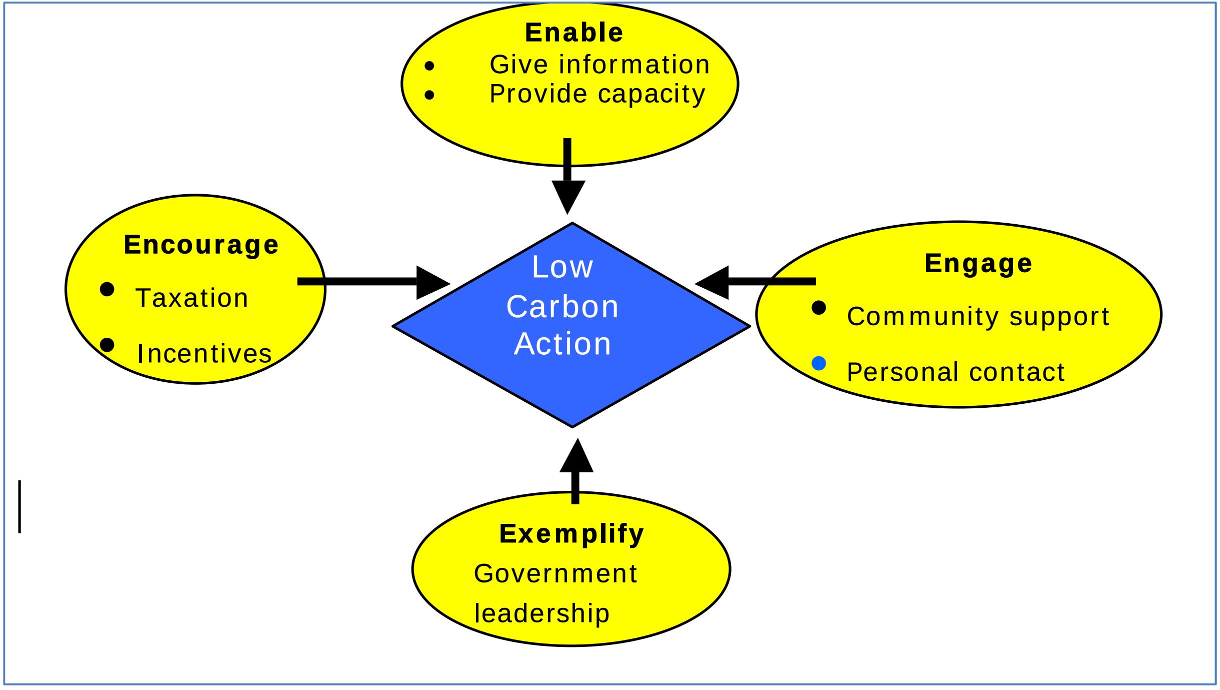
In the Lifestyle scenarios we assume an interaction between public policy and lifestyle change. This is not straightforward or uni-directional: public policy helps create the conditions in which different lifestyles are more or less acceptable, and pressure for particular lifestyles sets the parameters for public policy. Previous transitions in socio-technical systems show the inter-connectedness of social, technological and policy change (e.g. Geels, 2005).

In the Lifestyle scenario, environmental protection, and carbon emissions reduction in particular, continue to rise in prominence as policy objectives. Carbon reduction becomes a social norm, in a similar way to health and safety, with an expectation of Government leadership and regulation. The existing legislation for carbon budgets (HM Government, 2009) can be seen as an initial step in that direction. In this context, the relevant questions for policy are which pro-environmental behaviours government can effectively promote and how. The following sections set out the likely implications first for the broad framework of policy and then for the household and transport sectors.

7.2 Policy for social and behaviour change

There has been significant research in recent years on policy to promote pro-environmental behaviour change (e.g. Darnton et al, 2006; Halpern and Bates, 2004). A useful heuristic (Jackson, 2005) indicates that behaviour change is most likely when citizens face a set of influences that encourage, enable, exemplify and engage them in such change (Figure 34).

Figure 34: Illustration how policy can promote pro-environmental behaviour change



(based on Jackson, 2005)

Many policy instruments focus on ***'encouragement'***, in particular through economic instruments designed either to affect the prices of energy and carbon or to provide incentives for development and deployment of new low-carbon technologies. In the Lifestyle scenario, the social acceptability of carbon pricing will be relatively high. The emphasis on individual and community action points to a downstream focus to target individual energy use, through end user taxes or downstream permits. The challenge of the regressive nature of carbon pricing will be addressed through explicit revenue recycling and increased support for behaviour change. Market-based instruments will continue to have a strong role to support innovation, but with more focus on citizen and community involvement in innovation. This will be through fixed-price or long-term capital subsidies, designed to reduce the risks of previous approaches (Bergman and Jardine, 2009).

Non-financial interventions are also required to ***'enable'*** desirable change, as behaviour is not solely driven by economic factors. This will involve providing the relevant practical information to enable positive intentions to be put into practice, as well as the education, skills and industrial capacity to deliver low-carbon products and services. Enabling also includes 'choice editing' through energy standards to ensure products meet high environmental standards; with the cultural attitudes prevailing in the Lifestyle scenario, this type of intervention will be expected and generally welcomed.

Action to reduce Government's own energy use is already part of UK carbon mitigation plans (HM Government , 2009), but in the Lifestyle scenario this objective has additional importance to ***'exemplify'*** Government commitment. Government has the potential to lead both in terms of energy use investment, e.g. in social housing and via vehicle and ICT procurement, and in behaviour change, via energy management and travel substitution through telecommuting and teleconferencing.

'Engagement' of the general public in energy issues has traditionally been problematic for Government. Even with the growth of web-based information systems, significant behavioural change results primarily from more trusted role models, e.g. friends, family and community leaders. The implication is that similar principles to technological innovation need to be applied, with Government supporting rather than undertaking social innovation, e.g. by financing social entrepreneurs, in community projects and adopting a portfolio approach to recognize the inevitability of some innovation failure.

The implications of the Lifestyle scenario for policy extend far beyond simply adding in a set of new policies to 'deliver' behaviour change in the general population. The scenario envisions a society with significantly different attitudes, lifestyles and politics, which will have more far-reaching effects. Relationships between the state, market, communities and citizens will change, with implications for a range of public policies. We focus here on three: technology, taxation and governance; but there are potentially many more including health, education and foreign policy.

In the Lifestyle scenario, reduced energy use leads to less pressure for rapid innovation in energy supply than in low carbon scenarios without pro-environmental behaviour change (e.g. Anandarajah et al, 2009) or with an explicit focus on energy supply technology (e.g. Winskel et al, 2009). This results in a difference in emphasis in ***technology policy***, with a much greater focus on technologies that facilitate lifestyle change. Increased investment is required in both 'low-carbon community infrastructure', e.g. public transport and biomass community CHP, and for 'citizen-scale, low- and zero-carbon technologies', e.g. electric vehicles and microgeneration. The innovation challenge is recognized as socio-technical, i.e. not only to develop technologies but to deploy them in projects consistent with pro-environmental lifestyle choices.

There are major implications for ***taxation*** and public finances from reduced energy demand, particularly for highly taxed transport fuels. However, falling fuel use in this scenario may well be offset by greater acceptance of higher rates of fuel taxation and environmental taxes more generally, including energy and carbon taxes, and road user and parking charges. Increased social acceptance of the need for change and earlier implementation of energy demand reduction make a higher carbon price politically sustainable earlier. If current transport fuel tax rates were unchanged, lifestyle changes would reduce tax revenues by about £16 billion in 2050. However, even with 80% emissions reduction, this could be offset by an economy wide carbon price of £100/tCO_2, which is less than the shadow price for carbon in the scenario (see Section 6.5 above). We conclude that the ability to levy new taxes and higher carbon charges earlier can more than offset the impact of declining fuel use on public finances. A broader discussion of energy demand changes and the taxation implications is given in the recent Green Fiscal Commission Report (2009).

Energy '*governance*' becomes more distributed in this scenario. Assuming similar trends in other countries, there will be an effective international framework for carbon emissions reduction and a framework for trade that discriminates positively in favour of the environment with, for example, a strong international product policy, including high standards for vehicles and electrical goods. However, the main implications are for policy more locally. Energy regulation and fiscal policy are likely to remain primarily national, but the greater role of communities in energy decision-making implies that governance (in its broad sense) is more distributed. It seems likely that this will be reflected in formal structures, with more locally-based decisions on infrastructure development, investment, incentives and advice. For the finance sector, the shift in investment to the demand side implies a greater emphasis on financing decentralised technology, and therefore more locally-based lending with reference to the sustainability of investments. The need for new infrastructure (including for public transport, cycling and walking, heat networks and smart grids) implies a greater active role for publically regulated economic actors, building on the roles currently played by electricity District Network Operators (e.g. to deliver advanced metering, infrastructure for vehicle recharging and real time demand response services) and Passenger Transport Executives (to increase mass transit capacity in major conurbations and improved low-carbon bus services). The importance of public engagement implies much policy will need to be delivered primarily at a local level, e.g. through local Government, third sector groups or community-based businesses. This represents a major change for energy policy that has traditionally been highly centralized. It also implies a broadening of the focus of energy policy to recognize the role of sectoral policy, notably in housing and transport, to facilitate change.

7.2.1 Housing policy

Measures to improve housing energy efficiency will be very important. Existing incentives for relatively low cost measures (notably loft and cavity wall insulation) should continue until their market penetration is close to complete. The Carbon Emissions Reduction Target (CERT) has proved to be a successful approach to delivering these, which has been replicated in other European countries (Eyre et al, 2009). However, given the scale of investment required to deliver the more expensive fabric and low- and zero-carbon technologies required to achieve a low carbon housing stock, funding solely from energy supply revenues is not plausible, and new instruments will be needed. New approaches based around 'whole house retrofit' and 'pay as you save' are already being developed (DECC, 2009). These seek to lever investment against the very large fixed assets of the housing stock and energy infrastructure.

However, delivery of a housing stock that is low carbon will require more than just large investments. Refurbishment activities are complex, diverse and distributed. Making all refurbishment low carbon is a major challenge that needs to engage all of the building sector trades and professions in technologies and practices that are currently only very small niche markets (Killip, 2008). The re-skilling and attitudinal change for the sector is huge and requires an initiative of the type used to retrain gas heating engineers in condensing boiler technology in 2003/05, but covering the whole sector.

The social housing stock can provide an early large niche market, with large contracts, predictable clients and consistent standards to reduce transaction costs. This is an example of where public procurement (local housing authorities) and the third sector (housing associations) can play an important role in exemplifying change.

The goal of much stronger building regulations is already well-established for new buildings, with very ambitious goals for 2016 that will challenge the technical capacity of the housebuilding sector and building control enforcement. Standards can also be applied to refurbishment, and are already used effectively for replacement boilers and glazing.

Whilst a whole house retrofit is a practical approach for major refurbishment, most home improvement is piecemeal retrofit with owner-occupiers in residence. 'Rational' project management (area-based, whole-house based and cost effectiveness driven) alone will not deal with this complexity. Policy also needs to engage with improvement that is cyclical, building-specific and owner-determined through support for a range of measures at appropriate 'trigger points' in house life cycle (e.g. sale or extension, as well as major refurbishment). Building regulation could achieve this through use of a performance standard (rather than a fixed set of measures) at such points. Such a policy has historically been seen as controversial and interventionist, but would be consistent with social expectations in the Lifestyle scenario. The first steps to such a policy are already in place with the implementation of Energy Performance Certificates at the point of occupier change, although some technical and procedural improvements are needed (Banks, 2008) before these will be able to be used as a regulatory framework.

In this scenario, people will expect product suppliers of all types to label the energy efficiency of products. However, there will also be demand for greater market intervention and product standards. The EU (or more global) level is likely to remain the main forum for product regulation, even with the greater emphasis on 'localisation'. With similar lifestyle trends across Europe, EU policy-makers will be able to adopt more stringent product regulations and to base them on energy use rather than energy efficiency, for example to prevent the super-sizing of refrigerators and TV screens.

Carbon pricing can form part of the policy package. Currently, the EUETS provides no incentive for households except through electricity prices, and even here it is too small and insufficiently transparent to have any significant impact. More effective demand reduction incentives could be provided through transparent taxation of energy or carbon, through reformed (and therefore re-regulated) energy tariffs, or more radically through extending carbon trading to final users. Any of these options is likely to be more acceptable in this scenario than historically.

In the Lifestyle scenario, energy demand policy will not rely solely on investment, it will engage with energy users as well. With the rapid deployment of smart meters, there will be vastly improved energy billing and feedback. It is important that the short-term smart metering agenda is not captured by supply interests focused on load management through switching, thereby missing the potential for influencing behaviour. Future generations of electricity meters will allow identification of consumption profiles for individual appliances, and regulation of metering should require this as soon as practicable.

Energy efficiency advice has already proved highly cost effective (Defra, 2006). However, the next generation of technologies may not be amenable to the same low-cost telephone and web-based advice services. Face-to-face, in-home services are much more expensive, but will be needed at much larger scale. It is not yet possible to identify an ‘optimum solution’ for energy advice in a world of more complex home energy technologies. However, history would indicate it would be unwise to rely on a spontaneous energy services market. Social innovation is required. In the first instance, a range of pilot approaches is needed – covering different potential providers, different funding mechanisms and even different energy control philosophies (“smart home” or “smart person”) – to encourage the diversity from which viable models might emerge.

7.2.2 Transport policy

Current western societies are based on high levels of mobility, facilitated by high-quality infrastructures and low transport costs. One obvious approach is to push for further improvements in vehicle and fuel technologies that will reduce the environmental impacts of motorised transport without limiting distances travelled. But that leaves the problem that travel demand is growing faster than capacity possibly can. It also ignores the problem that efficiency gains can be offset by the uptake of vehicles with greater power and additional features and neglects the social issue that a significant share of the population cannot drive or does not have access to a car, for reasons of income, age, or ability (Handy, 2002).

Behaviour change is a strong natural force running through society and individuals as they move through the life course (e.g. changing locations of employment and residence). Yet, traditional forecasting models on which much current transport policy is based assumes business as usual behavioural choices and levels of mobility and rather implies that societal developments of significance to transport are ‘external’ to policy. By contrast, our Lifestyle scenario assumes that with appropriate and sufficiently robust policy levers, this behaviour change could be positively influenced for some immediately and substantially so that, over the course of the next 40 years, travel patterns are radically altered and the vehicle market transformed.

This requires taking the lessons from previous decades about the importance of price, quality and income so that policy can exert a positive influence on the type of society that is developing and the transport system required to support it.

Generally, the policy environment assumed in the Lifestyle scenario is one of ‘push and pull’ as fiscal and regulatory sticks are combined with the carrot of infrastructure investment (e.g. in car clubs, public transport, cycle infrastructure, railway capacity). In this context of more choice for local travel as the alternatives are improved, increasing acceptance of restrictive policies is assumed. These restrictions include the general phasing out of petrol/diesel vehicles in town/city centres through low-emission zones, increased parking charges and strict speed enforcement. This is balanced by the reallocation of road space towards public transport, walking and cycling as well as the recognition of telecommunications as a transport mode worthy of investment. To meet these demands requires transport policy makers to focus on those policies which bring the most benefits at least cost (such as smarter travel choices, parking charges and investment in car clubs), to withdraw environmentally ineffective, and sometimes inequitable, subsidies (such as concessionary fares schemes and scrappage incentives), plans for energy-intensive modes (such as High Speed Rail) and to look to remove the many inefficiencies in the way we travel and move goods (Marsden et al, 2010).

To achieve the level of production and sales of low-carbon vehicles demanded by the scenarios, market conditions and necessary infrastructure to support the rollout of grid-connected vehicles, particularly PHEV, beyond urban areas will need to be in place. The period after 2020 will need to see an increase in the range of vehicles available to consumers and freight operators in order to sustain the growth momentum. Market-based instruments and clear incentives for new technologies will continue to have a strong role for vehicles.

Delivering a radical change agenda will require a much better understanding than we currently have of how to engage the public with the various behaviour change initiatives which may be required. Non-price driven behaviour plays a significant role in transport choice. Although the relationship between attitudes and behaviour is by no means linear, it is likely that shifting attitudes in support of sustainable modes and practices will have a positive impact on actual behaviour, and allow more favourable responses to top-down measures. However, change requires both individual subjective responses in the form of self identity, moral norms and affective and instrumental attitudes, as well collective emotional response in the form of social norms. These in turn need to be complemented by a change in the physical and social context to make such change possible i.e. investment in attractive alternatives and restraint of car use (Anable et al, 2006). Altering the existing patterns of car dependence therefore depends critically on a shift in the physical and social context at the local level, the policy and cultural context at the national level and changes in individual attitudes and habits.

The changes to transport systems lead to significant other benefits, such as better health (much more regular walking and cycling), reduced congestion, noise and accidents, and better local air quality. These are often key drivers of the case for change at a local level.

8 CONCLUSIONS

This report has investigated the role of pro-environmental lifestyle change for the UK energy system to 2050. We make two assumptions, both of which seem obvious when stated, but are frequently forgotten or ignored in energy futures work. The first is that the behaviour of energy users is not fixed, but rather the outcome of developments in society, and that these are uncertain with the level of uncertainty increasing over time. The second is that any policy framework that seeks to deliver major changes in the energy system, such as an 80% reduction in CO_2 emissions, will be the outcome of a political process in which civil society, i.e. energy users in other roles, will play a key role.

Analysis of lifestyle change needs to consider the interaction between personal decisions and the social context in which they are made. Our assessment is that they are intimately linked: energy-using behaviours are affected by, and contribute to, changes in their social and economic context, the available technologies, physical infrastructures and public policy. Our analysis is therefore socio-technical. In particular, this analysis implies that the role of policy is not restricted to influencing pricing and technological change. For good or ill, it also plays a role in shaping lifestyles and energy-using behaviours.

Quantifying the energy implications of a pro-environmental lifestyle scenario involves assumptions about a large number of energy-using decisions across the whole population. The key reason for using a scenario approach rather than modelling each energy-using behaviour separately as a sensitivity to business as usual, is that these behaviours are likely to be correlated. ‘Lifestyle’ is a property of the social system not just a random collection of behaviours.

We have used an innovative methodology to combine the strengths of detailed end use models (UKDCM and UKTCM) and a cost-optimisation model of the whole UK energy system (MARKAL Elastic Demand). However, the models are individually well-established and have been tested extensively. We therefore have a high level of confidence that, given our assumptions, the energy system effects are broadly as modelled.

We have assumed changes to behaviour that we judge reasonable in an advanced economy, based on observation of energy-using activities across the developed world today. And we have assumed rates of change that seem feasible taking into account the need for both technologies and energy-using practices to diffuse and the external constraints to this, e.g., the need to change existing infrastructure.

Our results indicate that energy use in this sort of scenario might be expected to fall in both the household and transport sectors, by approximately 50% in each by 2050. This implies rates of change (energy demand decreases) of just below 2% annually. In the household sector, this is consistent with trends since 2004 (i.e. starting well before the recent recession) – demand has fallen approximately at this rate under the combined influence of rising prices and some stronger public policies. In transport, rising energy use trends have moderated for similar reasons, as well as some travel substitution by ICT.

The implications for energy demand in the economy are significant. Total final energy demand is projected to fall in the Lifestyle scenario by 30% by 2050, even without any allowance for an externally imposed explicit carbon constraint. Impacts are strongest for natural gas and oil, i.e. the fuels for which there are the highest energy security concerns.

Implications for electricity are initially less significant, as lifestyle change includes earlier switching to electric technologies, notably heat pumps and plug-in hybrid cars, which partly offsets lower service demands and improved efficiency in other uses of electricity. However, in the longer term (towards 2050) energy demand reduction means that the electrification of the economy, as expected by many commentators, does so to a lesser extent and more slowly.

Impacts on primary energy demand and carbon emissions are similar to those on final energy, i.e. a 30% reduction without supply side action, and with more early progress. We conclude that lifestyle change can make a significant contribution to delivering UK carbon emission goals, and assist early action, but that alone it is insufficient to deliver an 80% reduction goal, as this requires a wider transformation of the energy system.

One of the major findings of our analysis is that the cost of decarbonisation to the level of UK targets is much less in the Lifestyle scenario than other scenarios. Essentially this is because the energy system that needs to be decarbonised is smaller if energy service demands can be reduced and end use efficiency improved through changing lifestyles. The direction of the effect is obvious, but the scale is more significant than identified in analyses that assume ‘business as usual lifestyle change’.

The analysis in other chapters shows it is conceptually feasible to decarbonise the UK energy system within the context of a society which continues to be wastefully inefficient in energy use and primarily oriented towards consumerism. However, given that energy is a socio-technical system, such an outcome seems unlikely; in a democratic society some compatibility between the realms of public policy and social behaviour seems more probable. Energy consumers are also citizens capable of making intelligent choices about the future. Neglecting this in public policy risks foregoing the substantial opportunities for socio-economic benefits that are associated with decarbonising through pro-environmental lifestyle change.

The policy agenda for lifestyle change is less well developed than the equivalents for pricing and technological change. But the broad principles of what works are increasingly well-understood. The traditional discourse of ‘command and control’ versus ‘economic instruments’ is not particularly helpful, as it neglects the diversity of drivers, agents and scales of influence on human behaviour. Broadening the energy debate to include ‘energy citizens’ will necessitate a similar broadening of the policy agenda.

9 REFERENCES

Ackerman, J. & Hojer, M. (2006) How much transport can the climate stand? Sweden on a sustainable path in 2050. *Energy Policy*, Vol. 34 (14), pp. 1944-1957

AEA Technology (2005) *The Validity of Food Miles as an Indicator of Sustainable Development. Annex 1 Food Miles Dataset - Data sources and assumptions*. Final Report produced for DEFRA

Anable, J. (2005) 'Complacent Car Addicts' or 'Aspiring Environmentalists'? Identifying travel behaviour segments using attitude theory. *Transport Policy*, **12**, 65-78.

Anable, J., Brand, C., Tran, M. and Eyre, N. (2010) Modelling transport energy demand: A socio-technical approach . *Energy Policy*. doi:10.1016/j.enpol.2010.08.020

Anable, J., Lane, B and Kelay, T. (2006) *An Evidence Base Review of Attitudes to Climate Change and Transport*. Report for the UK Department for Transport, London.

Anable, J.; Mitchell, P. & Layberry, R. (2006) Getting the genie back in the bottle: limiting speed to reduce carbon emissions and accelerate the shift to low carbon vehicles. In *LowCVP Low Carbon Road Transport Challenge. Proposals to reduce road transport* CO_2 *emissions in the UK to help mitigate climate change.* The Low Carbon Vehicle Partnership, London.

Anandarajah, G., Strachan, N., Ekins, P., Kannan, R., and Hughes, N. (2009) *Pathways to a Low Carbon Economy: Energy Systems Modelling.* UKERC Energy 2050 Research Report 1. UKERC/RR/ESM/2009/001.

Baiocchi, G.; Minx, J.; Barrett, J. & Wiedmann, T. (2006) *The impact of social factors and consumer behaviour on the environment - an input-output approach for the UK*. Paper for the 2006 Input-Output Conference, Sendai, Japan, 26 - 28 July

Banister, D. and Stead, D. (2002) Reducing transport intensity*. European Journal of Transport Infrastructure Research* 2(2/3), pp 161-178.

Banks, N. (2008) *Implementation of Energy Performance Certificates in the Domestic Sector.* UKERC Working Paper WP/DR/2008/001

Bayliss, D., Banks, N. and Glaister, S. (2008) A Pricing and Investment Strategy for National Roads, *Proc. Institution of Civil Engineers: Transport*, **61**(3), 103-109

Bergman, N. and Jardine, C. (2009) Power from the People. Domestic Microgeneration and the Low Carbon Buildings Programme. ECI, Oxford

BERR & DfT (2008) *Investigation into the Scope for the Transport Sector to Switch to Electric Vehicles and Plug-in Hybrid Vehicles*. London, Department for Business Enterprise and Regulatory Reform & Department for Transport.

Brand, C. (2010a) *UK Transport Carbon Model: Reference Guide v1.0*. Oxford, Energy Demand Theme, UKERC.

Brand, C. (2010b) *UK Transport Carbon Model: User Guide v1.0*. Oxford, Energy Demand Theme, UKERC.

Brand, C., Tran, M. and Anable, J. (2010) The UK transport carbon model: An integrated life cycle approach to explore low carbon futures. *Energy Policy*. doi:10.1016/j.enpol.2010.08.019

Cairns, S., Hass-Klau, C., Goodwin, P. (1998) *Traffic Impacts of Highway Capacity Reductions: Assessment of the Evidence*, Landor Publishing, London.

Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A., Goodwin, P. (2008) Smarter Choices: Assessing the potential to achieve traffic reduction using 'soft measures'. *Transport Reviews*, **28**, 593-618.

Cairns, S.; Atkins, S. & Goodwin, P. (2002) Disappearing traffic? The story so far. *Proceedings of the Institution of Civil Engineers, Municipal Engineer*, Vol. 151 (1), pp. 13-22

Cairns, S.; Sloman, L.; Newson, C.; Anable, J.; Kirkbride, A. & Goodwin, P. (2004) *Smarter Choices - Changing the way we travel.* Report for the UK Department for Transport, London.

Carplus (2009) Lord Adonis Crowns 100 000th Car Club Member. Carplus Press Release, November 26th 2009

Civil Aviation Authority (2006) *No-frills carriers. A revolution or evolution*? A study by the Civil Aviation Authority. London: CAA.

Committee on Climate Change (CCC) (2009) *Meeting carbon budgets - the need for a step change. Progress report to Parliament*. London: Committee on Climate Change.

Crompton, T. (2008) *Weathercocks and Signposts. The environmental movement at a crossroads.* London: WWF.

Darby (2007) *Enough is as good as a feast - sufficiency as policy*. Paper presented to European Council for an Energy Efficient Economy (ECEEE) 2007 Summer Study, France, June

Dargay, J; Menaz, B and Cairns, S (2006) *Public attitudes towards aviation and climate change. Stage 1: Desk research.* Report to the Climate Change Working Group of the Commission for Integrated Transport. London: CfIT.

Darnton, A., Elster-Jones, J., Lucas, K., Brooks, M. (2006) *Promoting Pro-Environmental Behaviour: Existing Evidence to Inform Better Policy Making*. Report to Defra.

DECC (2009a) *Heat and Energy Saving Strategy: a consultation*. Department of Energy and Climate Change, London.

DECC (2009b) *Energy Consumption in the UK*. Department of Energy and Climate Change. http://decc.gov.uk/en/content/cms/statistics/publications/publications.aspx

DECC (2009c) *The UK Renewable Energy Strategy*. Department of Energy and Climate Change, London.

DECC (2009d) *Digest of UK Energy Statistics.* Department of Energy and Climate Change, London.

Defra (2006) *Synthesis of Climate Change Policy Evaluations*. Department of Environment and Rural Affairs, London.

Defra (2008) *A framework for Pro-environmental behaviours*. Department of Environment and Rural Affairs, London.

Defra (2009) *UK Climate Projections*. Department of Environment and Rural Affairs, London. http://ukclimateprojections.defra.gov.uk/content/view/824/517/

DETR (2000) *English House Condition Survey 1996: Energy Report.* Department of the Environment, Transport and the Regions, London.

DfT (2007). *Personal Travel Factsheet.* July 2007. Department for Transport, London.

DfT (2008a) *Road Transport Forecasts 2008 – Results from the Department for Transport's National Transport Model*. Department for Transport, London.

DfT (2008b) *Transport Statistics Great Britain 2008 Edition*. November 2008. Department for Transport, London.

DfT (2008c) *National Travel Survey: 2007 Interview data*. Department for Transport, London.

DfT (2010) *Transport Statistics Great Britain: 2010 Edition*. Department for Transport, London.

Diamond, R. (2003) A lifestyle-based scenario for US buildings: implications for energy use. *Energy Policy*, Vol. 31, pp. 1205-1211.

Ekins, P. and Skea, J. (2009) (Eds.) *Making the Transition to a Secure and Low Carbon Energy System: Synthesis Report.* UK Energy Research Centre, London.

Ekins, P., Anandarajah, G., Hughes, N., Kannan, R. and Strachan, N. (2009) Chapter 2 in: Ekins, P., Skea, J., (Eds.), *Making the transition to a secure and low-carbon energy system: synthesis report.* UK Energy Research Centre, London.

Elzen, B., Geels, F., Hofman, P. and Green, K. (2002) Socio-technical scenarios as a tool for transition policy: an example from the traffic and transport domain. Paper for 10th International Conference of the Greening of Industry Network, Gothenburg, Sweden, June 2002.

Enkvist, P-A., Nauclér, T. and Rosander, J. (2007) *A cost curve for greenhouse gas reduction*. The McKinsey Quarterly, No.1. McKinsey & Company.

Evans, D. & Jackson, T. (2007) *Towards a sociology of sustainable lifestyles*. RESOLVE Working Paper 03-07.

Eyre, N., Pavan, M. and Bodineau, L. (2009) Energy Company Obligations to Save Energy in Italy, the UK and France: What have we learnt? Proceedings of the European Council for an Energy Efficient Economy, 2009 Summer Study, France, June 2009.

Geels, F.W. (2005a) Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting & Social Change*, Vol 72, pp. 681-696.

Geels, F.W., (2005b) *Technological Transitions and System Innovation: A Coevolutionary and Socio-Technical Analysis*. Edward Elgar, Cheltenham.

Givoni, M., Brand, C. and Watkiss, P. (2009) Are railways 'climate friendly'? *Built Environment*, 35(1): 70-86.

Goodwin, P. (1999) *Action or Inertia? One Year on from 'A New Deal for Transport.* Transcript of Lecture given at Transport Planning Society Meeting at the Institution of Civil Engineers, 22 July 1999.

Goodwin, P. (2008) Policy Incentives to Change Behaviour in Passenger Transport, in *OECD International Transport Forum, Transport and Energy: The Challenge of Climate Change*.

Goodwin, P. and Lyons, G. (2009). Public attitudes to transport: scrutinising the evidence. Proc. 41st Universities Transport Study Group Conference, London.

Green Fiscal Commission (2009) *The Case for Green Fiscal Reform – The Final Report of the Green Fiscal Commission*, October 2009.

Gross, R.; Heptonstall, P.; Anable, J.; Greenacre, P. & E4Tech (2009) *What policies are effective at reducing carbon emissions from surface passenger transport? A review of interventions to encourage behavioural and technological change*. A report produced by the Technology and Policy Assessment Function of the UK Energy Research Centre (UKERC)

Halpern, D. and Bates C. (2004) *Personal Responsibility and Changing Behaviour: the state of knowledge and its implications for public policy*. Prime Minister's Strategy Unit, Cabinet Office

Handy, S. (2002) *Accessibility vs. Mobility: Enhancing strategies for addressing automobile dependence in the U.S*. Prepared for the European Conference of Ministers of Transport.

Hathaway, P. (2004) *The effect of the fuel 'protest' on road traffic*. Transport Statistics Road Traffic Division, Department for Environment, Transport and the Regions, London.

Headicar, P. (2009) Transport Policy and Planning in Great Britain. Routledge, Abingdon.

Henderson G. and Shorrock L.D. (1986) BREDEM, the BRE Domestic Energy Model: Testing the predictions of a two-zone version Building Serv. Eng. Res. Technol. 7(2) 87-91.

Henderson, G. (2005) Home air conditioning in Europe – how much energy would we use if we became more like American households? Proceedings of the European Council for an Energy Efficient Economy, 2005.

Hepworth, M. and Ducatel, K. (1992) Transport in the information age. Wheels and wires. London: Belhaven Press.

Hickman, R. & Banister, D. (2007) Looking over the horizon: Transport and reduced CO_2 emissions in the UK by 2030, *Transport Policy*, 14, 5, pp 377-387.

Hinnells, M., Boardman, B., Layberry, R., Darby, S., and Killip, G. (2007) *The UK Housing Stock 2005 to 2050: Assumptions used in Scenarios and Sensitivity Analysis in UKDCM2*. Environmental Change Institute, University of Oxford.

HM Government (2009) *The UK Low Carbon Transition Plan – National Strategy for Energy* *and Climate.* The Stationery Office.

HM Treasury (2006) *The Stern Review: The Economics of Climate Change*. HM Treasury and Cabinet Office, London.

IEA (2007) *Energy for the New Millenium – Trends in Energy Use in IEA Countries*, International Energy Agency, Paris.

IEA (2008) *Energy Technology Perspectives*. International Energy Agency, Paris, France.

IEA (2010) *Standby Power Use and the IEA One Watt Plan*. International Energy Agency, Paris, France. http://www.iea.org/subjectqueries/standby.asp

Institute for Transport Studies (ITS) Leeds (2001) *Updating Car Ownership Forecasts*. Final Report to the then Department of the Environment, Transport and the Regions. Institute for Transport Studies, Leeds.

Intergovernmental Panel on Climate Change (IPCC) (2007) Summary for Policymakers, in: Metz, B., Davidson, O. R., Bosch, P. R., Dave, R., Meyer, L. A., (Eds.), *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Jackson, T. (2005) *Motivating Sustainable Consumption: A Review Of Evidence On Consumer Behaviour And Behavioural Change*. London: Policy Studies Institute.

Jeffries, J. (2005) The UK population, past present and future. In: ONS, Focus on People and Migration, Office for National Statistics, London.

Jochem E., Barker T., Scrieciu S., Schade W., Helfrich N., Edenhofer O., Bauer N., Marchand S., Neuhaus J., Mima S., Criqui P., Morel J., Chateau B., Kitous A., Nabuurs G. J., Schelhaas M.J., Groen T., Riffeser L., Reitze F., Jochem E., Catenazzi G., Jakob M., Aebischer B., Eichhammer W., Held A., Ragwitz M., Reiter U., Turton H. (2009): *EU-Project ADAM: Adaptation and Mitigation Strategies: Supporting European Climate Policy – Deliverable M1.2: Report of the Reference Scenario for Europe*. Fraunhofer ISI, Karlsruhe.

Kannan R, Ekins P. and N. Strachan (2008) The Structure and Use of the UK MARKAL Model. Chapter 12 in: L. Hunt and J. Evans (Eds) *International Handbook on the Economics of Energy*. pp.285-310. Edward Elgar Publishing.

Kannan R. and Strachan N. (2009) Modelling the UK Residential Energy Sector under Long-term Decarbonisation Scenarios: Comparison between Energy Systems and Sectoral Modelling Approaches, *Applied Energy*, Vol. 86(4), pp.416-428.

Killip, G. (2008) *Transforming the UK's existing housing stock*. Final Report for Federation of Master Builders.

King, J. (2007) *The King Review of low-carbon cars – Part I: the potential for* CO_2 *reduction.* HM Treasury, London.

King, J. (2008) *Part 2: Policy Recommendations.* HM Treasury, London.

Koehler, J. (2009) Dynamics of socio-technical change in the transport sector: an application of transition theory to environmental policy. Dynamics of Institutions and Markets (DIME) workshop, Utrecht, Netherlands, 10th May 2009.

Layberry, R. et al (2007) *Modelling UK Residential Energy Consumption: a technical manual for the UKDCM.* Report available from http://www.eci.ox.ac.uk/research/energy/bmt.php

Loorbach, D., Rotmans, J., (2006) Managing transitions for sustainable development. In: X. Olshoorn, A.J. Wieczorek (Eds.), *Understanding Industrial Transformation: views from different disciplines*. Springer, Dordrecht.

Loulou R., Goldstein G. and Noble, K. (2004) *Documentation for the MARKAL family of models.* http://www.etsap.org/

Lutzenhiser, L. (1993) Social and Behavioural Aspects of Energy Use. *Annual Review of Energy and Environment*. Vol 18, pp. 247-289.

Lyons, G., Farag, S. and Haddad, H. (2008). The substitution of communications for travel? Chapter 11 in: Ison, S. and Rye, T. (Eds). *The Implementation and Effectiveness of Transport Demand Management measures: An International Perspective*.pp. 211-232. Ashgate.

Marsden, G., Lyons, G., Anable, J., Ison, S., Cherret, T. and Lucas, K. (2010) *Opportunities and Options for Transport Policy*. Universities Transport Study Group 42nd Annual Conference, Plymouth, 05-07/01/10.

McKinnon, A. (2007). CO_2 *Emissions from Freight Transport in the UK*. Commission for Integrated Transport, London.

McKinsey & Company (2009) Averting the Next Energy Crisis: The Demand Challenge. Mckinsey Global Institute, San Francisco, USA.

Metz, D. (2002) Limitations of Transport Policy. *Transport Reviews*, Vol. 22, pp.134-145.

Metz, D. (2008) *The Limits to Travel*. Earthscan.

Mohktarian, P. & Chen, C. (2004) TTB or not TTB, that is the question: a review and analysis of the empirical literature on travel time and money budgets. *Transportation Research Part A: Policy and Practice*, Vol. 28 (9-10), pp. 643-675.

Moriarty, P. & Nonnery, D. (2008) Low-mobility: The future of transport. *Futures*. Vol. 40, pp. 865-872.

OFT (2007) *Internet Shopping. An OFT Market Study*. Office of Fair Trading.

ONS (2009) *E-commerce and information and communication (ICT) activity, 2008. Statistical Bulletin*. November 2009. Office for National Statistics, London.

Oxera (2006). *Policies for energy efficiency in the UK household sector*. Report to Defra. Oxford, Oxera Consulting Ltd.

Palmer, J., Boardman, B., Bottrill, C., Darby, S., Hinnells, M., Killip, G., Layberry, R. and Lovell, H. (2006) *Reducing the environmental impact of housing*. Final Report of a study in support of the Royal Commission on Environmental Pollution's 26th Report on the

Urban Environment

Pearce, B. (2008) What is driving travel demand? Managing Travel's Climate Impacts IATA. In: *The Travel & Tourism Competitiveness Report*, World Economic Forum.

Perrels, A. & Weber, C. (2000) *Modelling impacts of lifestyles on energy demand and related emissions.* Vatt Discussion Paper No. 228. Government Institute for Economic Research, Helsinki.

Rajan, S.C. (2006) Climate change dilemma: technology, social change or both? An examination of long-term transport policy choices in the United States. *Energy Policy*, Vol. 34 (6), pp.664-679.

Reusswig, R.; Lotze-Campen, H. & Gerlinger, K. (2003) Changing Global Lifestyles and Consumption Patterns: the case of energy and food. PERN Workshop: Population, Consumption and Environment Dynamics: Theory and Method, Wyndham Hotel, Montréal, Canada, October 19, 2003.

Rotmans, J., Kemp, R., & van Asselt, M. (2001). More evolution than revolution: transition management in public policy. *Foresight*, Vol. 3(1), pp. 15-31.

Sanstad, A.H. and Howarth, R.B (1994) Normal Markets, Market Imperfections and Energy Efficiency. *Energy Policy* 22 (10), pp. 811-818.

Skea, J. and Ekins, P. (Eds.) (2009) Making the transition to a secure and low-carbon energy system: synthesis report. UK Energy Research Centre, London.

Skea, J., Ekins, P. and Winskel, M. (eds) (2011) Energy 2050: the transition to a secure and low carbon energy system for the UK. Earthscan.

Sloman, L., Cairns, S., Newson, C., Anable, J., Pridmore, A. and Goodwin, P. (2010) *The effects of smarter choice programmes in the Sustainable Travel Towns.* Report to the Department for Transport, January 2010.

Smith, A., Stirling, A., and Berkhout, F. (2005) The governance of sustainable socio-technical transitions. *Research Policy*, 34(10), pp.1491-1510.

SMMT (2009) *New Car* CO_2 *Report 2009*. The Society of Manufacturers and Traders, London.

Sorrell, S. (2007). *The Rebound Effect: An Assessment of the Evidence for Economy-wide Energy Savings from Improved Energy Efficiency.* UKERC Report ISBN 1903144035. UK Energy Research Centre, London.

Sorrell, S., Speirs, J., Bentley, R., Brandt, A. and Miller, R. (2009) An assessment of the evidence for a near-term peak in global oil production. UK Energy Research Centre.

Steg, L., 2004. Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A.* Vol. 39, pp.47-162.

Stern, N. (2006) *Stern Review on the Economics of Climate Change*. HM Treasury, London.

Stern, P.C. and Aronson, E. (eds.) (1984) *Energy Use: the Human Dimension*. Freeman, New York.

Strachan N. and Kannan, R. (2008) Hybrid Modelling of Long-Term Carbon Reduction

Scenarios for the UK. *Energy Economics*, Vol. 30(6), pp.2947-2963.

Strachan N., Kannan R. and Pye, S. (2008) *Scenarios and Sensitivities on Long-term UK Carbon Reductions using the UK MARKAL and MARKAL-Macro Energy System Models.* UKERC Research Report 2. UK Energy Research Centre, London. http://www.ukerc.ac.uk

Strachan N., Balta-Ozkan, N., Joffe, D., McGeevor, K. and Hughes, N. (2009) Soft-Linking Energy Systems and GIS Models to Investigate Spatial Hydrogen Infrastructure Development in a Low Carbon UK Energy System. *International Journal of Hydrogen Energy*, Vol. 34(2), pp.642-657.

Strachan N., Foxon, T. and Fujino, J. (2008) Policy Implications from Modelling Long-term Scenarios for Low Carbon Societies. *Climate Policy*, Vol. 8, S17-S29.

SWOV (2006) *SWOV Fact Sheet: Cyclists*. Institute for Road Safety Research, The Netherlands.

TfL (2007) *Central London Congestion Charging: Impacts Monitoring Fifth Annual Report.* Transport for London.

Thogersen, J. (2005) How many consumer policies empower consumers for sustainable lifestyles? *Journal of Consumer Policy*. Vol. 28 (2), pp.143-177.

TNO (2006) The effects of a range of measures to reduce the tail pipe emissions and/or the fuel consumption of modern passenger cars. IS-RPT-033-DTS-2006-01695. TNO, Delft, Netherlands.

Turrentine, T.S. and Kurani, K.S. (2007) Car buyers and fuel economy. *Energy Policy*, 25, 1213-1223.

UKERC (2009) *Interactive Manual of Policies to Abate Carbon from Transport* (IMPACT). Published online at http://www.impact-ukerc.org.

Utley, J. and Shorrock, L. (2008) *Domestic Energy Fact File*. BRE.

Van Wee, B., Rietveld, P., & Meurs, H. (2006) Is average daily travel time expenditure constant? In search of explanations for an increase in average travel time. *Journal of Transport Geography.* Vol. 14 (2), pp.109-122.

Weber, C., Perrels, A. (2000) Modelling impacts of lifestyles on energy demand and related emissions. *Energy Policy*. Vol. 28, pp.549-566.

Whelan, G., 2007. Modelling car ownership in Great Britain. *Transportation Research Part A: Policy and Practice*. Vol. 41, pp.205-219.

Winskel, M., Markusson, N., Moran, B., Jeffrey, H., Anandarajah, G., Hughes, N., Candelise, C., Clarke, D., Taylor, G., Chalmers, H., Dutton, G., Howarth, P., Jablonski, S., Kalyvas, C., and Ward, D. (2009) *Decarbonising the UK Energy System: Accelerated Development of Low Carbon Energy Supply Technologies*. UKERC Energy 2050 Research Report No. 2. UK Energy Research Centre, London.

Woodcock, D.; Banister, D. & Edwards. P. et al. (2007) Energy and Transport. *Lancet.* 370, pp.1078-1088.

Woodman, B. and Baker, P. (2008) Regulatory frameworks for decentralised energy. *Energy*

Policy. Vol. 12, pp.4527-4531.

World Business Council for Sustainable Development (2004) *Mobility 2030: Meeting the Challenges to Sustainability.* WBCSD, Geneva, Switzerland.

World Energy Council (2007) *Transport Technologies and Policy Scenarios to 2050*. WEC, London.

WWF (2008) *Weathercocks and Signposts. The environmental movement at a crossroads.* WWF, London.

Appendix A: UKTCM – approach

Transport Demand

The demand module uses a typical econometric model constructed around *income elasticities* and *population growth elasticities* for passenger and freight and all vehicle types, including international aviation. This is based on short-run elasticities of income/GDP, the number of households and transport intensity (passenger/tonne-km per GDP) as well as long run price elasticities of transport demand affecting overall demand for a given mode but also long-term modal shift. These elasticities represent the dependence of transport demand growth on the change of *relative costs*[5] provided by the vehicle stock module. The elasticities are defined for each year to avoid a simple static approach. To avoid an over-determination of transport demand, both elasticities are adjusted and therefore are not directly comparable with elasticities used in other studies.

In addition, the UKTCM is set up to simulate uncertainty in the future in up to four scenarios, which provide a series of variables that are used within the linked models. These variables describe exogenous factors such as GDP growth and demographic changes, which will affect the outcomes of the models, while being outside the control of policy-makers. The purpose of the scenarios within UKTCM is to simulate a series of contexts within which the UK transport system may develop, so that alternative policies can be tested for robustness against the uncertainties in the political, socio-economic and technological spheres.

A note on **'costs'**: costs are used in a number of ways, either as **exogenous** inputs (e.g. purchase *price* of a car as ONE factor in modelling technology/vehicle choice) or modelled **endogenously** (e.g. annual fuel costs, transport costs in £ per passenger/tonne-km by mode of transport used in demand/supply feedback loops). Note the emerging carbon market can be simulated by a price or tax on carbon (via fuel use, mileage, by vehicle type, size, propulsion type, etc) or indirectly via the pricing of transport usage (e.g. road pricing per vehicle-km driven).

Transport supply

The vehicle stock module provides two key functions within UKTCM:

- a breakdown of the numbers of vehicles present in the population, by vehicle type, ownership (private vs. fleet – for cars only), size, technology and age, as input to the lifecycle emissions module (for upstream and downstream emissions of producing, maintaining and scrapping vehicles);
- detailed disaggregation of the demand segments provided by the demand module, in terms of vehicle size, technology and age, as input to the energy and emissions module and the environmental impacts module.

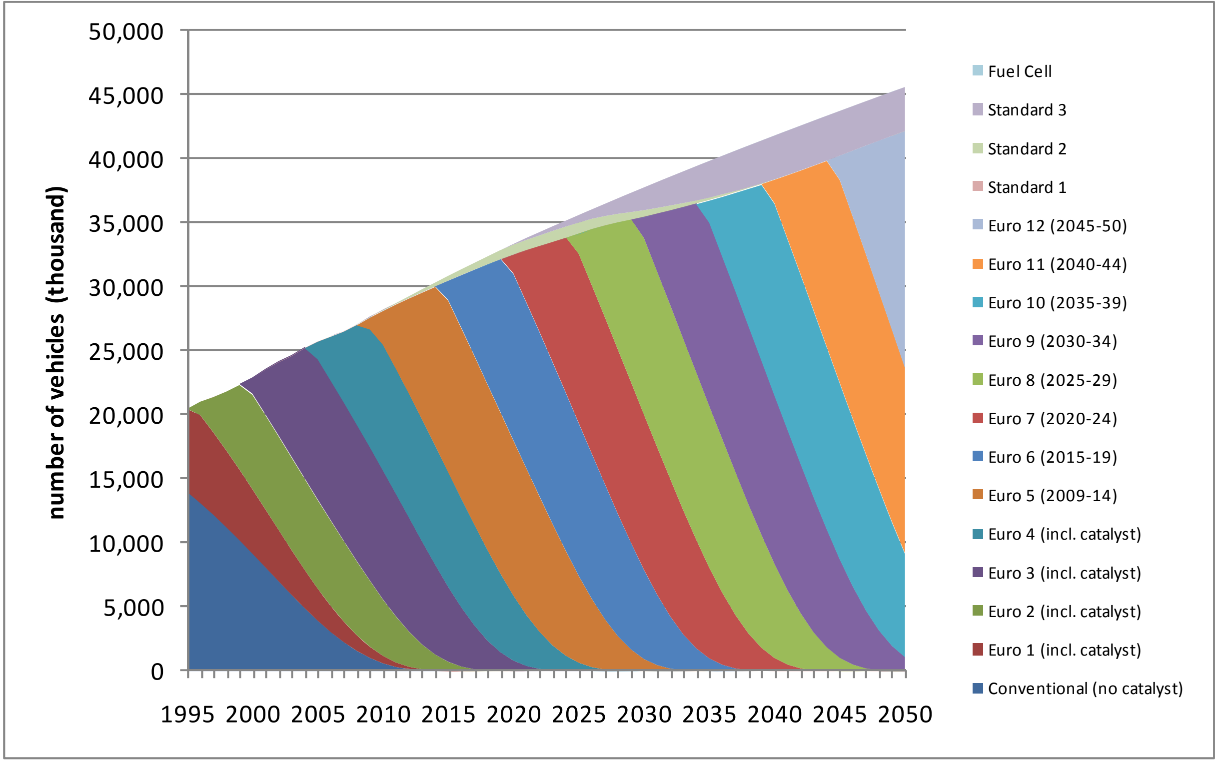
---

[5] The cost figures represent a vehicle-km weighted average of the running costs and purchase costs for a given vehicle type and year. The development of the costs over time is used in the transport demand module to determine modal shift between vehicle types for passenger and freight.

Evolving stock modelling

A crucial attribute of the stock model is that the user can test the effects of policy levers on the deployment of different technologies within the vehicle population. The basis of the vehicle stock model is the evolution of the vehicle stock, in size, age and technology terms, over time. In each year the structure of the vehicle population will change due to a combination of two processes: the purchase of new vehicles and the scrapping of old vehicles. The process is iterative, with changes year-on-year against the vehicle population distribution for the base year. New technologies enter the population through the purchase of new vehicles. This vehicle fleet evolution is illustrated for cars in a hypothetical scenario in Figure 35.

Figure 35: Example of the car stock evolution over time, by vintage/engine class*

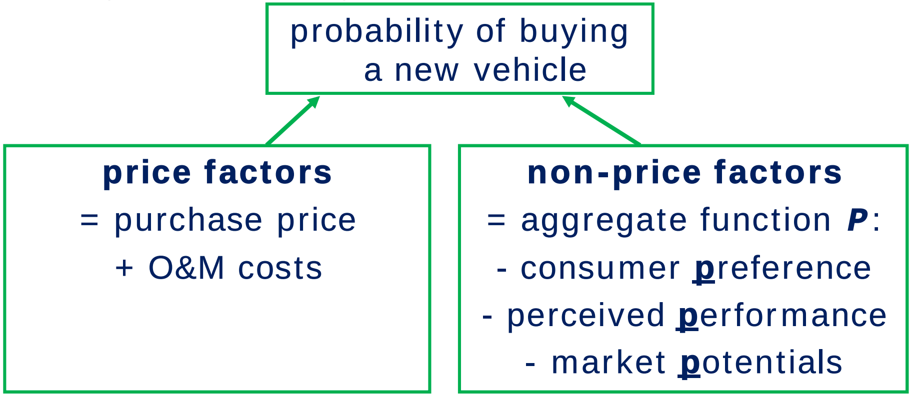


Notes: * 1995-2007 shows historic data – 2008-2050 shows modelled data. Euro 5 to Euro 12 are labels for future generations or vintages of car technologies – they do not denote EC regulated emissions standards. Standard 1 to 3 denote non-regulated standards for alternative fuelled cars, e.g. battery electric cars and internal combustion engine cars running on hydrogen (e.g. BMW hydrogen '7 series').

Modelling vehicle technology choice

The take-up of new vehicle technologies is calculated in a simple logit model that calculates the probability of buying a new vehicle as a function of *price* (i.e. the price to the consumer) and an *aggregate non-price function P*, which takes into account the combined effect of consumer *P*reference, perceived *P*erformance (power, range, acceleration) and market *P*otentials (availability of refuelling infrastructure, vehicle range limits technology to, say, urban areas), as shown in Figure 36. Here *price* includes purchase price, any fees, taxes and scrappage rebates as well as annual O&M costs over the economic lifetime of the technology, discounted to present value. For cars, for example, the discount rates applied to purchase costs are disaggregated by type of purchasing and ownership. Private buyers put considerably more emphasis on purchase price; hence the purchase costs for buying a new private car is annuitized with a higher discount rate of 30%, while investment costs for company and fleet cars are annuitized at a lower rate of 10%. The *P* function represents a technology's market share at maturity at equal lifetime 'cost' to a reference technology (e.g. medium sized Euro4 petrol ICE car). Historic values for existing technologies such as petrol and diesel cars can be derived from given price levels and observed take-up rates. *P* values for future technologies can be modelled on historic ones, developed in consultation with policy and industry experts or, as performed here, as part of a 'what if' scenario exercise.

Figure 36: Modelling vehicle technology choice for new vehicles



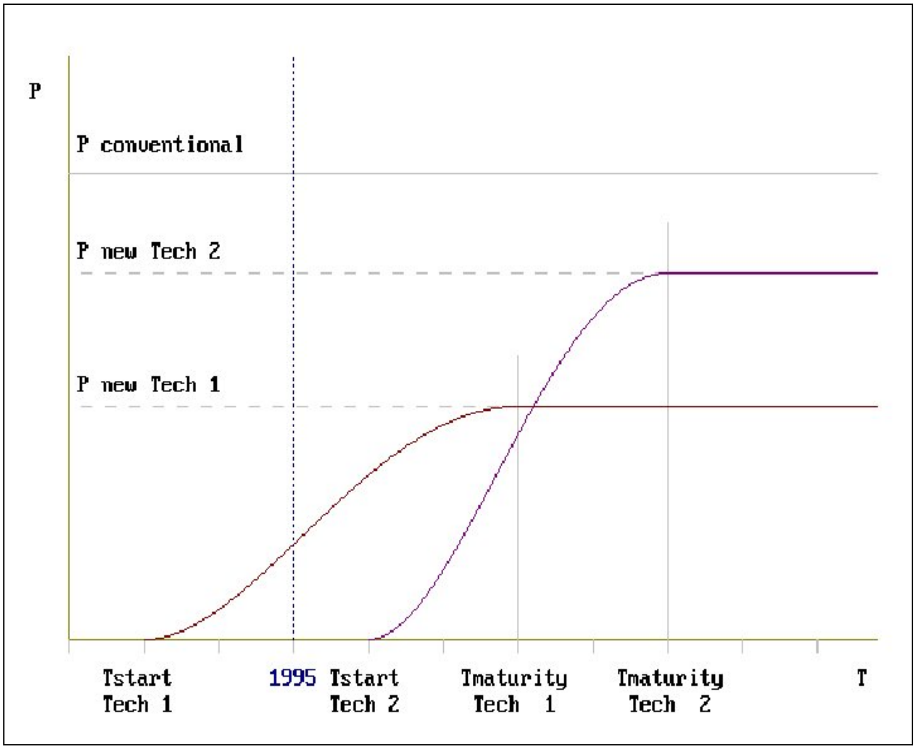
The temporal element of market take up is simulated using an S-curve[6] (defined by 'start' and 'maturity' years of the technology), as illustrated in Figure 37. Note the year of 'maturity' of a technology is not the date when the S-curve of market penetration (share of new vehicle sales) levels off for the new technology. Growth in new vehicle sales may lag behind the rise in the *P* function, as the number of sales will also be critically dependent on differences in technology costs and taxes.

The new car technology choice submodule employs the most detailed approach of the transport modes. New cars are modelled by size (small, medium, large – representing engine sizes for conventional propulsion systems) and ownership (private or fleet/company) – both of which are *not* modelled endogenously in MED. Consumers typically know what car class (and often make and model) they are looking to buy. This is linked to the family lifecycle (e.g. 'first car', 'student', 'young professional', 'family', 'mid life crisis', retirement/dream car', and so on). On average, the UK car size split has been nearly constant, with small cars taking up about around 30% of the market, medium 52% and large 18%. Small and medium car shares have fallen slightly over the past 10 years, while large cars are on the increase. In the current version of UKTCM the default size split is assumed to follow recent trends (small, medium down, large up) up to 2020 and then stay constant due to saturation effects. Vehicle size split is a scenario variable which can be changed over time for sensitivity analysis or exploration of scenario variants in UKERC Energy2050. Indeed, this has been done for the lifestyle scenario, where new large cars are being phased out up to 2020.

---

[6] This is distinct from the S-curve of market penetration, i.e. vehicle numbers.

Figure 37: Modelling non-price factors for vehicle technology choice



Notes: the graph shows the P function for three vehicle technologies: conventional (no S-curve as already mature), new Tech 1 (short term alternative technology with lower market share at maturity and longer take-up period) and new Tech 2 (longer term alternative technology with higher market share at maturity and shorter take-up period).

Car purchasing decisions are reportedly influenced by whether the vehicle is owned by a private individual / family or a fleet owner / company. Depending on the source, *new* fleet / company cars make up between 50% and 75% of all new cars sold. The UKTCM simulates this feature of the UK market by putting much more emphasis on purchase price in the private car model (high discount rate 30%) while the weighting between up-front costs, O&M and fuel costs are more balanced for fleet / company cars (lower discount rate of 10%). The distinction makes it possible to simulate, say, a push for company/fleet cars to be low carbon (e.g. defined by VED band).

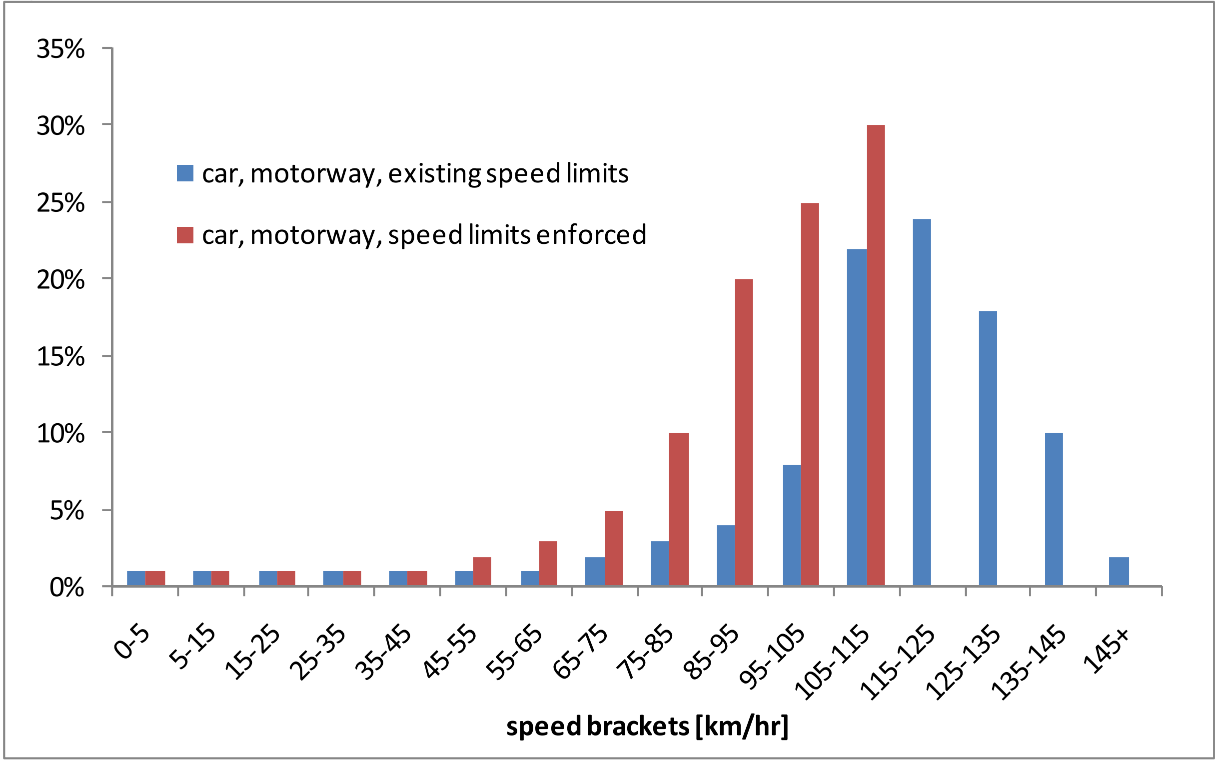
Energy use and emissions (at source)

The energy and emissions module calculates energy consumption and pollutant emissions for all modes of transport. It is able to model the combined effects of different fleet compositions, different sets of emission factors, traffic characteristics (speeds, congestion) and driver behaviour over the modelling period.

For road transport, the module uses a speed-dependant emission behaviour approach linked with road types urban, rural and motorway. This enables us to estimate the effects of speed limit enforcement on average road speeds or of information campaigns on driver behaviour, and thereby influence emissions results. Importantly, it allows a more realistic way of modelling any market increases of ‘new’ vehicles such as hybrid cars and buses, which have much lower emissions in urban areas than conventional internal combustion engine vehicles. In addition, the module allows to simulate improved fuels, cold start influence on emissions, congestion (via speed profiles and route types), driver behaviour (e.g. eco-driving) and, more general, any time dependency of emissions-factors.

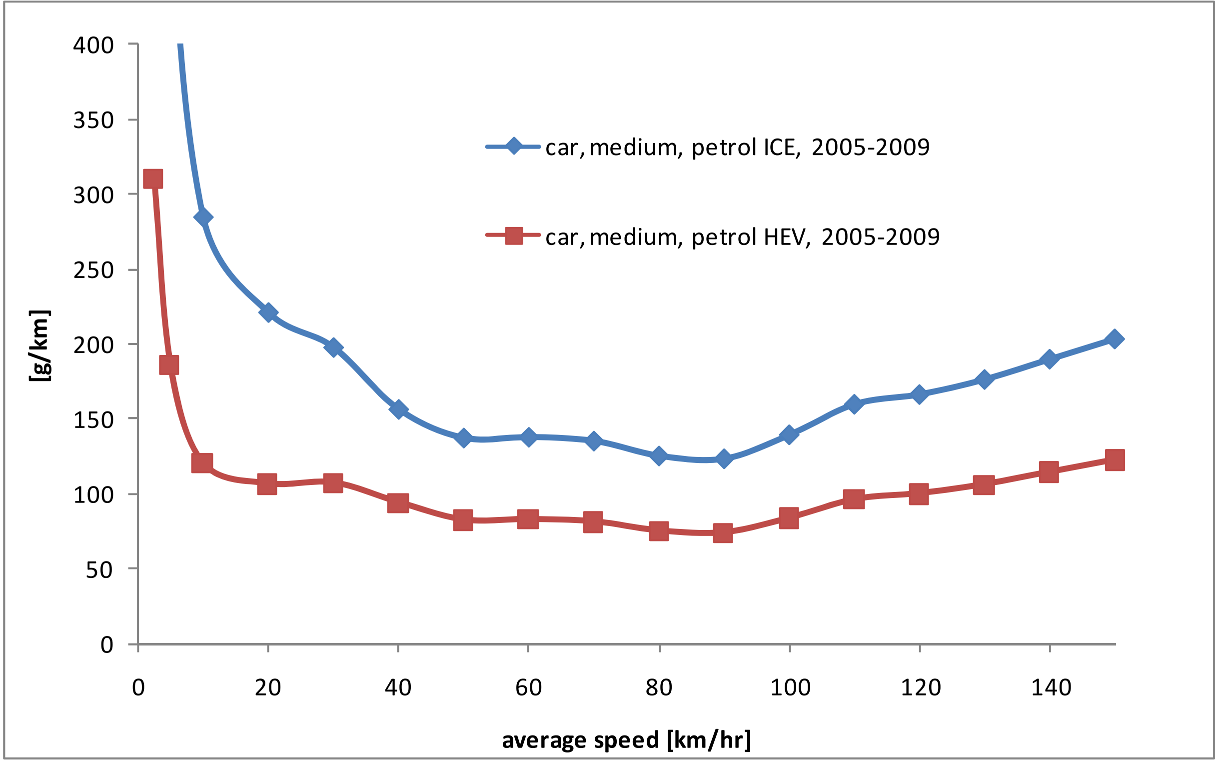
To illustrate this, Figure 38 shows two example speed profiles for car traffic on motorways – one simulating the existing situation in the UK where speed limits exist but are not properly enforced (about half of the cars travel at speeds above the limit), and one where we assume limits are enforced (hence the cut of point at 70mph/113 kph and redistribution of the speeders just below that point).

Figure 38: Example speed profiles for motorway car traffic



These speed profiles are then enveloped with speed-emissions curves such as the ones for CO_2 emissions of two classes of medium sized petrol cars shown in Figure 39. Given the shapes of the curves, the result of enforcing speed limits is a decrease in CO_2 emissions from motorway car traffic.

Figure 39: CO_2 speed-emissions curves for medium-sized petrol ICE and HEV cars, 2005-2009 vintage



Notes: ICE = internal combustion engine, HEV = hybrid electric/ICE vehicle

Lifecycle emissions and environmental impacts

Although not directly used in this work, the UKTCM life-cycle module calculates indirect energy use and emissions for the manufacture, maintenance and scrappage of vehicles, the construction, maintenance, and disposal of infrastructure, as well as for the supply of energy (e.g. fuels). The environmental impacts module then provides an assessment of the damage caused, i.e. it calculates impact indicators and external costs.

The model is based on previous EU research (the JRC/EUCAR/CONCAWE 'Well-To-Wheels' study, ExternE and STREETS) and includes:

- life-cycle emissions, primary energy demand and land use for the production, maintenance, and scrappage/disposal of vehicles and infrastructure;
- current and projected electricity generation mix of the UK;
- life-cycle emissions, primary energy demand and land use for the production and supply of all 13 fuels considered in UKTCM;
- impact potentials for the 8 impact indicators considered in UKTCM;
- average accident rates (fatalities, minor and serious casualties); and
- external cost data for the monetary valuation of direct emissions, indirect emissions and accidents based on the ExternE impact pathway approach.

The parameters the user can change are related to additional infrastructure (e.g. high-speed rail, airports); electricity generation mix; accident costs (monetary values for fatalities, minor and serious casualties); casualty rates; impact potentials; and population density.