

Living within a carbon budget

Report for Friends of the Earth and The Co-operative Bank, July 2006

Dr Alice Bows, Dr Sarah Mander, Mr Richard Starkey,
Dr Mercedes Bleda and Dr Kevin Anderson

Report nature and ownership

The intellectual content of this document is copyright of the authors at The University of Manchester. This Report is the property of the Friends of the Earth and The Co-operative Bank, but may be freely copied and distributed. This report is based on research conducted within and wholly funded by the Tyndall Centre for Climate Change Research (www.tyndall.ac.uk). Preparation of this report was funded by Friends of the Earth and The Co-operative Bank and delivered by the Tyndall Centre at the University of Manchester.

Tyndall contact

Dr Alice Bows
Tyndall Centre Manchester
Pariser Building (H Floor)
The University of Manchester
Manchester
UK
M60 1QD

Friends of the Earth contact

Mike Childs
Head of Campaigns
Friends of the Earth
26-28 Underwood St
LONDON
N1 7JQ

Acknowledgments

Many thanks to Bill Bows for proof reading and editing this document and to Dr Sylvia Knight and Harriet Pearson for assisting the team in production of this report.

1. INTRODUCTION	9
2. BACKGROUND AND FRAMING	11
2.1 The energy debate	11
2.1.1 The 2003 Energy White Paper and 2006 Energy Review	11
2.1.2 Why is the energy debate so narrow?	12
2.1.3 Joined-up thinking: beyond the rhetoric	12
2.2 Climate science.....	13
2.2.1 Avoiding dangerous climate change: From 550ppmv to 450ppmv	13
2.2.2 CO ₂ Equivalence.....	14
Box 2.1 - Uplift	16
2.2.3 The Client's position with respect to 450ppmv CO ₂	16
2.3 The UK's position.....	17
2.3.1 The need for an inclusive inventory	17
Table 2.1: 2004 energy-related carbon emissions	18
2.3.2 What emissions reductions are necessary & over what time frame ?	19
2.3.3 Observations from the plot	20
2.3.4 Supplementary Issues: economics and security	21
2.4 What are scenarios?.....	22
2.5 Research boundaries.....	25
2.5.1 Nuclear power	25
2.5.2 Renewable energy.....	25
Table 2.2: Renewable technologies.....	26
2.5.3 Biomass	26
2.5.4 Carbon Capture and Storage	27
2.5.5 'Static Mobility' and 'Mobility Plus' scenario	28
Table 2.3: Mobility characteristics for the two scenarios	28
3. HISTORIC PICTURE OF THE UK'S ENERGY SYSTEM	31
3.1 The UK economy	31
3.2 Demand and supply.....	31
3.2.1 Primary supply.....	31
Figure 3.1: 1990 and 2004 primary fuel mix	32
Table 3.1: 1990 and 2004 primary fuel mix	32
3.2.2 Electricity, transport and 'other-energy' demand	32
3.2.2.1 Electricity demand	33
3.2.2.2 Transport energy demand	33
3.2.2.3 Other energy demand	33
Figure 3.2: The contributions to final energy demand and carbon emissions in the baseline year (2004) split between electricity, transport and other energy.....	34
Table 3.2: Total final demand and carbon emission for the baseline year.....	34
3.2.3 Demand sectors.....	35
3.2.3.1 Households	35
3.2.3.2 Industry and services	36
3.2.3.3 Transport	37
Table 3.3: Comparison of energy intensity, carbon intensity and recent growth for the different modes of passenger travel. Data derived from passenger kilometre data and vehicle kilometre data from Transport Statistics Great Britain.	41

4. METHOD	45
Figure 4.1: Backcasting methodology	45
4.1 Defining the end-points	46
4.2 Scenario generator	47
4.2.1 Carbon calculations	48
4.2.2 Non-CO ₂ emissions	49
4.2.3 Non-energy CO ₂	52
4.2.4 UK boundary	52
5. SCENARIO DESCRIPTIONS	53
5.1 Overview of the <i>Static Mobility</i> and <i>Mobility Plus</i> scenarios	54
Table 5.1: Annual percentage changes in GVA – <i>Static Mobility</i> scenario	54
Table 5.2: Annual percentage changes in GVA – <i>Mobility Plus</i> scenario	54
Table 5.3: Household summary	54
Table 5.4: Annual percentage changes in energy intensity – <i>Static Mobility</i> scenario	55
Table 5.5: Annual percentage changes in energy intensity – <i>Mobility Plus</i> scenario	55
5.1.1 Mobility characteristics	55
5.2 Non- transport sectors	56
5.2.1 Short-term changes	62
Table 5.6: Short-term scenario summary in 2010	62
Table 5.7: 2010 primary fuel mix	64
Table 5.8: 2010 electricity supply summary	65
5.2.1.1 Sectoral characteristics	67
5.2.3 Medium-term changes	71
Table 5.9: Scenario summary for 2030	71
Table 5.10: 2030 primary fuel mix	74
Table 5.11: 2030 electricity supply summary	76
5.2.3.1 Electricity supply – <i>Static Mobility</i>	77
5.2.3.2 Hydrogen – <i>Static Mobility</i>	78
5.2.3.3 Electricity supply – <i>Mobility Plus</i>	79
5.2.3.4 Hydrogen – <i>Mobility Plus</i>	80
5.2.3.5 Sectoral characteristics	81
5.2.4 Long-term changes	85
Table 5.12: Scenario summary in 2050	85
Table 5.13: Primary energy demand	88
Table 5.14: 2050 Electricity supply summary	89
5.2.4.1 Electricity supply – <i>Static Mobility</i>	90
5.2.4.2 Hydrogen supply – <i>Static Mobility</i>	90
5.2.4.3 Electricity supply – <i>Mobility Plus</i>	92
5.2.4.4 Hydrogen supply – <i>Mobility Plus</i>	92
5.2.4.5 Sectoral characteristics	93
5.3 Scenario descriptions summary	96
6. TRANSPORT	98
6.1 Passenger transport	99
Table 6.1: Summary baseline data – data derived from the Department for Transport's Transport Statistics Great Britain.	100
Table 6.2: Scenario summary tables for growth and efficiency – <i>Static Mobility</i>	101
Table 6.3: Scenario summary tables for growth and efficiency – <i>Mobility Plus</i>	102
6.1.1 Short-term	103
Table 6.4: Summary 2010 data – <i>Static Mobility</i>	104
Table 6.5: Summary 2010 data – <i>Plus Mobility</i>	104

6.1.1.1 Aviation	104
6.1.1.2 Rail	105
6.1.1.3 Road	106
6.1.2 Medium-term.....	108
Table 6.6: Summary 2030 data – <i>Static Mobility</i>	109
Table 6.7: Summary 2030 data – <i>Plus Mobility</i>	109
6.1.2.1 Aviation	109
6.1.2.2 Rail.....	113
6.1.2.3 Road	113
6.1.3 Long-term	115
Table 6.8: Summary 2050 data – <i>Static Mobility</i>	116
Table 6.9: Summary 2050 data – <i>Plus Mobility</i>	116
6.1.3.1 Aviation	116
6.1.3.2 Rail	118
6.1.3.3 Road	119
6.2 Freight transport.....	121
Table 6.10: Scenario summary tables for growth and efficiency – <i>Static Mobility</i>	122
Table 6.11: Scenario summary tables for growth and efficiency – <i>Static Mobility</i>	123
6.2.1 Short-term	124
6.2.2 Medium-term.....	127
6.2.3 Long-term	130
6.3 Summary	132
7. POLICY	134
7.1 UK and EU consensus	134
7.2 Building public support.....	135
7.3 Government: reorganisation and legislation	135
7.4 Policy instruments and approach.....	136
Table 7.1: IEA classification of policies for reduction of greenhouse gas emissions	137
Table 7.2: UK and EU examples of policies for reduction of greenhouse gas emissions	137
7.5 Deep emissions cuts and feasibility	139
7.6 Emissions trading	139
7.6.1 EU ETS: A key instrument.....	140
7.6.2 Expanding EU ETS.....	140
7.6.3 Trading alongside EU ETS	141
7.6.4 Alternative approaches to emissions trading	142
Box 7.1 discusses the potential for EU ETS to evolve into a personal carbon trading scheme such as DTQs.....	143
7.7 Policy instruments by sector	145
7.7.1 Households.....	146
7.7.1.1 Households and price instruments.....	146
7.7.1.2 Improving the thermal efficiency of the housing stock	147
7.7.1.3 Household sector policies.....	149
7.7.2 Industry.....	150
7.7.3 Services.....	151
7.7.4 Transport.....	152
7.7.4.1 Aviation	153
7.7.4.2 Private Road.....	155

7.7.4.3 Public road	156
7.7.4.4 Rail	157
7.7.4.5 Shipping	157
7.7.4.6 Cycling and walking	158
7.8 Supply	158
7.8.1 Biomass	158
7.8.2 Other renewables	159
7.8.3 Hydrogen	159
7.8.4 CCS	160
8. CONCLUSIONS	162
The key message to policy makers	162
8.1 A realistic climate debate	163
8.1.1 450ppmv CO ₂ – a move in the right direction	163
8.1.2 Towards a real 2°C limit	163
8.1.3 A comprehensive and up-to-the-minute inventory	165
8.1.4 Co-ordination of carbon-related strategies and policies.	165
8.1.5 Urgent and unprecedented – 9 to 13% p.a decarbonisation	165
8.2 Scenario conclusions	166
8.2.2 Behaviour	166
8.2.3 Innovation	166
8.2.4 Resources	168
8.3 Policy conclusions	169
8.3.1 Short-term	169
8.3.2 Medium-term	170
8.3.3 Long-term	171
9. REFERENCES	172

Forward from Friends of the Earth and The Co-operative Bank

As part of The Co-operative Bank and Friends of the Earth joint campaign work in 2006, we asked The Tyndall Centre at The University of Manchester to explore if it is possible for the UK to move to a low carbon economy. And, in line with our solutions-based approach to tackling climate change, we also asked if so, how?

This report presents challenging new research that not only illustrates the scale of the carbon problem we face but also offers policy pathways for achieving our low-carbon future.

In order to conduct the research Tyndall needed to:

1. Identify a 'carbon budget' for the UK, i.e. how much carbon dioxide the UK could emit between 2000 and 2050 if the UK is to do its fair share in keeping atmospheric concentrations of carbon dioxide below 450 parts per million (in line with a growing scientific consensus that this is the maximum global concentration that should be allowed).
2. Identify the energy saving and energy producing technologies that could be deployed to ensure the UK lives within the carbon budget.

In funding this research, the Bank and Friends of the Earth wanted to see if it is possible to live within a carbon budget whilst allowing the economy to grow and people to maintain high quality lifestyles not dissimilar to today's (e.g. people still travelling, having warm homes, etc).

In conducting the research and writing the subsequent report, the Tyndall Centre researchers maintained their academic independence and intellectual freedom. We were eager to receive and digest the research findings. To us this research is important in that:

1. It shows that it is possible to live within the carbon budget and that the solutions to climate change exist, or are being fast-developed.
2. It opens the debate on what the UK's carbon budget should be: identifying a precise carbon budget is not simple, because of scientific uncertainties and political considerations. Some will say the budget identified is too lax and others too tight. Both Friends of the Earth and The Co-operative Bank consider global equity to be an important issue and therefore accept that the carbon budget identified by The Tyndall Centre is within an appropriate range. The Tyndall Centre research is the starting point for the debate not the final word. Next year the Intergovernmental Panel on Climate Change's assessment report on the science of climate change will be an important point to reassess the size of the carbon budget.
3. It demonstrates that we need a radical step-change in Government action on climate change to put us on a path to a low carbon economy and that action is needed now.

The report's carbon trajectory assumes, with rapidly increasing emissions from aviation, current levels of political inaction, the time required to introduce policies and the recent substitution of gas with coal-fired electricity it is unlikely emissions will reduce before 2012. Consequently, the rate of reductions needed after 2012 will

need to be more significant than if reductions start now. This is one valid assessment of the current political willingness to intervene to reduce emissions in the short-term.

Friends of the Earth and The Co-operative Bank are more hopeful that cuts can be made before 2010, as promised by the Government, and that a more steady reduction pathway can be followed from then, in line with the at least three per cent year on year reduction trajectory proposed by Friends of the Earth, other member groups of Stop Climate Chaos and supported by The Co-operative Bank. Our optimism is based upon tougher than expected cuts from the UK power sector, as part of the UK's National Allocation plan for the EU Emissions Trading Regime and the recent preparedness of many businesses to recognise and tackle the problem. The fullness of time will show which assessment to be accurate.

This research is important reading for all those interested in seeking the solutions to climate change, and the development of a more equitable world.

1. Introduction

This report describes two energy scenarios that paint a picture of the UK's economy in transition from a high to a low-carbon system over a 46-year period (2004-2050). The two scenarios are named *Static Mobility* and *Mobility Plus*. Under *Static Mobility*, the number of passenger kilometres travelled in 2050 is similar to the number travelled today. By contrast, under the *Mobility Plus* scenario, the numbers of passenger kilometres travelled on land and by air are higher than they are today – twice as high for land-based travel, and three times as high for air travel. The names chosen for the scenarios are simply factual descriptors and are not intended to imply any value judgement.

Although there are significant differences between the scenarios in terms of transport, both scenarios clearly illustrate the impact of the carbon constraints chosen. The UK's cumulative emissions budget used for the scenarios (4.6GtC) is in line with stabilising global atmospheric carbon dioxide emissions at 450ppmv. Furthermore, as in the *Tyndall Decarbonisation Scenarios* published in 2005,¹ these scenarios incorporate *all* sectors of the UK's economy. In other words, they incorporate emissions from international aviation and shipping, sectors excluded from previous energy analyses and scenarios. Incorporating all sectors, the UK is required to reduce its carbon dioxide emissions by some 90% by 2050, and around 70% by 2030. Hence, the decarbonisation required, even by 2030, is substantial, requiring the UK economy to break the long-established link between energy consumption and carbon dioxide emissions.

The report is structured as follows. Section 2 begins by putting the scenarios into context and describes some of political background to UK energy policy. Issues discussed include energy efficiency, energy security and what the authors regard as the inadequate level of debate regarding energy policy in the UK. The section then goes on to discuss the urgency and scale of the emissions reductions required to stabilise carbon dioxide concentrations at or below 450ppmv. The section concludes with an explanation of what differentiates a scenario from a forecast or prediction, and of the value of scenarios in exploring future energy systems that fit within the

¹ Anderson, K., S. Shackley, S. Mander and A. Bows (2005). Decarbonising the UK: Energy for a climate conscious future, The Tyndall Centre.

stringent carbon budget chosen. Section 3, provides an historical account of the UK's energy system in order to properly frame the transition within the scenarios to a low-carbon economy. Section 4 sets out the methodology behind the scenarios' generation and includes a description and discussion of the assumptions made in relation to non-carbon dioxide emissions, the UK boundary conditions and the other criteria the scenarios were required to meet.

Sections 5 and 6 of the report contain the scenario descriptions themselves in both quantitative and qualitative form and cover issues of innovation, demand management and resource use. Both sections are divided into descriptions of the short-term (2004 to 2010), the medium-term (2011 to 2030) and long-term (2031 to 2050). The policy setting, the policy framework and the particular policies implemented to bring about the transitions described in Sections 5 and 6 are described in Section 7. Section 8 concludes by drawing together the significant points that have emerged from this scenario analysis.

2. Background and framing

2.1 The energy debate

2.1.1 The 2003 Energy White Paper and 2006 Energy Review

The UK Government's announcement that it was to conduct 'another' energy review was received with surprise by many within the energy community, as it came just 23 months after the publication of the much heralded Energy White Paper (EWP). The EWP, with its strong emphasis on energy efficiency and renewable technologies as the central tenets of Government policy for reducing carbon emissions, had been broadly welcomed.

However, even at the time, concern was voiced regarding the absence of any real policy initiatives for bringing about the EWP's particular vision of a low-carbon, secure and affordable energy future.² The target for improvements in energy efficiency of 20% by 2020, as recommended by the Cabinet Office's PIU report, had been dropped in favour of a series of qualitative statements expressing support for improving energy efficiency. Similarly, the 'hard target' for renewable energy to be contributing 20% of the nation's electricity supply by 2020 was noticeably softened, becoming an 'aspiration' within the EWP. Had the EWP enshrined the PIU's recommended targets, it would have sent clear signals to the private sector and financial institutions and galvanised Government, at all levels, to put in place the appropriate mechanisms to initiate a step-change in energy conservation, efficiency improvements and renewable technologies.

The Government's continued reluctance to establish a policy framework for actually driving society towards a low-carbon future, led to the accusation that the EWP disguised a charter for nuclear power. More recently and ahead of the publication of the Energy Review, the roll call of MPs and ministers, as well as the prime minister, to voice their support for nuclear power has done nothing to quiet such accusations.

² For example, see the piece by Anderson, K., Shackley, S., and Watson, J. http://www.hero.ac.uk/uk/business/archives/2003/turn_fine_words_into_firm4308.cfm. Within the piece the authors suggest "there is a significant risk that the good intentions outlined in the White Paper will not be translated into action that shifts a growing UK economy onto a sustainable energy path within the short to medium-term. It would then become difficult to counter calls for a return to the orthodox route of further developing energy supply as the only viable option for achieving the requisite emissions reduction; in particular, a significant expansion of nuclear power and fossil fuel generation with carbon dioxide capture and storage."

2.1.2 Why is the energy debate so narrow?

From the perspective of UK's carbon emissions the authors of this report are essentially ambivalent about the role of nuclear power, viewing it as a misleading distraction from alternative and more effective means of reducing carbon emissions. In many respects the nuclear issue has come to symbolise the poor level of debate on energy and carbon. Opponents of nuclear power may argue it contributes less than 4% of final energy consumption³ and consequently is not a prerequisite for meeting the government's carbon targets. Whereas proponents may counter that nuclear power offers cost-effective low-carbon energy, which, unlike fossil fuel power stations, manages and internalises the costs of its principal waste streams.

Exacerbating the absence of dispassionate quantitative and qualitative analysis in relation to the energy debate, is the reluctance to recognise that the issues we face in terms of sustainability and security require a broader vision of the energy system as a whole. The current narrow interpretation of energy as an issue of supply, particularly electricity supply, will inevitably lead to an inappropriate and wasteful use of resources as well as ineffective policies for reducing carbon emissions. Moreover, the unwillingness of many of those contributing to the policy process to both address the carbon issue in terms of *absolute*,⁴ as opposed to *relative*, emissions, and to establish an *up-to-date* inventory of carbon emissions from *all* sectors, only serves to further separate the scale of the climate change problem from the inadequacy of our response.

2.1.3 Joined-up thinking: beyond the rhetoric

Whilst Government recognises the virtues of joined-up thinking, the functioning of the different ministries and various tiers of government continues to demonstrate a strong aversion to analyse and implement policy on such a basis. Explicit organisational structures to ensure the cross-ministerial acceptance of strategic goals, as well as coordinated policies and programmes to implement them, received little attention both in the EWP and in the documentation accompanying the Energy Review. For example, the scale of carbon emissions from aviation allied with very

³ UK final energy consumption is approximately 170Mtoe.

⁴ Even if the PIU targets had been adopted, in a continually growing economy they would not necessarily have achieved any absolute reduction in carbon emissions. Percentage improvements in efficiency and renewable uptake do not directly, or necessarily, lead to a reduction either in energy demand or the actual use of fossil fuels. Only when relative emission reductions are analysed in the context of economic growth (both in the aggregate and subdivided into particular sectors) can the effectiveness of carbon reduction policies, that do not include an explicit cap on emissions, be assessed.

Whilst the Government's 60% target does represent an absolute target, the policies being discussed are, with few exceptions, about either relative emissions or emission caps that are far removed from the values necessary to achieve the cumulative constraints necessary for even the 550ppmv target.

high annual growth in the industry and the limited opportunity for efficiency improvements should place aviation at the forefront of the climate change agenda. Despite this, Government is reluctant to actively curtail the rise in aviation emissions, when self evidently the associated emissions profile cannot be reconciled with the Government's existing 60% emission reduction target, and completely undermines any chance of achieving the more stringent targets that increasingly scientists connect with the 2°C threshold. The long-term repercussions of such an approach are difficult to overstate. If the Government continues to support current trends, by 2030 the carbon emissions from aviation alone will exceed the nation's total carbon allocation under a 450ppmv regime and represent between 50% and 100% of the allocation under a 550ppmv regime.⁵ Such inconsistency clearly undermines the credibility of the Government's claim to joined-up thinking and totally refutes the legitimacy of both the statement within the White Paper that *"the first challenge we [the Government] face is environmental"* and the Energy Review's claim that *"the Government has set four goals"* the first of which is to *"put ourselves on a path to cut the UK's CO2 emissions by some 60% by about 2050 with real progress by 2020"*.

2.2 Climate science

2.2.1 Avoiding dangerous climate change: From 550ppmv to 450ppmv

In the Energy White Paper (2003), the UK Government reiterates its oft-cited commitment to making its fair contribution to avoiding *"the worst effects of climate change"*; this the government correlates with *"a global average temperature increase of no more than 2°C above the pre-industrial level"*.⁶ Similarly, within the more recent documentation accompanying the Energy Review, the Government again emphasises the importance of the 2°C threshold.⁷ However, whilst the UK Government has an established track record of adhering to the language of 2°C within their various communications on climate change, it continues to interpret the policy implications of the threshold on the basis of what can reasonably be described as outdated science.

Within the EWP, the Government essentially adopts the position laid out in the earlier Royal Commission on Environmental Pollution report,⁸ namely, that a 2°C rise in

⁵ A 6.5% growth in aviation emissions exceeds the 450ppmv permissible emissions for the UK, and at 8.7% growth it exceeds the 550ppmv target. These estimates are based on ongoing work within the Tyndall Centre, and assume a contraction and convergence approach with parameters similar to those used within the RCEP's analysis in 2000.

⁶ DTI (2003). Our energy future - creating a low-carbon economy, Energy White Paper. DTI, Stationery office, London.

⁷ DTI (2006). Our energy challenge: securing clean, affordable energy for the long-term. DTI. London.

⁸ RCEP 2000

global mean surface temperature correlates with an atmospheric concentration of CO₂ of 550ppmv⁹ and that this in turn equates to the now familiar UK carbon-reduction target of 60% by 2050.¹⁰ However, whilst it is the 2050 carbon-reduction proportion that remains the headline target (i.e. 60%), it is the associated cumulative emissions between 2000 and 2050 that provides the meaningful target in terms of stabilising atmospheric carbon dioxide concentrations. In other words, what is important is that the UK constrains substantially the total quantity of carbon dioxide it emits between 2000 and 2050, and not whether the UK is able to reduce emissions by 60% on or by 31st December 2050. Although the concept of cumulative emissions seldom makes the main text or summaries of Government literature, it is acknowledged within the more detailed sections of Government reports to be the important target at which policies must aim. Within the remainder of this report it is this cumulative emissions figure that provides the basis for the analysis.

Whilst Government literature increasingly recognises that the scientific understanding of climate change has been significantly refined over the past decade, their emission-reduction targets are nevertheless calculated from a 550ppmv CO₂ stabilisation concentration. Correlating the 550ppmv concentration with permissible cumulative emissions from the UK, gives a total emissions figure for the period 2000 to 2050 of 6.3GtC. As the science of climate change has improved throughout the past decade, particularly in relation to feedbacks, so the correlation between 550ppmv and 2°C has been re-evaluated, with a scientific consensus emerging that achieving a reasonable-to-high probability of not exceeding 2°C correlates with concentrations of 450ppmv CO₂ equivalent or lower.¹¹

2.2.2 CO₂ Equivalence

Within the RCEP report, the EWP and even the recent Energy Review there is considerable ambiguity about whether the atmospheric concentration levels they refer to are for CO₂ alone or relate to CO₂eq (i.e. including the global warming potential associated with the full basket of six greenhouse gases). Consequently, the

⁹ The RCEP report remains vague as to whether it considers the 550ppmv figure to be related to CO₂ alone, or to CO₂ equivalent, i.e. including the "basket of six" greenhouse gases.

¹⁰ Within the RCEP report, the UK's contribution to stabilizing the atmospheric concentration of CO₂ at 550ppmv was based on the contraction and convergence apportionment principle. Whilst the EWP does not expressly endorse contraction and convergence, it would be at best disingenuous for the Government to reject the contraction and convergence apportionment principle yet enshrine the target that emerged from it. Consequently, the analysis within this report assumes the RCEP's and, by clear inference, the Government's approach to apportioning emissions to nation states. For a more detailed account of the pros & cons of different apportionment rules see reference 29.

¹¹ Meinshausen, M. (2006). "What does a 2C target mean for greenhouse gas concentrations? a brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates." [Avoiding Dangerous Climate Change Chapter 28.](#)

uncertainties in correlating temperature with CO₂ (or CO₂eq) concentrations that reasonably arise from scientific and policy uncertainties are unnecessarily inflated. Clearly, any responsible assessment of future emissions should be explicit about what is included and the subsequent correlation with temperature. For the purpose of this report a simple approach based on simple assumptions has been taken, in full recognition that this may lead to the 2°C threshold being exceeded.

The report focuses solely on CO₂ and adopts 450ppmv as the target atmospheric concentration. It is assumed that the drive to reduce CO₂ emissions applies similarly to the other greenhouse gases, with the outcome being that emissions are curtailed at a somewhat greater rate than is achieved for CO₂ alone.¹² Moreover, it is assumed that improvements in the scientific understanding of these additional gases do not suggest their relative impact is greater than is currently believed to be the case.¹³ With these assumptions, it appears approximately reasonable to equate the 450ppmv CO₂ figure with a CO₂eq range of approximately 475ppmv to 500ppmv. Such concentrations, whilst offering a substantially better chance of not exceeding the 2°C threshold than 550ppmv CO₂ (~ 600-630ppmv CO₂eq¹⁴), nevertheless still provide, assuming current scientific understanding of the issues, only a 30% to 40% chance of not exceeding 2°C (compared with 8% to 12% for 550ppmv CO₂).¹⁵

¹² The UK Government's own figures on reductions in the basket of six gases demonstrate, arguably, the greater scope for reductions in non-CO₂ as compared with CO₂ emissions. Between 1990 and 2004, whilst Government figures identify a 7% reduction in CO₂ emissions (excluding international aviation and marine), they identify a 44% reduction in non-CO₂ greenhouse gases. The assumption that there exists greater scope for reductions in non-CO₂ as compared with CO₂ emissions is made in full recognition that the diminishing returns in terms of non-CO₂ greenhouse gas reductions may exceed those related to CO₂ only. This is an issue that demands further science and policy research.

¹³ According to Meinshausen 2006 p.269, a 550ppmv CO₂eq equates to, approximately, a 475ppmv CO₂; in other words, that the non-CO₂ basket of six gases contribute in the region of 14% of the warming attributable to a 550ppmv CO₂eq concentration.

¹⁴ Based on a slightly lower reduction rate in non-CO₂ gases than is used for the 450ppmv CO₂ future. The lower rate is assumed as, *ceteris paribus*, the 550ppmv CO₂ future is unlikely to be as great a driver of reductions in non-CO₂ gases as is a 450ppmv CO₂ future.

¹⁵ Based on, Meinshausen, M. Table 28.1, p. 270. The figures presented here represent what Meinshausen refers to as "mean" likelihoods. Meinshausen also offers upper and lower band probabilities, for exceeding 2°C: for 475ppmv CO₂eq – 38 to 90%; for 500ppmv CO₂eq - 48 to 96%; for 600ppmv CO₂eq – 74 to 100%; and for 650ppmv CO₂eq – 82 to 100%.

Box 2.1 - Uplift

Within much of the literature on aviation and climate change there is substantial discussion of what are often referred to as 'uplift' factors. Put simply, these are non-greenhouse gas emissions that nonetheless impact the balance of incoming and outgoing radiation. Whilst the uplift factors for aviation include the very short lived vapour trails (with residence times of a few minutes to a few days), these are not, in the view of the authors, appropriately accounted for within the uplift approach (particularly as the concept of uplift is often conflated with that of 'global warming potential' - GWP). However, the uplift also includes the secondary impacts of nitrogen oxides (NOx) on methane and ozone. These have a decadal time frame and therefore are arguably adequately accounted for within the uplift approach, even when conflated with GWP. Although there is a considerable body of research estimating the impacts on the radiative balance caused by NOx emissions from aircraft flying at altitude, this is not matched by assessments of NOx impacts from other sources (e.g. cars, ships, power stations, etc); this is currently the subject of ongoing research. The point of raising this here, is to make the reader aware that there remains a very real prospect that the correlation between CO₂eq and temperature may require substantial revision in a direction that is likely to make the task of achieving 2°C even more demanding than is already the case.

For more information see Section 4.2.2

2.2.3 The Client's position with respect to 450ppmv CO₂

As with all client-consultant relationships, boundary conditions were established within which to conduct the analysis. Whilst the suite of constraints constituting the boundary were certainly challenging, the researchers nevertheless considered them to be intellectually defensible and practically achievable. The CO₂ concentration target, as one amongst a series of criteria and targets, is of particular relevance here. Friends of the Earth, in conjunction with a consortium of NGOs and with increasing cross-party support from MPs, have been lobbying hard for the introduction of a 'climate change bill', aimed principally at requiring the UK to actively pursue policies that would ensure it make its fair contribution to a 2°C future. The bill championed by the consortium of NGOs is founded essentially on a correlation of 2°C with 450ppmv CO₂. This correlation is interpreted within the draft bill in terms of a large initial reduction in carbon emissions by 2010 (of approximately 27MtC compared with

2004/5 emissions), and a 3% year-on-year reduction thereafter until 2050. Whilst the draft bill describes the skeletal framework of what needs to be achieved, it does not illustrate how such a future may be realised and what such a future may actually look like. Friends of the Earth's endeavour to offer an accompanying description of a 450ppmv future led Friends of the Earth and The Co-operative Bank to approach Tyndall-Manchester.

Consequently, from the perspective of the Tyndall-Manchester, the strong intellectual arguments for revisiting low-carbon scenarios based on 450ppmv, or lower, CO₂ concentration, was matched by the funding opportunity offered by Friends of the Earth and The Co-operative Bank. Furthermore, it was agreed with Friends of the Earth and The Co-operative Bank that the report would accept the apportionment rules adopted explicitly within the RCEP report and implicitly within the EWP and Energy Review documentation. Consequently, the UK's allocation of CO₂ emissions under a 450ppmv CO₂ regime equates to 4.6Gt between 2000 & 2050 (this compares with 6.3Gt for 550ppmv).

2.3 The UK's position

2.3.1 The need for an inclusive inventory

Given the cumulative allocations are derived from the UK's allotted proportion of the total permissible global emissions (4.6GtC in this report), which is itself derived from the 2°C target, it is essential that the UK's emissions are considered on the basis of a comprehensive and not a partial carbon inventory.¹⁶ Unfortunately, the UK Government's carbon reduction policies continue to be informed by a partial inventory that omits to include two important and rapidly growing sectors;¹⁷ this despite their more recent acknowledgement of the importance of one of the neglected sectors (aviation). The UK's proportion of emissions from international shipping continues to, at best, receive scant regard within Government. The latest, though still very provisional, assessment of shipping emissions made by the Tyndall Centre, are that it equates to almost one-third of the carbon emissions from private car transport; clearly shipping is an important source of carbon emissions that needs to be included in the inventory. The neglect of aviation, however, is of particular concern. Not only do its carbon emissions start from a relatively high base

¹⁶ It could reasonably be argued that the inventory should also include non-CO₂ basket of six gases. However, it appears more appropriate to have complementary rather than combined inventories for CO₂ and non-CO₂ emissions (it may still be appropriate to combine the inventories in terms of CO₂eq for approximate correlations with temperature), the inventory discussed here is for CO₂ only. It is assumed that non-CO₂ emissions will also be subject to a suite of reduction policies (see footnote 12 for a discussion of non-CO₂ emissions).

¹⁷ The UK Government is similar to all other nations in this regards.

(approximately a half of the carbon emissions from private car transport), but its unprecedented growth rate, unless urgently and dramatically curtailed, will rapidly make aviation the dominant CO₂ emission sector. The inclusion of emissions from both international aviation and shipping is central to this report, and represents a substantial numerical and analytical departure from all previous non-Tyndall assessments of UK emissions trajectories and decarbonisation pathways.

Including international aviation and shipping emissions, significantly changes the UK's energy-related carbon position, increasing the stated energy-related emissions for 2004 by 10% (see Table 2.1). Given that aviation growth since 2004 is likely to have very significantly exceeded that occurring in all other sectors, it is probable that today (2006) the increase in emissions is greater than 10%.¹⁸

Table 2.1: 2004 energy-related carbon emissions

Government Total MtC	Aviation (international) MtC	Shipping (international) ¹⁹ MtC	Tyndall Total MtC
150	9	5	164

The shift from a partial to a full energy-related carbon inventory places a very different complexion on the scale of the problem to be addressed. Whilst Government figures suggest the UK is making significant reductions in its carbon emissions, the reality is that despite the substantial penetration of relatively low-carbon gas into the electricity mix allied with the relative decline in the UK's heavy industries, emissions are little changed in 2004 from those in 1990. Moreover, the emissions reductions that have occurred within the power and heavy industry sectors were, to some extent, one-off and fortuitous opportunities and not the product of a strategic and judicious climate change programme.

Even with climate change moving up the political, business and public agenda, there remains a clear void between the scale of the problem as characterised by the Government's target and accompanying literature, and the actual policy mechanisms either in place or proposed for the near term. The recent publication of "Climate Change – The UK Programme 2006" only serves to illustrate the scale of this void. Whilst the language is clearly "on message", there is an absence of a complimentary

¹⁸ In analysing reductions rates over time, it is necessary to estimate the aviation and shipping emissions for the start as well as the final year.

¹⁹ This remains a provisional figure and is subject to adjustment as analysis is ongoing within Tyndall-Manchester.

and strategic suite of stringent policy mechanisms to achieve the necessary reductions within the very short time frames available (such time frames are discussed in the next section).²⁰ This is not to say that important policy initiatives will not be developed and perhaps even instigated during this period, but even if such policies are implemented it will probably take several years to translate them into workable and effective legislation, measures and actions.

2.3.2 What emissions reductions are necessary & over what time frame ?

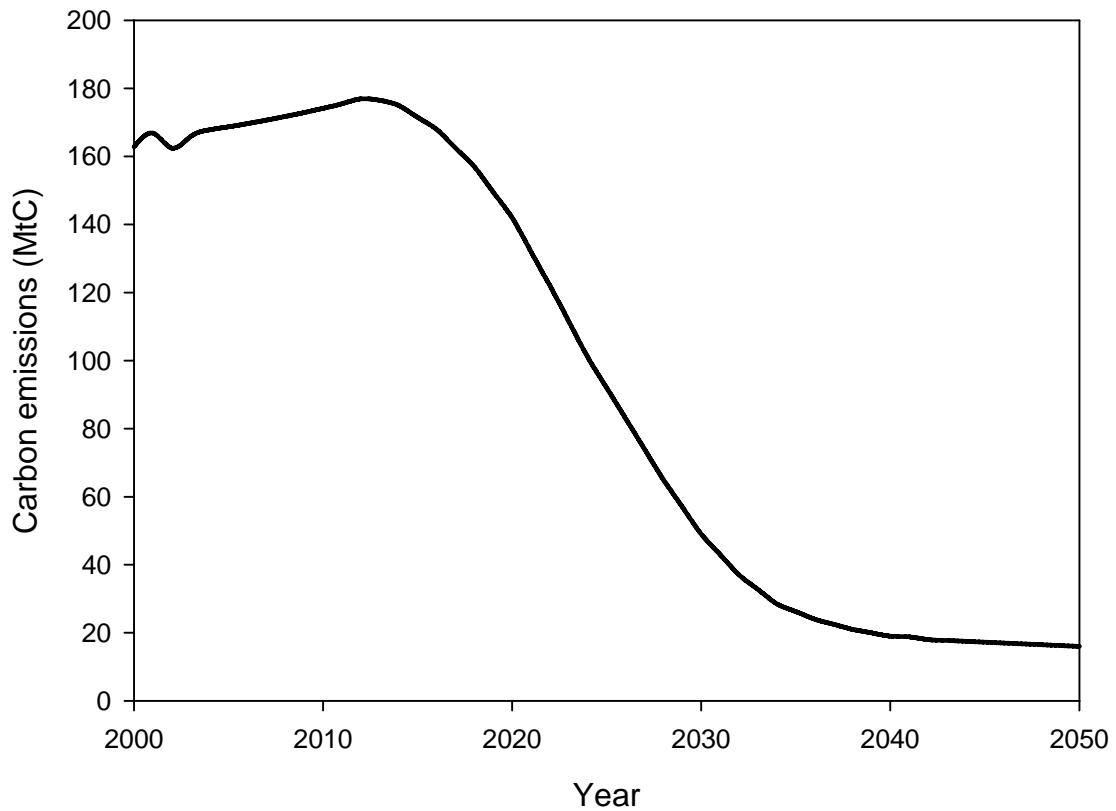
There is little evidence that the UK is about to embark on an absolute and significant reduction in its carbon emissions. However, if the UK is to make its fair contribution to a 450ppmv CO₂ future, this is a situation that will necessarily have to change within the coming 2 to 4 years.²¹ This report is premised on such a change and suggests how the UK could make the radical transition onto a 450ppmv trajectory.

Before being in a position to generate quantitative and qualitative pathways illustrating how such a transition could be achieved, it is necessary to understand the highly constrained emissions trajectory that accompanies 450ppmv CO₂. The following plot illustrates the shape of the emissions profile over the period 2000-2050, assuming a total cumulative emissions burden of 4.6GtC. The plot initially describes an annual increase in emissions driven, primarily, by continued growth in the aviation industry. The level of emissions growth assumed is 7% (below the latest annual growth figures for 2003-4), with the remainder of the economy essentially static in terms of carbon emissions (i.e. any growth in output is compensated by either improved energy efficiency or a shift to less carbon intensive energy).

²⁰ This is both a judgment of the authors of this report, but also captures the conclusion of the many energy analysts with whom the authors have had discussions about the 2006 Climate Change Programme. Whilst the detailed conclusion of those canvassed about the CCP have varied, to date there has been a universal dismissal of it as a document that seriously addresses the issue. Moreover, those who commented on the quantitative reductions claimed for the policies discussed within the document, all viewed the actual scale of the reductions to be highly unlikely unless the policies were substantially modified or additional policies implemented.

²¹ See Figure 2.2 to show the short time period available to reverse the current trajectory. The 2-4 year time frame, is suggested as it gives some opportunity for policies to actually deliver real carbon reductions

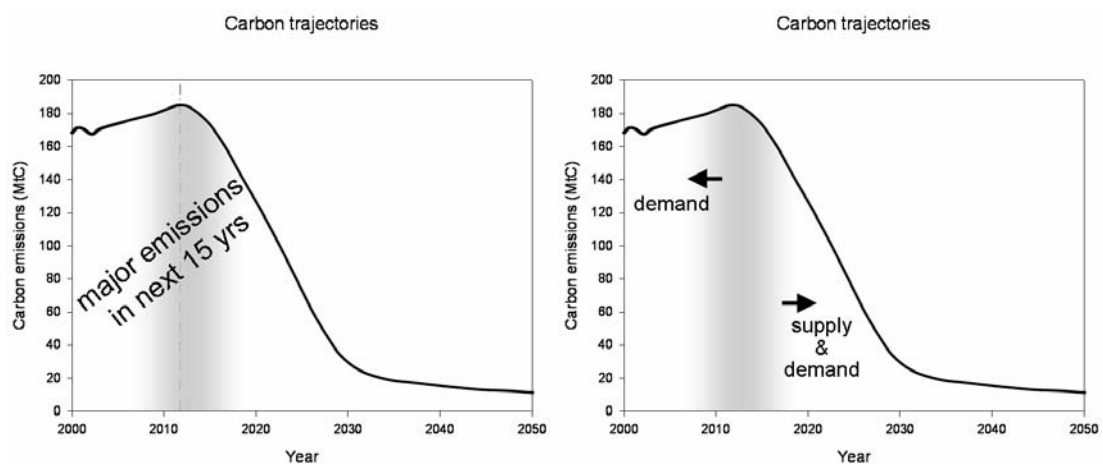
Figure 2.1: UK's contribution to 450ppmv CO₂



Combining 450ppmv with existing emissions between 2000 & 2006 and an assumption that emissions between now and 2010 are unlikely to deviate significantly from that described above, equates to a cumulative emissions burden for 2000-2010 of ~ 1.85GtC; leaving around 2.8GtC for 2010-2050. This combination essentially locks the emission trajectory between 2010 and 2050.²²

2.3.3 Observations from the plot²³

Figure 2.2: Time implications of the emissions trajectories



Whatever the arguments for and against alternative low-carbon supply options, under the 450ppmv regime society does not have the luxury of waiting the decadal time frame necessary to bring about a low-carbon supply transition. Consequently, if the UK is to demonstrate effective leadership on climate change and actively pursue a 450ppmv trajectory, it is incumbent on the Government to redress the balance of its policy agenda in favour of reducing energy demand.

Research contained within the Tyndall Centre's 2005 report, "Decarbonising the UK" (DUK), clearly illustrates a suite of opportunities to substantially reduce current energy demand within the short-to-medium time frame. Across the board, Tyndall research found that substantial reductions in emissions are possible using currently available technologies; with often the most efficient technology consuming just 30% to 70% of the typical product sold within the class. Moreover, Tyndall research published earlier this year on "Public Perceptions of Nuclear Power, Climate Change and Energy Options", indicates three-quarters of the UK population favours "lifestyle changes and energy efficiency" over, for example, nuclear power, as an appropriate response to climate change.

Certainly, for a government serious in its desire to tackle climate change, whether to meet a 450ppmv or even 550ppmv target, the cogency of the arguments for reducing energy demand as a means of mitigating our carbon dioxide emissions can no longer be ignored.

2.3.4 Supplementary Issues: economics and security

Whilst the carbon issue is in itself, in the view of the authors of this report, sufficient reason for government to act, reducing the energy consumed in providing services, such as warmth, refrigeration and lighting, offers two further and significant benefits.

First, in light of the rapidly escalating price of fossil fuels, any nation that substantially reduces the energy intensity of its commercial and industrial sectors will gain competitive advantage over those that are less successful in achieving such reductions. If a decade ago the UK Government had recognised the dwindling contribution from indigenous fossil fuel supply and had embarked on a programme of

energy efficiency improvements, the UK would, to some extent, have mitigated the economic implications of the recent rapid and erratic rises in world energy prices.

Second, and perhaps more abstractly, couching the issue of energy security – central to the current energy review and the nuclear issue in particular – in terms of energy supply, arguably misses the point. Energy security is really a second-order concern, subordinate to the security of energy services. All consumers, whether industrial, commercial or domestic are concerned, not with the security of energy directly, but rather with the security of the services they receive. Again, this subtle re-framing of the security issue as one of demand as opposed to supply, leads to a very different policy response. Whilst maintaining secure supplies of energy is of course important, the most immediate and cost effective means of maintaining security of energy services is to reduce their energy intensity.

2.4 What are scenarios?

Scenarios are images of potential futures, which provide a framework to enable a range of stakeholders to think about the future and the processes which will shape it. The strength of a scenario lies in the limitless variety of driving forces they can be used to explore. Thus a scenario developer can articulate the implications of factors such as technology developments, societal changes, policy implementation or environmental change. The assumptions which can be included are not limited to things which can be quantified, but instead scenarios allow qualitative and quantitative information to be blended together, bringing to life a set of assumptions to explore their future impact. Scenarios are not predictions, but instead allow the exploration of the possibility space through the articulation of a set of ‘what if’s’. Ultimately, scenarios can be considered ‘learning machines’ through which understanding of future diversity can be increased.²⁴

Scenarios have become an accepted tool within policy making in the UK; some focus on a single sector, such as the Royal Commission on Environmental Pollution energy scenarios, whereas others have a wider focus such as the UKCIP Climate Change scenarios.²⁵ The UKCIP scenarios, in particular, set the framework for much of the research into climate change impacts, which in turn informs policy formulation across the range of sectors where climate change is a driver. This short review will focus on

²⁴ Berkhout et al, 2002

²⁵ RCEP, 2000; UKCIP 2001

those scenarios that have been used to shape energy policy, and introduce the specific scenarios that have informed this research.

The 60% carbon reduction target, formally adopted by the UK Government within the Energy White Paper, was informed by a number of energy scenario studies, beginning with the work of the RCEP in 2000.²⁵ The RCEP report included four scenarios which explored options for a 60% reduction in carbon emissions by 2050. These scenarios take a 'backcasting' approach whereby a 60% reduction in CO₂ emissions is taken as a starting point for the scenarios, each of which explores different assumptions concerning the extent of reduction in energy demand, and various mixes and levels of low-carbon supply technologies.

Energy scenarios were also developed by the Performance and Innovation Unit (PIU) in its Energy Review as an input to the Energy White Paper, based upon the Foresight scenario framework.²⁶ This framework combines two axes to generate a typology; one axis represents social values (from community values to consumerist values), whilst the other represents spatial scales of governance (from autonomous to interdependence). Using this typology, drivers can be projected into the future, to develop 'prospective' scenarios, and this approach is the most common approach used in the UK to date. Thus, the key difference between 'backcasting' and 'prospective' scenarios is that the latter explores 'what might happen?' whilst the former considers 'where do we want to be?'

Limited quantification of the PIU scenarios was undertaken and used as an input in the analysis and modelling undertaken by the Government's Interdepartmental Analysts Group (IAG) for the Energy White Paper.²⁷ The IAG focused upon the economic implications of the 60% target.

The assessments outlined above, suffer from one serious limitation, however, and that is the exclusion of emissions from international aviation and shipping. The exclusion of these emissions is acknowledged by all three bodies who have contributed to the analyses that support the Energy White Paper. Of these, the IAG alone estimate the additional emissions that would result from international aviation, and suggests they would be in the range of 14-21 MtC depending on the rate of improvement in carbon intensity (page 25 IAG, 2002). However, it is not included as

²⁶ PIU, 2002; DTI 1999

²⁷ IAG, 2002

part of the overall energy demand in the modelling work. None of the assessments attempt to quantify the contribution that will result from international marine transport. It has to be noted that there is little data available concerning the current level of emissions from, or energy consumption of, this sector, which of course makes such quantification more difficult.

Although these sectors are by no means currently the largest in terms of their overall energy consumption, and hence carbon emissions, they are two of the highest growth sectors in the economy and therefore must not be ignored given that the ultimate objective of climate change policy refers to a target atmospheric CO₂ stabilisation level. The White Paper on aviation published at the end of 2003 highlighted that UK air travel could increase as much as three fold in terms of passenger movements by 2030 from a 2003 baseline.²⁸ The Tyndall aviation project illustrates that should the aviation sector continue to grow at rates similar to those experienced today, then without a step change in technology, aviation is likely to become the single most important emission sector by 2050.²⁹ Similarly, in a world with increasing international trade, most of it transported by ship, carbon emissions from international marine transport will also represent a significant proportion of the permitted level of emissions.

This work for Friends of the Earth and The Co-operative Bank, has been informed by a number of other scenarios studies. These are listed briefly below:

- Tyndall Centre research: Decarbonising the UK; Lower Carbon Futures: the 40% House Project; How can we reduce carbon emissions from transport?; Evaluating the Options for Carbon Sequestration; The Hydrogen energy economy: its long-term role in greenhouse gas reduction.³⁰
- Supergen research: the work of the biomass and bioenergy consortium; the UK sustainable hydrogen energy consortium.³¹
- Visioning and backcasting for UK Transport Policy: The Bartlett School of Planning and Halcrow Group.³²
- Carbon Trust: The Marine Energy Challenge; Building options for UK renewable energy.³³

²⁸ DfT, 2003

²⁹ Bows, A., K. Anderson and P. Upham (2006). Contraction & Convergence: UK carbon emissions and the implications for UK air traffic. T. Centre, Tyndall Centre.

³⁰ Anderson et al, 2005; Boardman et al, 2006; Bristow et al, 2004; Gough et al, 2002;

³¹ McDowell and Eames, 2006.

³² DfTb, 2005

2.5 Research boundaries

As with any client-consultant relationship the consultants are required to conduct their work within a structure agreed with the client. In this particular case, the scenarios have been developed within a stringent suite of quantified criteria which have been set by Friends of the Earth and The Co-operative Bank. Whilst it is true to say that we, as analysts, would not necessarily have chosen the same suite of criteria it is also true to say that we consider the Friends of the Earth and Co-operative Bank criteria to be workable and represent one of many similarly valid views of the energy system. The set of energy system boundaries which have been set by Friends of the Earth and The Co-operative Bank are outlined below:

2.5.1 Nuclear power

The Friends of the Earth and Co-operative Bank scenarios assume a declining contribution to the energy mix from nuclear power in-line with the projections in the Government's Energy Paper 68³⁴, adjusted to take into account the lifetime extension to Dungeness B which will remain in operation until 2018.³⁵ By 2030, only one UK nuclear plant, Sizewell B, will remain in operation, with a capacity of 1188MW. The research has explicitly explored whether the UK can meet stringent carbon targets without including nuclear power in the supply mix, hence once Sizewell B is decommissioned in 2035, there will be no nuclear capacity in the UK.

2.5.2 Renewable energy

The Friends of the Earth and Co-operative Bank scenarios have been framed within renewable energy boundaries set by the Friends of the Earth electricity model.³⁶ Renewable energy assumptions to 2030 are set out in Table 2.2. Since 2050 is beyond the time frame of their model, the long-term contribution from renewable energy was assumed to increase at a maximum rate of 60TWh per decade after 2030, giving a total renewables contribution of 320 TWh by 2050 for large scale centralised renewables. The scenarios also include a significant contribution of on-site renewable electricity, notably PV and building integrated wind turbines. A number of studies have made estimates of UK renewable energy generation in 2050 and a range has been included in the table for comparison purposes. Based on Table 2.2,

³³ Carbon Trust, 2003; Carbon Trust 2005

³⁴ Energy paper 68, DTI; <http://www.dti.gov.uk/files/file11257.pdf>

³⁵ <http://www.british-energy.com/article.php?article=99>

³⁶ http://www.foe.co.uk/resource/evidence/bright_future_data.pdf

and given estimates for increase in capacity of specific technology, for example 5MW offshore wind turbines are currently being tested, the overall renewable capacity increase is deemed acceptable. That said, achieving the desired renewable capacity is dependent on appropriate research and development to ensure that improvements in technology occur.

Table 2.2: Renewable technologies

Technology	2010	2020	2030	2050
Onshore wind		33-50 TWh/yr		RCEP: 56.94 Twh/yr or 15.15 GW capacity ³⁷ Carbon Trust: 20 GW capacity ³³
Offshore wind		31 TWh/yr	94TWh/yr ³⁸	RCEP: 99.86 Twh/yr or 27 GW capacity ⁴ Carbon Trust: 30 GW capacity ⁵
Wave		5-12 TWh/yr		RCEP: 32.85 Twh/yr or 7.5 GW capacity ⁴ Carbon Trust: 20 GW capacity ⁵
Tidal Stream				RCEP: 2.19 Twh/yr or 0.5 GW capacity ⁴ Carbon Trust: 5 GW capacity ⁵
Other ³⁹		1-7 TWh/yr		
Tidal lagoon/barrage		20 TWh/yr		RCEP: 19.27 Twh/yr or 8.60 GW capacity ⁴
Existing hydro and pumped storage				RCEP: 6.85 Twh/yr or 4.26 GW capacity ⁴
New small scale hydro				RCEP: 2.63 Twh/yr or 0.45 GW capacity ⁴
Total		80-100 TWh/yr	200 TWh/yr	220.59 TWh/yr – RCEP 63.46 GW RCEP 75 GW – Carbon Trust

2.5.3 Biomass

The contribution of biomass to the UK energy mix within the Friends of the Earth and The Co-operative Bank scenarios is framed by Biomass Task Force estimates of UK biomass resources. These indicate that 14.4 to 17.3 TWh/yr of electricity generation could come from domestic resources, excluding municipal solid waste (MSW), by 2020. Given these limited resources, Friends of the Earth have estimated the

³⁷ Watson, 2003

³⁸ BWEA, 2006

³⁹ Landfill gas; hydro; PV; coal bed methane; micro turbines; geothermal etc

amount of biomass which the UK could import, assuming an equitable share of global biomass production and taking into account the energy consumed in producing and transporting the biomass. Including these imports, therefore, the Friends of the Earth and The Co-operative Bank scenarios assume a maximum biomass consumption of 132-182 TWh/yr. This level of biomass consumption has been assumed to be reached in 2030, and to continue at this level until 2050.

2.5.4 Carbon Capture and Storage

All the scenarios assume carbon capture and storage (CCS) from both gas- and coal-fired power stations, and from plants making hydrogen by steam reformation of methane, and coal gasification. Given the carbon trajectory set out in Section 2, the scenarios require that these technologies are the norm by 2030. Whilst CCS has been included in both scenarios, this has been done because of the carbon imperative. It has to be recognised that the use of CCS has wider implications:

- Whilst there are existing CCS demonstration projects, for example CO₂ has been stored in the Sleipner gas field in the North Sea since 1996, wide scale deployment of CCS remains reliant on new, undemonstrated technologies. Although the CCS research community is confident that technical issues related to CO₂ capture, transport and storage within geological formations can be addressed, the use of CCS to achieve carbon targets is risky given the reliance on future technological developments.
- There is a requirement for financial incentives for CCS schemes given the short-term nature of EU ETS, and the low-carbon price.
- Deployment of CCS would be more economically attractive if it is deployed in conjunction with enhanced oil recovery (EoR). That said, there is a limited window of opportunity for EoR CCS since it is hard to apply late in the life of a field, once the reservoir pressure has been allowed to significantly decline. This window of opportunity is in the region of ten years, therefore commercial EoR CCS must be ready for deployment around 2010-2012. Any support mechanism for CCS EoR based on a carbon trading scheme must take into account additional oil that is extracted from a field which would otherwise have stayed in the ground.
- There may be environmental impacts resulting from leakage of CO₂ from storage sites. Leakage would mean that anticipated carbon savings are not achieved.
- Long-term storage of CO₂ will require institutional, monitoring and regulatory frameworks to be implemented.

2.5.5 ‘Static Mobility’ and ‘Mobility Plus’ scenario

The Friends of the Earth and The Co-operative Bank scenarios explore two alternative visions for how mobility in the UK will develop between today and 2050. Passenger mobility is grouped into land transport and air transport. The insignificant proportion of shipping transport for passenger travel in comparison to shipping freight transport has led to an assumption that all shipping is related to freight within the scenarios. Land transport includes car transport, bus transport and rail transport. Air transport includes both domestic and international aviation. The scenarios have been named ‘Static Mobility’ and ‘Mobility Plus’ to illustrate the difference between them in terms of passenger travel. Thus, within ‘Static Mobility’, levels of passenger kilometres by 2050 remain similar to those seen today, whereas in the ‘Mobility Plus’ scenario, the numbers of passenger kilometres travelled on land and by air are higher than they are today, as shown in Table 2.3. The scenarios have been named so as to demonstrate these differences without imposing any value judgement.

Table 2.3: Mobility characteristics for the two scenarios

Scenario	Characteristic
<i>Static Mobility</i>	The same levels of passenger-kilometres for both land and air transport in 2050 as there are in the baseline year of 2004. International aviation is currently growing at around 8% per year in terms of passenger-kilometres which points to a swift move to below zero levels of growth in passenger-kilometres. The implications of this will be discussed within the scenario description and policy sections.
<i>Mobility Plus</i>	A doubling of passenger-kilometres in land transport in 2050 compared with 2004, and a trebling for air transport in 2050 compared with 2004.

The fact that the constraints have been placed on passenger-kilometres rather than passenger numbers or kilometres travelled, does allow some leeway for the different modes of transport in terms of their overall impact on the UK’s road, rail and airport infrastructure. As mentioned in Section 6 a doubling in vehicle load factor⁴⁰ for example, could increase the number of passenger-kilometres travelled, but have no impact on overall energy consumption, or indeed the number of kilometres travelled. Modifications to the occupancy rate have therefore been included within the scenarios, as have modal shifts from one form of transport to another. In this way,

⁴⁰ Load factor is the percentage of total seats occupied.

although the total land and air passenger-kilometres will meet the constraints set out, there may be more passenger-kilometres travelled by rail at the expense of road travel in the '*Static Mobility*' scenario for example.

Implications for the scenarios

At the start of the research we held considerable, open, frank and constructive discussions with Friends of the Earth and The Co-operative Bank about their suite of criteria, ultimately agreeing that valuable analysis could be conducted of the 450ppmv future. We recognised, from the outset, that the Friends of the Earth and The Co-operative Bank criteria would place significant constraints on the range of options emerging from the analysis of 450ppmv futures. Nevertheless we have all been surprised at how very little scope for generating substantially different futures the combined effect of the criteria has had. Clearly the central constraint on the analysis has been the choice of 450ppmv (i.e. 4.6MtC between 2000 & 2050). However, this criterion is one that is accepted as reasonable by stakeholders from all spheres of climate change – including, in many respects, the UK government and the EU; both of whom repeatedly emphasise the importance of the 2°C target, and, by implication, empathise with, if not directly support, the adoption of a 450ppmv future. Following on from the list of Friends of the Earth and The Co-operative Bank criteria previously outlined, their implications in terms of constraints on the analysis are as follows:

- The non-transport sectors all have very similar economic make-up, both individually and collectively.
- The non-transport sectors all have very similar energy demands, both individually and collectively.
- The non-transport sectors all have similar carbon emissions, both individually and collectively.

Whilst the first two were to be expected, the similarity in terms of carbon only emerged as the analysis developed. The 450ppmv criterion places very severe constraints on carbon emissions from very early on in the analysis period. The carbon that is available has been allocated to those areas of society where alternative energy forms are either not available or more problematic – this is, and we envisaged would remain, transport and, in particular, aviation. Consequently, given this assumption, there is little carbon left for the other sectors – hence there are

many similarities between the two scenarios. These points are further developed in the conclusions in Section 8.

3. Historic picture of the UK's energy system

When constructing long-term future scenarios, it is important to understand that much can change over a 50-year period⁴¹. It is therefore extremely valuable not to be too constrained by past energy supply or demand developments, or even the historic make-up of the economy. However, historic changes to the UK's energy system can help to put the future energy system into context, and provide important guidance in developing the scenarios, particularly in the short-term. With this in mind, the following section aims to describe some of the important and interesting trends seen within the UK's energy system over the 6⁴², 15 and 35 years prior to 2004⁴³. These periods will, for the remainder of this section, be referred to as the short-, medium- and long-term respectively, with 2004 being referred to as the scenario baseline year.

3.1 The UK economy

There has been little variation in the average annual Gross Domestic Produce over the historic short-, medium- or even long-term; the UK's economy has grown at 2.5% per year over the medium and long-term, and a little faster, at 2.8% per year over the short-term.

The make-up of that same economy has altered significantly over time, with manufacturing dominating in the long-term past, but gradually declining in economic importance from comprising 30% of the economy in 1970, to just 16% in 2004. On the other hand, the commercial sector has seen continued growth over that same period, and contributed more than half of the nation's GDP in 2004.

3.2 Demand and supply

3.2.1 Primary supply

The UK's energy supply has been increasing in size over the long-term, and stands at around 240Mtoe today. The dominant primary supply sources continue to be fossil fuels, with a small shift from 97% in the 1970s to 88% of the total energy mix today. The changes have been primarily due to an absolute doubling of the nuclear

⁴¹ For example, within the UK, there has been a doubling of gas consumption over the fifteen years between 1980 and 1995, a four-fold increase in the passenger-kilometres travelled by air over the past 25 years, and a 20% decrease in the number of people per UK household during the previous 35 years.

⁴² In previous work, the year 1998 to date was chosen for the short-term, as the most comprehensive energy dataset was available for this date.

⁴³ These dates are chosen primarily due to the availability of energy and emission data, and the relevance of looking at policy developments over the short, medium and longer term.

contribution over that period, and the recent inroads made by biofuels and renewable technologies. Figure 3.1 and Table 3.1 clearly illustrate that the biggest change within the UK's primary energy supply mix has been the shift to gas in the 1980s and 90s; 40Mtoe of primary energy supply came from gas in 1980, which had more than doubled in absolute terms by 2004, whilst the overall primary energy supply increased by just 20% over the same period. By contrast, coal consumption halved between 1990 and 2000, although there has been no decline between 2000 and 2004.

Figure 3.1: 1990 and 2004 primary fuel mix

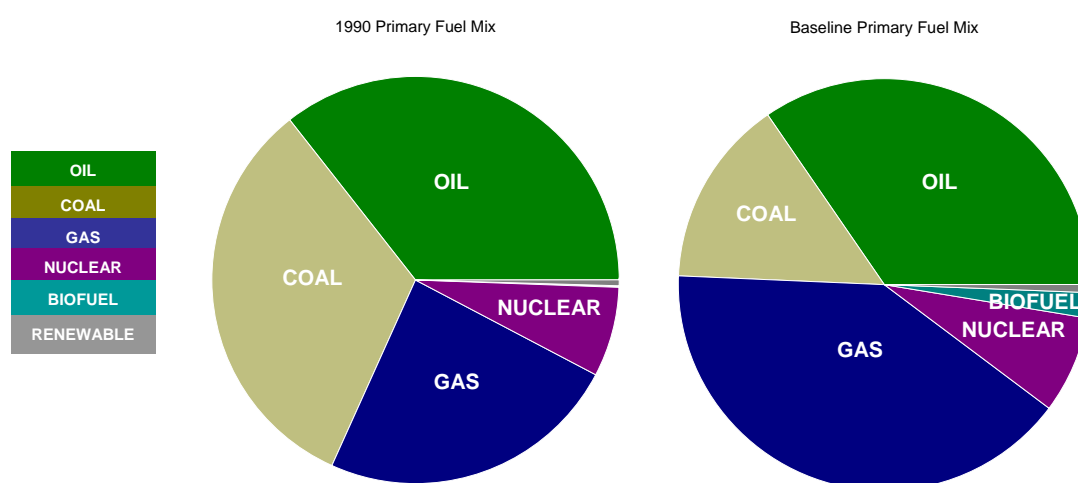


Table 3.1: 1990 and 2004 primary fuel mix

Total primary fuel (Mtoe)							
	Oil	Coal	Gas	Nuclear	Biofuel	Renew	Total
1990	68.3	74.4	50.2	14.9	0.3	1.0	209
2004	81.6	34.9	95.4	18.0	4.7	1.5	236

3.2.2 Electricity, transport and 'other-energy' demand

Figure 3.1 illustrates the UK's energy supply mix, but only by analysing the pattern of energy demand is it possible to discern how best to tackle the issue of decarbonisation. Much emphasis has been placed on electricity when discussing the issue of reducing the UK's carbon dioxide emissions, as discussed in Section 2. However, an overemphasis on decarbonising the electricity supply is likely to lead to an unbalanced policy response. It is helpful, therefore, to split the energy system into three key areas: electricity demand, transport energy demand and other energy demand (mainly heat). Although there is a small amount of electricity consumption

within the transport sector, this is insignificant when considering the sector's total energy consumption and carbon emissions.

3.2.2.1 Electricity demand

Historically, electricity production formed a smaller portion of final energy demand than it does today, ranging from 13% of final demand in 1970 to around 18% in 2004. In absolute terms, this is an increase from around 18Mtoe in 1970 to 32Mtoe in 2004. One key progression however, is the change in carbon intensity of the UK's electricity grid. Over the long-term, the grid has gradually become less carbon intensive, with a step change during the 1980s and 1990s with the move from coal-fired power to gas. Therefore, despite the near doubling of electricity demand over the long-term, the carbon emissions associated with electricity generation have shown a very moderate increase of around 8% (4MtC) over the same period.

3.2.2.2 Transport energy demand

In contrast to electricity generation, the carbon intensity of the transport sector⁴⁴ has essentially remained the same over the long-term. Therefore, it is almost entirely the changes in total final energy consumption within this sector that contributes to changes in overall carbon emissions. Specific issues relating to some of the individual modes of transport will be discussed in more detail below, but in general terms, transport has grown significantly over the long and medium-terms, and in some areas, such as aviation, continues to grow at staggering rates – 7% in terms of passenger-kilometres between 2003 and 2004. In terms of overall energy consumption therefore, the transport sectors' contributions have doubled between 1970 and 2004 from around 30Mtoe to over 60Mtoe. This represents an increase from 19% of the final energy demand in 1970 to 34% in 2004. Similarly, in relation to carbon emissions, the transport sector now accounts for a significantly higher proportion than in 1970 – over 30% in 2004 compared to just 15% in 1970.

3.2.2.3 Other energy demand

The remaining energy demand is dominated by heat production, either for space heating or for industrial processes. The carbon intensity of this type of energy demand has marginally decreased over time, but only marginally. Again, this improvement can generally be attributed to the shift to gas heating from coal and oil. Of the three types of final energy demand: electricity, transport and other, this form of

⁴⁴ The transport sector includes aviation, shipping and all modes of land-transport

demand is the only one to have decreased, in absolute terms, over time. Some of this change can be attributed to improvements in energy efficiency for heating, and to a switch from gas to electrical heating. The improvements in carbon intensity coupled with a reduction in overall energy demand have led to a reduction in carbon emissions from other energy by about a third from 1970. Over the medium-term however, this trend has levelled off with similar carbon emissions in 1990 to those in 2004.

A summary of the different contributions to both final energy demand and carbon emissions is illustrated below for 2004.

Figure 3.2: The contributions to final energy demand and carbon emissions in the baseline year (2004) split between electricity, transport and other energy.

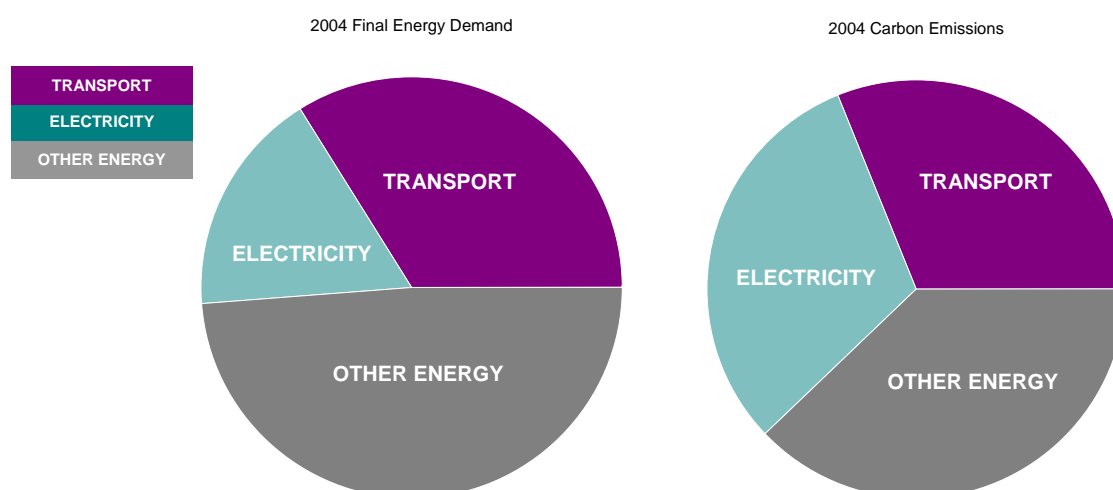


Table 3.2: Total final demand and carbon emission for the baseline year

Total final demand (Mtoe) and Carbon Emissions (MtC)				
	Transport	Electricity	Other Energy	Total
Energy	61.8	31.7	89.0	183
Carbon	51.1	51.0	62.2	164

Clearly 'other energy' dominates the final energy demand, relegating the importance of electricity generation in terms of final energy demand to third place after transport. In carbon emissions however, as shown in Figure 3.2, the split between electricity, transport and other energy is much more even. However, the 'other energy' category remains responsible for the largest portion of emissions, with electricity and transport equally contributing 31% of total carbon emissions. In other words, over two thirds of

the carbon emissions in the UK's economy are generated by our demand for transport and heat, and less than a third from our demand for electricity. This is particularly relevant in relation to the current energy debate, which tends to focus very much on electricity supply rather than heat or transport.

Changes to the whole system carbon intensity over the long-term have been primarily due to the decarbonisation of the electricity grid as mentioned above. As electricity, transport and other energy are now of relatively equal importance in terms of the economy's carbon emissions, it is necessary to attempt to reduce the carbon intensity of all of these areas, either through demand or supply transitions.

3.2.3 Demand sectors

The scenarios produced by the Tyndall Centre begin from a baseline constructed from the various energy datasets readily available. As a consequence, the sectoral split chosen follows these datasets closely. Energy demand is split into 17 sectors in all – Households; Intensive Industry; Non-intensive Industry; Construction; Energy Industry; Commercial; Public Administration; Agriculture; Domestic and International Air Travel; Private Road Transport; Public Road Transport; Rail Passenger; Rail Freight; Road Freight; Inland and International Shipping. However, throughout the report, the sectors are often grouped into four main categories: Households, Industry, Services and Transport, with the aggregation self-explanatory. Where necessary, however, individual sectors will be referred to in more detail, particularly the various transport sectors, due to the emphasis on mobility within this report.

3.2.3.1 Households

The household sector⁴⁵ is a particular challenge when it comes to the issue of decarbonisation within the UK's energy system, as firstly, it has historically been responsible for the largest proportion of overall energy consumption in the economy, and secondly, it has also been the largest consumer of electricity over the long-term. Furthermore, energy consumption per person and per household continues to rise: over the short-term, there has been a 0.5% per year increase in energy consumption per person, and 0.2% per household. However, the energy consumption per consumer expenditure has actually been on the decrease, with a 2.6% per year decrease over the short-term, and 2% decrease over the long-term. Consumer

⁴⁵ The household sector comprises the energy use by householders within the home. It does not include personal transport, or the energy required to construct buildings.

expenditure has been increasing at 3.3% in the short-term, 2.6% in the long-term, hence the overall increase in energy consumption. Another long-term trend has been a reduction in the number of people per household, from around 3 people per household in 1970 to 2.4 today. This type of trend also contributes to the increase in overall energy consumption of the household sector. Overall, energy consumption has, and continues to grow at about 1% per year. The two fuels that have declined in terms of household consumption over the long-term are coal and oil, with a roughly 2% annual average increase in gas use over the medium and short-term, and a 1.5% increase in the use of renewable energy and energy from waste in the short-term.

In relation to carbon emissions, the decarbonisation of the grid during the switch to gas, plus the move away from coal and oil has led to an overall decrease in the carbon intensity of the household sector. However, in 2004, this sector emitted around 40MtC compared with 20MtC from car transport. Consequently, despite these carbon intensity improvements, this is an extremely difficult sector to address when trying to reduce carbon emissions to around 50MtC by 2030 and 16MtC by 2050.

3.2.3.2 Industry and services

In economic terms, the dominance of the commercial sector over manufacturing in 2004 provides little guidance to the pattern of energy consumption across the different sectors. Aggregating the commercial, public administration and agriculture sectors into 'services', and manufacturing, construction and the energy industry into 'industry', shows that although 'services' make up 75% of the economy, and 'industry' makes up 25%, 'services' consume less than half of the energy consumed by 'industry'⁴⁶. In other words, the energy intensity⁴⁷ of the service sectors is much smaller than that of 'industry'. As such, it might be expected that the increased dominance of the 'service economy' would likely go hand-in-hand with a reduction in overall energy consumption. However, despite the fact that manufacturing and, in particular, the energy intensive industries, have been declining in terms of their proportion of the overall economy over the past 35 years, the fact that the UK's economy has more than doubled since 1970 means that these industries have still grown in real terms.

⁴⁶ GVA from the office of national statistics blue book is grouped into either service sectors or production sections. Consequently, households and different modes of transport are not given GVA values.

⁴⁷ Energy per unit of expenditure

It is the more energy intensive sectors that have shown the biggest improvements in terms of energy intensity. For example, in the chemicals, metals and mineral industries, the overall energy intensity has been improving at around 4% to 5% per year over both the short- and longer-term. There are a number of factors that come into play in explaining such a trend, including a shift from more large-scale bulk manufacturing of construction materials to more niche markets such as the manufacture of speciality metals for use in high temperature processes. The construction industry has seen similarly large improvements. As a consequence of higher improvements in energy intensity than the rate of economic growth, energy consumption has declined in both the energy intensive industry sector, as well as construction. On the other hand, in the non-energy intensive manufacturing sectors such as in the production of food or paper, economic growth, energy intensity and, as a consequence, energy consumption have been on the increase.

The two largest sectors within the 'services' category are the public and commercial sectors. The public sector has demonstrated improvements in energy intensity of 4.5% per year over the short-term, and around 2-3% over the long-term, more than compensating for economic growth rates. Whereas the improvements in energy intensity within the commercial sector have been negated by the rate of economic growth, and hence increased this sector's overall energy consumption by between 0.5 and 1% over the long-term. The fact that the commercial and non-intensive industry sectors made up 64% of the UK's economy in 2004, and a sixth of the total energy consumption, coupled with a trend towards their increasing energy demand, makes them of particular concern in relation to the energy and decarbonisation challenge.

3.2.3.3 Transport

The scenarios presented within this report differ primarily in terms of their levels of personal mobility – land and air based passenger transport. When considering the implications of differing levels of mobility therefore, it is essential to analyse occupancy and size of vehicle in order to determine whether there is an increase or otherwise in the number of passenger kilometres travelled.

Firstly, it is important to understand what is meant by passenger-kilometres. This is a measure of the activity of passenger transport, and is calculated by multiplying the number of passengers travelling by a particular mode, by the vehicle kilometres they travel. For example, if plane A carries 100 passengers and travels 2 km, it will be

generating 200 passenger kilometres. Similarly, plane B carrying 200 passengers but travelling 1 kilometre will also generate 200 passenger kilometres. If both these planes are identical, then plane A will consume more fuel, and emit more carbon dioxide than plane B, due to the additional kilometres travelled. If, on the other hand, plane A were half the size, and twice as fuel efficient per passenger-kilometre, as plane B, then these two journeys would account for similar levels of energy consumption and carbon dioxide emissions. This example illustrates the importance of vehicle size and fuel efficiency per passenger-kilometre as key factors in teasing out the impact on energy consumption and carbon emissions for different levels of passenger-kilometres travelled.

Similarly, the load factor of a vehicle is of great importance. If plane A is identical to plane B, and we assume that plane B is full, then plane A has a 50% load factor, and plane B 100%. But, if plane A has half of the capacity of plane B, and they are both full, then both have 100% load factors. Obviously, transporting 100 passengers on a full plane will consume half of the energy of an identical plane making two journeys to transport the same total number of passengers on half full aircraft. Modifications to vehicle capacity and the ability to increase vehicle load factors are therefore crucial aspects of passenger transport energy consumption and carbon emissions.

The section below illustrates how some of these factors have been evolving over time, and therefore aims to provide indicators as to what might need to be modified in the future to bring about a low-carbon, but mobile society.

Land-based travel

Passenger transport by road has dominated land-based transport over the long-term. In terms of passenger-kilometres, road transport (both car and bus) was 10 times larger than rail transport in 1970 and 15 times larger in 2004. Both car transport and rail transport have continually grown over the long-term, although car transport, unlike rail transport, has seen a reduction in growth over the short-term. Travel by bus has been on decline over the long-term, stagnating to roughly zero growth in terms of passenger-kilometres in the short-term. However, there has been a recent increase in bus use within London following significant improvements to the system in the form of newer more efficient vehicles, more frequent services and a simpler fare system. As with all modes of transport, load factors over the various modes of land-based transport have generally been declining over the long-term⁴⁹. The average occupancy of cars has continually declined over the long-term, and stood at

around 1.59 in 2004 compared with 1.8 in 1990⁴⁸ if based on the available passenger-kilometre and kilometres travelled data⁴⁹. The average occupancy of rail travel stood at 93 in 2004, with little change over the short-term, and 9 for transport by bus, again with little change over the short- to medium-term. When comparing these figures with similar measurements for other European nations⁴⁹, it can be seen that varying occupancy rates occur across the various modes. For example, car occupancy has varied between 1.4 in Sweden and 3 in Spain during the 1990s, bus occupancy between 9 in the UK and 32 in Belgium during the same period, and train occupancy from 47 in Luxembourg to 183 in France. Clearly, such variety stems from different infrastructure and culture that has developed over time, but it also illustrates that figures very different to those seen in the UK today are possible in nations similar to our own.

Fuel efficiency for the different modes of transport can be analysed by assessing the energy consumed per passenger-kilometre travelled. Road and rail have shown big improvements in terms of fuel efficiency over the long-term, but bus travel has declined over the same period. Comparing the different modes in terms of energy consumption per passenger-kilometre shows that rail travel is now far and away the most fuel efficient mode of passenger transport, consuming less than 10 thousand toe per billion passenger-kilometre compared with 37 and 28 for car and bus respectively in 2004. Translating these energy consumption figures into carbon intensities, rail travel has halved its carbon intensity in the short-term, and is three times less carbon intensive than car transport, and around half as carbon intensive as bus travel in 2004 as demonstrated in Table 3.3. The carbon intensity of both modes of road transport has essentially stagnated over the short-term. The latest figures from The Society of Motor Manufacturers and Traders⁵⁰ however indicate that the average new car on the market in 2005 emitted 169.4g/km compared with 171.4g/km in 2004. This apparently reflects a larger proportion of diesel cars on the market.

Air travel

The aviation industry is the fastest growing sector of the UK economy, both in terms of activity and carbon emissions, and arguably the most problematic in its impact on the climate. The latest figures show that international aviation emissions increased by 11% between 2003 and 2004, and contributed to over 6% of all of the UK's carbon

⁴⁸ If based on the available passenger-kilometre and kilometre travelled data from DfT (2005). Transport Statistics Great Britain. TSGB. N. Statistics. London.

⁴⁹ EEA (2002). TERM 2002 29 EU - Occupancy rates of passenger vehicles. Indicator Fact Sheet. E. E. Agency.

⁵⁰ SMMT (2005). UK New Car Registrations by CO2 Performance. T. S. o. M. M. a. T. Ltd.

emissions. From a policy perspective, complications in relation to forming climate-friendly policies can arise from attempting to apportion aviation emissions emitted during international flights between nations. Or, from individual nations making unilateral decisions to tax aviation fuel, which is often arguably suggested would be at the expense of their competitive advantage. In relation to propulsion, jet engines are a mature technology, and consequently the efficiency of the current fleet is not set to change substantially within the foreseeable future. Exacerbating this absence of a step-change in fuel efficiency is the long design life of aircraft, effectively locking society into current technology for at least the next 30-50 years⁵¹.

Since 1960, global air passenger traffic in terms of passenger-kilometres has increased by nearly 9% per year – 2.4 times the growth rate of global mean Gross Domestic Product⁵². By 1997, growth in global air passenger traffic had slowed to approximately 5% per year as the industry matured in some parts of the world; however, according to the IPCC, this 5% per year figure is now expected to continue until 2015. Across Europe, growth since the 1980s has often exceeded the global mean figure, with the UK experiencing a 7% annual rate of growth in total domestic and international traffic over the medium-term⁵³, and 7% between 2003 and 2004 alone^{54,32}.

Historically there have been significant improvements in fuel efficiency for the global aviation industry – 70% in the past 40 years through improvements in airframe design, engine technology and rising load factors. More than half of this has come from advances in engine technology⁵². Such improvements give an annual compound fuel efficiency gain for the global fleet of 1.14% in terms of seat-km per kg of fuel consumed. Continued improvements are expected to continue, with airframe improvements likely to play a larger role through improvements in aerodynamic efficiency, new materials and advance in control and handling systems. New, larger aircraft with, for example, a blended-wing body or double-deck cabin offer prospects of further benefits by relaxing some of the design constraints attached to today's large conventional aircraft. But, with the very long total lifetimes of today's aircraft (up to 30 years) replacement rates are low, and the without an external driver towards further fuel efficiency improvements, the whole fleet is likely to improve slowly.

⁵¹ Aircraft last for around 30 years once manufactured, but aircraft designs are often produced for 20-30 years, producing a design lifetime of around 50 years.

⁵² IPCC (1999). Aviation and the global atmosphere. Cambridge, Cambridge University Press.

⁵³ ATAG (2000). European air traffic forecasts 1985-2015. IATA.

⁵⁴ CAA (2004). Main outputs of UK airports. C. A. Authority.

Stakeholders within the aviation industry often criticise any emphasis on aircraft and their impact on the climate on the grounds that the industry is being treated as a special case for no good reason. However, if the historical picture of developments in energy efficiency and carbon intensity are analysed and compared with other sectors, alongside the high levels of growth and the technological limitations predicted in the future⁵⁵, it is clear why aviation must receive both energy analysts and policymakers urgent and special attention.

In terms of fuel efficiency, although globally, improvements have been made over the long-term, both international and domestic air travel are the most energy intensive, or fuel inefficient, modes of transport per passenger-kilometre. Moreover, the fuel efficiency of international aviation associated with the UK has deteriorated in the short-term. Historically and currently, domestic aviation is bottom of the fuel efficiency ratings with efficiencies around double that of international aviation. International aviation is placed second bottom of the list. Not surprisingly then, domestic aviation is also the most carbon intensive mode of travel, twice as carbon intensive per passenger-kilometre as car transport. International aviation fares somewhat better, but is still the second most carbon intensive mode of travel per passenger-kilometre.

Table 3.3: Comparison of energy intensity, carbon intensity and recent growth for the different modes of passenger travel⁵⁶. Data derived from passenger kilometre data and vehicle kilometre data from Transport Statistics Great Britain.⁴⁸

Mode of passenger transport	Energy intensity (Mtoe/Bill pax)	Carbon intensity (MtC/pax)	2003-2004 growth rate in passenger km
Rail	0.006	0.008	4%
Car	0.04	0.030	0%
Bus	0.03	0.020	2%
Domestic aviation	0.08	0.060	8%
International aviation	0.04	0.035	7%

It cannot be denied therefore that with an industry with the worst performance in terms of energy efficiency and carbon intensity as illustrated in Table 3.3, coupled with a growth rate of more than three times the current annual GDP growth rate,

⁵⁵ Air Transport Action Group (ATAG) predicts increases of around 4% per year for European passenger traffic, and 4.4% per year for international air transport to and from European nations up to 2015. Airbus on the other hand predicts the aviation industry across Europe growing at 5.2% per year until 2023 and Boeing forecasts European aviation growth at 4.3% per year over a similar period

⁵⁶ Carbon intensity is not a linear function of energy intensity due to the fact that different fuels have different carbon contents.

managerial and technological improvements to bring about change are essential if the UK is to follow a path of decarbonisation. However, unfortunately for the aviation industry, this is not a straightforward task. When it comes to other modes of transport, there are a number of step changes in energy efficiency and carbon intensity that can be achieved through the use of existing technologies as well as new forms of transport fuel such as biofuel, electricity and hydrogen. For example, it is already possible to manufacture cars that run at 70 miles per gallon, and yet the current average for the UK's car fleet is closer to 35 miles per gallon. However, the aviation industry does not have the same flexibility as these other modes of transport.

To summarise, without a sea-change in policy, technology and implementation, aviation emissions are likely to continue to grow globally as a consequence of the growth in passenger demand outstripping the fuel efficiencies changes associated with improved engine performance, airframe design and air traffic control rationalisation.

Shipping

The shipping sector is the most problematic of all energy consuming sectors in terms of assessing its climatic impact, due the insufficient and inadequate level of data and information in relation to fuel and hence energy consumption. Although fuel consumed by inland and coastal traffic around the UK is recorded within government statistics, fuel for international shipping is not. The inland data includes all UK inland waterways, and UK coastal shipping. But, it does not include the fuel consumed by a ship from China for example, that first docks at Plymouth, and then continues its journey around the UK to unload.

In relation to the UNFCCC, nations are not required to include a submission relating to international shipping, as is also the case for aviation, within emissions inventories. However, international bunker fuels are recorded, and as such, international aviation and shipping carbon dioxide emissions are calculated based on these sales. As explained in the previously, this is an appropriate approximation for carbon dioxide emissions from the aviation industry because there is no tax on fuel, and therefore its price is similar world-wide, providing no incentive for airlines to fuel up in particular nations. As a consequence, the purchase of bunker fuels for aviation approximates to 50% of fuels used for flights departing and arriving in the UK. Furthermore, there are more time constraints on planes, which are predominantly led by passenger demand. The picture is very different for shipping, which is dominated by the transportation of

freight. The price of fuel can vary widely from continent to continent, and there are many more opportunities to stop and refuel at cheaper nations than is practical for commercial aircraft. As a consequence, UK marine bunker fuel data is not a reliable source from which to derive the UK's 'fair' proportion of carbon dioxide emissions from international shipping.

There has, however, been some recognition in more recent years that shipping is an important energy sector that must receive closer attention⁵⁷, but in relation to historical trends within this industry, there is very little information. In terms of global marine bunker sales, around 144Mtoe were sold in 2003 compared with 109Mtoe in 1970, an increase of 32% over 23 years according to the EU and the International Energy Agency⁵⁸. Over the short-term, global marine bunker sales have increased from 137 in 1998 to 144 in 2003, but remained relatively unchanged between 2002 and 2003.

In relation to the UK, the amount of freight loaded and unloaded at UK ports should provide an indication as to the historical changes in energy consumption related to shipping, at least in terms of growth. Over the short-term, the net amount of freight loaded and unloaded at UK ports has remained static, with annual increases of 1.3% over the long-term. The most recent years for which data are available indicates that the net amount of freight increased by 3% in one year, with the amount of foreign freight passing through UK ports increasing by 3.7% between 2003 and 2004.

In relation to energy efficiency, the only data available is for inland shipping, where fuel efficiency per freight-tonne-kilometre improved by 0.8% over the short-term, around 1% over the medium-term, and by 2.3% over the long-term. Activity on the other hand, grew at around 1.1% in the short-term, and 2.2% over the long-term. In other words, for inland shipping, energy efficiency improvements have been approximately matched by growth, leading to little change in the overall energy consumption in the long-term. However, it is not necessarily appropriate to assume that fuel efficiency improvements for ships used for international freight transport are similar to those for inland and coastal traffic. Consequently, other than knowing that the amount of freight passing through UK ports, in particularly coming from abroad, rather than being exported by the UK, is on the increase, it is difficult to attribute any

⁵⁷ Page 9 of ONS (2005). United Kingdom National Accounts, The Blue Book. New York, Palgrave MacMillan.

⁵⁸ http://europa.eu.int/comm/environment/air/pdf/beicipfranlab_report.pdf and for the later years: IEA statistics - energy balances of non-OECD countries, 2001-2002, 2002-2003

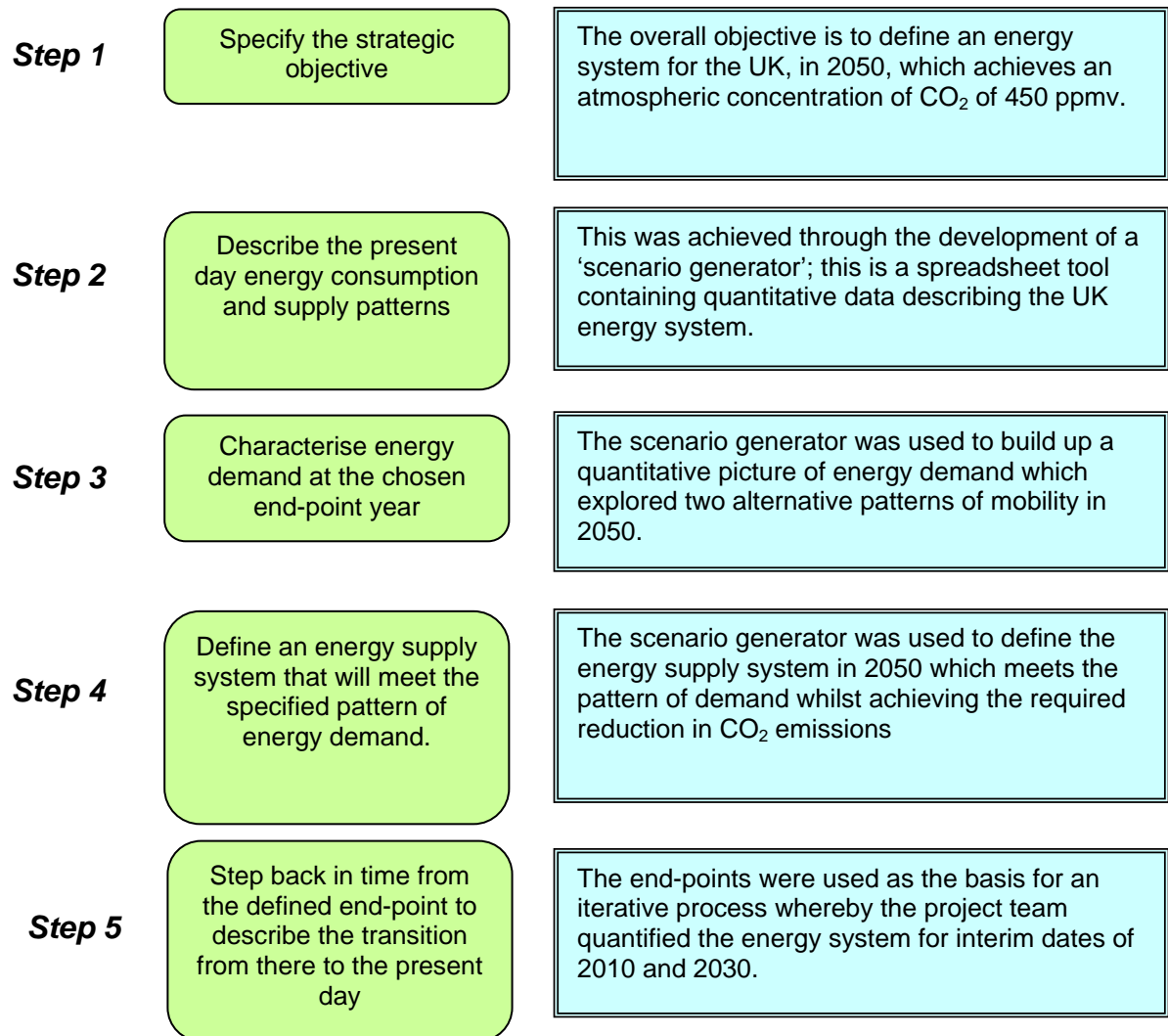
fuel efficiency improvements to this sector. To address this, and provide an estimate for the baseline year, an approximation for shipping emissions was made by investigating the range of values determined when dividing the total global marine bunker fuels by some appropriate proportion in relation to freight passing through UK ports, or UK GDP as a percentage of global GDP. Preliminary results suggest that UK carbon emissions from international shipping amount to between 4 and 6MtC in 2004. Consequently, the figure of 5MtC was chosen as an average for this sector. It is accepted that these figures may need adjustment in the future, by there are a number of reasons why they are thought to be a) reasonable, and b) more likely to be on the low than the high side, as described in the footnote.⁵⁹

⁵⁹Total marine bunker sales data is likely to be a conservative estimate; the UK is a major trading nation and an island state whose principal mode of transporting freight is by ship, therefore it is likely that the amount of shipping associated with the UK in relation to other non-island nations may be higher than its proportion of global GDP

4. Method

The scenarios have been developed using a 'backcasting' methodology as follows:

Figure 4.1: Backcasting methodology



(Based on Anderson, 2001)

The remainder of the scenario method chapter describes each of the steps outlined above.

4.1 Defining the end-points

The backcasting methodology requires the development of a comprehensive picture of the 2050 energy system (steps 1 to 4 outlined above). The only explicit constraint imposed on the system is that an atmospheric concentration of 450 ppmv of CO₂ must be achieved by this date. In order to characterise the energy system, a 'scenario generator' was used. Essentially, this is a spreadsheet model which enables a detailed picture of energy consumption and its associated supply system to be built up.

The scenarios were developed in line with the energy system boundaries which have been outlined in section 2.1. Energy demand in each of the sections is based on study of the literature, and an assessment of the likely improvements which could, within the correct policy framework, be achieved by 2050. At this point it should be emphasised that the strength of backcasting scenarios are that they inform us as to ***what has to happen*** if a certain target is to be achieved, rather than ***where we will get to***. As such, therefore, these scenarios set out one particular route whereby the UK can achieve its carbon target. They do not make a judgement as to how likely it is that we will achieve it.

Initially, two end-point scenarios were developed for 2050, one for each of the patterns of mobility previously outlined. For each of these scenarios, the end-point was described in a qualitative sense in terms of the 15 demand-side sectors and the rate of economic growth was specified. The qualitative description was then considered in terms of a number of parameters contained within the scenario generator, such as the rate of annual change in efficiency of energy use, change in mobility, change in the number of households, etc. The scenario generator was then used to calculate the energy demand in 2050 for each of the demand sectors.

A similar procedure was used to devise the energy supply system for each of the scenarios, within the specified system boundaries. Hence for each scenario, the relevant supply technologies that would form part of the mix were chosen and a qualitative description written. Using the scenario generator, the energy supply system was matched to the pattern of consumption envisaged within each of the demand components of the scenarios, on the basis of matching energy from the specified fuel sources to the most appropriate end use. Once both the demand- and

supply-sides have been specified within the scenario generator, the carbon emissions are calculated. A certain amount of iteration is necessary to ensure that the end-point is in line with the carbon constraint.

The process outlined above was repeated for each of the interim dates, namely 2010 and 2030.

4.2 Scenario generator

The model uses 2004 as the baseline year and contains historical information going back to 1970, allowing the energy future to be placed in the context of the energy past. Energy demand is divided into 15 sectors: households; six business sectors (energy intensive industry⁶⁰, non-intensive industry, public, commercial, agriculture, construction); seven transport sectors (road, passenger and freight; air, domestic and international; rail; marine freight, domestic and international), and the energy industry itself. A distinction is also made between electricity and other energy since these have different implications for the supply system.

For both international air and marine transport an assumption for a 50:50 allocation of emissions between the UK and the departure and destination country has been made. Due to the absence of accurate and readily available data, combined with the complication of a high proportion of goods being carried in the bellies of passenger aircraft, aviation freight has not been explicitly included.

A number of other parameters are included as follows:

- *Household sector*: population (POP), the number of households (HH), the percentage change in number of households by 2050, the change in per capita affluence, the change in efficiency with which energy is used in the household and the change in energy intensity of economic activity.
- *Industrial, commercial, agricultural, construction and public administration sectors*: change in economic activity (GVA⁶¹), change in energy intensity and change in efficiency with which energy is used.

⁶⁰ Energy intensive industry is defined as the metals, minerals and chemical sectors which are a blend of subcategories from DUKES and ONS. This was necessary as economic activity (GVA) data is from one source and energy consumption from the other.

⁶¹ Aggregated GVA of the defined sectors (the aggregation of GVA is one of the ways of constructing GDP).

- *Transport sectors*: change in mobility (i.e. passenger km or tonne km), change in mobility intensity of economic activity, change in energy intensity of mobility and change in the efficiency of fuel use.

For any given sector, the energy consumption in 2050 is calculated on the basis of an annual change in energy consumption compounded over the 46 years from 2004 to 2050.

The energy supply system is matched to the pattern of consumption envisaged within each of the demand components of the scenarios, on the basis of matching energy from different fuel sources to the most appropriate end use. In accepting that decisions made now will influence innovation, it was decided to focus on current technologies operating at state-of-the-art efficiencies and to include those potential technological options which are firmly established 'on the horizon'. The available options include:

- Grid electricity sources: highly efficient coal combustion (with and without CO₂ capture and storage CCS), gas (combined cycle gas turbines with and without CO₂ capture and storage), biofuels and renewable sources (on and offshore wind, hydro-energy and marine sources)
- Combined heat and power (CHP) fuelled by coal, gas and biomass
- Hydrogen production: produced by electrolysis from renewables, steam reformation of methane or coal gasification.
- Direct use for heat and motive power biofuels, coal, gas and oil

Within the spreadsheet model, a number of assumptions concerning the efficiency of supply-side technologies have been made.

4.2.1 Carbon calculations

To calculate the carbon emissions for the chosen year, the standard National Emissions Inventory primary emission factors are used for the directly combusted fuels. For the electricity consumption, the carbon emissions are calculated by firstly multiplying the primary emission factors by the amount of each fuel consumed, and secondly, by adding to this the amount of each fuel lost in the transmission and distribution of the electricity, also multiplied by the primary emission factor. The total carbon emissions for the UK's energy system can then be calculated by summing each sector's emissions.

A 90% reduction in carbon emissions from a 2004 baseline (165 MtC) necessitates that final carbon emissions generated by the UK's primary energy demand are in the region of 16 MtC. Devising the end-points was an iterative process with a certain amount of adjustment of sectoral energy consumption and associated supply mix to ensure that the end-point supply system matches the pattern of energy demand specified within the carbon constrained end-point.

4.2.2 Non-CO₂ emissions

Within this research no 'uplift' factors have been applied to any of the transport sectors to account for the warming or cooling attributable to additional non-carbon dioxide emissions. It is often argued however, that it is necessary to include some form of 'uplift' when considering the impact of the aviation industry on the climate.⁶² According to the IPCC, the additional emissions from aviation may have an impact of between 2 and 4 times that of the carbon dioxide alone (IPCC, 1999). Indeed, the Tyndall report 'Growth Scenarios for EU & UK Aviation: Contradictions with climate policy'⁶³ did employ an uplift factor to illustrate climate warming caused by aviation. However, using a cautionary approach similarly applied to the previous aviation work⁶⁴, the reasons for excluding the use of an uplift factor for aviation within this work are in relation to its scientific robustness, and to make a fair comparison between sectors, as explained below:

Scientific robustness of the uplift factor

The 'uplift' factor that was mentioned in the IPCC's Special Report on Aviation (IPCC, 1999) was based on Figure 4.2, where the contributions of the different aviation emissions are compared in terms of their relative radiative forcing. Radiative forcing is a measure of a change in the radiation budget at the top of the atmosphere due to some perturbation in the earth's atmosphere or biosphere. For example, an increase in atmospheric carbon dioxide will prevent some of the earth's radiation from escaping back into space, and therefore produce a larger radiative forcing than if there had been no carbon dioxide increase. Figure 4.2 therefore indicates that all of

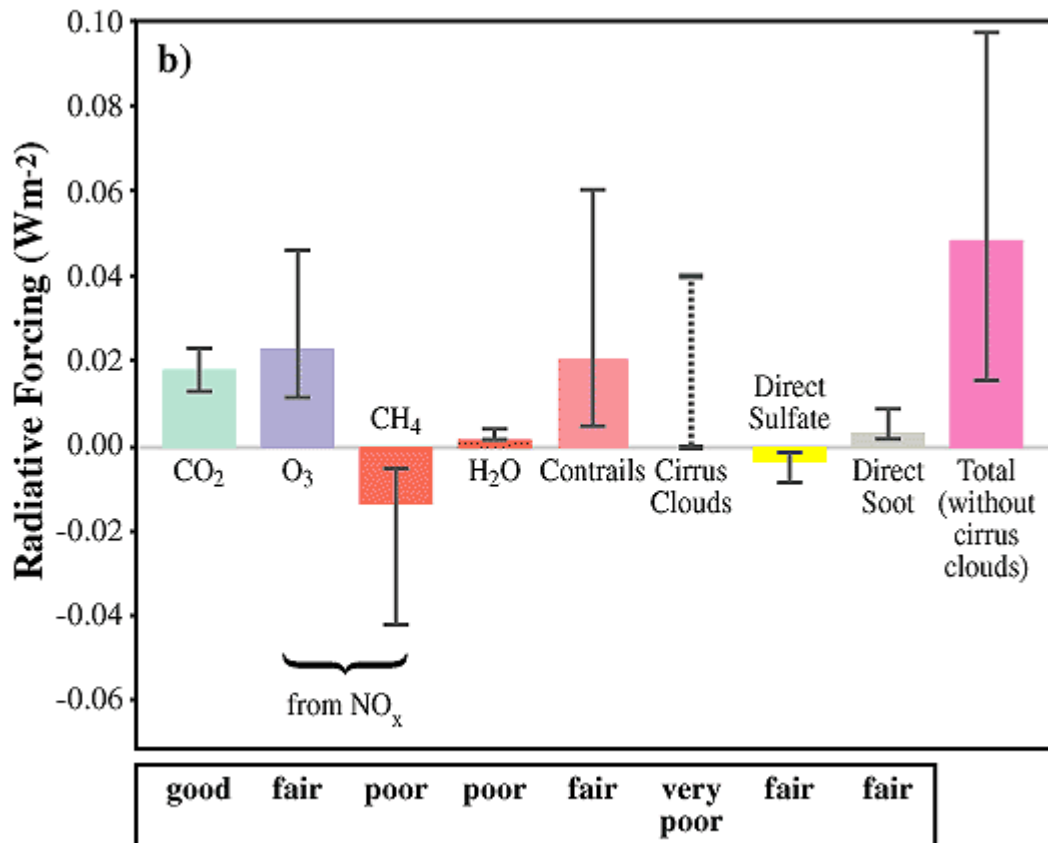
⁶² To account for the significant additional climate impacts generated by emissions such as nitrous oxides that form ozone and methane at altitude, and the soot and water vapour that lead to the formation of contrails and cirrus clouds.

⁶³ Bows, A., K. Anderson and P. Upham (2005). Growth Scenarios for EU & UK Aviation: Contradictions with Climate Policy. T. Centre, Tyndall Centre.

⁶⁴ See page 58 of 'Growth Scenarios for EU & UK Aviation: Contradictions with climate policy' for the caveat used in relation to uplift within that piece of work.

the non-carbon dioxide emissions, excluding cirrus clouds, result in a radiative forcing around 2.7 times that of the carbon dioxide alone.⁶⁵

Figure 4.2: Bar charts of radiative forcing from aviation effects in 1992 compared with the pre-industrial period. Base estimate (bars) and high-low 67% probability intervals (whiskers) are given. No best estimate is shown for the cirrus clouds; rather, the dashed line indicates a range of possible estimates. The evaluations below the graph are relative appraisals of the level of scientific understanding associated with each component.



When analysing the importance of emissions for policy purposes however, it is not the radiative forcing of different climate-change agents that have been compared in the past, but their Global Warming Potentials (GWPs). The difference being that GWPs consider the time-integrated radiative forcing from a pulse emissions rather than just the radiative forcing alone⁶⁶. As the emissions released by aircraft have very different lifetimes ranging from a few minutes to hours, in the case of contrails, to 100 years, for the case of carbon dioxide, it is inappropriate to compare their emissions in terms of their radiative forcing. For example, if their annual

⁶⁵ This bar chart has recently been updated by the TRADEOFF project, and although finds a lower radiative forcing due to contrails, indicates that due to the increase in air traffic, overall the figure remains similar to the 1992 estimate (Sausen et al., (2005).

⁶⁶ Forster, P. M. d. F., K. P. Shine and N. Stuber (2006). "It is premature to include non-CO₂ effects of aviation in emission trading schemes." Atmospheric Environment 40(6): 1117-1121.

instantaneous radiative forcings are analysed, carbon dioxide emitted by aircraft appears to have a low impact on climate compared with a contrail, but since carbon dioxide lasts for 100 years, its importance in climate terms is in fact much greater⁶⁶. The danger therefore of comparing aircraft emissions in terms of radiative forcing is that it might encourage policy responses that are at best inadequate, and at worst, have the opposite effect on climate change to that desired. For example, lowering the altitude that aircraft fly at could eliminate contrail formation⁶⁷, and reduce the overall radiative forcing, but the increase in the amount of fuel burn required to fly at such altitudes will increase carbon dioxide emissions, and over a long time period, exacerbate climate change.⁶⁸

A fair comparison

It was mentioned in Section 3 that the aviation industry often accuses the energy and climate change communities of treating aviation as a special case. In our view, this industry *is* of particular importance for the reasons outlined previously in relation to high growth, few technological alternatives, high carbon intensity and long aircraft lifetimes. However, although concerns in relation to the additional climate warming of non-carbon dioxide emissions from aviation are valid, in order to be consistent, all of the sectors considered here must be treated identically. If an uplift factor were to be applied to the aviation industry, then unless a similar factor were applied to all the other sectors to account for their additional emissions, we would indeed be treating aviation as a special case. Furthermore, extending the radiative forcing index approach to other sectors would reveal complications in trying to account for non-Kyoto gases. For example, diesel engines in ships emit tiny aerosol particles believed to cool the climate. Using a radiative forcing index in shipping may indicate that increasing those emissions could be incorrectly interpreted as being beneficial to the climate.

Clearly, it is important when addressing climate change not to ignore significant contributions to climate warming. However, until a suitable scientific method for comparing these kinds of local and short lived emissions with long-lived well-mixed greenhouse gases over all sectors, uplift factors will be deemed inappropriate for

⁶⁷ Williams, V., Noland, R.B., Toumi, R. (2003). "Air transport cruise altitude restrictions to minimize contrail formation." *Climate policy* 3: 207-219.

⁶⁸ For a clear explanation of the problem with radiative forcing in policy terms, see Forster, P. M. d. F., K. P. Shine and N. Stuber (2006). "It is premature to include non-CO2 effects of aviation in emission trading schemes." *Atmospheric Environment* 40(6): 1117-1121.

policy formation.⁶⁹ It should be born in mind however, that if all such effects were included for all sectors, the aviation industry is likely to be found to account for a somewhat larger amount of additional warming than indicated by carbon dioxide alone.

4.2.3 Non-energy CO₂

In 2004, approximately 3MtC were attributable to non-energy sources such as carbon dioxide emissions during cement production. This is a small proportion of the UK's overall emissions (~2%) and as such is given little relevance within these energy scenarios. However, the figure is taken into account in the baseline year, and adjusted to reflect changes over the 46 years of development within the scenarios.

4.2.4 UK boundary

Within this report, we address the UK's energy consumption and carbon emissions without considering the life-cycle impact of for example, goods purchased outside of the UK or imports and exports of energy. We fully recognise however that to reach a carbon dioxide stabilisation level of 450ppmv, global carbon emissions need to be curbed, and hence it is not an option for the UK to simply export its emissions elsewhere. For the purpose of this work however, the following boundaries are assumed:

- Imports or exports of energy incur no additional emissions than those related to their direct combustion
- International aviation and shipping emissions are assumed to be approximately 50% of emissions generated by all planes and ships arriving and departing the UK
- Embodied energy is not included within the calculations

⁶⁹ A new project called 'QUANTIFY' is hoping to analyse the contributions to climate change from non-Kyoto emissions by the other modes of transport over the coming 2 years <http://www.pa.op.dlr.de/quantify/>

5. Scenario descriptions

Two scenarios exploring contrasting mobility patterns have been developed within the energy system boundaries defined by Friends of the Earth and The Co-operative Bank. The combination of the energy system boundaries, the stringent 2050 carbon target and the brief from Friends of the Earth and The Co-operative Bank to investigate differences in mobility has resulted in two scenarios which are broadly similar in terms of energy demand and carbon emissions across all the non-mobility sectors. Differentiation in the supply-side has emerged as a consequence of differences in the pattern of demand for transport fuel within the two scenarios. These issues have been discussed in greater detail in Section 2.

With this in mind, where the *Static Mobility* and *Mobility Plus* scenarios share the same characteristics, the descriptions are applicable to both scenarios and specific details are drawn out to highlight where they differ. This section opens with an overview of the scenarios, before focusing upon short-, medium- and long-term characteristics. Essentially Section 5 provides snapshots of the UK energy system required to meet a specific carbon budget over three different time frames. The changes outlined have not been based on an assessment of *where we will be* if certain trends and drivers are projected forward, but instead of *where we have to be* if we are to remain within the carbon budget. This analysis has considered the output of other research to ensure that the numerical component is based on feasible carbon reductions. The descriptions make no judgements as to the desirability or likelihood of the scenarios, so as to provide a neutral context for the policy framework by which the carbon reductions can be achieved that is presented in Section 7. More detailed descriptions of the transport sectors are outlined in Section 6 of this report.

5.1 Overview of the *Static Mobility* and *Mobility Plus* scenarios

Both scenarios are medium economic growth, low energy demand scenarios. With rates of economic growth similar to today, the economy by 2050 is three times bigger than in 2004 with an associated energy consumption which has been reduced to half of current levels. The UK remains a service economy, which is driven by the commercial and public administrative sectors. The productive sectors collectively contribute the remaining 14% of GVA, primarily from industry and construction. Tables 5.1 and 5.2 outline the changes in GVA for the two scenarios over their 46 year timescale.

Table 5.1: Annual percentage changes in GVA – *Static Mobility* scenario

	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Intensive industry	2.0%	2.2%	1.9%	1.9%	1.6%
Non-intensive industry	0.5%	1.2%	1.1%	0.6%	0.5%
Construction	2.4%	2.1%	2.0%	1.8%	1.5%
Energy industry	-0.5%	-0.5%	0.2%	1.0%	1.9%
Public sector	2.0%	2.0%	2.4%	2.5%	2.5%
Commercial	2.8%	3.0%	3.1%	3.0%	2.8%
Agriculture	0.0%	0.5%	1.0%	2.5%	3.9%

Table 5.2: Annual percentage changes in GVA – *Mobility Plus* scenario

	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Intensive industry	2.0%	2.0%	1.9%	1.8%	1.9%
Non-intensive industry	0.5%	0.8%	1.0%	0.9%	0.7%
Construction	2.5%	2.3%	2.0%	1.5%	1.5%
Energy industry	-0.5%	0.0%	0.5%	0.9%	1.2%
Public sector	2.3%	2.2%	2.3%	2.4%	2.3%
Commercial	2.8%	2.9%	3.0%	3.1%	3.1%
Agriculture	0.0%	0.8%	1.6%	2.5%	3.0%

Overall, during the 46 years explored in the scenarios, population has grown by 7%, and there has been a 9.6% increase in household numbers. The same changes to energy consumption have been seen in households in both scenarios; these are summarised in table 5.3.

Table 5.3: Household summary

	2004	2010	2030	2050
Household numbers (thousands)	25,300	25,605	26,649	27,735
Population (thousands)	59,835	60,376	62,213	64,106
People per household	2.4	2.4	2.3	2.3
Energy per household: <i>Static</i>	1.93	1.90	1.25	0.82
Energy per household: <i>Plus</i>	1.93	1.90	1.16	0.83

Energy consumption has been reduced across all sectors of the economy through improvements in energy efficiency. These changes have been brought about both by increases in the technical efficiency for delivering goods and services and by changes to consumption habits. Change in energy intensity is a measure of the change in energy required to deliver a unit of GVA; these changes in energy intensity in the short-, medium- and long-term for each of the scenarios are outlined in tables 5.4 and 5.5.

Table 5.4: Annual percentage changes in energy intensity – *Static Mobility* scenario

	2004-2010	2010-2030	2004-2050
Intensive industry	-4.6%	-3.0%	-3.3%
Non-intensive industry	-0.2%	-3.3%	-2.5%
Construction	-4.3%	-3.4%	-2.8%
Energy industry	0.0%	-2.5%	-2.5%
Public sector	-3.4%	-4.2%	-4.2%
Commercial	-3.2%	-4.9%	-4.9%
Agriculture	-2.0%	-2.0%	-3.6%

Table 5.5: Annual percentage changes in energy intensity – *Mobility Plus* scenario

	2004-2010	2010-2030	2004-2050
Intensive industry	-4.6%	-3.6%	-3.3%
Non-intensive industry	-0.2%	-3.3%	-2.8%
Construction	-4.4%	-3.3%	-2.8%
Energy industry	0.0%	-1.9%	-2.5%
Public sector	-3.7%	-4.5%	-4.2%
Commercial	-3.2%	-5.1%	-4.9%
Agriculture	-3.6%	-3.2%	-3.6%

The carbon reductions have been brought about in a governance system similar to that of today. Despite the overall reduction in energy consumption, meeting the stringent carbon target has also necessitated considerable decarbonisation of the supply system, and a shift to the use of hydrogen as an energy carrier.

5.1.1 Mobility characteristics

The *Static Mobility* scenario is characterised by a ceasing of growth in passenger transport, so that the same numbers of passenger kilometres are travelled in 2050 as today. By contrast, in the *Mobility Plus* scenario, although current rates of increase in mobility are not maintained, rather growth rates are curbed, UK individuals are travelling twice as many passenger kilometres by road and rail in 2050, and three times more passenger kilometres by air.

The most marked change occurs within the aviation industry which undergoes a radical shift between 2006 and 2050 with a reduction in growth rates from the current level of 7% per annum to annual averages of 0 or 2.4% depending on the scenario⁷⁰. Moreover, the scenarios require that the aviation industry improves fuel efficiency above current rates, and significantly increases its load factor by 2050, carrying many more people per plane. Essentially, policy levers must be strong enough to force a sustained response from the industry which has the effect of improving fuel consumption and driving a transition to low-carbon fuels.

Within the *Mobility Plus* scenario, aviation fuel efficiency improvements occur more quickly than in the *Static Mobility* scenario, peaking at an average of 2.2% per annum between 2020 and 2030. However, improvements drop to 1% per year between 2040 and 2050. This is because, in the *Mobility Plus* scenario, the industry is able to continue to expand, albeit at a significantly reduced rate, in return for achieving greater improvements in energy efficiency. The uptake of new fuels is also much higher, with 5% biofuel by 2020 and 50% biofuel used across the fleet by 2050. Furthermore, in the *Mobility Plus* scenario, planes are larger, with an average capacity of 250 people per plane compared with 177 today and 200 in the *Static Mobility* scenario.

5.2 Non- transport sectors

Whilst both scenarios achieve the same overall rate of reduction in energy consumption in 2050, there are different patterns to the changes within the two scenarios, illustrated in figures 5.1 and 5.2⁷¹.

In the *Static Mobility* scenario, the rate of reduction in energy consumption initially increases more slowly, but a higher rate is maintained between now and 2050. By contrast, high rates of reduction in energy consumption begin earlier in the *Mobility Plus* scenario, but these high rates level off. These differences are seen as a response to the faster pace of innovation which is required in the *Mobility Plus* scenario to bring about the improvements in energy efficiency required in the transport sector.

⁷⁰ Current refers to the latest published figures for 2003-2004.

⁷¹ The parameters in the graphs of final energy demand and carbon emissions, are split into broad demand sectors – Households, Industry (which includes intensive industry, non-intensive industry, energy industry and construction), Services (which includes commercial, public sector and agriculture), Road transport (which includes car, lorry and bus transport), and Other transport (which includes aviation, shipping and rail).

Overall, by characterising the two scenarios in this way, the final energy demand by 2050 differs between the two scenarios by 16Mtoe, or 18% of energy demand in *Static Mobility*. The majority of this difference is attributable to the additional energy required for the increase in passenger-kilometres in the *Mobility Plus* scenario.

Figure 5.1: Final energy demand by sector - 'Static mobility'

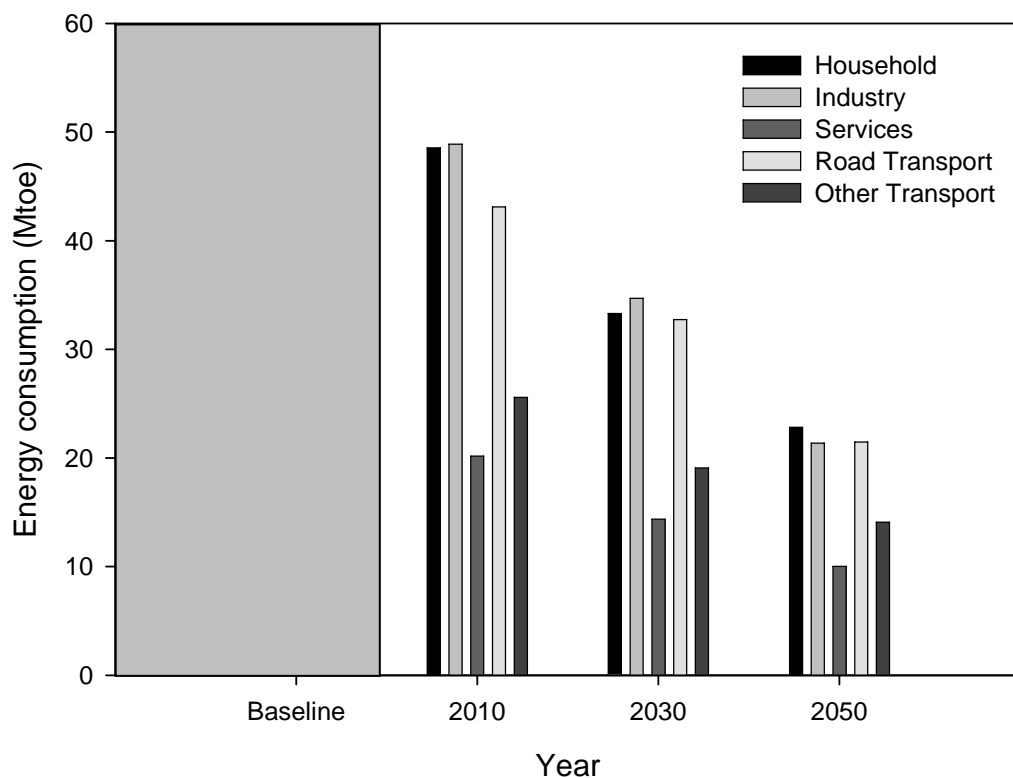
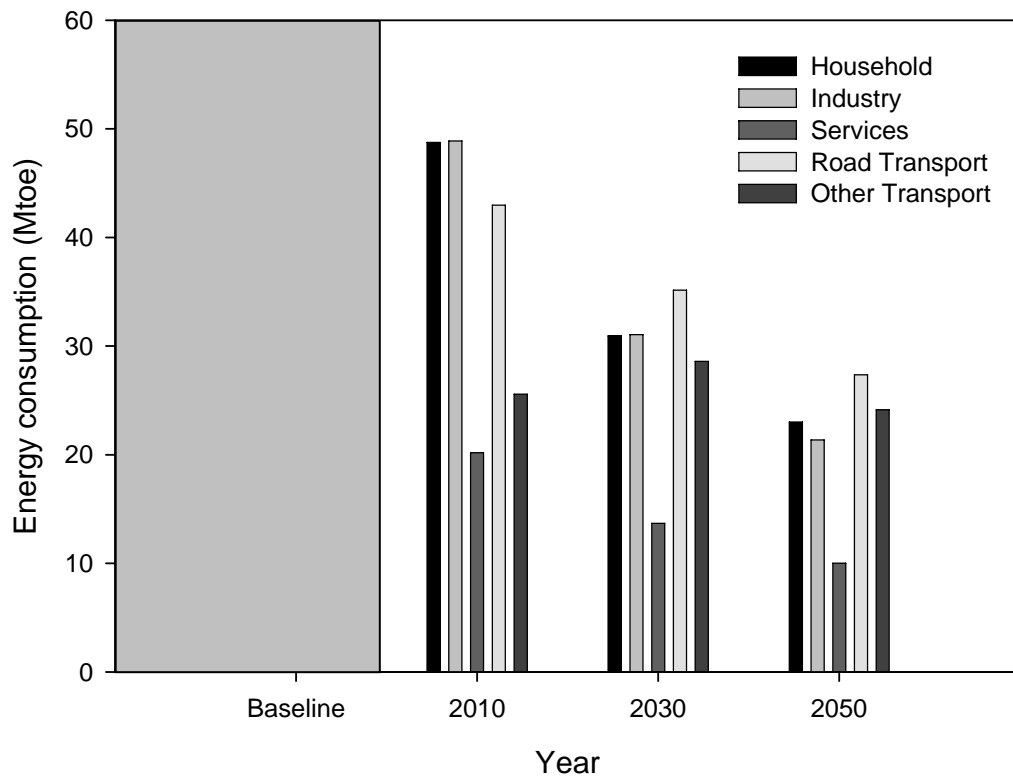


Figure 5.2: Final energy demand by sector - 'Mobility plus'



In terms of carbon emissions, the carbon trajectory is the same for both scenarios therefore overall carbon emissions are similar in 2050, though there are different patterns of emissions between the two scenarios. Energy demand is met through different supply mixes, with a larger penetration of hydrogen within the transport sector in the *Mobility Plus* scenario, and a zero-carbon grid. Quantitative illustrations of the transition from high to low-carbon economy will be presented throughout this section. In relation to non-energy carbon dioxide emissions, they are assumed to decrease at a rate of 1% per year until 2030, and at 1.5% per year between 2030 and 2050, reflecting opportunities to capture the carbon, as in the main, they are generated by large processing cement plants. This reduces these carbon emissions from 3MtC in 2004 to around 1.5MtC in 2050.

Figure 5.3: Carbon emissions by sector over time - 'Static mobility'

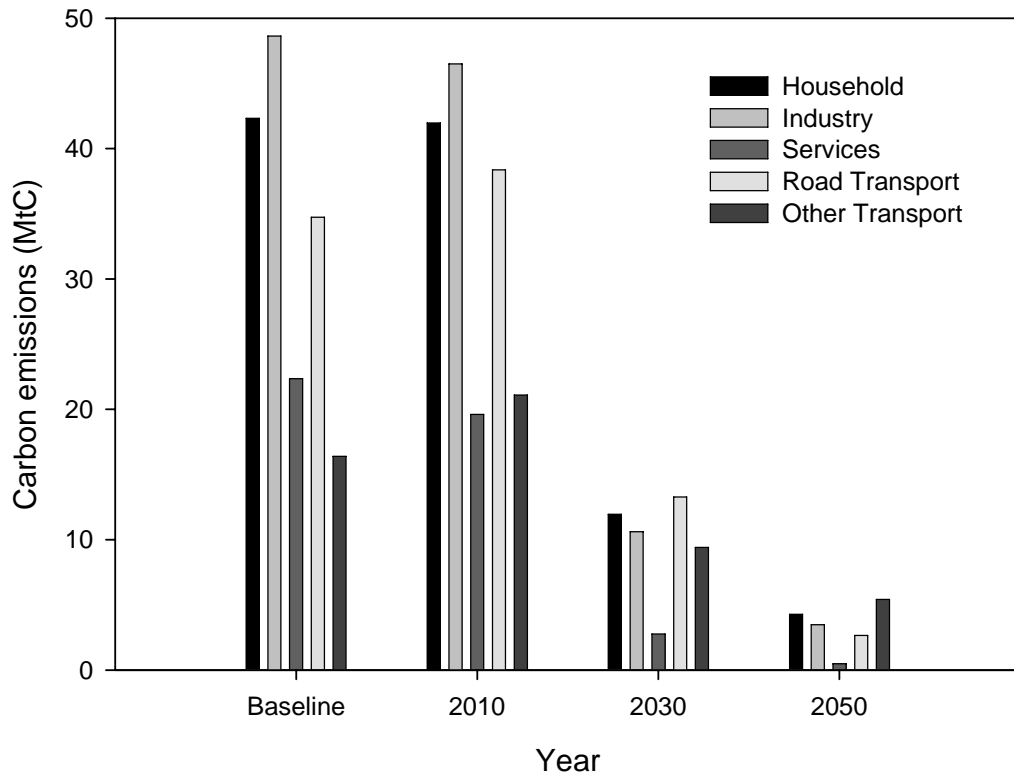


Figure 5.4: Carbon emissions by sector over time - 'Mobility plus'

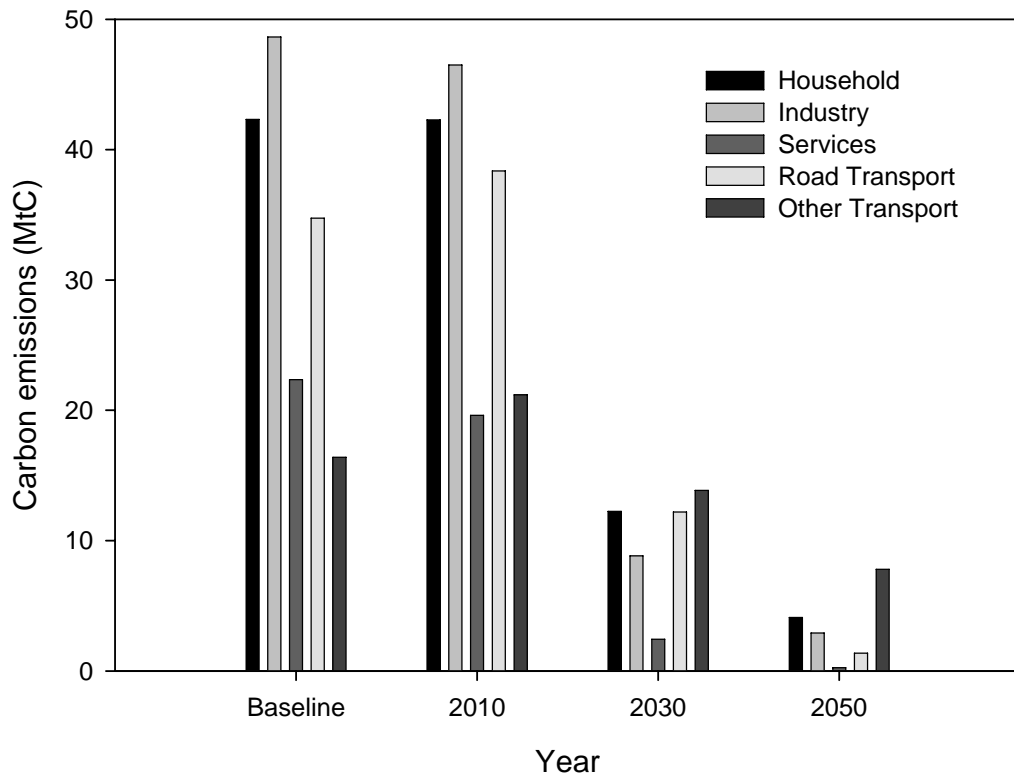
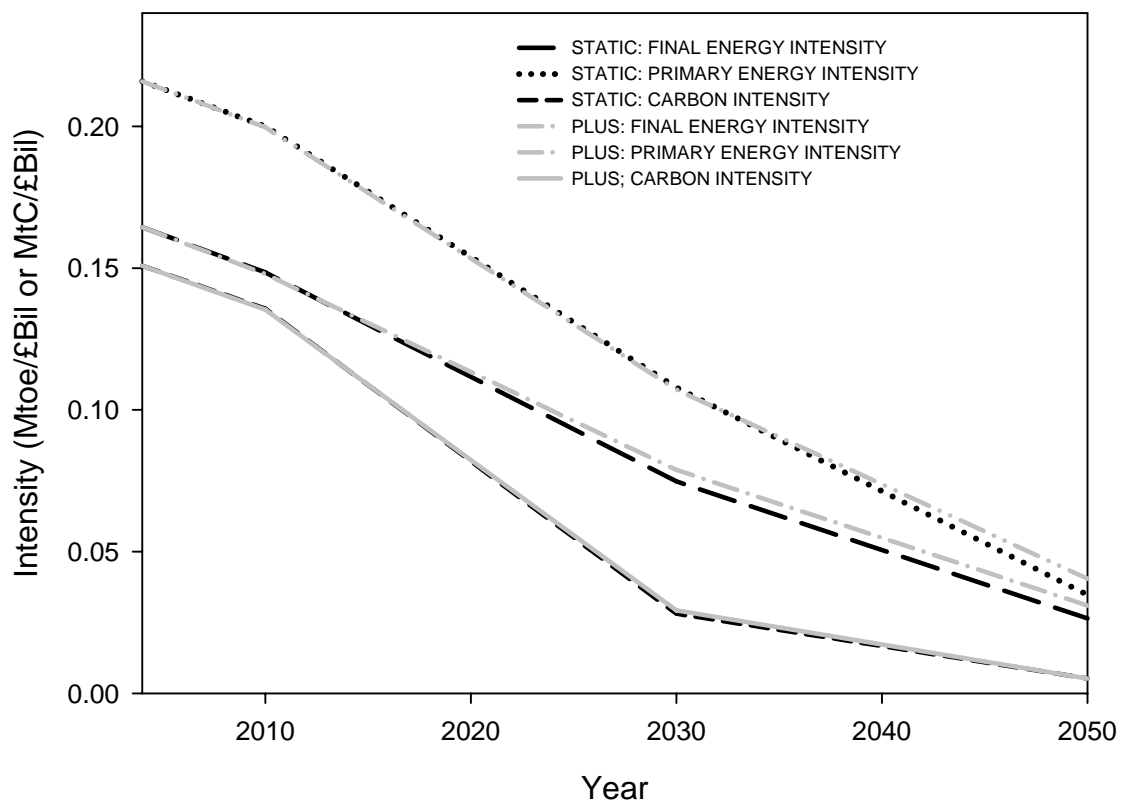


Figure 5.5 illustrates the energy and carbon intensities of the scenarios over time. Energy intensity is a measure of the energy required per unit of economic activity, and similarly, carbon intensity is a measure of the carbon which is emitted per unit of economic activity. A differentiation has been made between final energy intensity and primary energy intensity so that the impact of transformation and losses upon the economy can be considered. For example, in an energy system with a large electricity grid fed by fuel sources requiring transformation such as natural gas, the energy consumed per unit of GDP will be much higher than where there is more decentralised supply and a grid dominated by renewable supply.

Figure 5.5: Final and primary energy intensities and carbon intensity



Considering the scenarios have similar levels of economic growth and carbon constraints, it is unsurprising that their carbon intensities are practically identical over the 46 years of transition to a low-carbon economy. Although the primary and final energy intensities do evolve slightly differently for the two scenarios, more apparent is the decreasing gap between primary and final energy intensity over time that is demonstrated by both scenarios. There are two key reasons for this behaviour. Firstly, the losses in transforming fuels into electricity are a smaller percentage of the

final energy demand in 2050 than they are in 2004. For example, in 2004, an additional 40% of the final energy demand is added to produce the primary energy demand figure⁷². Whereas, in 2050, the lower figure of 30% of final energy demand is added to give the primary energy demand figure. The reasons for the lower percentage losses are due to the improved efficiency of conversion for fossil fuel technologies into electricity, the phasing out of nuclear power from the electricity mix, and the greater penetration of renewable technologies that are not susceptible to such conversion losses. Secondly, the fact that the final energy demand in 2050 is around half that of the final energy demand in 2004, further reduces the difference between final and primary energy demand. For example, even if the higher figure of 40% were to be lost in transforming fuels into electricity, the difference between final and primary energy demand in 2050 would be just 40Mtoe compared with 70Mtoe in 2004.⁷³

In relation to the differences in energy intensity by 2050 between the two scenarios, *Mobility Plus* incurs higher transformation losses than *Static Mobility* because of the higher demand for electricity in *Mobility Plus*. As the economy is approximately the same size in both scenarios, this translates into a small difference in their energy intensities. The higher levels of mobility and hence consumption of transport fuels within the *Mobility Plus* scenario has pushed society to rely on a zero-carbon grid to meet its carbon targets. Consequently, electricity is, sometimes substituted for other forms of energy such as domestic gas. For example, with a zero-carbon grid, carbon dioxide is emitted if heating is provided by electricity rather than CHP systems. This shift of energy carrier leads to a higher level of electricity consumption in *Mobility Plus* compared with *Static Mobility*.

⁷² 2004: final energy demand is ~170Mtoe, primary energy demand is ~240Mtoe. $0.4 \times 170\text{Mtoe} = \sim 70 \text{ Mtoe}$.

⁷³ 2050: final energy demand is ~ 100Mtoe, 40% of this would be 40Mtoe, giving a primary energy demand of 140Mtoe.

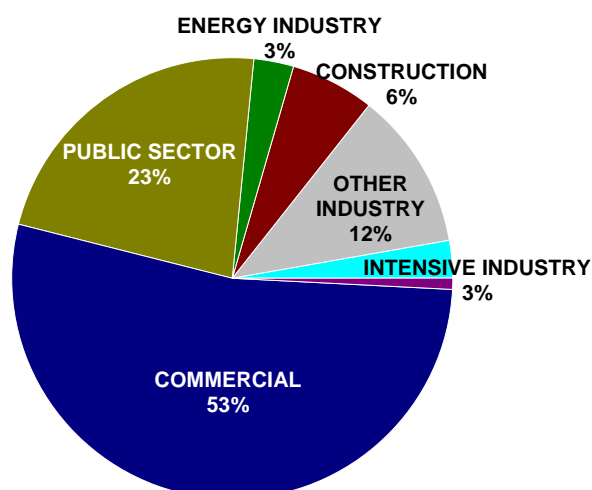
5.2.1 Short-term changes

The important features of the two scenarios are summarised in Table 5.6 and the make-up of the economy in 2010 is outlined in Figure 5.7.

Table 5.6: Short-term scenario summary in 2010

		Baseline (2004)	Static Mobility	Mobility Plus
Final energy demand (Mtoe)		183	186	186
Primary energy demand (Mtoe)		237	251	252
Primary fuel proportion	Renewables	1%	2%	2%
	Fossil fuels with carbon capture & storage	0%	0%	0%
	Biomass	2%	3%	3%
	Nuclear	8%	6%	6%
Grid electricity proportion			93%	93%
Decentralised electricity			7%	7%
Transport	Passenger km: road	736	740	759
	Passenger km: rail	51	56	57
	Passenger km: air	273	407	407
	Occupancy: car	1.6	1.6	1.62
	Occupancy: rail	93	95	95
	Occupancy: air international	177	180	182
Carbon emissions (MtC)	Land transport	34.7	38.4	38.4
	Air transport	9.75	13.8	13.8
	Industry	48.6	46.5	46.5
	Services	22.3	19.6	19.6
	Households	42	42	42
Energy consumed: households (ttoe/household)		1.93	1.9	1.9
Hydrogen demand (Mtoe)		None	None	None
Total energy carbon emissions		164	168	168

Figure 5.7: The economy in 2010



In 2010, UK energy consumption and carbon emissions have only increased slightly from 2004 levels as can be seen from Table 5.5. Against a backdrop of increasing energy consumption within many sectors in the baseline year, by 2010 Government has to have instigated policies which put the 'brakes' on energy consumption. Figures 5.8 and 5.9 are snapshots of energy consumption and carbon emissions for the two scenarios in 2010. In the short-term, there is little difference between either the energy demand or carbon emissions within these two scenarios. This is to be expected, given that the economy is effectively the same in both, and policy measures implemented in 2006 have yet to yield significantly different outcomes between the scenarios in four years.

Figure 5.8: 2010 'Static Mobility' final energy demand and carbon emissions

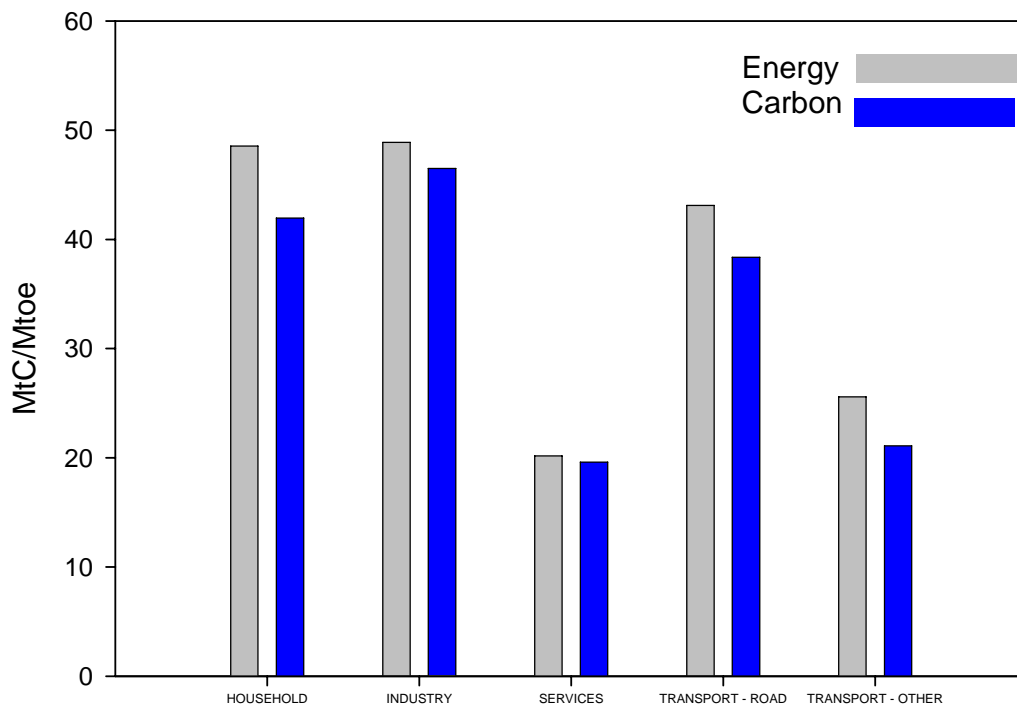
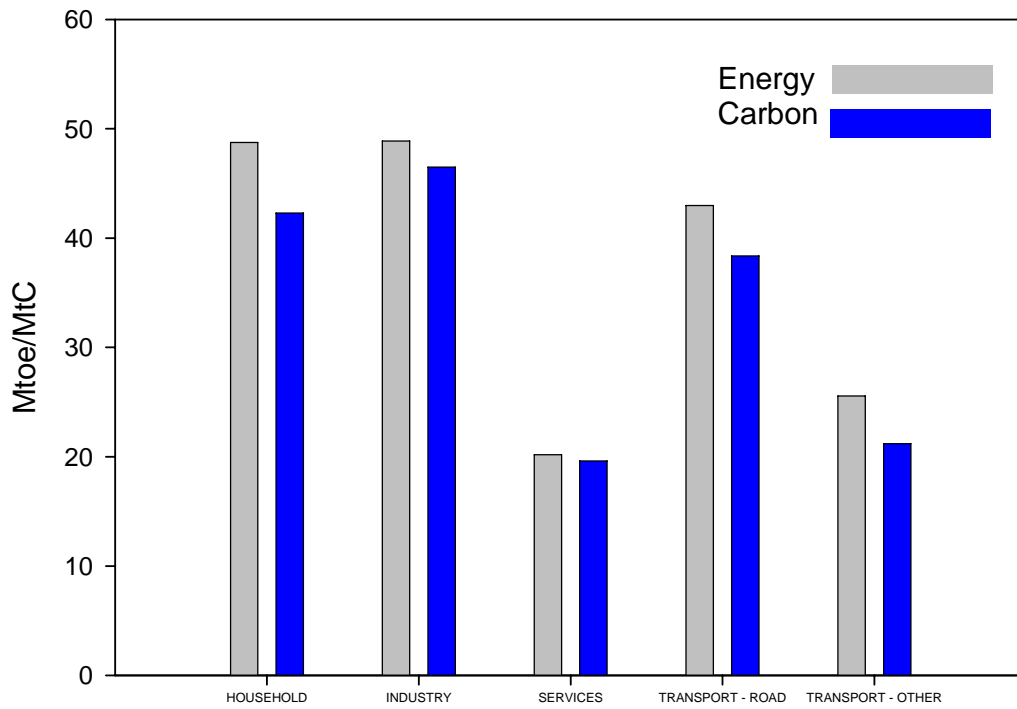


Figure 5.9: 2010 'High mobility' final energy demand and carbon emissions



The primary fuel mix for the two scenarios is shown in table 5.7, and illustrated graphically in figures 5.10 and 5.11.

Table 5.7: 2010 primary fuel mix

Total primary fuel (Mtoe)							
	Oil	Coal	Gas	Nuclear	Biofuel	Renew	Total
Static	80.2	44.7	97.3	16.1	8.7	4.0	251
Plus	80.1	44.9	98.0	16.2	8.6	4.0	252

Figure 5.10: 2010 'Static' primary fuel mix

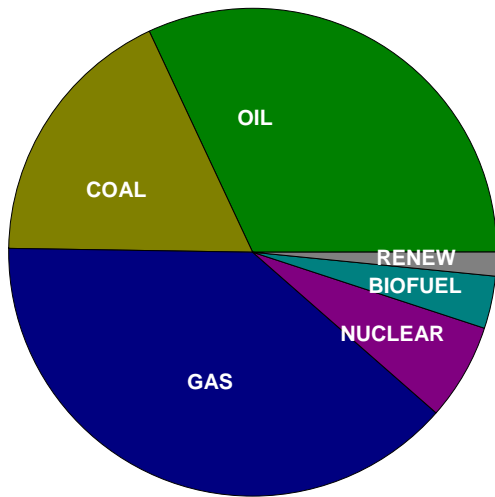
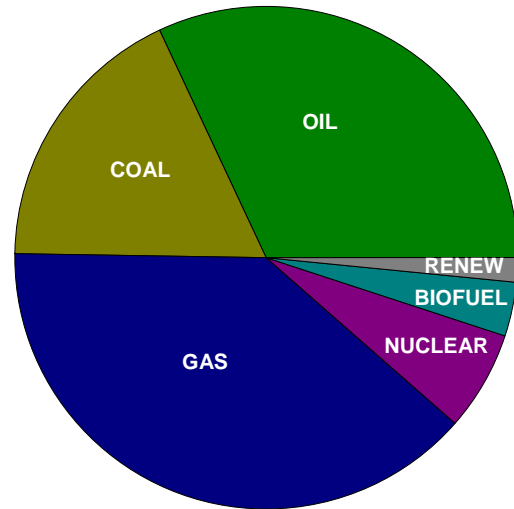


Figure 5.11: 2010 'Plus' primary fuel mix



The mix of primary fuels is very similar to the baseline year, with negligible differences between the two scenarios.

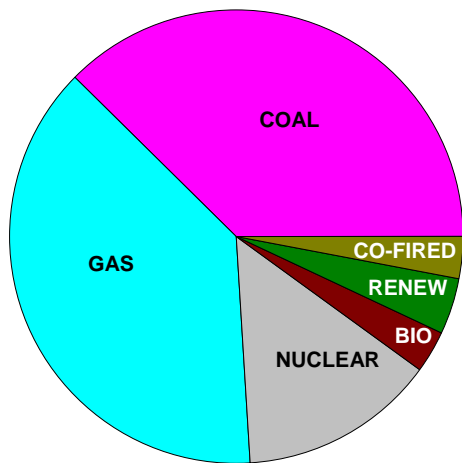
Table 5.8 presents a summary of the sources of electricity supply. The total refers to all electricity produced, including that for the production of hydrogen. The final two columns disaggregate the total electricity produced into that which is supplied as electricity, and that which is used to produce hydrogen.

Table 5.8: 2010 electricity supply summary

Electricity supply								
	Fossil fuels	Fossil fuel CCS	Nuclear	Biofuel	Renew	Total	For H ₂	For electricity
Static (Mtoe)	30.4	0.0	5.2	1.4	2.7	39.7	0.0	39.7
Static (TWh)	353.7	0.0	60.2	16.7	31.2	461	0.0	461
Plus (Mtoe)	30.8	0.0	5.2	1.4	2.7	40.1	0.0	40.1
Plus (TWh)	357.6	0.0	60.7	16.8	31.3	466	0.0	466

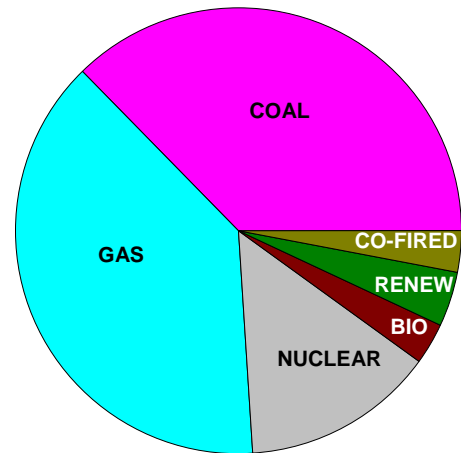
Figures 5.12 and 5.13 illustrate the make-up of the grid in 2010, with figure 5.14 illustrating the grid make-up for the baseline year.

Figure 5.12 'Static' 2010 electricity grid



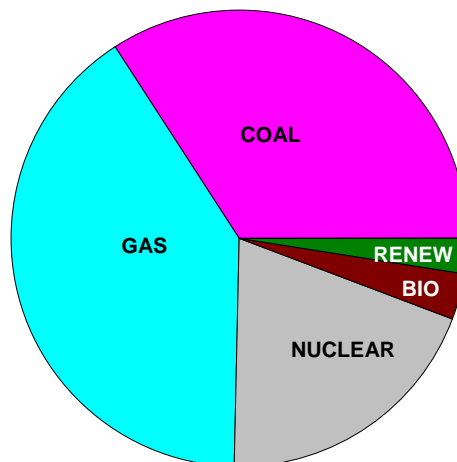
Total grid: 37Mtoe/430TWh

Figure 5.13 'Plus' 2010 electricity grid



Total grid: 37Mtoe/430TWh

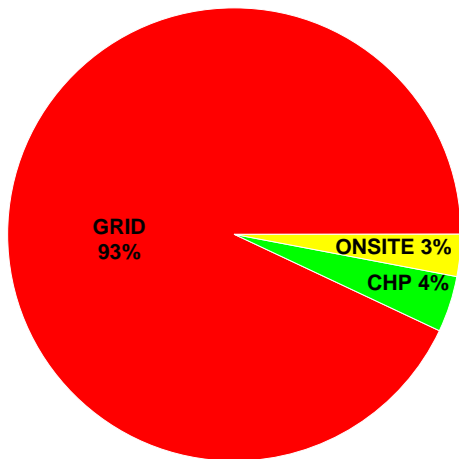
Figure 5.14: Baseline electricity grid



Total grid: 31Mtoe/361TWh

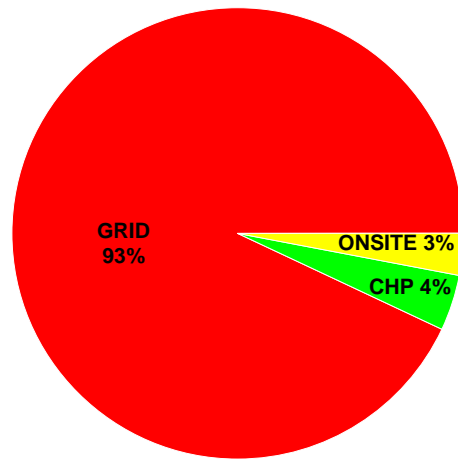
By 2010, there has been little change to the UK energy supply system. New renewable and CCGT capacity is built to replace nuclear and conventional coal power stations following their programmed closure. The Government target for 10% of electricity generated from renewables has been achieved. The majority of electricity comes from centralised generation, with onsite renewables and CHP electricity accounting for just 7% of the total. Figures 5.15 and 5.16 illustrate the electricity supply split between the grid, onsite renewables and CHP.

Figure 5.15: 2010 Electricity split - 'Static'



Total electricity supply:
40Mtoe/462TWh

Figure 5.16: 2010 electricity split - 'Mobility'



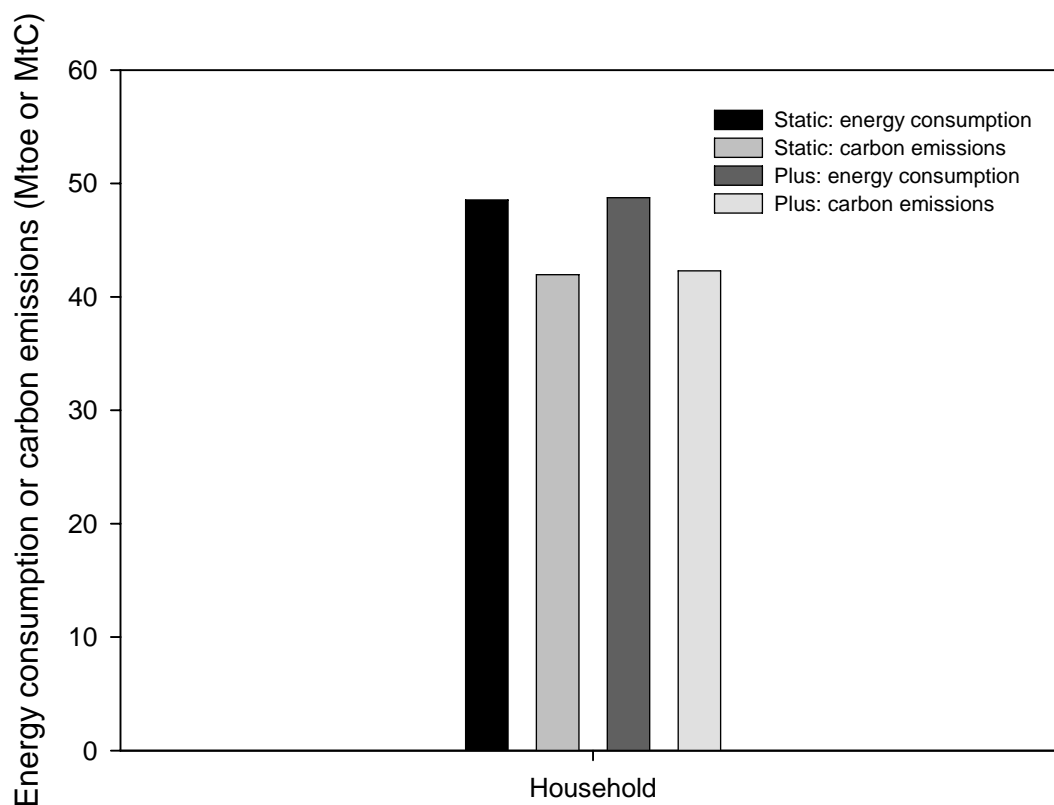
Total electricity supply:
40Mtoe/466TWh

5.2.1.1 Sectoral characteristics

Households

Energy consumption in the households remains constant, with an overall reduction in the consumption of 'other energy', and a slight increase in the consumption of electricity. These changes have been brought about by a combination of measures to improve the performance of the fabric of buildings, thus reducing demand for space heating, and to change the consumption behaviour of householders. Carbon emissions and energy consumption in households for the two scenarios are illustrated in Figure 5.17.

Figure 5.17: 2010 energy consumption and carbon emissions from households

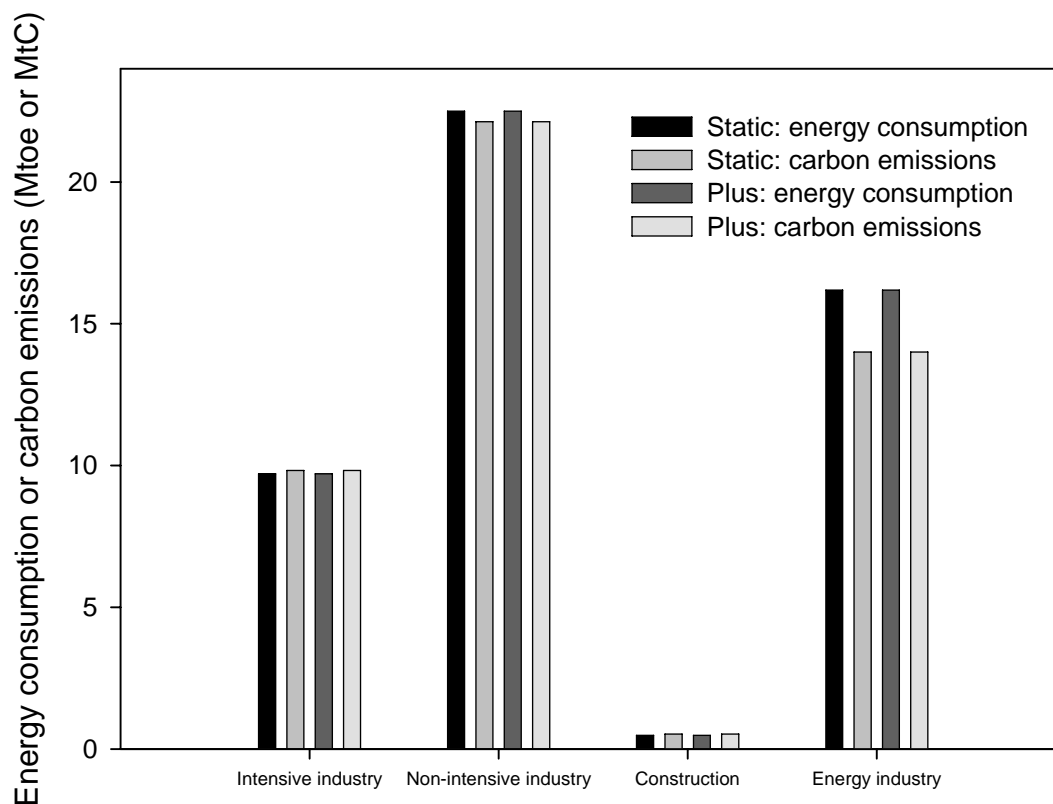


Industry

Since 1970, there has been a sustained reduction in the share of energy consumed by energy intensive industries. This reduction has occurred in part because of the decline in traditional energy intensive industries such as steel, highlighting that the UK has in effect exported carbon emissions overseas. That said, improvements in industrial energy efficiency have played a part and the sector has been subject to concerted policy pressure, and has also been driven to reduce energy consumption by rising energy prices. The scenarios therefore assume that energy intensive industries have already taken advantage of the low hanging fruit, and made those improvements in energy performance that are currently cost effective. Hence, current and historic, rates of decreasing energy intensity are not maintained.

By contrast, energy consumption within non-energy intensive industries, such as food and drink, has been rising in recent years. In the short-term, the rate of rise has been reduced, concentrating on the demand for non-electrical energy. Industrial carbon emissions, and energy consumption, for both scenarios are outlined in Figure 5.18.

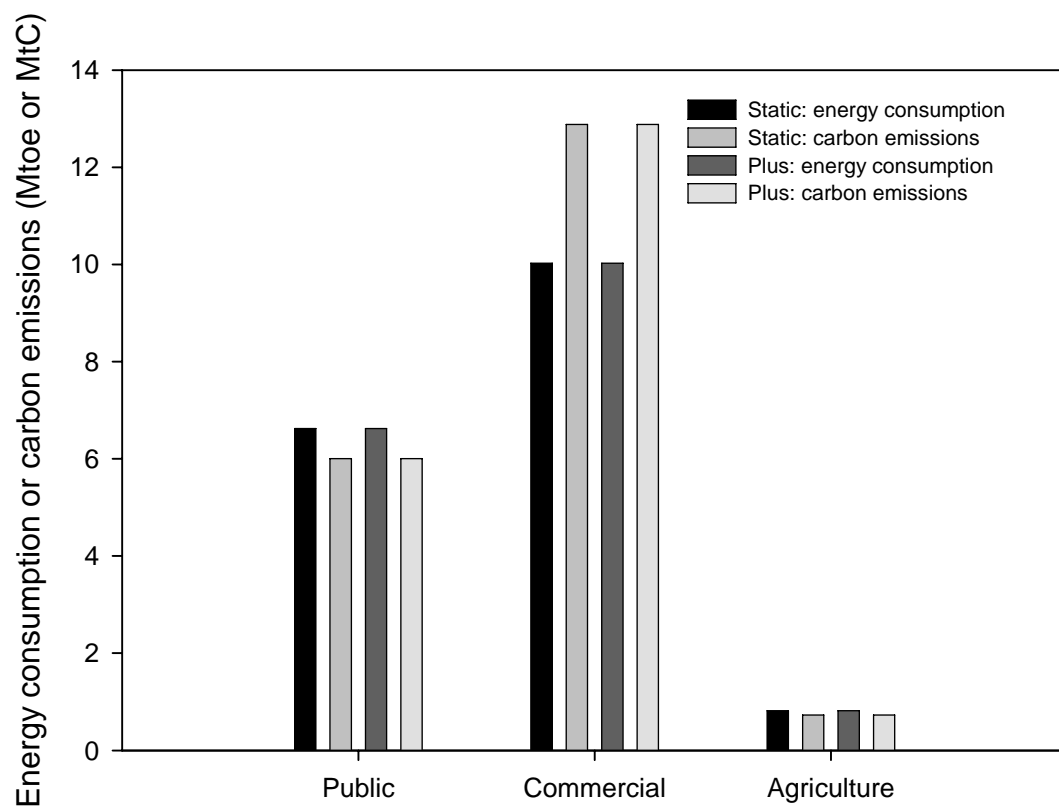
Figure 5.18: 2010 energy consumption and carbon emissions from industrial sectors



Services

There has been a long-term trend of increasing energy consumption from the commercial sector, driven by increasing use of electrical equipment such as computers, increased demand for air conditioning and a lack of engagement with energy management issues. This trend for increasing consumption has been reversed so that by 2010 there are small improvements in the rate of energy efficiency. Short-term measures have concentrated on reducing demand for non-electrical energy. Within public administration, current rates of improvement in energy efficiency in this sector are maintained, once again with a focus in reducing demand for non-electrical energy. The carbon emissions and energy consumption from the service sector are illustrated in figure 5.19.

Figure 5.19: 2010 Final energy consumption and carbon emissions from services



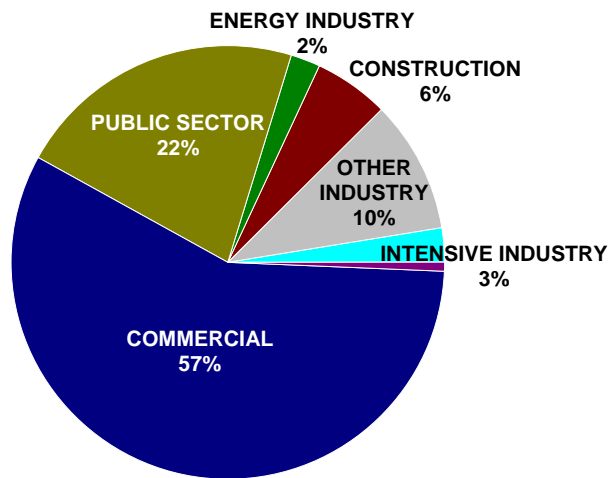
5.2.3 Medium-term changes

The important features of the scenarios are summarised in Table 5.9 and the make-up of the economy is outlined in Figure 5. 20. Although all sectors of the economy continue to expand, the commercial sector continues to increase its percentage contribution to the wealth of the UK. In percentage terms, the economic make-up is broadly the same in both scenarios.

Table 5.9: Scenario summary for 2030

		Baseline (2004)	Static Mobility	Mobility Plus
Final energy demand (Mtoe)		183	134	139
Primary energy demand (Mtoe)		237	194	189
Primary fuel proportion	Renewables	1%	13%	15%
	Fossil fuels with carbon capture & storage	0%	43%	40%
	Biomass	2%	10%	11%
	Nuclear	8%	1%	1%
Electricity proportion: grid			81%	81%
Electricity proportion: decentralised			19%	19%
Transport	Passenger km: road	736	728	946
	Passenger km: rail	51	65	103
	Passenger km: air	273	353	692
	Occupancy: car	1.6	1.75	1.68
	Occupancy: rail	93	110	115
	Occupancy: air international	177	195	230
Carbon emissions (MtC)	Land transport	34.7	13.3	12.2
	Air transport	9.75	7.2	11.9
	Industry	48.6	10.6	8.8
	Services	22.3	2.8	2.4
	Households	42	11.9	12.2
Energy efficiency: households (ttoe/household)		1.93	1.3	1.2
Hydrogen demand (Mtoe)		None	23	25
Total energy carbon emissions		164	50	51

Figure 5.20: The economy in 2030



By 2030 the carbon trajectory, outlined in Section 2, requires that significant reductions are made in both energy consumption and carbon emissions. The rates of improvement in energy efficiency have been slightly higher in the *Mobility Plus* scenario. This is a consequence of the greater innovation in a society where policies imposing strict emission limits on the transport sector have not only driven greater technological improvements within that sector, but also fostered an innovation culture across which is felt across other sectors of the economy. The increased levels of mobility result in a slightly higher energy consumption in the *Mobility Plus* scenario than in the *Static Mobility* scenario.

Keeping carbon emissions within the required trajectory in 2030 requires the rate of reduction in carbon intensity to be greater than the rate of reduction in energy intensity. Whilst there have been incremental improvements in the energy efficiency of technology, changes in consumption practises and step changes in technology, these have greater impact in the longer term, thus meeting the carbon target in 2030 is more challenging than in 2050, since the rate of overall energy demand is higher. The higher energy demand in 2030 has to be met with low-carbon energy supply therefore there is extensive deployment of renewables and fossil fuel with carbon capture and storage (CCS) in both scenarios. The extensive capacity of both renewables and CCS mean that not only do there have to be technological developments between 2010 and 2030, but also the pace of deployment has to be high. Moreover, the need to reduce emissions from transport, whilst keeping within the Friends of the Earth and The Co-operative Bank boundaries for biomass and

electricity, has required the use of hydrogen as an alternative low-carbon energy carrier for transport.

Across all sectors of the economy, new-buildings have to be built to the highest standards of energy efficiency, and similarly all retro-fits and refurbishments must reduce carbon emissions by improving energy consumption and incorporating low-carbon supply technologies. These measures have to be on a rolling programme of improvement and tie in with maintenance schedules.

The energy demand and carbon emissions for the two scenarios are illustrated in figures 5.21 and 5.22, revealing differences in the patterns of energy demand and carbon emissions between them. Most notably, a larger portion of final energy demand is consumed by the household and industry sectors than by transport in the *Static Mobility* scenario, whereas in the *Mobility Plus* scenario, transport constitutes the largest portion of final energy demand. However, the picture for carbon emissions is slightly different, with aviation emitting the most carbon in the *Mobility Plus* scenario, in contrast to *Static Mobility* where carbon emissions from cars and international aviation are roughly equal. Another significant point to note is the difference between final energy demand and carbon emissions across the sectors and across the scenarios in 2030 compared with 2010. This shows a break from the link between energy and carbon emissions as the supply system becomes more decarbonised.

Figure 5.21: 2030 'Static mobility' final energy demand and carbon emissions

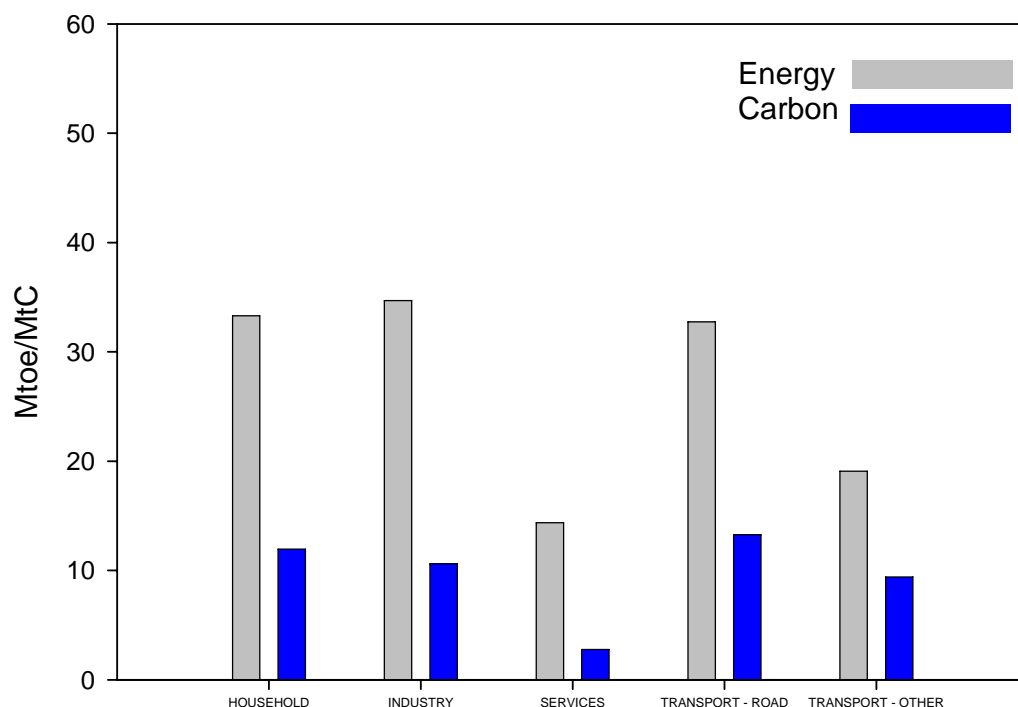
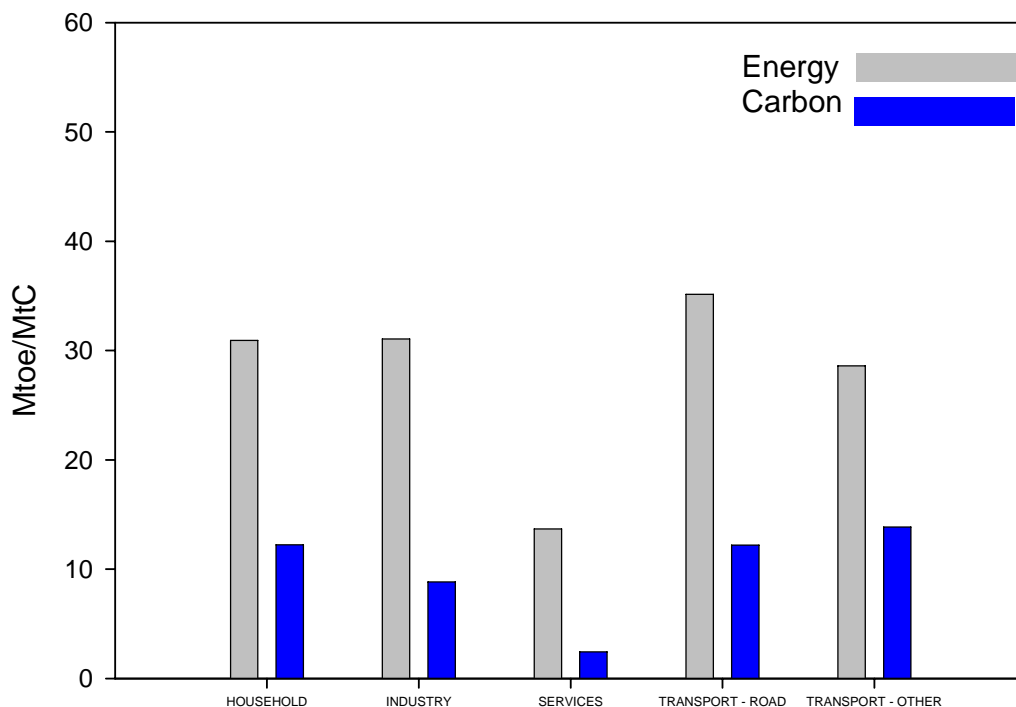


Figure 5.22: 2030 'Mobility plus' final energy demand and carbon emissions



The primary fuel mix for the two scenarios is shown in Table 5.10, and illustrated graphically in Figures 5.23 and 5.24. The greater emphasis upon innovation, and on improving the technical efficiency of energy use in the *Mobility Plus* scenario results in a lower energy demand in this scenario in 2030 compared to the *Static Mobility* scenario. The higher consumption of oil in the *Mobility Plus* scenario is a consequence of the energy consumption from transport.

Table 5.10: 2030 primary fuel mix

Total primary fuel (Mtoe)							
	Oil	Coal	Gas	Nuclear	Biofuel	Renew	Total
Static	27.5	42.2	76.9	2.0	20.0	25.6	194.2
Plus	31.9	45.3	61.4	1.7	20.6	28.5	189.4

Figure 5.23: 2030 'Static' primary fuel mix

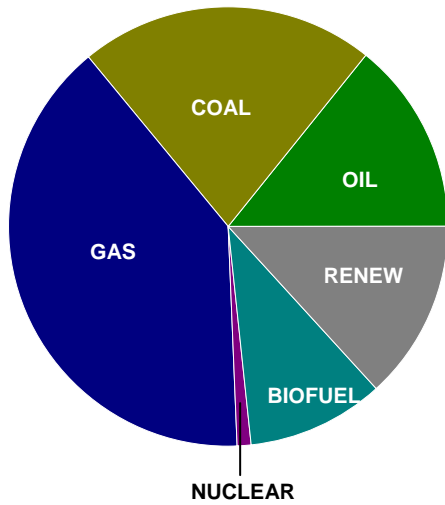
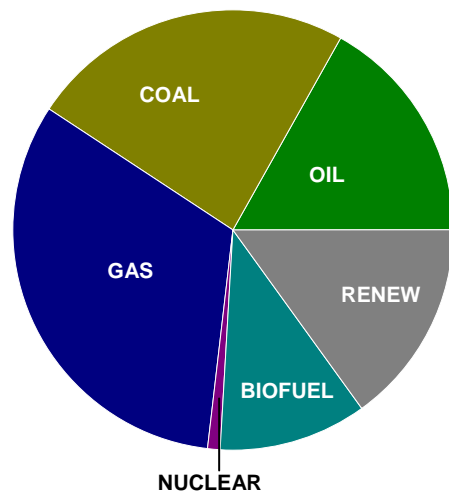


Figure 5.24: 2030: 'Plus' primary fuel mix



By 2030, the higher energy consumption from transport in the *Mobility Plus* scenario, and the higher emissions associated with the use of petrol, diesel and kerosene to meet that demand, require more extensive decarbonisation of the energy supply for the remaining sectors than in the *Static Mobility* scenario. This is illustrated in table 5.11, which presents a summary of the sources of electricity supply⁷⁴ with more electricity supplied by renewables, and less by fossil fuels without CCS, in the *Mobility Plus* scenario. Table 5.11 includes electricity used in the production of hydrogen by electrolysis; the additional hydrogen which is used in the *Mobility Plus* scenario is principally within the transport sector. As is the case by 2010, greater energy savings are made in the use of 'other-energy', hence the proportion of electricity to other energy continues to increase in both cases.

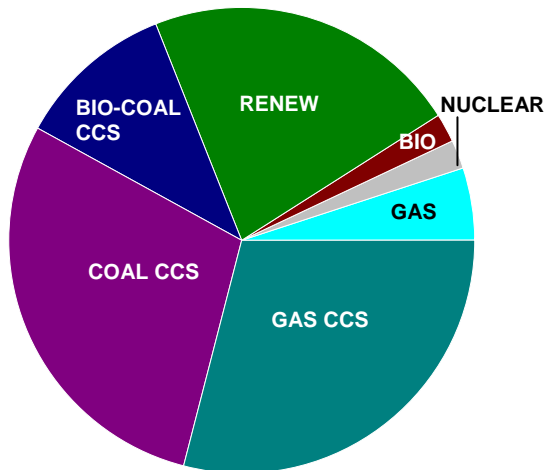
⁷⁴ The total refers to all electricity produced, including that for the production of hydrogen. The final two columns disaggregate the total electricity produced into that which is supplied as electricity and that which is used to produce hydrogen.

Table 5.11: 2030 electricity supply summary

Electricity supply								
	Fossil fuels	Fossil fuel CCS	Nuclear	Biofuel	Renew	Total	For H ₂	For electricity
Static (Mtoe)	7.0	24.5	0.7	2.9	17.2	52.3	6.5	45.8
Static (TWh)	80.9	284.8	8.6	33.6	200.1	608	76	432
Plus (Mtoe)	6.48	24.32	0.72	2.8	19.6	53.9	9.1	44.8
Plus (TWh)	75.3	282.8	8.4	32.5	227.7	626.7	105	521

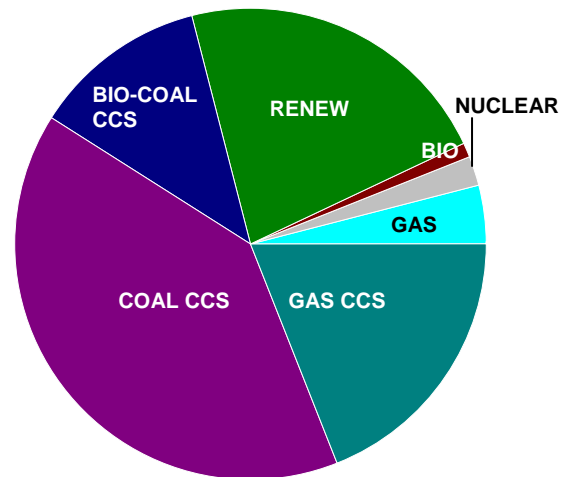
Figures 5.25 and 5.26 illustrate the make-up of the grid in 2030.

Figure 5.25: 'Static' 2030 electricity grid



Grid supply: 37Mtoe/430TWh

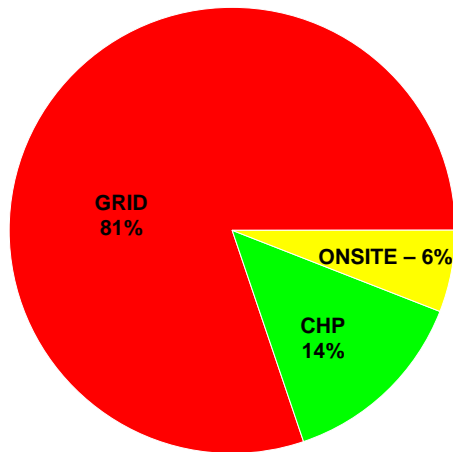
Figure 5.26: 'Plus' 2030 electricity grid



Grid supply: 36Mtoe/419TWh

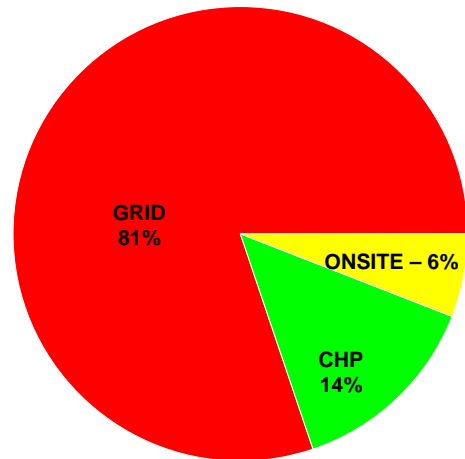
Figures 5.27 and 5.28 illustrate the electricity supply split between the grid, onsite renewables and CHP. In both scenarios, there is around a third of electricity being generated by decentralised sources. In addition, there is on-site production of hydrogen through electrolysis from renewables, though this element is not included in figures 5.27 and 5.28.

Figure 5.27: 2030 electricity split - 'Static'



Total electricity supply:
46Mtoe/532TWh

Figure 5.28: 2030 electricity split - 'Mobility'



Total electricity supply:
45Mtoe/521TWh

5.2.3.1 Electricity supply – *Static Mobility*

In 2030, to remain within the carbon trajectory, carbon emissions must reduce at a faster rate than the associated rate of reduction in energy demand. Within the scenario, there has been a decentralisation of energy supply, with 14% of electricity coming from CHP, and 6% coming from on-site renewables, such as solar PV and building integrated wind turbines. CHP is fuelled by both biomass and gas, with district scale schemes, and micro CHP in the household and commercial sectors. There has been a similar level of penetration in the use of on-site renewables for heating, and furthermore hydrogen is being used as an energy carrier for stationary end uses. Although the move to hydrogen is primarily driven by the need for a low-carbon fuel for transport, in this scenario there has been a stronger penetration of hydrogen within stationary sources; a point which is returned to later.

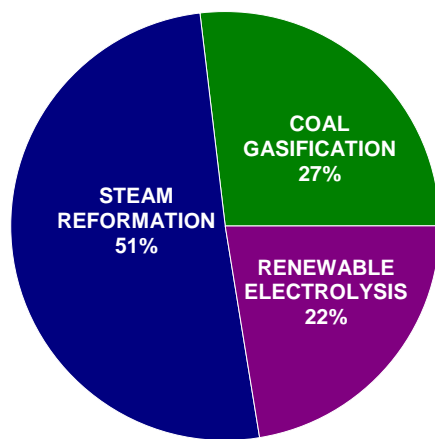
In terms of the electricity grid, despite the decentralisation of energy supply, and the use of CHP, which is inherently more efficient in terms of carbon, there is the need for the electricity grid to become increasingly carbon-free. Given the programmed closure of nuclear power stations, and despite an increase in the proportion of grid electricity coming from renewables, carbon capture and storage from fossil fuels is a central element of the electricity grid. In this scenario, carbon is captured from high efficiency gas generation and from coal generation. The linking of CCS with the co-firing of biomass results in a carbon sink. Deployment of large scale renewables has continued such that 33% of electricity is supplied by renewables in the form of both large scale centralised generation and smaller distributed capacity. These levels of

renewable deployment may necessitate the use of electricity storage to buffer intermittency and more active network management. Given that large offshore renewable resources are concentrated in specific locations, upgrades to the transmission network will be required to bring electricity from, for instance, Scotland or the South West of England, to demand centres.

5.2.3.2 Hydrogen – *Static Mobility*

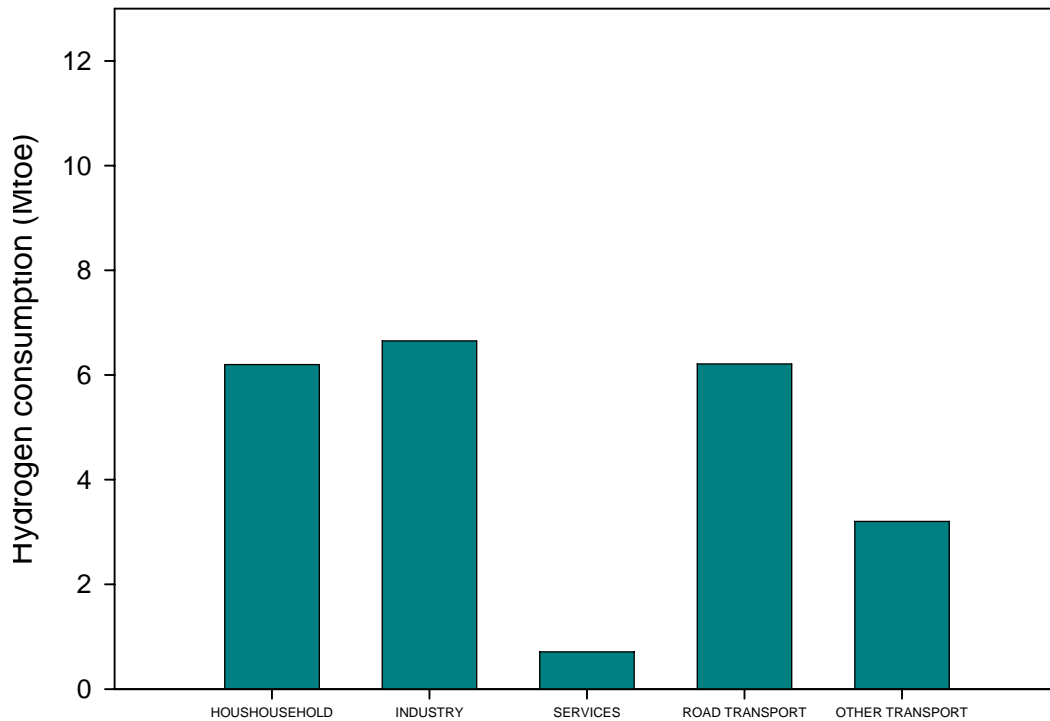
Figures 5.29 and 5.30 illustrate the methods of hydrogen production, and final hydrogen demand by sector in 2030. Hydrogen is made both from fossil fuels, and by renewable electrolysis with steam reformation of methane the most widespread production route due its greater maturity as a technology for early deployment. To ensure that the hydrogen is carbon-free, fossil fuel production is linked to CCS, and is therefore centralised with an associated distribution network. By 2030, there is greater hydrogen penetration for stationary applications in this scenario, particularly in industry where it is used to buffer intermittent generation from renewables and is replacing gas and coal for the generation of process heat. Renewable electrolysis allows for on-site production of hydrogen from wind and PV.

Figure 5.29: 2030 hydrogen supply - 'Static'



Total hydrogen supply: 23Mtoe

Figure 5.30: 2030 final hydrogen demand - 'Static'



5.2.3.3 Electricity supply – *Mobility Plus*

Within the scenario, there has been a *decentralisation* of the energy supply, with 14% of electricity supplied by CHP, and 6% from on-site renewables. CHP is inherently more efficient in terms of carbon, and schemes are fuelled by both biomass and gas, with district scale schemes, and micro CHP in the household and commercial sectors. There has been a similar level of penetration in the use of on-site renewables for space and water heating, and furthermore hydrogen is being used as an energy carrier for stationary end uses. The transition to hydrogen is primarily driven by the need for a low-carbon fuel for transport and there has been more extensive penetration of hydrogen within transport in this scenario.

In terms of the *electricity grid*, despite the decentralisation of energy supply there is a need to reduce the carbon intensity of the electricity grid to allow-carbon 'space' for emissions from transport. Despite widespread deployment of large scale renewables, including wave, tidal stream and a tidal lagoon, carbon capture and storage from fossil fuels is a central element of the electricity grid. In this scenario, carbon is captured from high efficiency gas generation and from coal generation. The linking

of CCS with the co-firing of biomass results in carbon savings. Centralised and distributed renewables supply 36% of electricity. These levels of renewable deployment may necessitate the use of electricity storage to buffer intermittency and more active network management, as well as net metering arrangements. Given that large offshore renewable resources are concentrated in specific locations, upgrades to the transmission network will be required to bring electricity from, for instance, Scotland or the South West of England, to demand centres.

5.2.3.4 Hydrogen – *Mobility Plus*

Figures 5.31 and 5.32 illustrate the methods of hydrogen production, and final hydrogen demand by sector in 2030. Hydrogen is made both from fossil fuels, and by renewable electrolysis. To ensure that the hydrogen is carbon-free, production is linked to CCS, and is therefore centralised and requires a distribution network. By 2030, there is greater hydrogen penetration for transport applications in this scenario. The production of hydrogen by renewable electrolysis allows for on-site production at a network of hydrogen filling stations, with PV arrays on motorway embankments allowing decentralised generation.

Figure 5.31: 2030 hydrogen supply split - 'Plus'

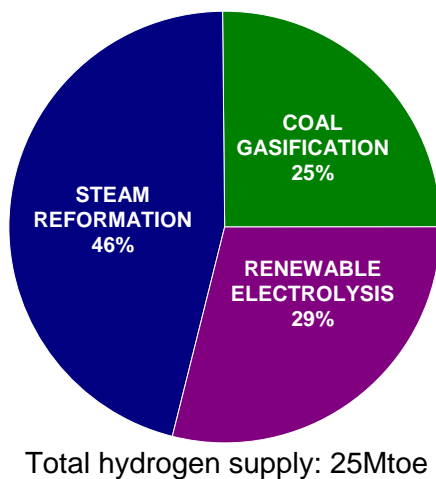
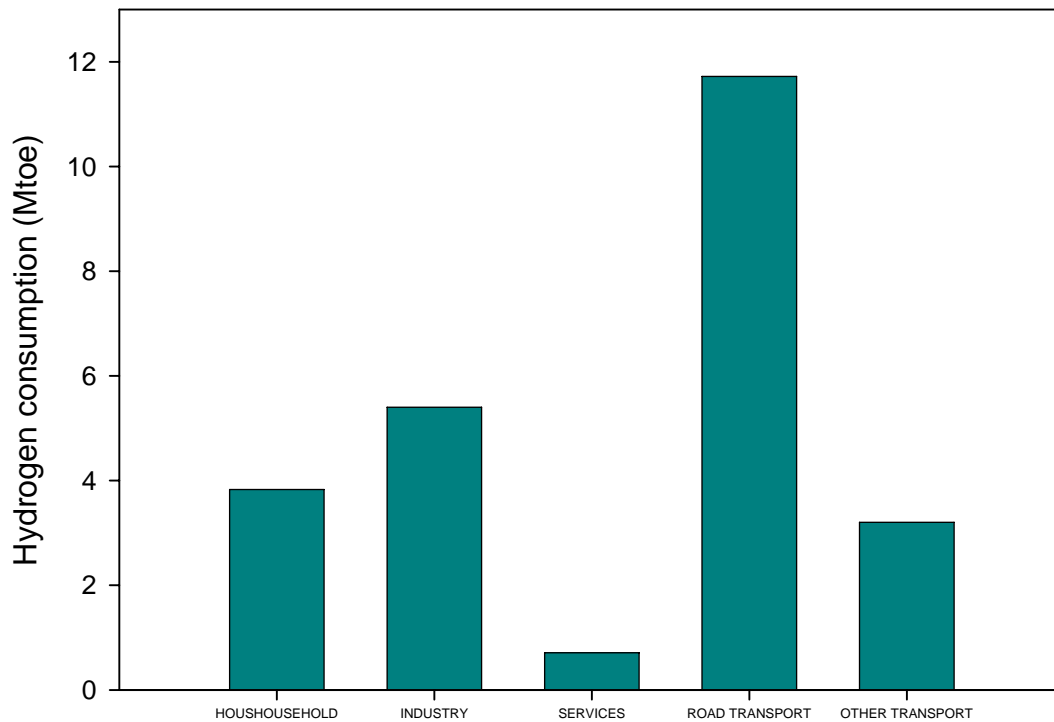


Figure 5.32: 2030 final hydrogen demand - 'Plus'



5.2.3.5 Sectoral characteristics

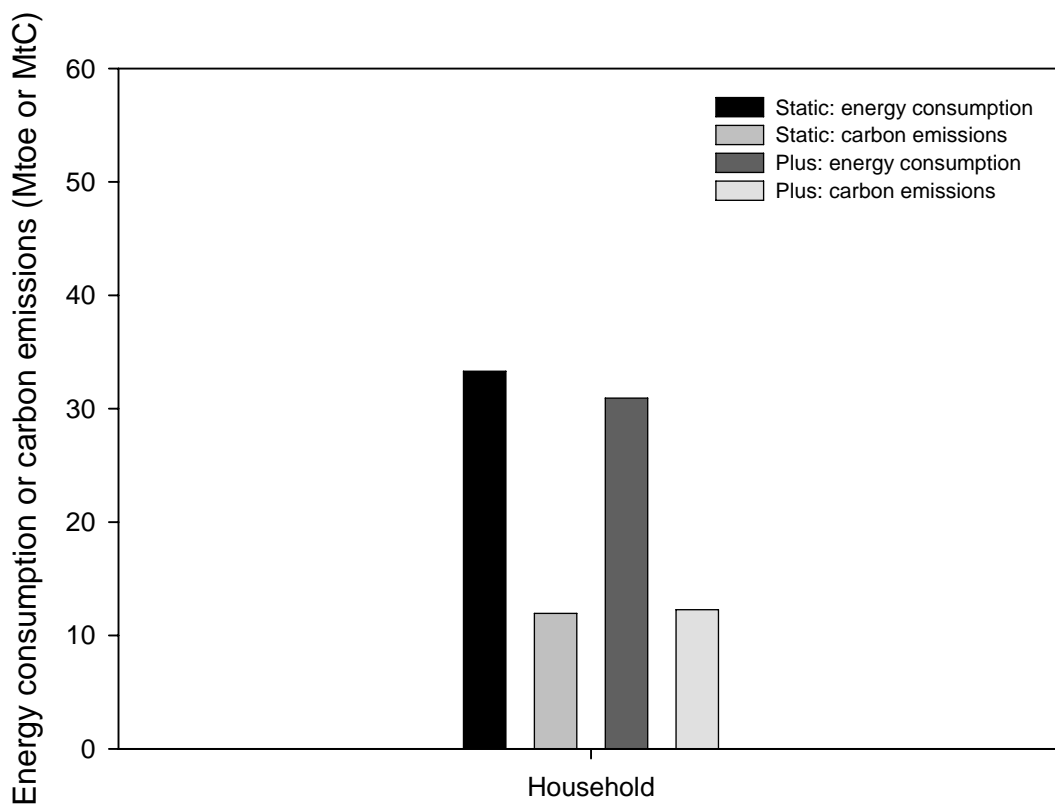
Households

By 2030, energy demand from households has been reduced by a quarter from 2010 levels. Whilst demand for electricity from appliances has remained constant, the bulk of reductions have come from the demand for space and water heating. There has been a focus on improving building fabric through the provision of insulation, and ensuring that new-build properties have a near zero demand for space heating. Moreover, where possible, domestic solar hot water heating is installed as standard in all new properties and when existing properties undertake roofing replacement. Similarly, there is a rolling programme of installation of on-site renewables for electricity generation and CHP, which is tied into natural building maintenance cycles, and driven through strongly enforced building regulations.

The trend for increasing electricity demand has been reversed through the regulation of the energy consumption of appliances. There has been a transformation of the lighting market so that LED is the dominant lighting technology. Ensuring that electrically powered air conditioning is not used in the domestic sector is essential to

control electricity demand. New properties are designed to reduce the need for air conditioning, through the use of solar shading, for instance. Demand management in the home is also facilitated through the provision of smart metering. Energy consumption and carbon emissions from households are illustrated in figure 5.33. The lower energy consumption from households in *Mobility Plus* is the consequence of a faster rate of reduction which could have been brought about in a number of ways. One route may be that the faster pace of technical innovation has led to the development of appliances with lower energy consumption in the *Plus* scenario. An alternative explanation is that the public has itself made greater behavioural changes to allow for increased levels of mobility.

Figure 5.33: 2030 energy consumption and carbon emissions from households



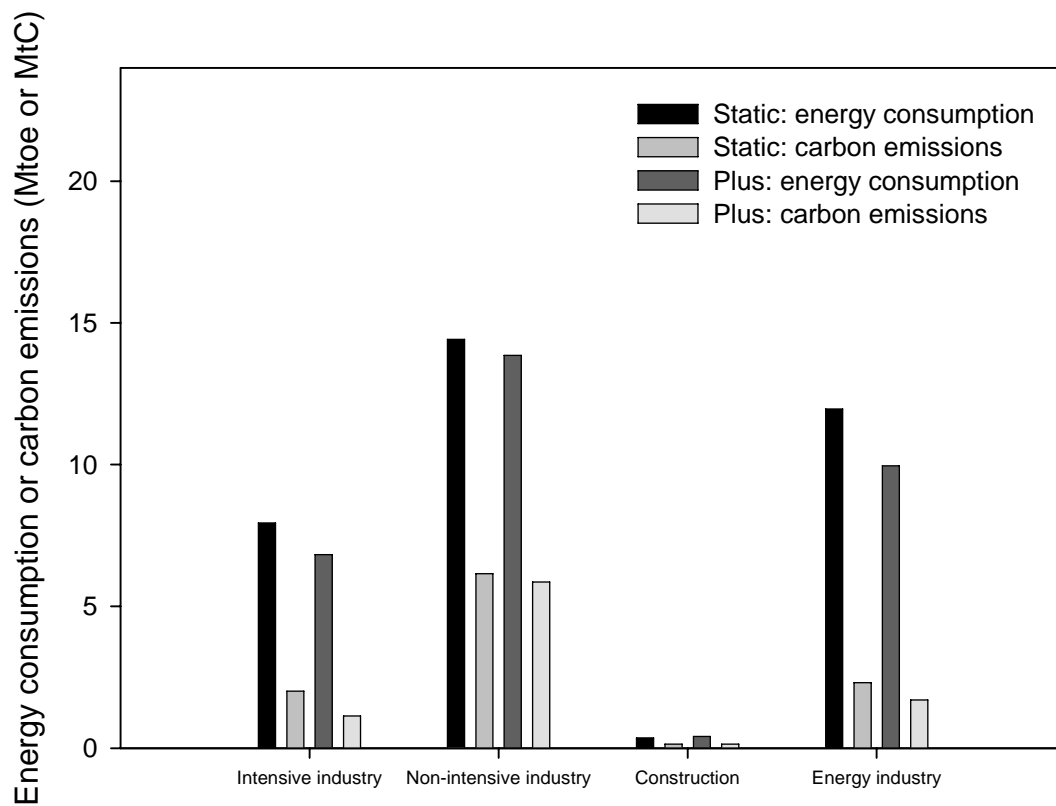
Industry

Energy intensive industries have seen a reduction in the rate of improvement in energy intensity, though reductions continue to be made, particularly in the use of non-electrical energy. Carbon intensity has been reduced through a substitution of gas by hydrogen, and a shift towards the use of electricity. Policy measures have been concentrated upon the non-energy intensive industries, with the result that

energy consumption is now reducing year on year, at rates once seen within the energy intensive industry sector. Once again, the use of non-electrical energy has been reduced with a corresponding increase in the use of hydrogen whilst demand for electricity has remained constant.

Achieving the required reduction in carbon intensity from industry requires a step-change in industrial processes and technologies so that reducing energy consumption and carbon is an essential design and development criteria. Moreover, greater attention will need to be paid to the location of industries, to ensure that the waste from one process, be this heat or physical resources, can become the raw materials for another. Given that the use of recycled, rather than virgin, materials in manufacturing reduces energy consumption, UK based production will have to take full advantage of the potential savings.

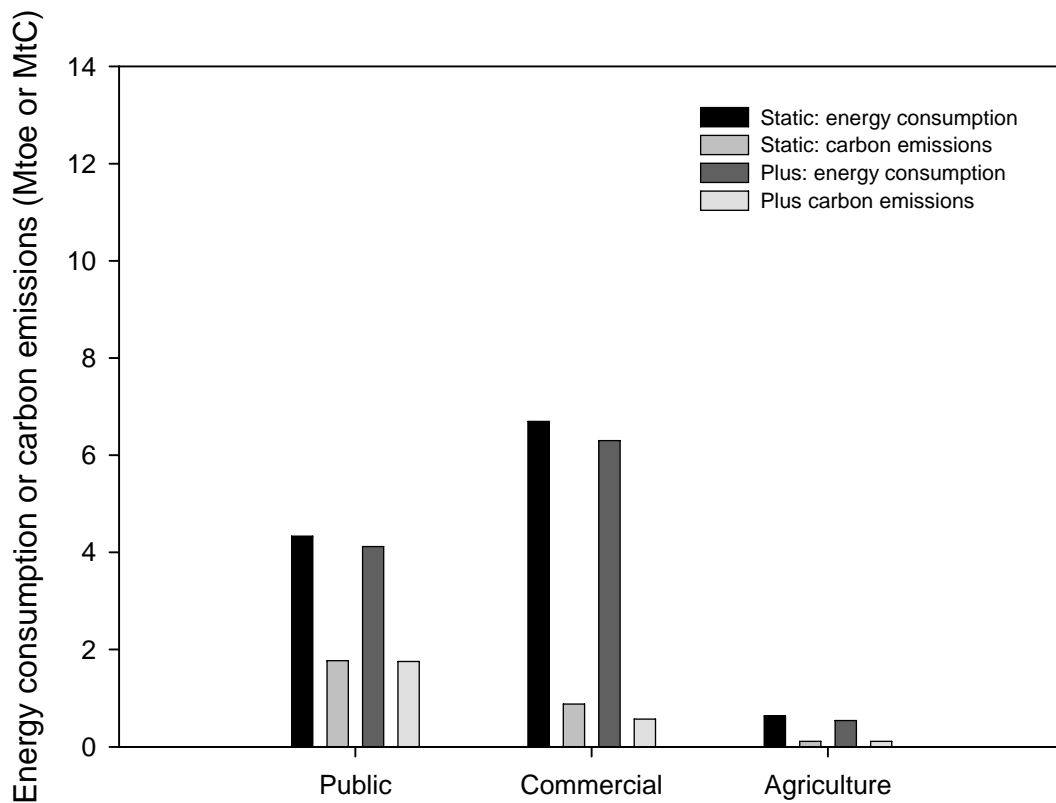
Figure 5.34: 2030 energy consumption and carbon emissions from industry



Services

By 2030, energy demand in the commercial sector is decreasing, with a reduction in demand for both electrical and non-electrical energy. Non-electrical energy use is reduced through measures that focus on upgrading building fabric across the whole built environment. In a similar vein to other sectors, the services sector needs to implement measures which address the energy consumption of appliances. Importantly, new-buildings have to be designed to reduce the need for electrical air conditioning, and where its use is essential, must be delivered in the most efficient manner, for instance through combining CHP with adsorption CHP cooling. In public administration, current rates of energy improvement are maintained in the sector, focusing on the need to reduce non-electrical energy demand.

Figure 5.35: 2030 Final energy consumption and carbon emissions services



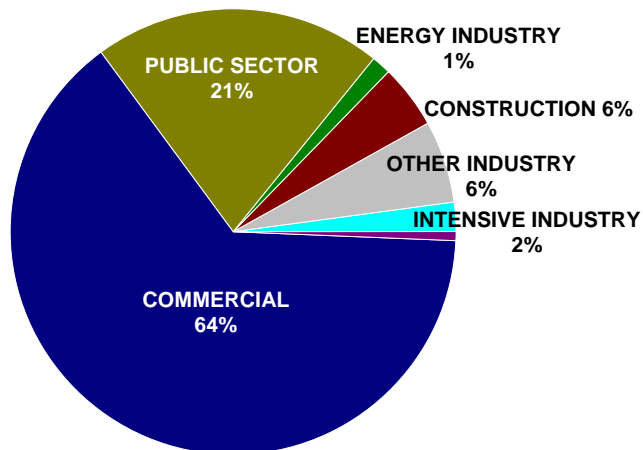
5.2.4 Long-term changes

The important features of the scenarios are summarised in table 5.12 and the make-up of the economy in 2050 is outlined in Figure 5.35. Although all sectors of the economy continue to expand, the commercial sector continues to increase its percentage contribution to the wealth of the UK. The economic make-up is the same in both scenarios.

Table 5.12: Scenario summary in 2050

		Baseline (2004)	Static Mobility	Mobility Plus
Final energy demand (Mtoe)		183	90	106
Primary energy demand (Mtoe)		237	118	138
Primary fuel proportion	Renewables	1%	32%	29%
	Fossil fuels with carbon capture & storage	0%	40%	42%
	Biomass	2%	11%	14%
	Nuclear	8%	0%	0%
Electricity proportion: grid			75%	78%
Electricity proportion: decentralised			35%	33%
Transport	Passenger km: road	736	717	1379
	Passenger km: rail	51	71	199
	Passenger km: air	273	271	793
	Occupancy: car	1.6	1.8	1.7
	Occupancy: rail	93	120	130
	Occupancy: air international	177	200	250
Carbon emissions (MtC)	Land transport	34.7	2.7	1.4
	Air transport	9.75	3.6	6.08
	Industry	48.6	3.5	3.9
	Services	22.3	1.4	1.1
	Households	42	4.3	4.1
Energy efficiency: households (ttoe/household)		1.93	0.82	0.83
Hydrogen demand (Mtoe)		None	26	29
Total energy carbon emissions		164	17	17

Figure 5.36: The economy in 2050



Between 2030 and 2050, it is important that rates of reduction in energy consumption in both scenarios are maintained. This reduction will continue to be brought about both by technical improvements in the efficiency with which energy is used (so that the same level of energy 'service' can be provided with a smaller energy input) and changes to consumption practices. By 2050, despite greater improvements in energy efficiency in the transport sector in the *Mobility Plus* scenario, energy consumption is higher than in the *Static Mobility* scenario and consequentially there is a larger energy supply system. In overall terms, whilst society has to be on a low-carbon path by 2030 this transition must continue between 2030 and 2050, albeit at a slower rate.

In both scenarios, the reduction in final energy demand and carbon emissions is marked compared with 2030. By 2050, the two scenarios differ in terms of the pattern of carbon emissions, with higher emissions from the from transport sectors in the *Mobility Plus* scenario. In this scenario, aviation effectively uses fossil fuel at the expense of all other sectors. That said, due to the very limited carbon budget available, the difference between carbon emissions in real terms is marginal, compared to the difference between 2050 and 2004 levels. Figures 5.37 and 5.38 illustrate the 2050 energy demand and carbon emissions for the two scenarios.

Figure 5.37: 2050 'Static mobility' final energy demand and carbon emissions

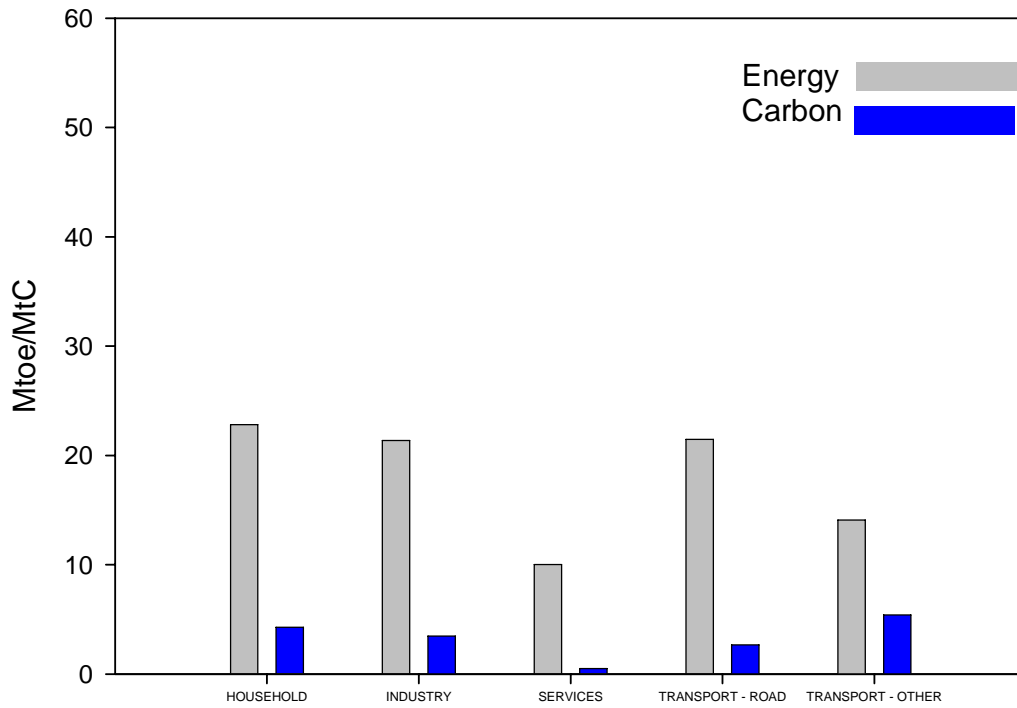
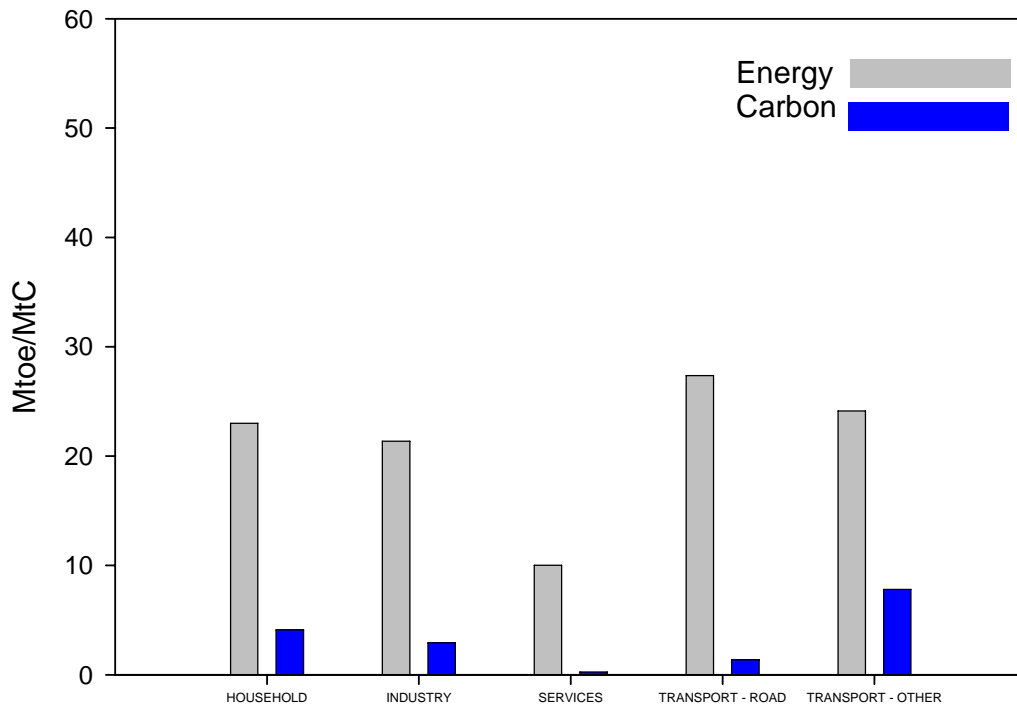


Figure 5.38: 2050 'Mobility plus' final energy demand and carbon emissions



The primary fuel mixes for the two scenarios are shown in table 5.13, and are illustrated graphically in figures 5.39 and 5.40. By 2050, year-on-year improvements in the energy consumption within the *Static Mobility* scenario, in conjunction with the smaller transport sector, result in a final energy demand that is 17% lower than for the *Mobility Plus* scenario.

Table 5.13: Primary energy demand

Total primary fuel (Mtoe)							
	Oil	Coal	Gas	Nuclear	Biofuel	Renew	Total
Static	8.7	34.1	24.8	0.0	13.3	37.2	118.1
Plus	11.2	39.1	27.8	0.0	20.0	40.2	138.3

Figure 5.39: 2050 'Static' primary fuel mix

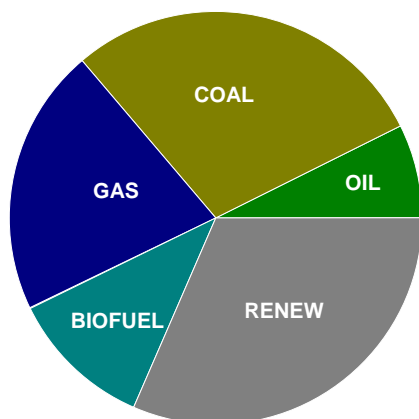
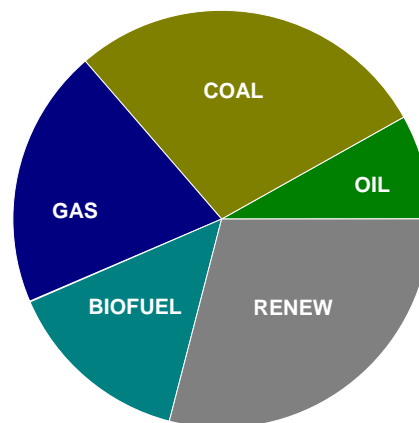


Figure 5.40: 2050 'Plus' primary fuel mix



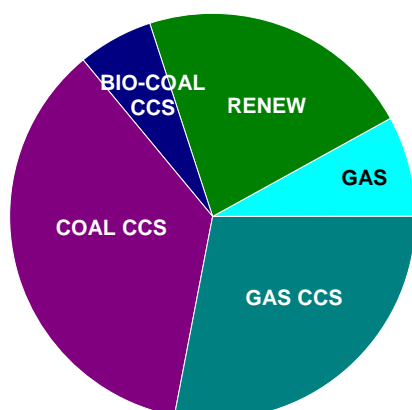
A continuation of the 2030 trends sees the electricity supply being further decentralised, although within *Mobility Plus*, the overall consumption of electricity is higher and therefore the electricity grid is also larger. The higher electricity consumption is a consequence of the zero-carbon grid enabling end users to consume electricity without contributing further to carbon dioxide emissions.

Table 5.14: 2050 Electricity supply summary

Electricity supply								
	Fossil fuels	Fossil fuel CCS	Nuclear	Biofuel	Renew	Total	For H ₂	For electricity
Static (Mtoe)	3.8	18.3	0.0	2.2	23.9	48.1	16.5	31.6
Static (TWh)	43.6	212.9	0.0	25.4	277.8	559.7	192	368
Plus (Mtoe)	1.6	23.5	0.0	2.2	26.5	53.8	18.9	34.9
Plus (TWh)	18.6	273.7	0.0	25.1	307.9	625.3	220	406

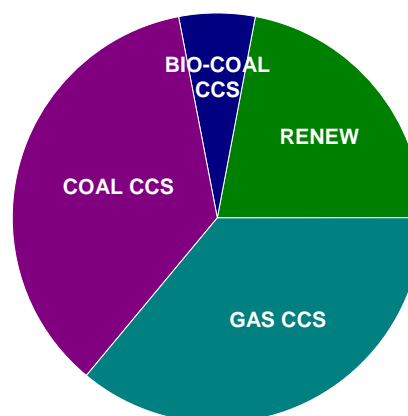
Figures 5.41 and 5.42 illustrate the make-up of the grid in 2050. In the *Static Mobility* scenario, the lower carbon emissions from transport take some of the pressure off the electricity supply grid and enable a limited amount of generation from gas without CCS.

Figure 5.41: 'Static' 2050 electricity grid



Grid supply: 24Mtoe/279TWh

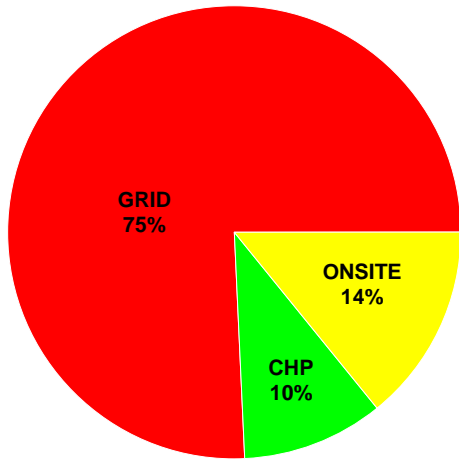
Figure 5.42: 'Plus' 2050 electricity grid



Grid supply: 27Mtoe/314TWh

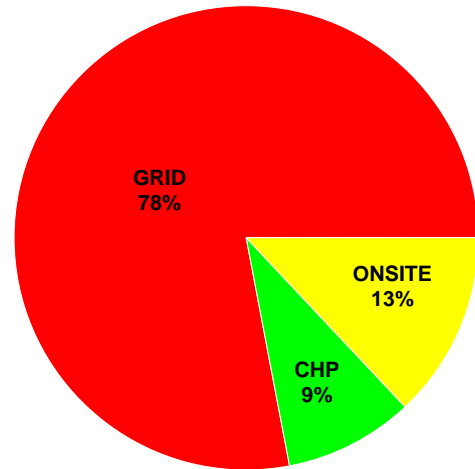
Figures 5.43 and 5.44 illustrate the electricity supply split between the grid, on-site renewables and CHP for both scenarios in 2050. The smaller contribution from conventional CHP in the *Mobility Plus* scenario is due to the need to reduce carbon emissions from non-transport sectors that has driven a move away from gas-fuelled CHP.

Figure 5.43: 2050 electricity split - 'Static'



Total electricity supply:
32Mtoe/368TWh

Figure 5.44: 2050 electricity split - 'Mobility'



Total electricity supply:
35Mtoe/406TWh

5.2.4.1 Electricity supply – *Static Mobility*

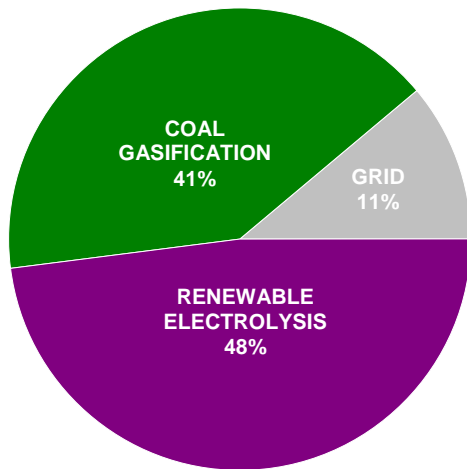
Meeting the carbon target in 2030 required the deployment of an extensive low-carbon supply infrastructure, both for electricity, and for hydrogen production and distribution. The reduction in energy demand by this date, and a continued growth in decentralised energy supply, allows the electricity grid to contract in size slightly. The grid does not have to be carbon-free hence there is some generation from conventional gas plant which allows for some centralised generation in areas which are remote from carbon capture and storage infrastructure.

The established programmes of deployment of on-site generation in the built environment continue, and there has been an increase in the amount of distributed electricity generated as the efficiency of technologies such as PV, or building integrated wind turbine, increase and the costs decrease.

5.2.4.2 Hydrogen supply – *Static Mobility*

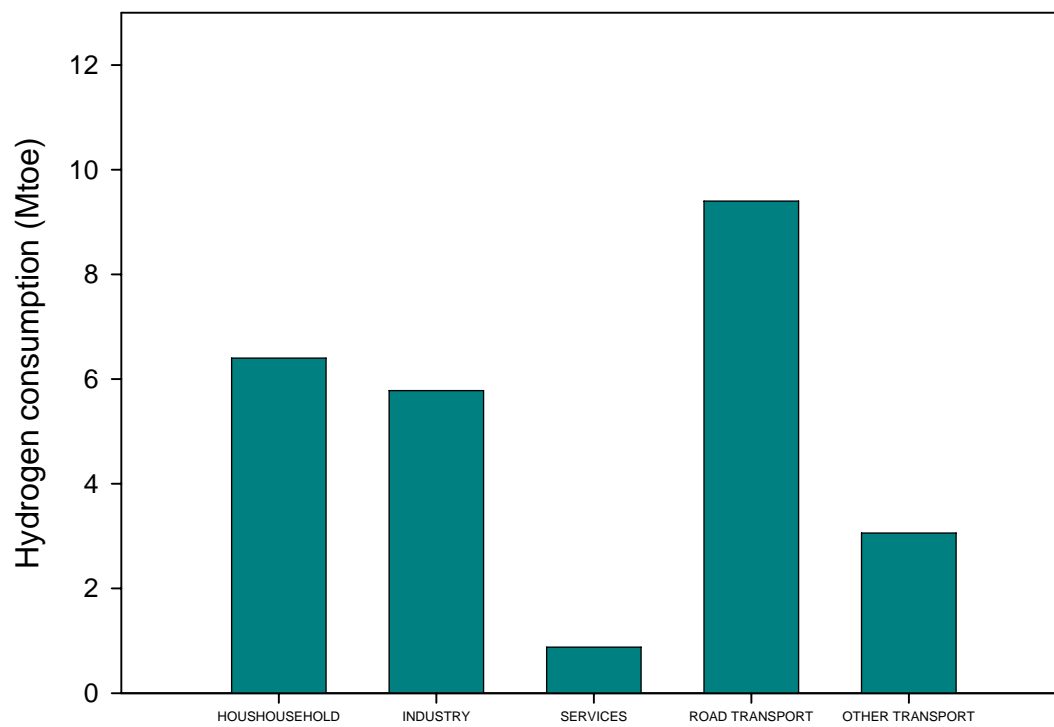
The proportion of energy needs supplied by hydrogen continues to grow as the infrastructure is deployed and end use technologies are developed. In the home, hydrogen fuel cells replace gas micro CHP units. Figures 5.45 and 5.46 illustrate the methods of hydrogen production and a break down of sectoral end-use.

Figure 5.45: 2050 hydrogen supply - Static



Total hydrogen supply: 26Mtoe

Figure 5.46: 2050 final hydrogen demand - 'Static'



5.2.4.3 Electricity supply – *Mobility Plus*

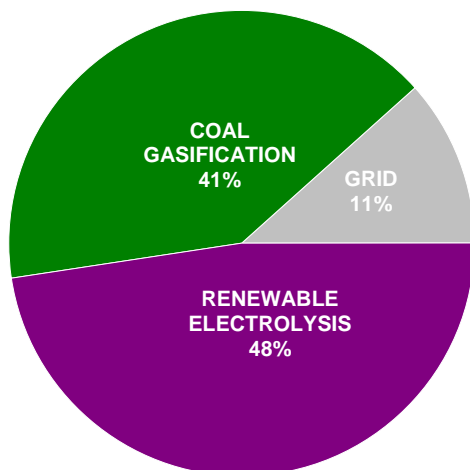
Meeting the carbon target in 2030 required the deployment of an extensive low-carbon supply infrastructure, both for electricity, and for hydrogen production and distribution. Demand for electricity has remained more or less constant between 2030 and 2050, hence the grid is the same size as in 2030. To remain within the carbon trajectory, all fossil fuel generation is combined with CCS.

The established programmes of deployment of on-site generation in the built environment continue, and there has been an increase in the amount of distributed electricity generated as the efficiency of technologies such as PV, or building integrated wind turbines, increase, and the costs decrease.

5.2.4.4 Hydrogen supply – *Mobility Plus*

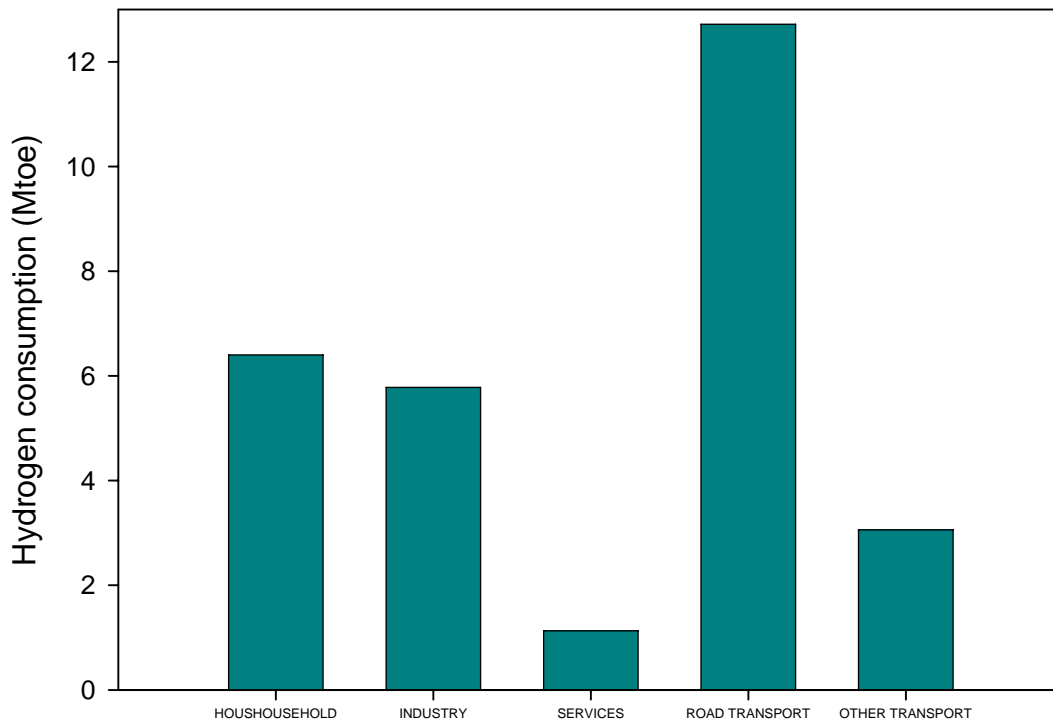
The proportion of energy needs supplied by hydrogen continues to grow as the infrastructure is deployed and end use technologies are developed. Figures 5.47 and 5.48 illustrate the methods of hydrogen production and a breakdown of sectoral end-use. In the home, hydrogen fuel cells replace gas micro CHP units. If figure 5.46 is compared with 5.48, it demonstrates the greater penetration of hydrogen within land transport in the *Mobility Plus* scenario.

Figure 5.47: 2050 hydrogen supply split -'Plus'



Total hydrogen supply: 29 Mtoe

Figure 5.48: 2050 final hydrogen demand - 'Plus'

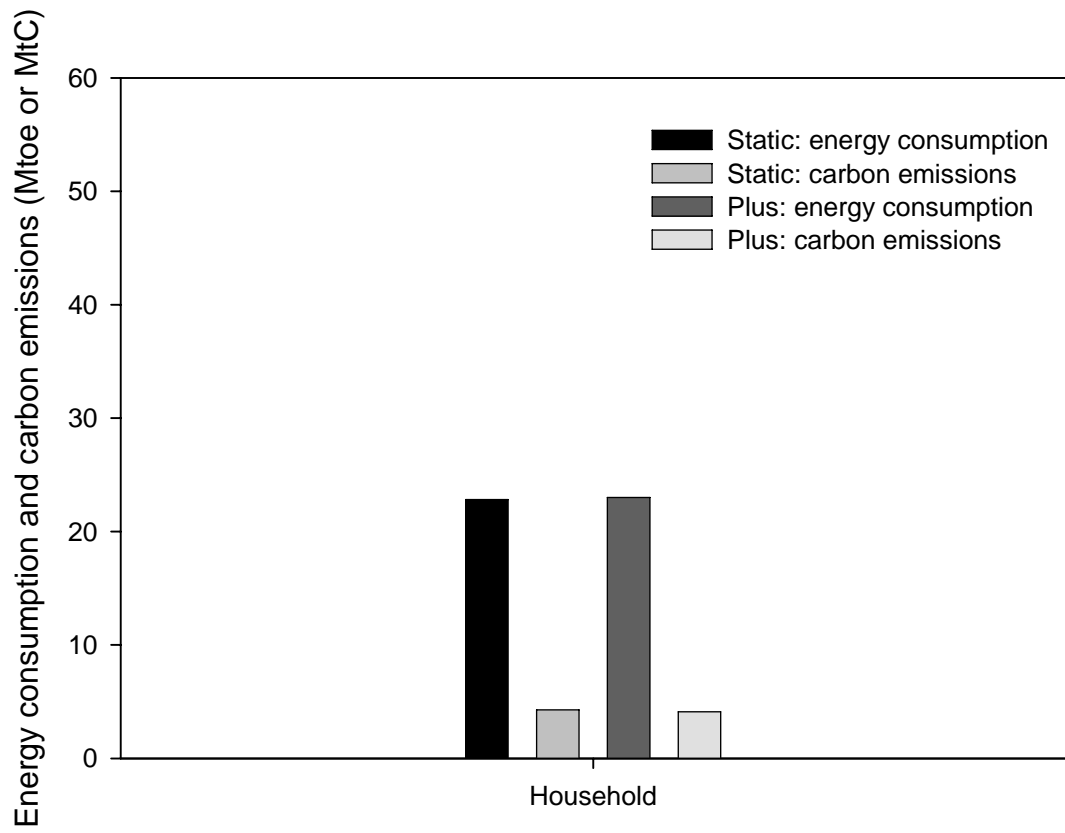


5.2.4.5 Sectoral characteristics

Households

In 2050, household energy consumption is less than half of current levels, and there has been a high level of decentralisation of energy supply with 83% of non-electrical energy coming from on-site renewables and CHP along with 26% of electrical energy also supplied by on-site generation. The policies which have instigated these changes have been in place for several decades and there has been an incremental and continuous programme of improvement across the building stock. There has also been increasing penetration of hydrogen for energy supply in the built environment. The slightly lower carbon emissions from households in the *Mobility Plus* scenario are a consequence of the zero-carbon grid.

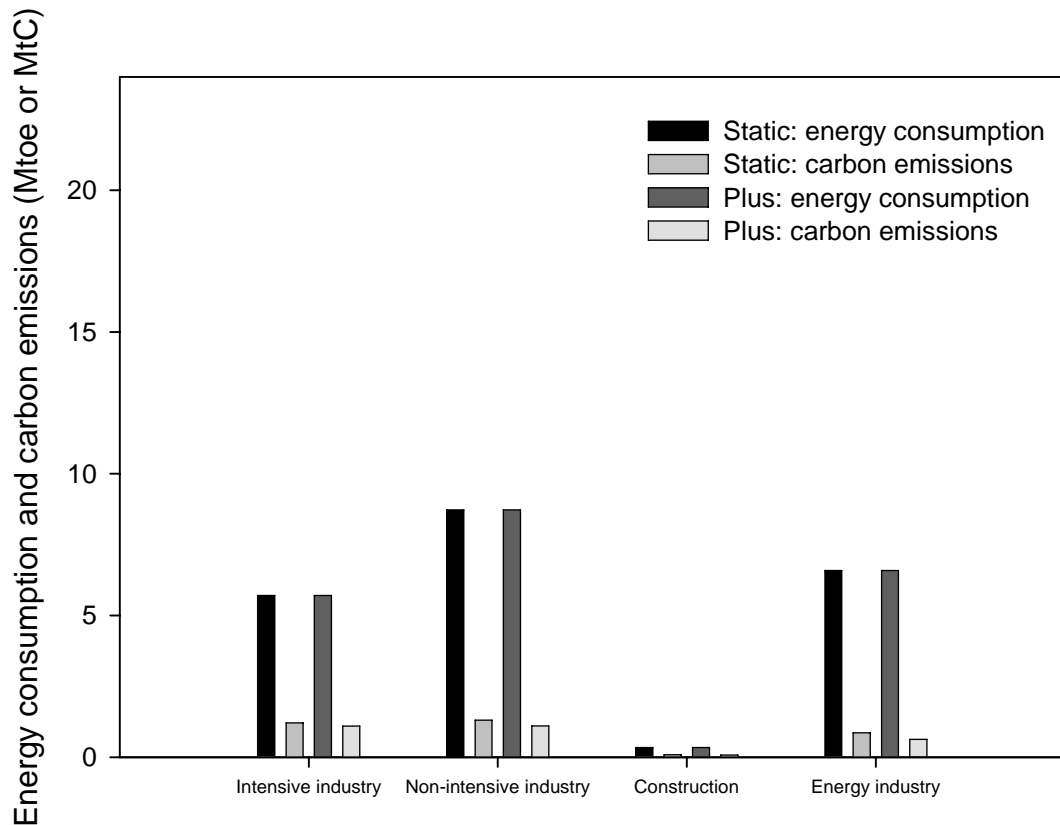
Figure 5.49: 2050 energy consumption and carbon emissions from households



Industry

In 2050, energy consumption in the industrial sectors is half of current levels. By 2050, industrial production is based around manufacturing hubs which allow efficient resource recycling between processes and move towards 'closing' the manufacturing loop. Hydrogen continues to replace gas use to provide process heat.

Figure 5.50: 2050 energy consumption and carbon emissions from industry

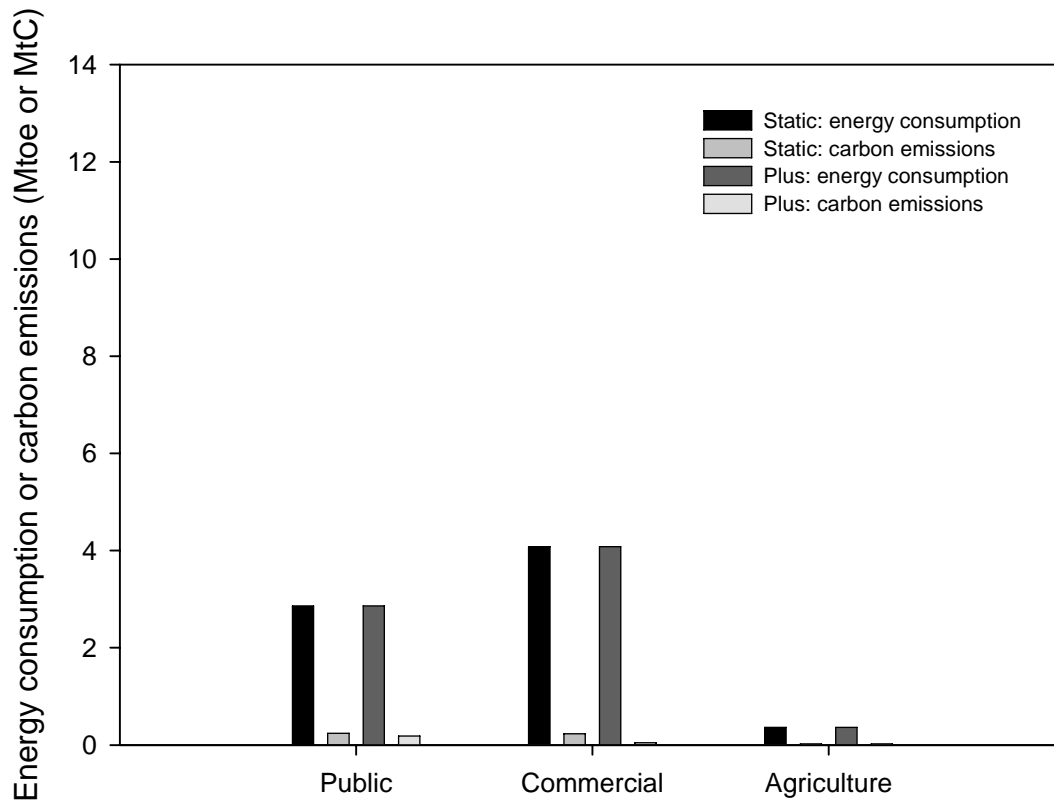


Services

In 2050, energy consumption in the commercial sector is less than half of current levels, with significant reductions in electricity use as well as of 'other energy'. Such a significant reduction in electricity consumption is contingent upon stringent controls on the energy consumption of appliances, and the use of very low energy consumption and passive air conditioning systems. The lower carbon emissions in the mobility plus scenario are a consequence of the zero-carbon grid.

Ultimately, by 2050, the entire system of building procurement, design, construction and management of buildings in the commercial sector has to be an important market criterion.

Figure 5.51: 2050 Final energy consumption and carbon emissions from services



5.3 Scenario descriptions summary

Section 5 has outlined the main characteristics of the Friends of the Earth and The Co-operative Bank scenarios, focusing on the short-, medium- and long-term. These scenarios demonstrate two alternative routes by which the UK can achieve cuts in carbon emissions in the region of 90% by 2050. The transitions set out what needs to happen if a particular target is to be reached and are within the bounds of possibility in terms of changing patterns of supply and demand but they are not forecasts or predictions.

In many ways there are great similarities between the scenarios. In both, there has been a decentralisation of electricity supply, and greater reductions have been made in the use of non-electrical energy (for heat and transport) than in the use of electricity. Carbon capture and storage, and hydrogen as an energy carrier, also feature strongly in each of the scenarios, though there have been different penetrations of hydrogen across the economy. There are also different patterns of energy demand, and final energy consumption. Although *Static Mobility* has a higher

energy consumption in 2030, by 2050 it is 17% lower than consumption in *Mobility Plus*. The higher level of mobility in *Mobility Plus* not only results in higher consumption, but necessitates that the grid is carbon-free, since a greater proportion of carbon is emitted by transport, particularly aviation. A faster rate of reduction of energy consumption is evident in the scenario, driven by a greater focus on innovation, technical improvements and demand management. Although the carbon intensities of the two scenarios are the same in 2050, this is achieved with different energy intensities such that energy intensity in *Static Mobility* is always lower.

6. TRANSPORT

The following section outlines the characteristics of Friends of the Earth and The Co-operative bank mobility scenarios in terms of passenger and freight transport. Passenger transport will be dealt with in the first section with freight following in the second. As the two scenarios developed for this piece of research differ most markedly in terms of their levels of passenger mobility, more emphasis and detail will be given to the passenger transport section.

In a similar vein to Section 5, the transport characteristics of the scenarios will be described in this section without any elaboration when it comes to issues of policy, or indeed in terms of ease or otherwise of attaining the measures necessary for the chosen level of decarbonisation. The reader is reminded therefore that the scenarios aim to paint a picture of what the UK needs to do if it is to achieve the chosen endpoint, and therefore illustrates some of the technical and behavioural options that will be necessary for the UK to achieve its goal. The relevant policies that aim to bring these technical and behavioural options about are described in Section 7.

As mentioned previously, the scenarios have been named '*Static Mobility*' and '*Mobility Plus*' as an indication of the difference between them in terms of passenger travel. The names illustrate that within *Static Mobility*, levels of passenger kilometres by 2050 remain similar to those seen today, whereas, within the *Mobility Plus* scenario, the numbers of passenger kilometres travelled on land and by air are higher than they are today – twice as high for land-based travel, and three times for air travel. The given names therefore attempt to label the scenarios, without imposing any value judgement.

6.1 Passenger transport

Within the passenger transport sector, private road travel currently dominates both in terms of energy consumption and carbon emissions, contributing roughly double the amount of carbon dioxide emissions into the atmosphere compared with international air travel. Whilst rail travel in 2004 is the only mode of transport to consume significant amounts of electricity, leading to the production of more carbon emissions per unit of energy consumed than any other form of transport, it remains the least carbon intensive mode of transport per passenger kilometre, as illustrated in Table 6.1. This is a consequence of the energy per passenger-kilometre being the lowest of any of the passenger transport modes.

Figure 6.1: Baseline energy consumption and carbon emissions
Passenger transport sectors

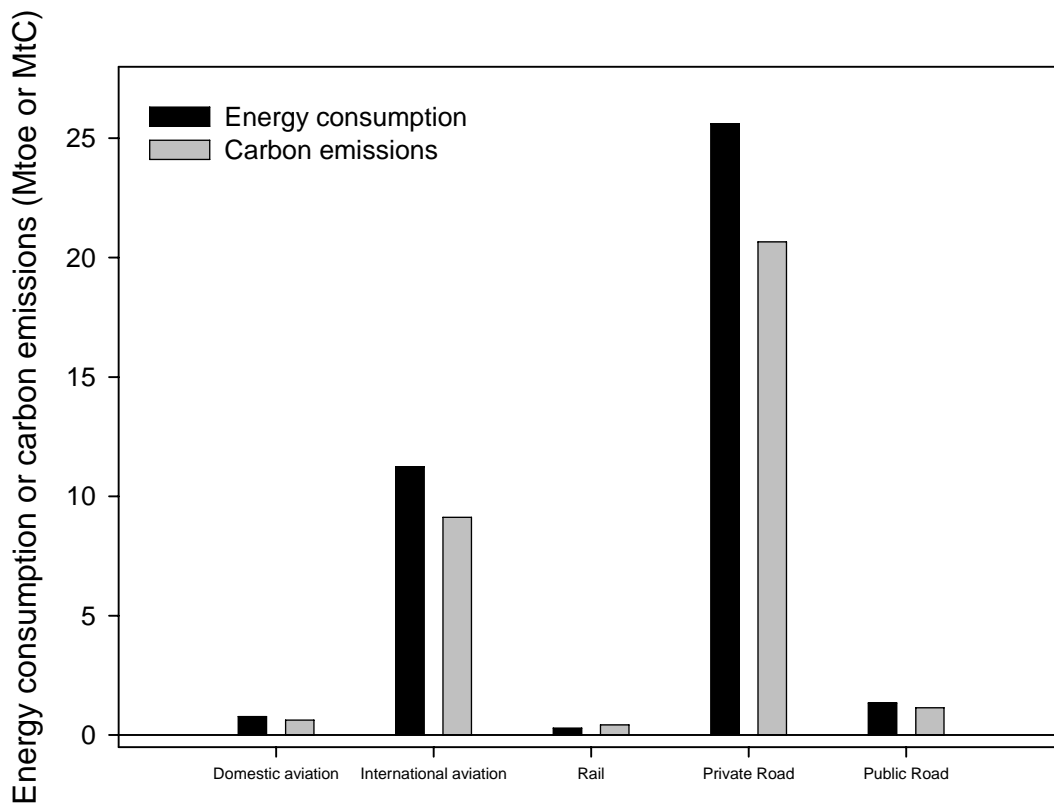
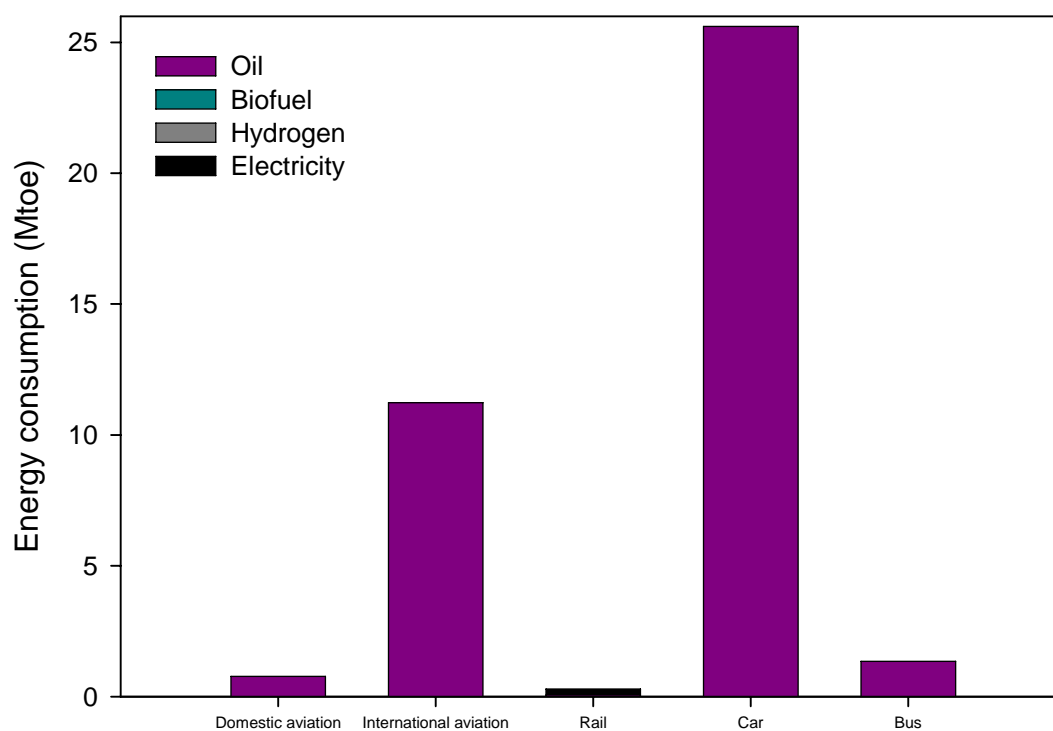


Table 6.1: Summary baseline data – data derived from the Department for Transport's Transport Statistics Great Britain⁷⁵.

Mode	Occupancy	Kilometres (Billion) ⁷⁶	Pax ⁷⁷ (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	71	0.1	9.8	0.8	0.6	0.08	0.060
International aviation	177	1.5	263.0	11.2	9.1	0.04	0.034
Rail	93	0.6	51.0	0.29	0.43	0.01	0.008
Private road	1.6	432.7	688.0	25.6	20.7	0.04	0.030
Public road	9	5.2	48.0	1.35	1.1	0.03	0.023
TOTAL		440	1060	38.4	31.3		

Table 6.1 illustrates that domestic aviation is the most carbon intensive mode of transport, as previously highlighted in Section 3. Interestingly, despite the fact that a similar number of passenger-kilometres are travelled by rail as by bus, the number of vehicle kilometres travelled by buses is 10 times larger. This can be explained by buses' low occupancy, frequent journeys.

Figure 6.2: Baseline passenger transport fuel split



⁷⁵ (DfT, 2005)

⁷⁶ Data from Transport Statistics Great Britain, 2005, DTI.

⁷⁷ Pax is passenger kilometres

Figure 6.2: illustrates that apart from rail transport, which uses a high proportion of electricity, oil is the dominant transport fuel.

In the following sections, the scenarios will be described in relation to short, medium and long-term developments, as in Section 5, and include descriptions in relation to energy, carbon, passenger kilometres and modal shift. However, prior to the descriptions in relation to the short, medium and long-term summary data, two tables are presented to illustrate the annual average changes in growth and fuel efficiency between 2004 and 2050, as well as some recent trend data. These tables will be referred in the subsequent sections, but are presented here to give the reader a flavour of the developments to come. Note that 'Growth' refers to a change in the sector in terms of passenger kilometres, and 'Efficiency' refers to the energy efficiency per passenger kilometre, and is therefore influenced not only by technological changes to a particular vehicle, but also behavioural change in relation to vehicle occupancy or size of vehicle.

Table 6.2: Scenario summary tables for growth and efficiency – *Static Mobility*

Mode	Parameter	Recent trend	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Domestic aviation	Growth	5.8%	4.0%	1.5%	-1.0%	-1.5%	-1.8%
	Efficiency	0.2%	-1.0%	-1.5%	-2.2%	-2.1%	-2.0%
International aviation	Growth	7% <i>(2.3%)⁷⁸</i>	7.0%	1.0%	-2.5%	-1.5%	-1.0%
	Efficiency	2.2%	-0.8%	-1.5%	-2.2%	-2.1%	-2.0%
Rail	Growth	2.5%	1.5%	0.8%	0.7%	0.5%	0.5%
	Efficiency	-79	-1.5%	-2.0%	-2.3%	-2.2%	-2.0%
Private road	Growth	1.1%	0.1%	-0.1%	-0.2%	-0.3%	-0.4%
	Efficiency	-1.7%⁸⁰	0.0%	-1.0%	-2.7%	-2.8%	-2.8%
Public road	Growth	0.5%	0.3%	0.5%	1.0%	2.0%	2.4%
	Efficiency	2.2%	-0.5%	-0.5%	-0.7%	-2.0%	-3.3%

⁷⁸ Although the trend over the period 1998 to 2004 was 2.3%, this period was severely affected by the events of September 11th 2001. The recent figure of 7% per year is the figure that has been consistently seen throughout the 1990s and indeed was the figure between 2003 and 2004 according to the UK's Transport Statistics Great Britain, 2005.

⁷⁹ Trend data is difficult to calculate due to the fact that most rail data does not split freight and passenger. The only figure for freight and passenger data was taken from the Rail Emission Model, 2001 from the Strategic Rail Authority, which splits carbon dioxide emissions between passenger and freight travel by rail SRA (2001). Rail Emission Model. S. R. Authority, AEA Technology..

⁸⁰ Between 2003 and 2004, car fleet efficiency deteriorated by 1%.

Table 6.3: Scenario summary tables for growth and efficiency – *Mobility Plus*

Mode	Parameter	Recent trend	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Domestic aviation	Growth	5.8%	3.5%	1.5%	-0.5%	-1.5%	-1.5%
	Efficiency	0.2%	-1.0%	-1.5%	-2.1%	-2.1%	-2.1%
International aviation	Growth	7% (2.3%)⁸¹	7.0%	3.5%	2.0%	0.9%	0.6%
	Efficiency	2.2%	-0.8%	-1.5%	-2.1%	-2.1%	-2.1%
Rail	Growth	2.5%	1.8%	2.5%	3.5%	3.4%	3.4%
	Efficiency	-0.2%	-1.5%	-2.5%	-3.5%	-4.5%	-4.7%
Private road	Growth	1.1%	0.5%	0.7%	1.0%	1.2%	1.4%
	Efficiency	-1.7%⁸³	-0.5%	-1.5%	-2.5%	-3.1%	-4.0%
Public road	Growth	0.5%	1.0%	3.0%	4.5%	5.0%	5.3%
	Efficiency	2.2%	-1.0%	-1.5%	-2.5%	-2.5%	-2.3%

Clearly the aviation industry is currently experiencing the highest rates of growth of all of the sectors in the economy. Furthermore, despite claims to the contrary, the fuel efficiency of the aviation industry is not improving at 1-2% per year as was the case historically for the global aviation industry (Section 3), but declining at around 2% per year for international aviation and at 0.2% per year for domestic aviation.⁸⁴

As illustrated in Figure 6.1, private road transport accounts for the largest proportion of energy consumption of all of the transport sectors, and second only to the household sector when analysing the economy as a whole. According to Table 6.2, car energy efficiency has been improving over recent years at a rate of around 1.7% per year. However, if the data for 2003 to 2004 is considered, fuel efficiency actually declined for the first time in many years. This is thought to be the result of a boom in larger heavier vehicles which traditionally exhibit poor fuel efficiency – some as low as 13 miles per gallon. This is also despite an improvement in the grams of carbon dioxide emitted per kilometre for the average new car in 2004 compared with 2003⁸⁵. According to the recent trend data, despite being the second least carbon intensive mode of transport, bus travel is showing a decline in energy efficiency of the order of 2% per year.

⁸¹ See footnote in previous table

⁸² See footnote in previous table

⁸³ See footnote in previous table

⁸⁴ The energy data for the international aviation sector and the relevant passenger kilometre data do not measure exactly the same group of aircraft. The fuel data is derived from bunker fuel purchased for the use of aircraft within the UK, and approximates to 50% of flights arriving and departing the UK. Whereas, the passenger kilometre data is for UK owned airlines and taken from the Transport Statistics Great Britain, (DfT, 2005). Justification for assuming that the UK airline passenger kilometre figures can provide a good estimate for the passenger km associated with 50% of flights arriving and departing UK airports, is that UK operators account for 53% of international air transport movements DfT (2005). Transport Statistics Great Britain. [Transport Statistics Great Britain](#). TSO. London, Department for Transport.

⁸⁵ SMMT (2005). UK New Car Registrations by CO2 Performance. T. S. o. M. M. a. T. Ltd.

6.1.1 Short-term

Over the short-term, both scenarios show significant increases in terms of energy consumption and carbon emissions from the baseline year in the international aviation sector, with little change to these parameters within the other transport sectors. This is the result of a near matching of growth in passenger-kilometres with fuel efficiency improvements in all but the air transport sectors. However, a key difference between the two scenarios, when looking at the bigger picture, is the overall increase in passenger-kilometres for *Mobility Plus* compared with *Static Mobility*. This is primarily a result of the small difference in growth within private road transport of just 0.4% between *Mobility Plus* and *Static Mobility*. As the private road transport sector accounts for by far the largest number of passenger-kilometres travelled, as illustrated in table 6.1, any small difference in growth results in a large difference in passenger kilometres.

Figure 6.3: 2010 energy consumption and carbon emissions
Passenger transport sectors

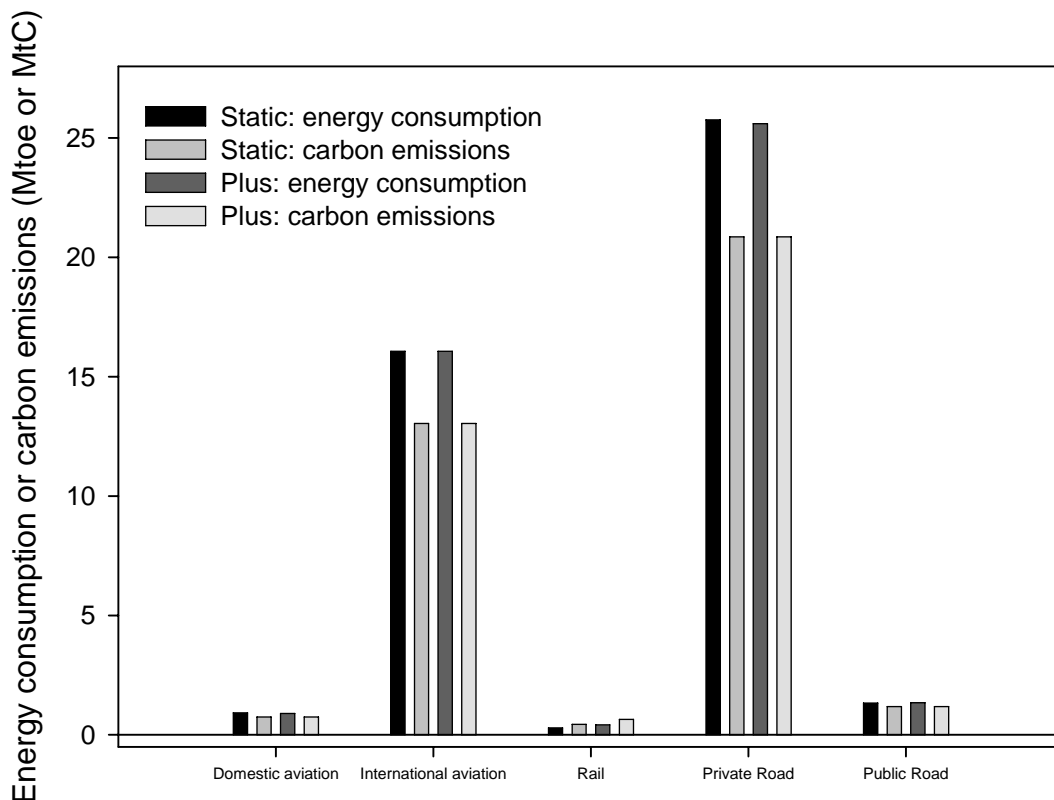


Table 6.4: Summary 2010 data – *Static Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic Aviation	73	0.2	12.4	0.92	0.75	0.07	0.060
International aviation	180	2.2	394.7	16.06	13.04	0.04	0.033
Rail	95	0.6	55.8	0.29	0.44	0.01	0.008
Private road	1.6	432.6	692.1	25.76	20.86	0.04	0.030
Public road	10	4.9	48.9	1.33	1.19	0.03	0.024
TOTAL		440	1203	44.36	36.28		

Table 6.5: Summary 2010 data – *Plus Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	70	0.2	12	0.9	0.73	0.08	0.061
International aviation	182	2.2	394.7	16.06	13.04	0.04	0.033
Rail	95	0.6	56.8	0.42	0.65	0.01	0.011
Private road	1.62	437.6	708.9	25.60	20.86	0.04	0.029
Public road	10	5.1	51.0	1.35	1.19	0.03	0.023
TOTAL		445	1223	44.33	36.47		

6.1.1.1 Aviation

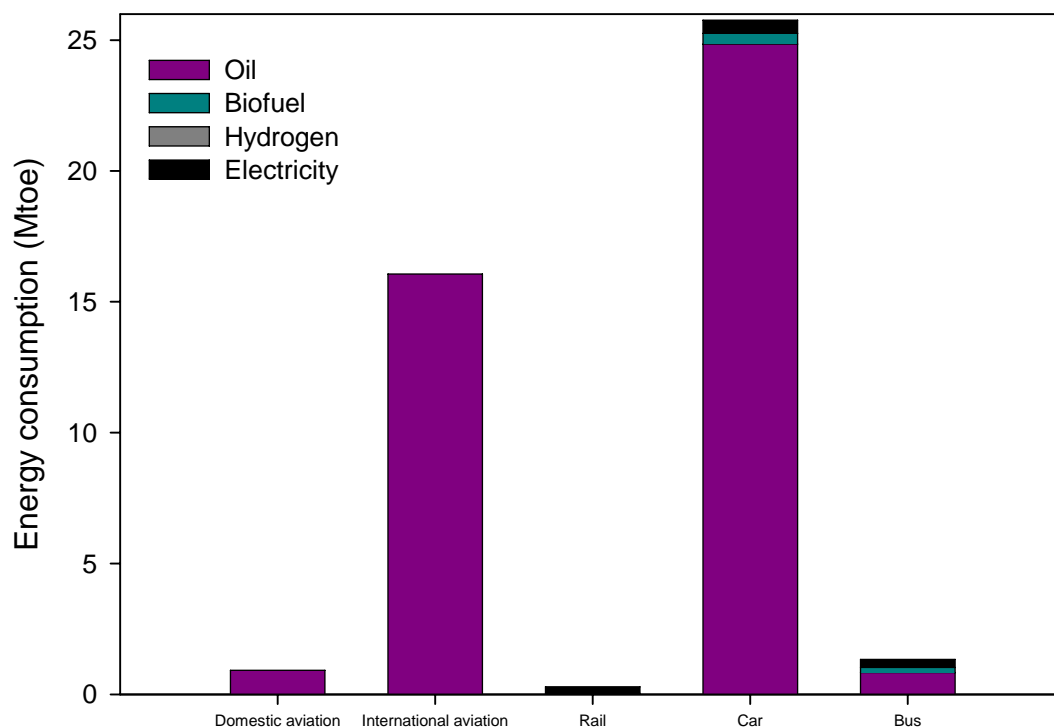
In both scenarios between 2004 and 2010, international aviation carbon emissions grow at 2% lower than the rate seen between 2003 and 2004, with growth in terms of passenger-kilometres continuing at current rates (Tables 6.4 and 6.5), reflecting the likely continuation of the boom in low cost airlines and the attempts to mimic low cost models by more traditional airlines. Recent energy efficiency trends have been reversed in both domestic and international aviation to rates considered to be well within those achievable by the aviation industry⁸⁶. However, the two scenarios begin to deviate from each other, even by 2010, in terms of their occupancy rates.

For domestic aviation, growth has been reduced to 4% per year, and occupancy increased from 71 to 73 in *Static Mobility*, reflecting an increased load factor. The reduction in growth reflects the beginning of a necessary shift of some of the

⁸⁶ The aviation industry produced a document in 2005 'A strategy towards sustainable development of UK aviation' which states on page 20 that aircraft fuel efficiency is expected to increase at a rate of 1.2% per year for some time to come.

domestic aviation passengers onto the rail and road networks, if future carbon targets are to be attained. Within *Mobility Plus*, growth in domestic aviation has reduced to 3.5% with occupancy dropping slightly to 70. The trend within this scenario is towards smaller, lighter aircraft for domestic use, coupled with a general shift from domestic aviation to land based modes of travel. The occupancy rates for both the scenarios for international aviation are larger in 2010 than in the baseline year, demonstrating an increase in load-factor to improve the fuel efficiency per passenger-kilometre. However, within *Mobility Plus*, this increase is also a reflection of the trend towards larger aircraft for long-haul flights, such as the Airbus A380 and Boeing Dreamliner. Overall, the changes in occupancy rates, growth and efficiency lead to significant increases in both energy consumption and carbon emissions, particularly from international aviation.

Figure 6.4: 2010 'Static' passenger transport fuel split



6.1.1.2 Rail

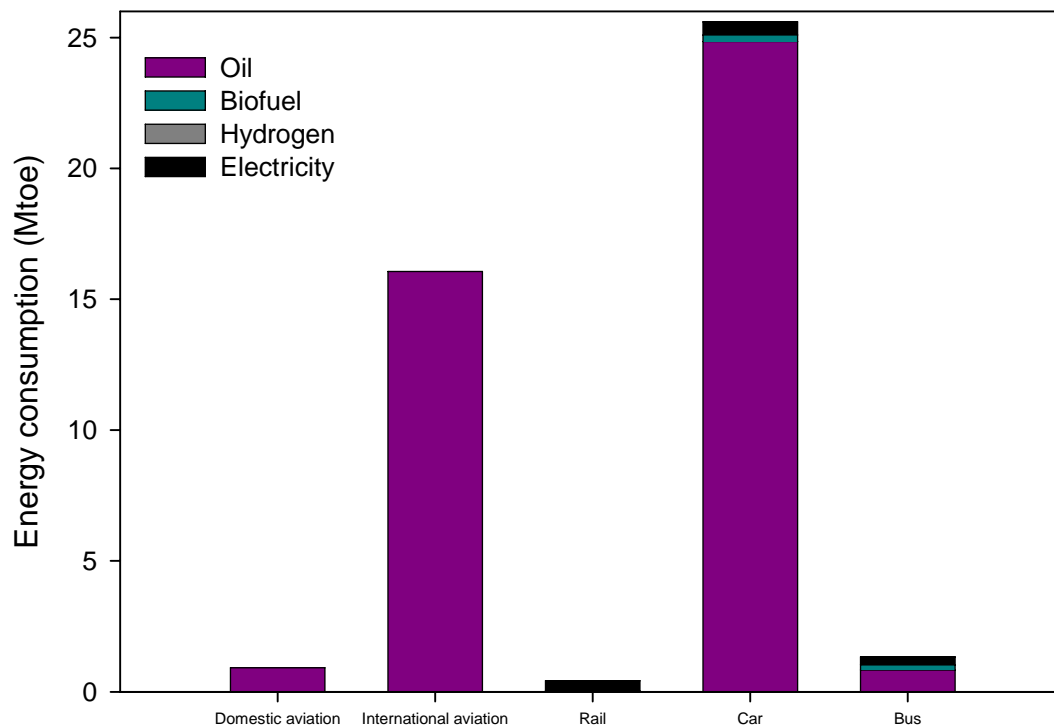
Rail travel within both scenarios continues to grow with more frequent, more efficient trains required across the network, developing in a similar way to the recent improvements seen on the Manchester to London lines. This sector also gains the largest relative increase in passenger-kilometres of any of the land-based modes as a result of demand management to encourage passengers to travel by public transport as an alternative to domestic aviation and private road transport.

Occupancy is up only slightly on 2004 levels to 95 from 93, with efficiency improving at 1.5% per year. The fact that the growth figure is larger than the efficiency improvement figure within *Mobility Plus* leads to a small increase in the energy consumption from this sector.

6.1.1.3 Road

For *Static Mobility*, travel by both private car and bus are on the increase, but both at lower rates of growth than recent trends due to some demand management strategies particularly for car transport, as discussed in Section 7. The biggest change in this sector compared with recent developments is the reversal of the energy efficiency trend for public road transport. Efficiency increases have been non-existent as of late, whereas by 2010, a 0.5% per year improvement is seen across the bus fleet. Lessons learnt from significant improvements to the bus network in London and the South East have been replicated in many of the UK's big cities, with 'bendy buses' for high capacity routes, and smaller, lighter vehicles being used as run-arounds within city centres. Occupancy rates overall are slightly larger than in 2004.

Figure 6.5: 2010 'Plus' passenger transport fuel split



The recent worrying trend in energy efficiency within car transport has been stabilised, as the purchase of heavier, inefficient vehicles subsides, and the small car regains popularity through a variety of incentives and new legislation presented in Section 7. The combination of growth and efficiency changes in buses leads to a reduction in energy consumption from this sector, whereas the opposite is true for private cars. However, carbon emissions from both sectors are larger due to the increased take-up of electric vehicles such as the G-Wizz⁸⁷, as the carbon intensity of the national grid continues to be high. This is also despite an increase in the use of biofuels to power both cars and buses.

Within *Mobility Plus*, there is no change in energy consumption from either the use of the private car or public road transport due to a matching of growth in passenger kilometres with fuel efficiency improvements. However, as a consequence of an increase in electrically powered vehicles being charged from the national grid, the carbon emissions from both sectors have increased slightly compared with 2004. The improvements seen within this scenario in terms of energy efficiency are higher than in *Static Mobility* due to a big increase in smaller more efficient cars, a slightly higher car occupancy rate and newer public buses in both cities and more rural areas.

⁸⁷ Over 500 plug in electric vehicles of this type had been sold as of April 2006

6.1.2 Medium-term

The most noticeable element of Figure 6.6 in relation to carbon emissions and energy consumption is a break in the link between them. The 2030 energy supply system has undergone a necessary radical transition in both scenarios as described in Section 5, with a very low-carbon grid, a hydrogen infrastructure and significant amounts of renewable technologies and biofuels contributing to a lower carbon energy system. Whereas of road transport requires fuel from biofuel, oil, hydrogen and electricity, rail uses similar fuels to those used today, and the aviation sector has needed some penetration of bio-kerosene and bio-diesel. Demand management has also played a significant role in reducing the energy consumption, and hence the carbon emissions from the different modes of transport. Growth rates within the aviation sector have had to be significantly curtailed, and in the case of *Static Mobility*, reduced below zero. Similarly, car transport is declining within *Static Mobility*, with very low rates of increase even within *Mobility Plus*. In terms of overall mobility, the total vehicle kilometres travelled in *Static Mobility* are lower than the baseline year, despite an increase in passenger-kilometres. *Mobility Plus*, on the other hand, exhibits increases in both passenger-kilometres and vehicle kilometres travelled.

Figure 6.6 2030 energy consumption and carbon emissions
Passenger transport sectors

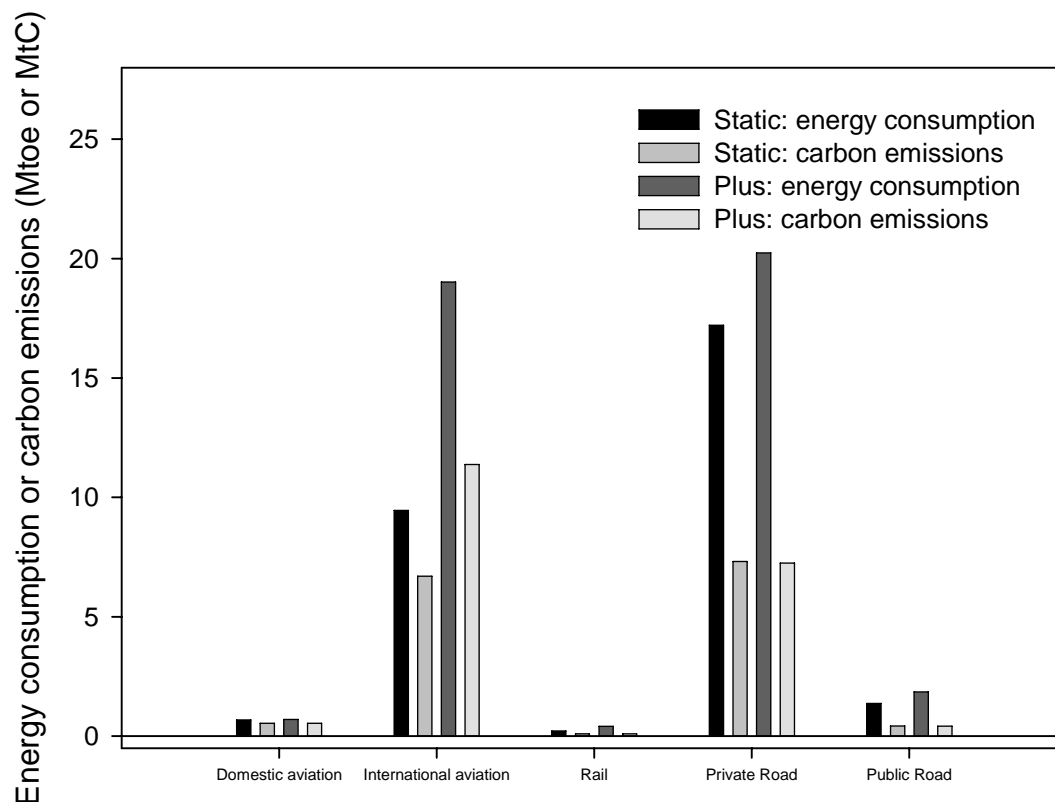


Table 6.6: Summary 2030 data – *Static Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	77	0.17	13.1	0.68	0.54	0.05	0.041
International aviation	195	1.74	339.5	9.45	6.7	0.03	0.020
Rail	110	0.59	64.8	0.22	0.1	0.003	0.002
Private road	1.75	383.81	671.7	17.21	7.31	0.03	0.011
Public road	11.5	4.93	56.7	1.37	0.43	0.02	0.008
TOTAL		391	1146	28.93	15.08		

Table 6.7: Summary 2030 data – *Plus Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	65	0.2	13.3	0.7	0.54	0.05	0.041
International aviation	230	2.95	679	19.02	11.4	0.03	0.017
Rail	115	0.89	102.5	0.41	0.1	0.004	0.001
Private road	1.68	499.8	839.7	20.24	7.25	0.02	0.009
Public road	15	7.09	106.4	1.85	0.42	0.02	0.004
TOTAL		511	1741	44.22	19.17		

6.1.2.1 Aviation

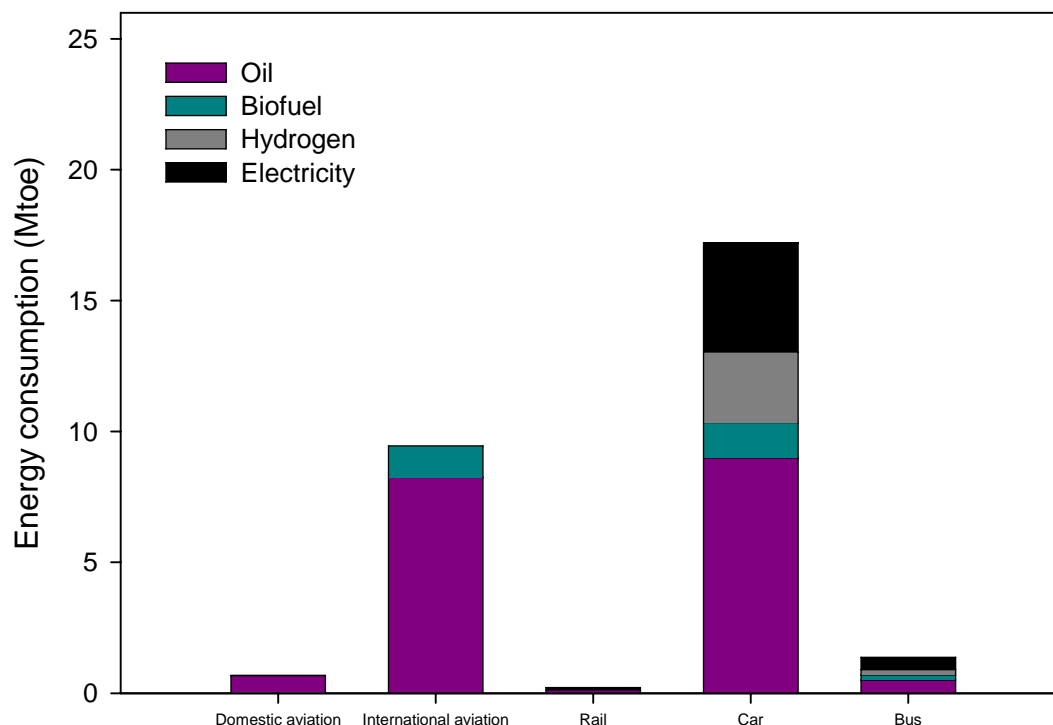
For both domestic and international aviation in both scenarios, the industry is under extreme pressure to reduce its overall carbon dioxide emissions. Given that aviation was the fastest growing sector in the UK economy, both in terms of activity and emissions until 2010, to meet the UK's carbon targets, this sector must employ a combination of demand management measures, improvements in energy efficiency through technological advances and managerial change, and, particularly in the case of *Mobility Plus*, the use of alternative low-carbon fuels.

The urgency and importance placed on climate change has persuaded the aviation industry in both scenarios to incorporate some additional but simple non-technological measures, previously found to be unacceptable, in order to improve fuel efficiency above the 1-2% per year figure attained under a more business as usual approach. The managerial changes required include, for example, new ticketing arrangements to ensure that plane load factors are greatly increased in relation to the baseline year. The proposed improvements to the air traffic

management system highlighted by the industry in 2005⁸⁸ must be implemented by 2020 to deliver the one-off 5% improvement in fuel efficiency enabled by more direct flights, less holding patterns and less taxiing and delays on runways. Furthermore, all domestic and intra-European flights fly at slower speeds, vastly improving fuel efficiency.

Additional technological changes are also required if the necessary efficiency improvements are to be reached. As such, new regulations provide the industry with a climate change focus for their R&D. Consequently, design features focus much more prominently on improving fuel efficiency. More unfamiliar airframes such as turbo-prop planes and lighter carbon composite planes are also used more widely for many flights. As a result of these technological and managerial changes, fuel efficiency improvements reach a maximum of 2.2% per year during the 2020s for *Static Mobility*, and 2.1% for *Mobility Plus* as illustrated in Table 6.2.

Figure 6.7: 2030 'Static' passenger transport fuel split



⁸⁸ Aviation (2005). A strategy towards sustainable development of UK aviation. S. AOA, BATA, NATS.

The two scenarios differ most markedly in terms of their growth rates and use of aviation fuels. Demand management is critical within both scenarios, and by 2030, growth rates in both domestic and international aviation have been forced to decline at rates as high as 2.5% per year within *Static Mobility*. Modal shift to rail transport accounts for much of the decline in domestic aviation, and for a small amount of the passenger-kilometres from some international flights, particularly within Europe. However, the fact that within this scenario, the aviation industry focused on fuel efficiency in the early years, rather than carbon efficiency and hence alternative fuels, the industry is left with no choice but to curtail emissions through reducing growth.

Domestic aviation growth follows a similar pattern in *Mobility Plus*, to that of *Static Mobility*, with demand being stabilised at mid-2020 levels by 2030 as more passengers are encouraged to travel around the UK by rail, and to some extent, by road. Capacity at airports is also reserved primarily for the more lucrative international flights in preference to short-haul trips.

Demand management is also of key importance in reducing the international aviation industry's impact on climate within *Mobility Plus*. Growth rates must reduce to 3.5% per year on average between 2010 and 2020, and down to 2% per year between 2020 and 2030 as illustrated in Table 6.3, despite fuel efficiency improvements, and the use of some alternative fuels. Within this scenario, the industry has not only needed to improve fuel efficiency and reduce growth to curtail carbon emissions growth, but also improve carbon efficiency through the use of alternative fuels. In addition to the demand management and fuel efficiency improvements therefore, a third of aviation fuel must come from low-carbon, technologically compatible sources such as bio-diesel and bio-kerosene to ensure that the industry meets its carbon obligations.⁸⁹

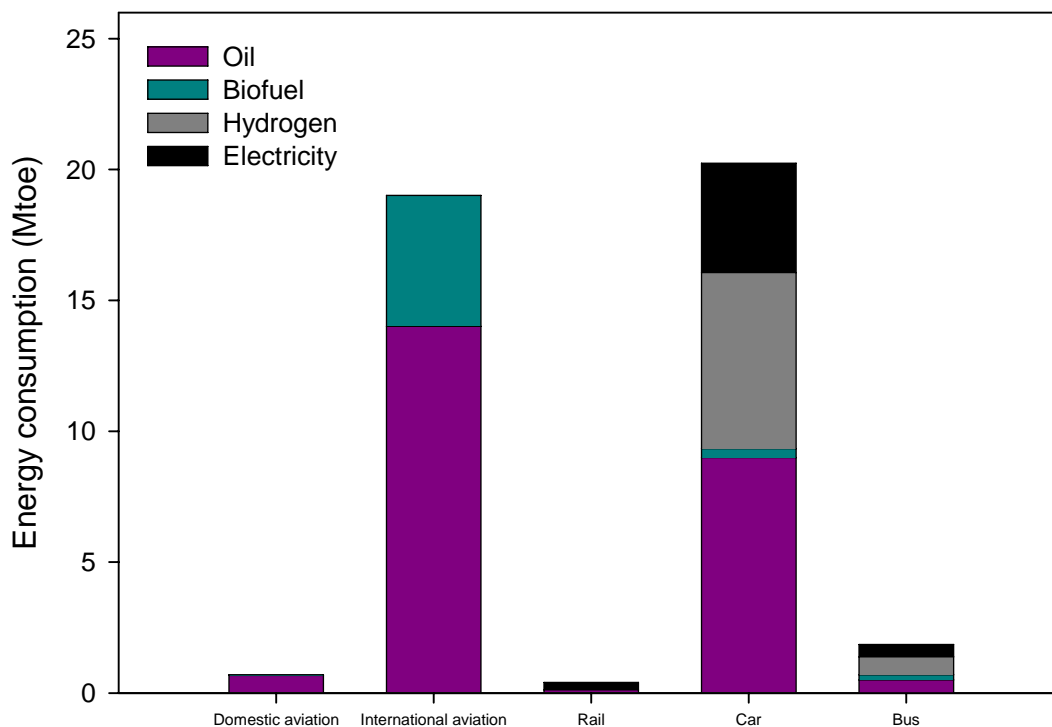
Despite these improvements to fuel efficiency and the use of some alternative fuels within the aviation industry, this sector remains both the most energy intensive and carbon intensive mode of transport.

Clearly, the two scenarios differ in terms of their levels of mobility, and hence *Mobility Plus* has many more planes fuelled by a low-carbon source than *Static Mobility*, to

⁸⁹ Although some stakeholders within the industry indicated that alternative fuels would not be used within the aviation sector prior to 2030, Fischer-Tropsch kerosene produced from biofuel and biodiesel are both considered viable in today's aircraft with some marginal improvements and R&D (Sausen, 2005)

keep within the carbon budget. However, there are also implications for airport infrastructure based on the make-up the airline fleets. Within *Static Mobility*, occupancy rates have increased marginally for both domestic and international flights. Assuming within this scenario that the airline fleets have similar capacity planes to those seen today, international aviation will see a 10% increase in load factor⁹⁰. This increase in load-factor, coupled with the 28% increase in passenger-kilometres, could theoretically be accommodated by increasing landing rates on average by around 17% at existing airports. If, on the other hand, landing rates remained as they are today, this increase in passenger-kilometres would require around 16% more runway capacity.

Figure 6.8: 2030 'Plus' passenger transport fuel split



It is assumed in *Mobility Plus*, that the aviation industry has taken a slightly different route in terms of aircraft fleet, with a trend towards smaller, lighter aircraft for domestic use and higher capacity aircraft for long-haul flights within *Mobility Plus*. In this case, the larger aircraft are reserved for the long-haul flights by placing limitations on their use for medium and shorter journeys. Assuming that the average

⁹⁰ International planes are 80% full in 2004, with an average capacity of around 260 seats. Therefore, increasing the occupancy from 177 to 195 produces a 10% increase in load factor.

aircraft for international aviation has 15% more capacity, and that load factors are increased to 90%, no increase in landing rates on current runways would require a doubling of the number of runways in existence today. If, on the other hand, planes could land on average a third more frequently, then roughly 50% more runways would be required. Clearly, there are additional issues in relation to sustainability that are apparent even with this basic analysis⁹¹.

6.1.2.2 Rail

Within *Static Mobility*, growth in rail travel is moderate, but higher than car and air transport, which, due to the demand management measures described in Section 7, are declining in terms of passenger kilometres. Aside from policies to reduce growth within the domestic aviation sector, the modal shift from domestic aviation to rail travel has been further encouraged through significant improvements to journey times. These improvements have been brought about through, for example, the introduction of larger high-speed trains between major urban centres, including those on the continent, more fuel efficient engine technology and extensive track improvements. The average occupancy on UK trains has also increased from 93 in 2004 to 110 in 2030, resulting in rail travel retaining its position in the transport league table for energy efficiency (Tables 6.1 and 6.6). In relation to infrastructure, if the average train had a capacity of 250 passengers – approximately 7% larger than in 2004, then with a very marginal increase in load factor, there would effectively be less trains travelling on the network than there were in 2004.

Passenger rail travel has been encouraged to grow rapidly within *Mobility Plus*, to provide opportunities for a modal shift to rail from both domestic and international aviation. Double-decker trains have been introduced to increase capacity, but despite higher load factors, and a 30% increase in the frequency of services, 25% more rail network would be required to meet the increase in demand. Fuel efficiency improvements per passenger kilometre are matched by growth within *Mobility Plus*, leading to no increase in energy consumption. Despite the continued use of conventional fuels, rail travel remains the most carbon efficient mode of transport.

6.1.2.3 Road

Road travel is declining in *Static Mobility* through demand management measures to shift car drivers onto trains and buses as well as onto bikes and into walking.

⁹¹ This is based on there being 47 runways in 2004

Consequently, passenger-kilometres in private road transport have declined within *Static Mobility*. This has been brought about by restricting private transport in city centres and providing alternatives such as park and ride schemes, effective school bus systems and car-sharing arrangements by companies. A result of improved car occupancy from 1.6 to 1.8 in 2030, coupled with the demand reduction measures leads to approximately 13% less private road vehicles on the roads. A further consequence of the measures to tackle growth has led to an increase in bus occupancy rates, improving the effectiveness of the bus transport system. In terms of road transport fuels, hydrogen, electricity and to a lesser extent, biofuels are now used widely in both cars and buses. This necessitates a network of multi-fuel filling stations, including those with onsite renewable technologies to produce hydrogen.

Mobility Plus sees a doubling of passenger kilometres for buses and trains, with more moderate increases in car transport, although commuting to work by car is much less popular than in 2004. Alongside measures to curb the growth in car transport, fuel efficiency improvements have been encouraged by 2020 through an extension of the policies outlined in Section 7, pushing drivers towards smaller, lighter, more fuel efficient vehicles. City and town centres are now virtually private vehicle free, with excellent public transport services throughout the nation's urban centres and significant improvements to rural and semi-rural bus routes and services. However, despite an increase from 1.6 to 1.7 in car transport, and measures to reduce growth rates, the number of cars on the roads increases by about 14%. Load factors within public transport have also increased, with buses carrying 15 people per vehicle compared with just 9 in 2004. As a result, more frequent bus services generate around 6% more road use by buses, despite a slightly higher average bus capacity.

Hydrogen is more widely used within this scenario than in *Static Mobility*. Electricity is also successful, with biofuels made unavailable for road transport due to their requirement for the aviation industry, as other alternatives are not viable to bring about decarbonisation.

6.1.3 Long-term

It is clear from Figure 6.9 that carbon emissions have been significantly reduced from all of the transport sectors by 2050. Similarly, there have been marked reductions in energy consumption in all sectors, with the exceptions of aviation within *Mobility Plus* and public road transport in both scenarios. Moreover, buses show the largest relative increases in passenger-kilometres brought about through a modal shift from private to public transport.

Aside from these similarities, the scenarios differ by 2050 on a number of levels. Within *Static Mobility*, although less vehicle kilometres are travelled, they result in the same number of passenger-kilometres, compared with 2004 figures. Whereas, both passenger-kilometres and vehicle kilometres travelled have increased in the *Mobility Plus* scenario. However, both scenarios exhibit degrees of modal shift, which will be described in more detail below. In terms of energy consumption, in the *Static Mobility* scenario, a combination of demand management and fuel efficiency improvements result in transport energy consumption being around half that consumed in the baseline year. Combining these changes with a number of alternative transport fuels, carbon emissions have been reduced to an eighth of 2004 levels by 2050. Energy consumption within *Mobility Plus* is only marginally lower than the baseline year figure, and split roughly equally between private road transport and aviation. Carbon emissions are a fifth of those in 2004 within *Mobility Plus*.

Figure 6.9: 2050 energy consumption and carbon emissions
Passenger transport sectors

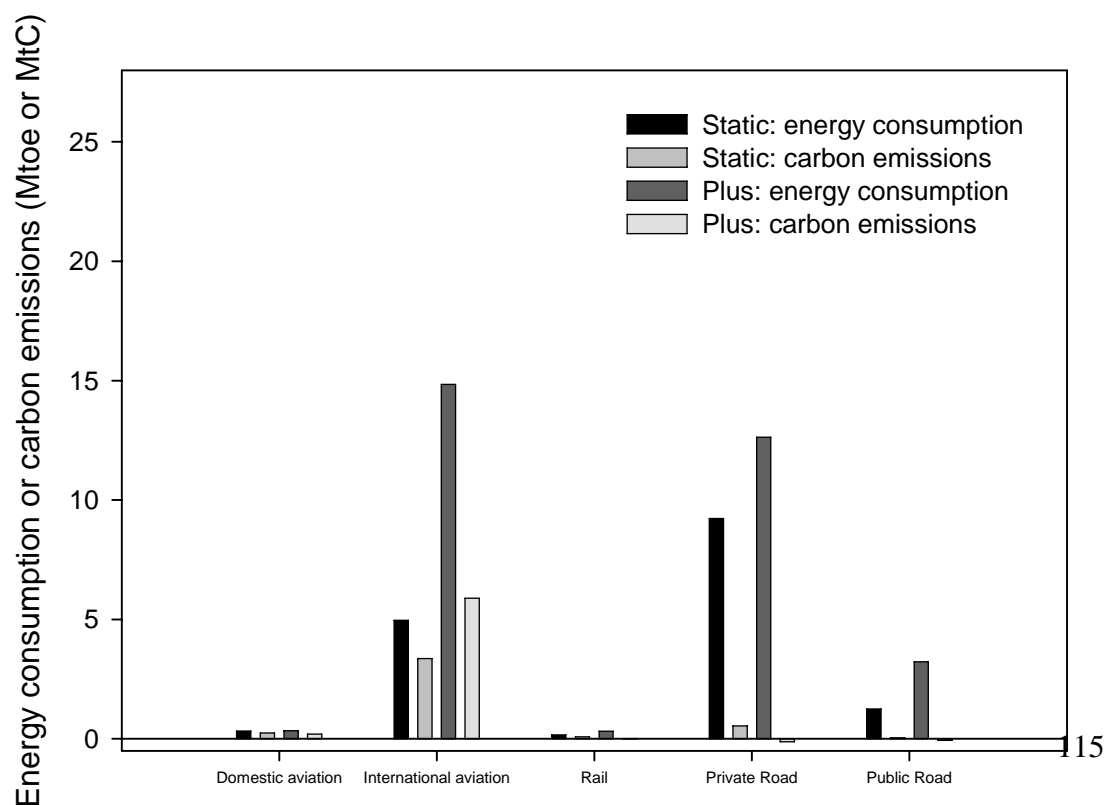


Table 6.8: Summary 2050 data – *Static Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	80	0.1	9.3	0.33	0.24	0.04	0.026
International aviation	200	1.3	261.8	4.96	3.36	0.02	0.013
Rail	120	0.6	71.2	0.16	0.08	0.002	0.001
Private road	1.8	349.0	628.3	9.23	0.54	0.01	0.001
Public road	12	7.4	88.9	1.25	0.04	0.01	0.000
TOTAL		359	1060	15.93	4.26		

Table 6.9: Summary 2050 data – *Plus Mobility*

Mode	Occupancy	Kilometres (Billion)	Pax (Billion)	Energy (Mtoe)	Carbon (MtC)	Energy/Pax (Mtoe/Bill pax)	Carbon/Pax (MtC/ Bill pax)
Domestic aviation	60	0.2	9.8	0.34	0.19	0.03	0.019
International aviation	250	3.1	783.0	14.85	5.89	0.02	0.008
Rail	130	1.5	198.6	0.32	0.01	0.002	0.000
Private road	1.7	639.6	1087.4	12.63	-0.12	0.01	0.000
Public road	20	14.6	291.6	3.23	-0.06	0.01	0.000
		659	2370	31.37	5.91		

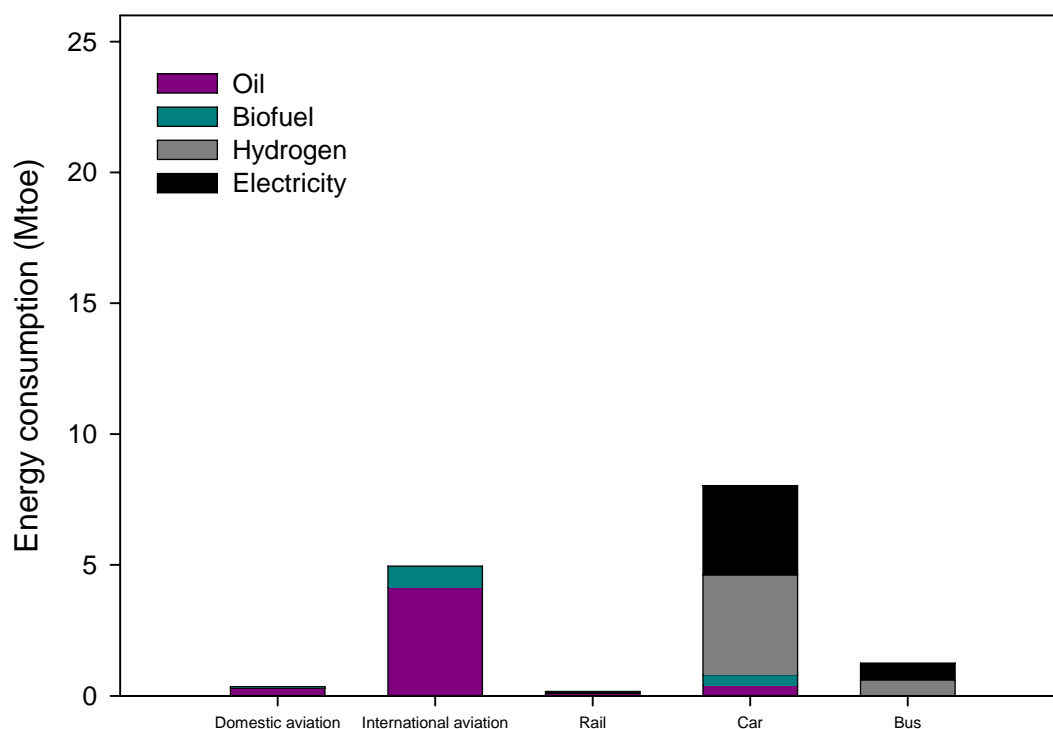
6.1.3.1 Aviation

By 2050, the passenger-kilometres travelled by domestic aviation have decreased in the *Static Mobility* scenario. This indicates demand management measures that have encouraged further modal shift onto cars and trains primarily by business travellers and those who have, in the past, preferred to travel medium distance journeys by aircraft. Continued engine efficiency improvements, coupled with better air traffic management and higher load factors on planes similar in size to current models have resulted in a lower energy consumption than in the baseline year. Carbon emissions are also reduced to around a third of the 2004 figure.

Domestic aviation passenger kilometres are also no higher in 2050 than they are in 2004 within the *Mobility Plus* scenario, with a continuation of effective policies to reserve airport capacity for international trips. As aircraft for domestic use have continued to become lighter, smaller and more fuel efficient, occupancy rates have declined to 60 people per plane compared with 71 in 2004. This leads to an overall increase in the numbers of kilometres being travelled by aircraft, despite the same number of passenger kilometres. Overall, energy consumption has decreased, as

have carbon emissions, although this mode of transport continues to be the most carbon intensive.

Figure 6.10: 2050 'Static' passenger transport split



Passenger-kilometres within *Static Mobility* are a fraction smaller than in the baseline year for international aviation due to a small modal shift onto cars and trains, particularly for leisure travel around Europe. In addition to demand management and continued fuel efficiency improvements, the carbon budget has required a small increase in the use of bio-kerosene within this scenario. As a consequence, this sector now emits a third of the carbon emissions associated with the baseline year and consumes half of the 2004 energy figure. Whilst most planes are similar in size to current models, the amount of fuel consumed per passenger-kilometre is improved through increased load factors. Many new airframes that started to enter the market in 2030 are now spread throughout a considerable number of nations' fleets, incorporating all of the latest low-energy technologies. Taking both these factors into account, the industry has continued to improve its overall fuel efficiency per passenger kilometre at rates at the upper end of those envisaged in 2004. As there are no more passenger-kilometres being flown in this scenario compared with the baseline year, no additional infrastructure is required. Furthermore, improved air

traffic management systems have relieved congestions at the UK's major hub airports.

The aviation industry within the *Mobility Plus* scenario is significantly larger in 2050 than in 2004 despite demand management measures to curb growth from 7% per year in 2004 to less than 1% per year between 2030 and 2050. By 2030, and indeed 2050, the attitude within the aviation industry has altered significantly in relation to alternative fuels, due to the national and European drive towards eliminating carbon dioxide emissions, as described in Section 7. Bio-kerosene, and bio-diesel are therefore widely used to comply with the nation's drive towards a low-carbon economy, contributing to 50% of aviation fuel by 2050.

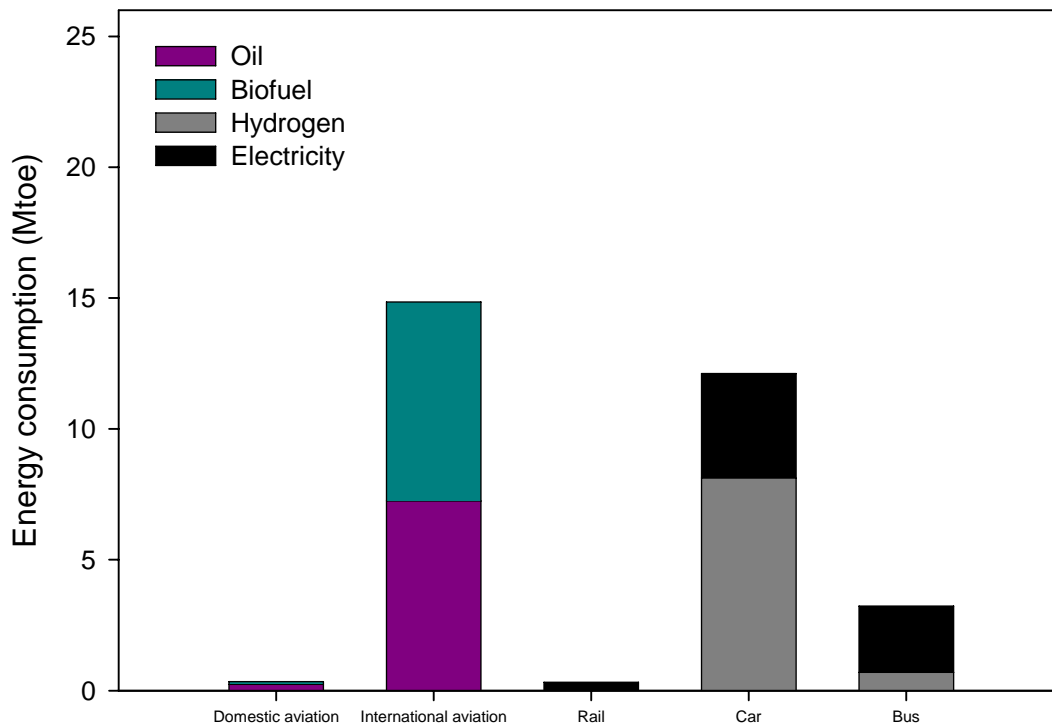
In the same way that the current aviation industry focuses on improving fuel efficiency to stay profitable, coupled with the strong drive to eliminate human induced carbon dioxide emissions, aircraft fuel efficiency continues to improve at around 2% per year. This is brought about through more fuel efficient engines, lighter aircraft with more aerodynamic airframes and the use of appropriate aircraft for different flight lengths. For example, restricting the use of the largest aircraft to long-haul flights and ensuring that load-factors are around 95%. Further developments include a shift away from using aircraft for shorter flights, such as between Manchester and Paris, and increases in plane occupancy to 250 from 177 in 2004. As a consequence, although energy consumption is a little higher in 2050 than in 2004, there are three times more passenger kilometres but about 40% less carbon emissions. To accommodate the additional passenger-kilometres being travelled, increased capacity and load factors coupled with a doubling of the landing rate, would result in the need for around 5% more airport capacity. However, without improvements to landing rates, a doubling of runway capacity would be needed. Both changes have sustainability implications.

6.1.3.2 Rail

Within *Static Mobility*, rail transport has seen its market expand due to reduced domestic air travel, and its increased importance for short- to medium-distance commuting (ie 10-20 miles). Capacity has continued to rise with load factors also increasing, improving energy consumption further. Consequently, total energy consumption by rail is minimal, and carbon emissions close to zero.

Larger, double-decker trains are commonplace within *Mobility Plus*, contributing to a four-fold increase in passenger kilometres, but only a doubling in vehicle kilometres from 2004 levels. Capacity has therefore been stretched, and despite good use of existing infrastructure and more than a doubling in the frequency of trains, around 10% more track is needed. Much of this infrastructure increase has been through the redevelopment of old disused track. The majority of trains are now electric, and therefore, as a consequence of the zero-carbon grid within *Mobility Plus*, carbon emissions from rail are less in this scenario than in *Static Mobility*.

Figure 6.11: 2050 'Plus' passenger transport fuel split



6.1.3.3 Road

Demand management within the integrated transport strategy eluded to in Section 7 has led to a significant modal shift within passenger transport to eliminate growth within the private transport sector in the *Static Mobility* scenario. Consequently, private road transport has declined by 60 billion passenger-kilometres from 2004 levels and two thirds of these passenger-kilometres have been shifted to buses, reflecting the significant decline in commuting within largely car-free cities. As a result of this, and continued fuel efficiency improvements, energy consumption within private transport has decreased by around 65% from 2004 levels. Furthermore, the

shift away from the dominance of petrol-fuelled vehicles, to predominantly fuel-cell or electric cars and buses has delivered significant decarbonisation, reducing emissions from 20 MtC in 2004 to just 0.5 MtC in 2050.

Within the *Mobility Plus* scenario, 400 billion more passenger-kilometres are being travelled on roads, an increase of 2/3 on 2004 figures. In addition, this sector accounts for an increase of 200 billion vehicle kilometres, i.e. 50% more than in 2004. This increase is smaller than that for passenger-kilometres due to a small increase in car occupancy. Unless car sizes increase, this would in turn result in around 50% more cars on the roads. Public road transport is particularly focussed in city centres and has increased six-fold compared with the baseline year. However, increasing the occupancy of the vehicles from 9 to 20 results in just three times more kilometres being travelled. If buses remain the same size as they are today, this would result in a doubling of the number of buses on the roads.

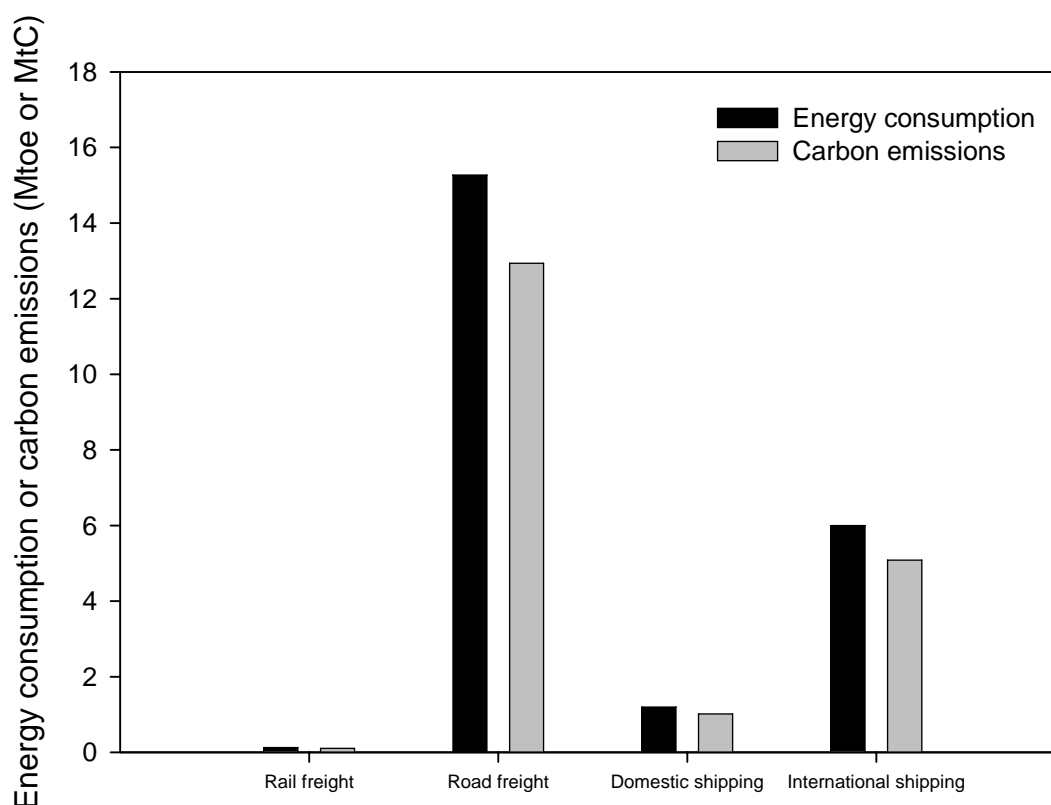
Despite these increases in mobility, energy consumption by private road transport is approximately half that of the baseline year, and carbon emissions from cars are actually contributing to a reduction in carbon dioxide. This is due to a large proportion of their energy being derived from a lower than zero-carbon electricity grid⁹². Although energy consumption in bus transport has doubled, electricity use within this sector also contributes to a carbon sink. Biofuels are no longer used within the land transport sectors as carbon reduction policies have reserved biofuels for the aviation industry as no other alternative fuels are deemed viable.

⁹² Within *Mobility Plus*, the grid is zero-carbon, but also incorporates carbon capture and storage from co-fired biofuel/coal power stations. This results in an effective overall carbon sink for electricity use generated by the national grid.

6.2 Freight transport

Freight transport is another broad sector that currently contributes to a significant portion of the UK's carbon dioxide emissions. Energy consumption by road freight is the largest energy consuming sector of all freight modes, with international shipping also consuming a significant amount of energy. As shown in Figure 6.13, oil and more specifically diesel oil, clearly dominates freight transport fuels in 2004.

Figure 6.12: Baseline energy consumption and carbon emissions
Freight transport sectors



The following section describes the scenarios in relation to developments within the freight industry in terms of short-, medium- and long-term time frames. However, as in previous sections, prior to the short-, medium- and long-term summary data, Tables 6.10 and 6.11 illustrate the annual average changes in growth and fuel efficiency⁹³ between 2004 and 2050, as well as some recent trend data. These tables will be referred in the subsequent sections, but are presented here to give the reader a flavour of the developments to come. Note that 'Growth' refers to changes to the number of freight-tonne-kilometres, and 'Efficiency' refers to the energy efficiency per freight-tonne-kilometre, and is therefore influenced not only by

⁹³ Fuel efficiency is per freight tonne kilometre

technological changes to a particular vehicle, but also by organisational changes in relation to the amount of freight that can be carried, and where it is being carried from and to.

Figure 6.13: Baseline freight fuel split

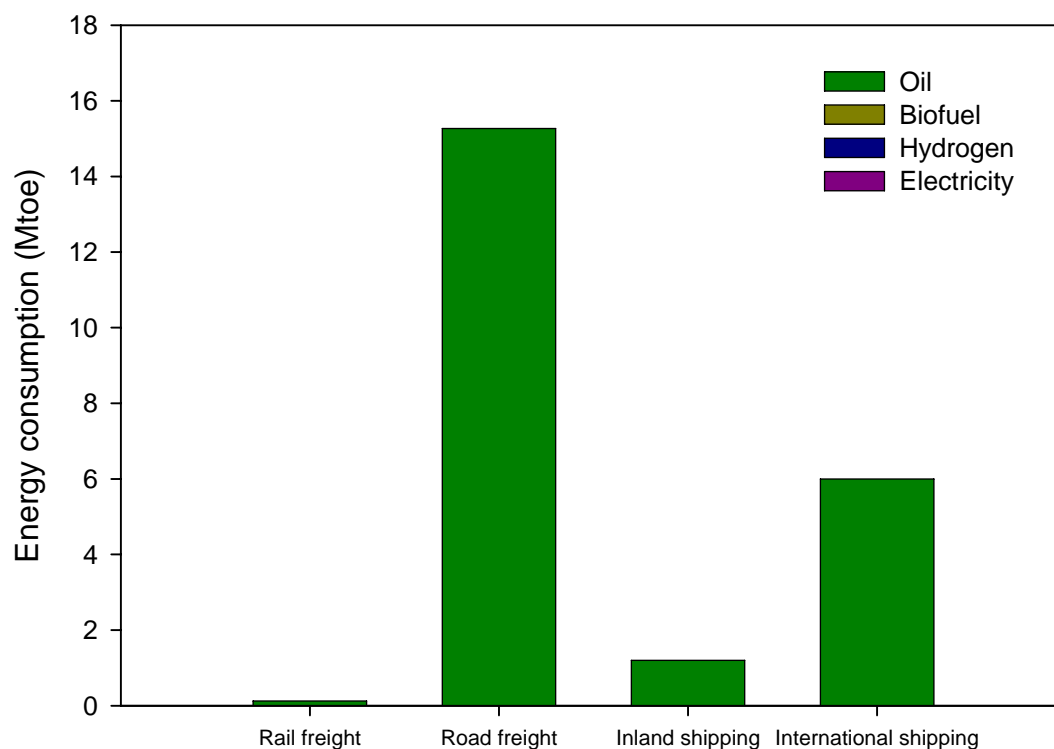


Table 6.10: Scenario summary tables for growth and efficiency – *Static Mobility*

Mode	Parameter	Recent trend	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Rail freight	Growth	3.6%	0.2%	-0.1%	0.0%	0.0%	0.0%
	Efficiency	-. ⁹⁴	-0.8%	-1.3%	-1.7%	-2.1%	-2.3%
Road freight	Growth	0.1%	0.8%	0.9%	0.9%	0.8%	0.6%
	Efficiency	1.2%	0.0%	-1.5%	-1.5%	-1.8%	-2.0%
Inland shipping	Growth	1.1%	2.0%	1.2%	1.2%	1.6%	1.7%
	Efficiency	-0.8%	0.0%	-0.6%	-1.0%	-2.2%	-3.0%
International shipping	Growth	3% ⁹⁵	2.5%	1.9%	1.8%	1.9%	2.1%
	Efficiency	-. ⁹⁶	0.0%	-1.5%	-1.8%	-1.8%	-1.8%

⁹⁴ Like rail passenger transport, the historical efficiency improvement figures are only available for the rail industry as a whole, rather than broken down into passenger and freight.

⁹⁵ This figure is based on the change in freight being loaded and unloaded in the UK between 2003 and 2004

⁹⁶ No data available for historical energy consumption

Table 6.11: Scenario summary tables for growth and efficiency – *Static Mobility*

Mode	Parameter	Recent trend	2004-2010	2010-2020	2020-2030	2030-2040	2040-2050
Rail freight	Growth	3.6%	0.3%	0.7%	1.2%	1.3%	1.3%
	Efficiency	⁹⁷	-0.8%	-1.6%	-1.8%	-1.8%	-1.8%
Road freight	Growth	0.1%	0.8%	0.9%	0.9%	0.9%	0.9%
	Efficiency	1.2%	0.0%	-2.0%	-1.8%	-1.5%	-1.5%
Inland shipping	Growth	1.1%	1.0%	1.3%	1.5%	1.6%	1.9%
	Efficiency	-0.8%	0.0%	-0.9%	-1.5%	-1.8%	-2.5%
International shipping	Growth	3% ⁹⁸	2.4%	2.2%	2.0%	1.8%	1.8%
	Efficiency	⁹⁹	0.0%	-2.0%	-1.8%	-1.6%	-1.5%

As the scenarios focus upon the impact of varying amounts of passenger mobility, the freight transport within the two scenarios has been kept similar to avoid complicating the picture with differences in other sectors.

⁹⁷ See footnote 18

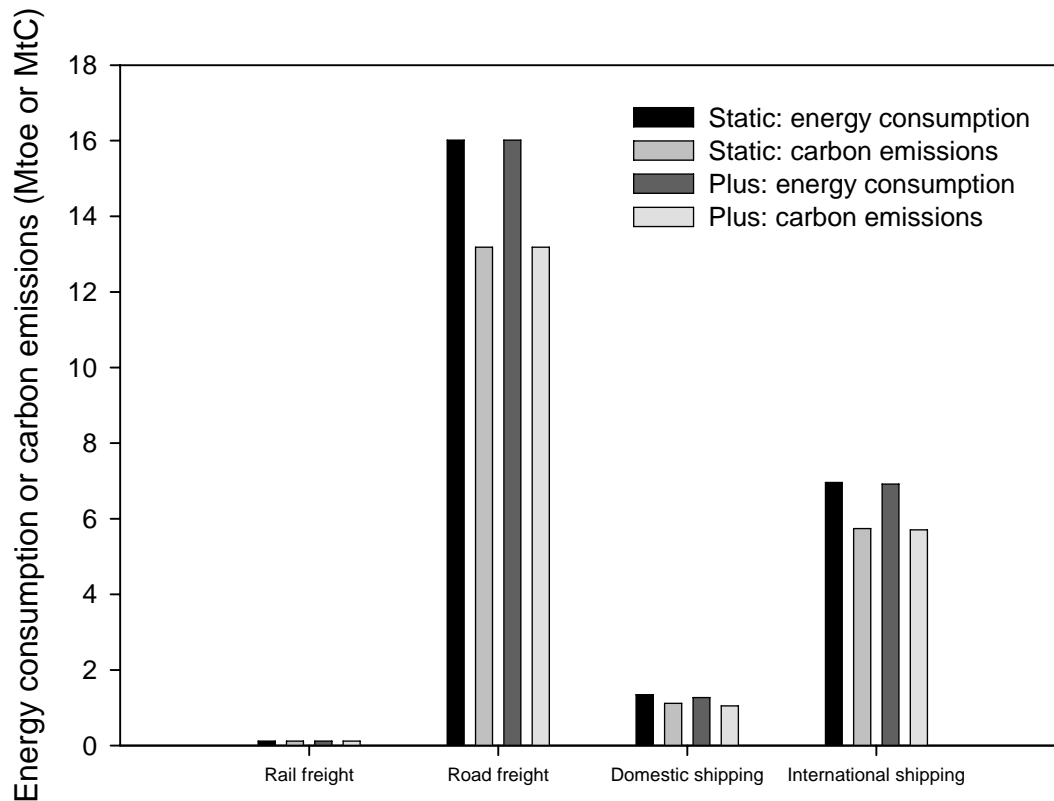
⁹⁸ See footnote 19

⁹⁹ See footnote 20

6.2.1 Short-term

Energy consumption and carbon emissions are only marginally different in 2010 compared with 2004. Road freight continues to dominate, with shipping consuming approximately half as much energy as road.

Figure 6.14: 2010 energy consumption and carbon emissions
Freight transport sectors



In terms of freight transport fuels, both scenarios see small inroads for biodiesel, particularly in road freight, as shown in figures 6.15 and 6.16.

Figure 6.15: 2010 'Static' freight transport fuel split

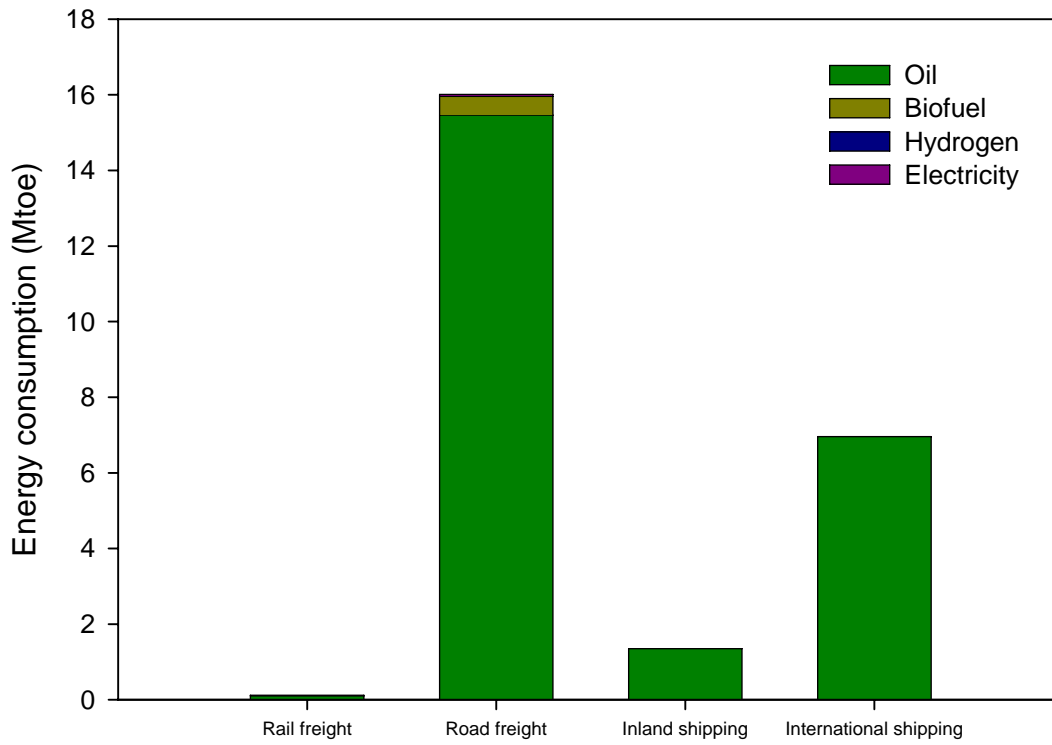
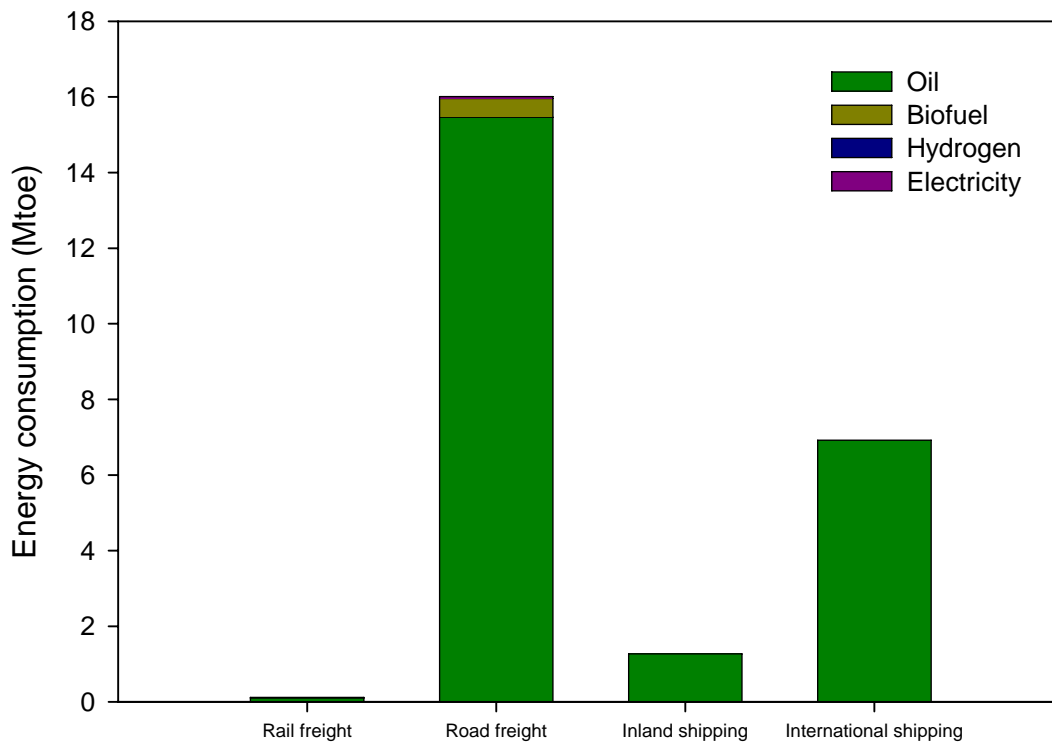


Figure 6.16: 2010 'Plus' freight transport fuel split

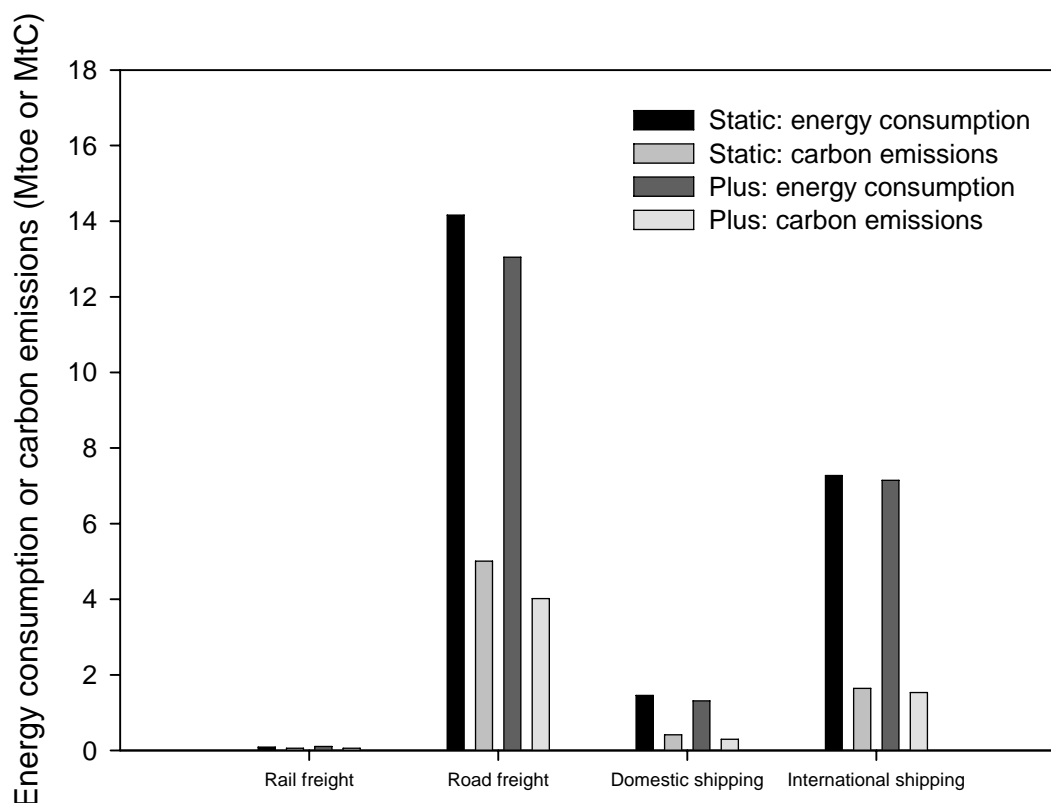


Road freight continues to grow in both scenarios at lower rates than the more long-terms trends seen between 1990 and 2004, or 1980 and 2004 for example, but slightly higher than rates seen in more recent years. This is the result of a buoyant economy, and the continued increase in international shipping, bringing more goods to the UK that require transportation by road, rail and boat to their final destinations. Fuel efficiency within road freight has had a very poor record in the past. Consequently, efforts are being made to reverse this trend, and by 2010, the average fuel efficiency change has reached zero as an annual average. Moderate increases in rail freight in both scenarios are seen by 2010, coupled with a similar improvement in fuel efficiency per freight-tonne-kilometre. This results in no change to energy consumption within rail freight. As a consequence of this, and no change to the fuel used for rail freight, carbon emissions remain the same.

6.2.2 Medium-term

The difference between energy consumption and carbon emissions is more marked by 2030 than in 2010, with a necessary improvement to carbon intensity across the various modes of freight transport. Road freight continues to dominate however, in terms of energy consumption.

Figure 6.17: 2030 energy consumption and carbon emissions
Freight transport sectors



Electricity, hydrogen and biofuel are widely used for freight transport for both scenarios by 2030, with a larger proportion of biofuel being used in *Static Mobility*. This is a knock-on effect of the availability of biofuels for transport within this scenario in contrast to *Mobility Plus* where biofuel is more concentrated in the aviation sector. The energy efficiency trends encouraged from 2010 within the road freight sector have continued, and by 2030 fuel efficiency gains are outstripping growth. Coupling this with the use of alternative fuels leads to a significant reduction in the carbon emissions from road freight. Although rail freight has continued to grow, the pace of expansion seen in earlier years has not been maintained. This is due to a rapid expansion of rail travel for passenger purposes, resulting in a more frequent use of lines and limiting the amount of freight that can be moved around the network during the day.

Figure 6.18: 2030 'Static' freight transport fuel split

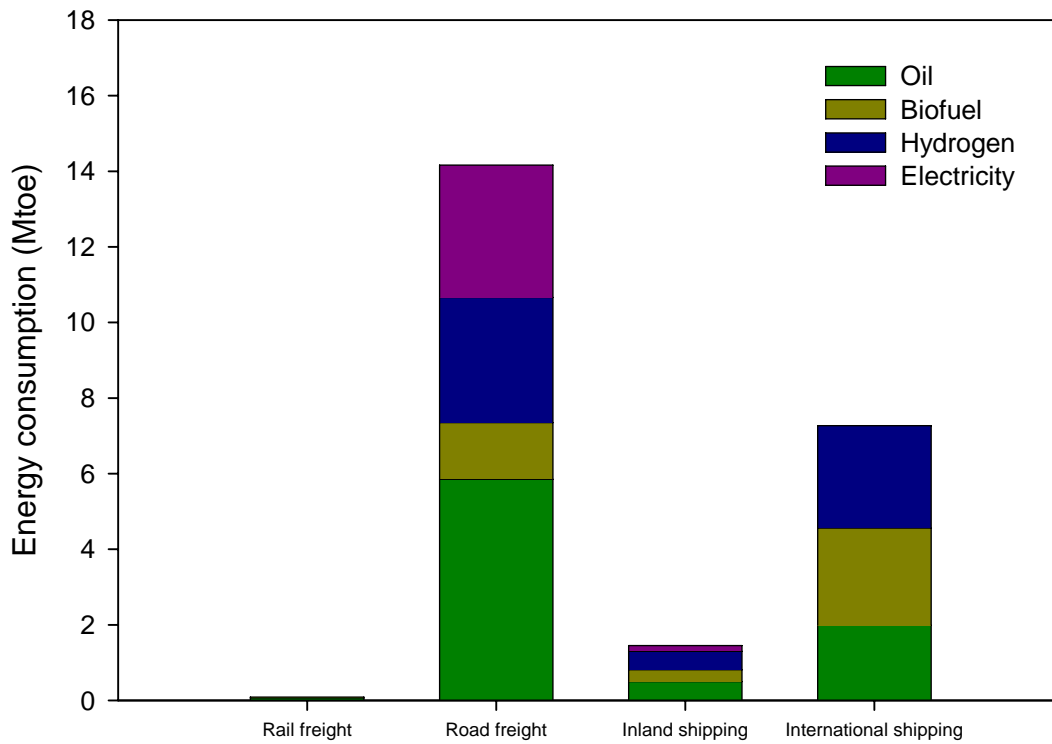
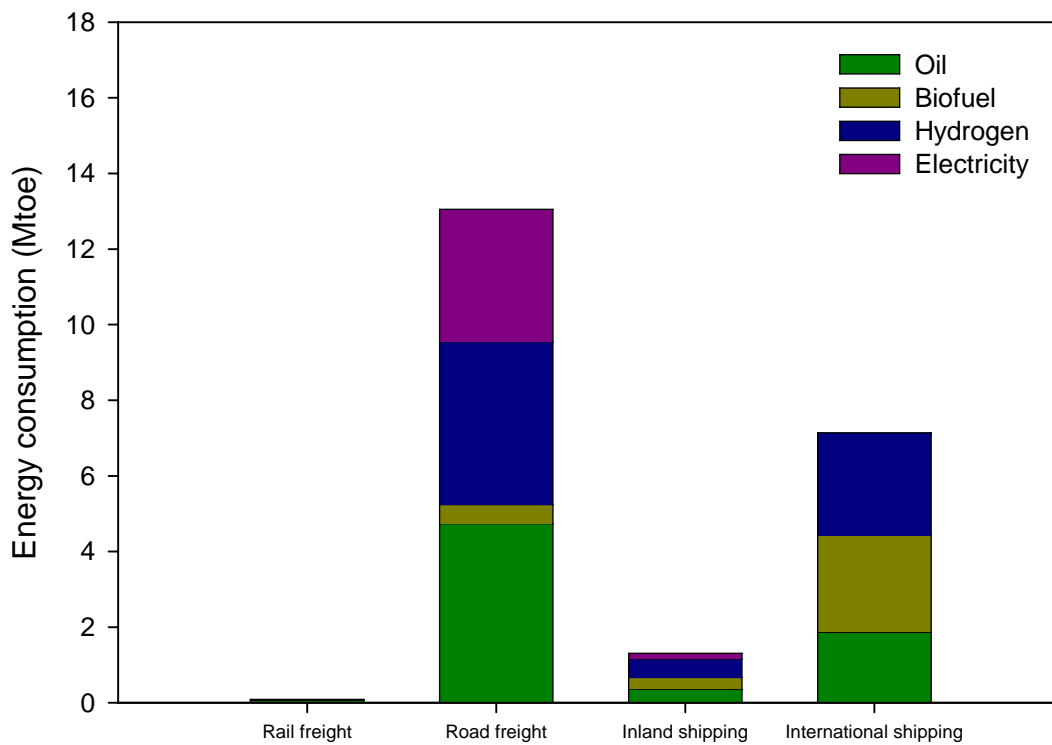


Figure 6.19: 2030 'Plus' freight transport fuel split



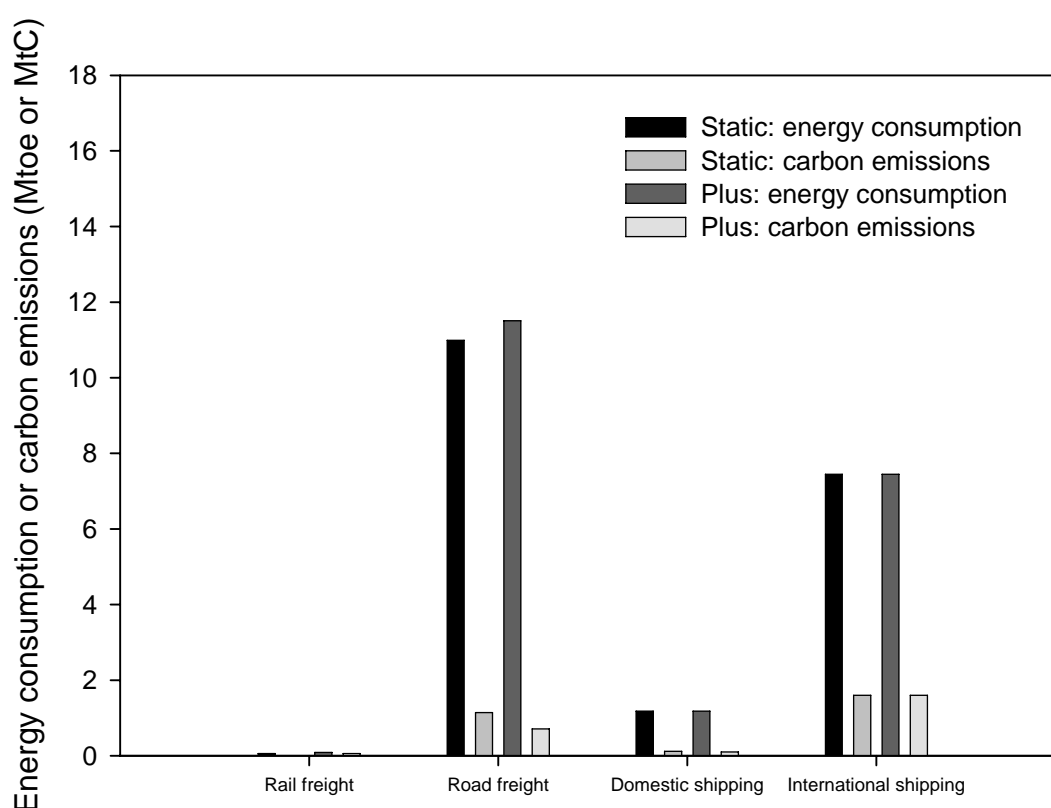
International shipping has continued to grow in both scenarios, with higher rates of imports in *Mobility Plus* resulting in slightly more freight-tonne-kilometres than in *Static Mobility*. Due to the recognition of the importance of this industry in relation to the climate change challenge, high rates of energy efficiency improvements are required in both scenarios. These have been brought about through engine improvements and more efficient loading practices.

A new innovation within inland shipping is the use of electrically powered narrow boats to transport less-time dependent lighter-weight goods such as fabrics and foam. Hydrogen has also made inroads into both international and domestic shipping, requiring hydrogen production infrastructure in other nations.

6.2.3 Long-term

The gap between energy consumption and carbon emissions continues to widen, as shown in Figure 6.19, resulting in a very low-carbon freight network by 2050. Despite consuming more energy in absolute terms, carbon emissions from road freight are lower than those from international shipping by 2050. This is primarily because of the continued use of oil by a proportion of the non-UK fleet. International and consequently inland shipping have maintained strong growth during the period between 2030 and 2050, as many goods continue to be manufactured overseas.

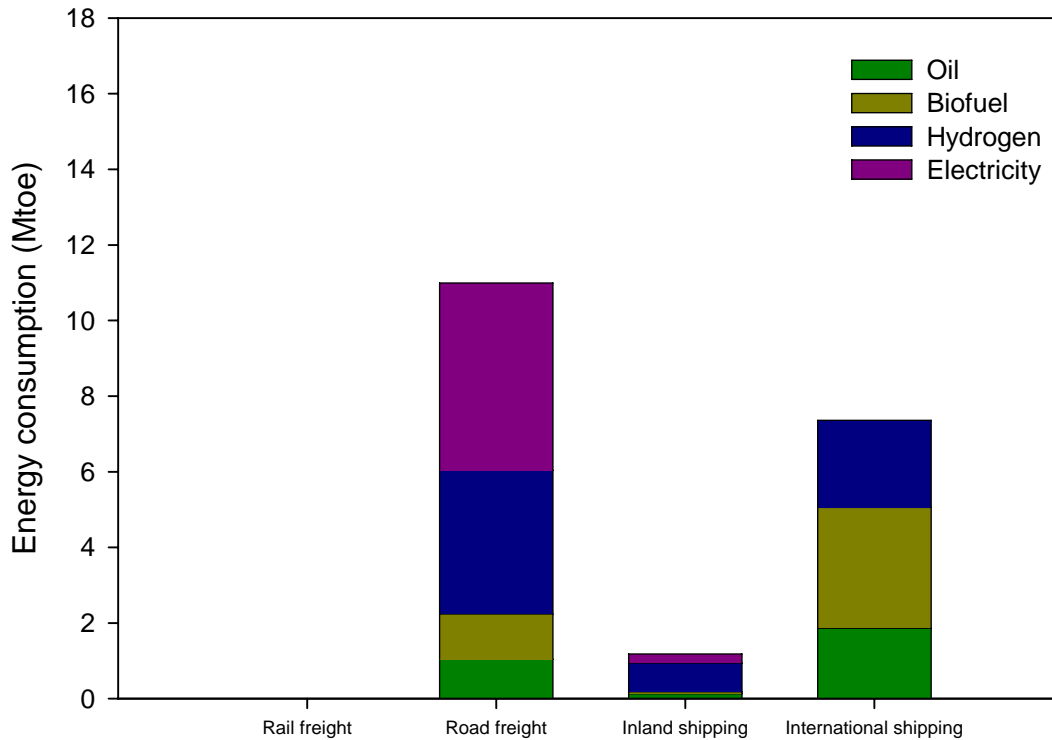
Figure 6.20: 2050 energy consumption and carbon emissions
Freight transport sectors



As a result of improved practices, for example, connecting small distribution hubs to appropriate transport networks, rail freight transport has reached a plateau within the *Static Mobility* scenario with road freight growing slowly. Whereas, within *Mobility Plus*, the larger rail infrastructure, much of which has been redeveloped to improve passenger services, has allowed provided additional capacity for rail freight. Previously unused, but existing rail tracks into old factory sites have been redeveloped and renovated, and new spurs built to boost the opportunities for transporting a variety of goods by rail. As efficiency improvements continue to

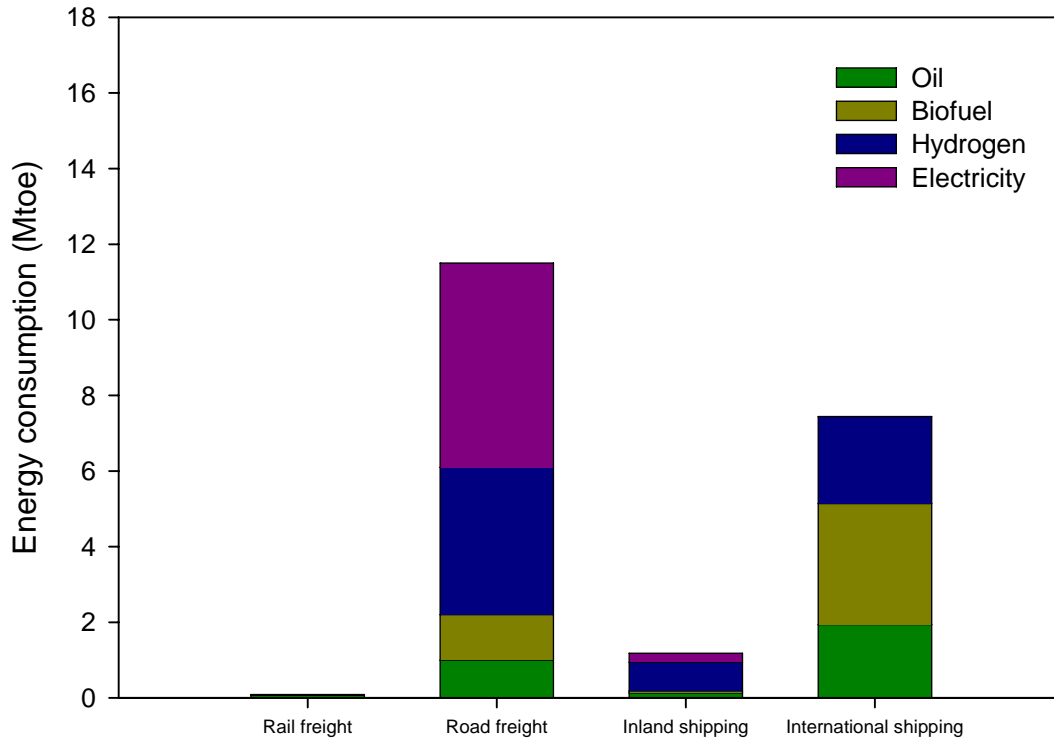
outstrip growth, energy consumption has further reduced by 2050, and carbon emissions are now insignificant from this sector.

Figure 6.21: 2050 'Static' freight transport fuel split



The biggest change to fuels used within the scenarios by 2050 is the move away from oil as shown in figures 6.21 and 6.22. Energy consumption overall is smaller by 2050 than in 2030, which means that although less oil is being used, the amount of alternative fuels has declined since 2030. This reflects the continued improvements to fuel efficiency per freight-tonne-kilometre through new efficient road and ship fleets, sensible routing and ensuring high cargo load factors. The fact that around a quarter of international shipping continues to be fuelled by diesel oil means that, as already illustrated in Figure 6.19, this sector accounts for the largest proportion of carbon emissions from freight within both scenarios. Interestingly, the carbon emissions from road freight within *Mobility Plus* are lower than in *Static Mobility* despite a larger energy consumption, and, at first sight, similar fuel sources. This is a result of the lower than zero-carbon grid for electricity in *Mobility Plus*⁹². Consequently, the electricity use is contributing to a reduction in the overall carbon emissions from the freight sectors.

Figure 6.21: 2050 'Plus' freight transport fuel split



6.3 Summary

Within this section, the scenarios have been described in relation to the various transport sectors, with particularly emphasis on passenger-transport, due to the nature of the research conducted. Some clear conclusions can be drawn from the analysis. To achieve the carbon reduction necessary for the UK to play its part in stabilising atmospheric carbon dioxide concentrations at around 450ppmv, both land and air transport must significantly decarbonise. In 2004, passenger road transport was responsible for around 22MtC, road freight for 13MtC and aviation around 10MtC – a total of 30% of total UK carbon emissions. By 2050, these figures are reduced to 0.5MtC, 1MtC and 3.5MtC respectively in the *Static Mobility* scenario, and 0MtC, 0MtC and 6MtC in *Mobility Plus*. No one measure is responsible for the reductions, but rather a comprehensive package of demand management, large incremental improvements and/or step changes in vehicle efficiency and a new low-carbon fuel chain.

In particular, the aviation industry has had to take responsibility in reducing the impact of transport emission on climate, with significant reductions in growth rates over the 46 year time period, in both scenarios. Fuel efficiency improvements at rates higher than those expected by the industry in 2004, coupled with the use of biofuels to replace some oil-based kerosene were also deemed necessary, if the UK is to succeed in its quest to decarbonise by 90% by 2050.

Car transport has needed to make a similar transformation. There are less passenger-kilometres being travelled by 2050 within *Static Mobility*, with significant modal shift onto buses and trains. Demand management has also been necessary within *Mobility Plus* to reduce the impact on transport infrastructure. Within both scenarios, public transport has grown to accommodate the shift away from domestic aviation and car transport.

Finally, the transport sector has made a radical shift from oil-based fuel to a system dominated by hydrogen and electricity. As such, and due to constraints on the biofuels available, a nation-wide hydrogen infrastructure is required by 2030, in tandem with charging stations for electrically powered vehicles.

The developments in transport required to stay within the carbon reduction trajectory in both scenarios are extremely challenging both in terms of demand reduction and innovation. However, *Static Mobility* and *Mobility Plus* illustrate two possible routes to the significant and urgent decarbonisation necessary.

7. Policy

Sections 5 and 6 set out two possible scenarios for constraining cumulative CO₂ emissions between now and 2050 to 4.6GtC. This section discusses the various policy instruments that can be implemented to bring about such scenarios.

In order to implement policy instruments to constrain cumulative emissions, public support is required for the very large emissions reductions such constraint implies. And in these scenarios, public support results from a firm cross-party consensus on the need to limit cumulative emissions to 4.6GtC. Given that such a cross-party consensus is at the heart of these scenarios, this section begins with a discussion on how it might emerge.

7.1 UK and EU consensus

The Government's recently published "Climate Change: The UK Programme 2006" notes that

the more recent work of the IPCC suggests that a limit closer to 450ppm or even lower, might be more appropriate to meet a 2°C stabilisation limit.¹⁰⁰

And as a member of the Council of the European Union, the Labour Government has endorsed the Council conclusion that

reduction pathways by the group of developed countries in the order of 15-30% by 2020 and **60-80% by 2050** compared to the baseline envisaged in the Kyoto Protocol should be considered.¹⁰¹

The Liberal Democrats, Conservatives, Plaid Cymru and the SNP also accept the need for large emissions reductions and have signed a joint statement which accepts that

a cut in both global and UK emissions of **at least 60% by 2050** is necessary.¹⁰²

¹⁰⁰ Defra (2006, p13)

¹⁰¹ CEU (2005, p5). Emphasis added.

¹⁰² Lib Dems (2006). Emphasis added.

Under the scenarios set out in Section 5 and 6, the various political parties build on this cross-party understanding of the need for emissions reductions of 60% or more by 2050 and a cross-party consensus quickly emerges around the cumulative emissions budget of 4.6 MtC and the associated emissions reduction trajectory set out in Figure 2.1.

This UK consensus leads to intense lobbying within the EU for the adoption of similar cumulative emissions targets. Given the concern over climate change in many member states, the UK is very much pushing at an open door and there quickly emerges an EU-wide consensus that very large emissions cuts are needed, and needed quickly.¹⁰³ This EU consensus leads, in the words of the government, to concerted international diplomacy in an attempt to

build consensus on the scale of action needed to stabilise the climate and avoid dangerous climate change, and build on the progress made at the G8 Summit in Gleneagles and the Montreal climate change conference to strengthen the international regime.¹⁰⁴

7.2 Building public support

A high level of public support for the very large emissions cuts required by 2050 is a prerequisite of support for any suite of policy instruments put in place to ensure these cuts are achieved. Hence, the main political parties, both in the UK and throughout Europe make concerted efforts to raise public awareness of, and generate public support for the very large emissions cuts required. Climate change is a frequently recurring theme in political speeches and party-political broadcasts, and the Government makes use of various communication channels – TV and radio, the web, billboard posters, printed literature etc - to drive the climate message home.

7.3 Government: reorganisation and legislation

In recognition of the seriousness of the emissions reduction task ahead, the Government appoints a Secretary of State for Climate Change. Sitting in the Cabinet, the minister is responsible for ensuring genuine “joined-up government” on climate

¹⁰³ One could, of course, propose a scenario in which there is an absence of an EU-wide consensus and the UK “goes it alone”. However such a scenario is problematic as (1) the UK’s stringent emissions reductions could put it at a (severe) competitive disadvantage in relation to the rest of Europe and (2) a European consensus on the need for deep and urgent reductions action is, arguably, a necessary step to achieving international consensus.

¹⁰⁴ Defra (2006, p4)

change, co-ordinating activity both across central Government departments and between the various layers of government within the UK. A Cabinet Committee on climate change is created on which representatives of two main opposition parties are invited to sit.

Given the importance of transport in these scenarios, an truly *integrated* transport strategy is required. Hence the Department for Transport is renamed the Department for Integrated Transport and the Department is the Secretary of State's sole ministerial responsibility - unlike today, when the minister is also Secretary of State for Scotland. A Minister for Integrated Transport and Climate Change is appointed within the Department, who not only works closely with the Secretary of State for Integrated Transport but also with the Secretary of State for Climate Change.

In order to demonstrate its commitment to tackling emissions reduction, the Government enshrines the emissions reductions required under the scenarios in statute with the passing of the Greenhouse Gas Emissions Reduction Bill.¹⁰⁵ Reflecting the cross-party consensus on cumulative emissions, all MPs other than a very few diehard climate change sceptics vote for the bill.

7.4 Policy instruments and approach

Having created a political environment conducive to the implementation of policy instruments, an appropriate suite of instruments must be chosen from the array available. The International Energy Agency (IEA) divides policies for the reduction of greenhouse gas emissions into six types, as set out in Table 7.1.¹⁰⁶ Table 7.2 provides examples of these six policy types that have been implemented in the UK and Europe.

¹⁰⁵ This Bill is similar to the Climate Change Bill supported by Friends of the Earth and others.

¹⁰⁶ IEA (200

Table 7.1: IEA classification of policies for reduction of greenhouse gas emissions

Policy Type	Classification
Fiscal	Taxes (tax, tax exemption, tax reduction, tax credit) Fees/charges, refund systems Subsidies (transfers, grants, preferential loans)
Tradable permits	Emissions trading Green certificates Project-based programmes (including CDM and JI)
Regulatory instruments	Mandates/standards Regulatory reform
Voluntary agreements	“Strong” “Weak”
Research, development And demonstration (RD&D)	Research programmes Technology development Demonstration projects Technology information dissemination
Policy process and Outreach	Advice/aid in implementation Consultation Outreach/information dissemination Strategic planning Institutional development

Table 7.2: UK and EU examples of policies for reduction of greenhouse gas emissions

Policy Type	UK/EU examples
Fiscal	Fuel Duty Escalator Climate Change Levy Energy Efficiency Commitment
Tradable permits	United Kingdom Emissions Trading Scheme (UK ETS) European Union Emissions Trading Scheme (EU ETS)
Regulatory instruments	Building regulations Energy Efficiency (Fridges and Freezers) Regulations (1997)
Voluntary agreements	Climate Change Agreements Agreement on Vehicle Emissions (140g/km)
Research, development And demonstration (RD&D)	The Technology Programme (DTI) UKERC Tyndall Centre
Policy process and Outreach	Energy Savings Trust activities Carbon Trust activities EU energy label for appliances

The first two types of policies in Table 7.1 are referred to here as “price instruments” and the remaining four as “non-price instruments”.¹⁰⁷ The general policy approach adopted here is that every sector should, at the earliest opportunity, be subjected to some sort of price instrument i.e. an emissions trading scheme or a carbon tax. Whilst trading schemes cap emissions *directly*, taxes aim to cap emissions *indirectly* through the mechanism of price. However, given the uncertain relationship between price increases and emission reductions, it is not guaranteed that taxes will precisely achieve a particular emissions target or cap. On the other hand, arguably, taxes can be put in place more quickly and easily than emissions trading schemes.

Capping emissions by way of emissions trading or taxes, will encourage behavioural changes (e.g. switching off lights), greater adoption of existing energy efficient demand-side technologies (e.g. compact fluorescent light bulbs), and innovation to develop both new energy efficient demand-side technologies (e.g. LED lights) and energy-efficient and low/zero-carbon supply-side technologies (e.g. electricity from biomass CHP to power the LEDs). As a 2003 Carbon Trust report on innovation notes:

The improved understanding of the innovation process...strengthens, not weakens, the arguments for public policy to...internalise the carbon externality, through a carbon tax or emissions trading scheme. It is clear that ‘getting the prices right’ in this way would greatly improve the incentives for low-carbon innovation.¹⁰⁸

However, it is argued here that price instruments alone are not sufficient but should be implemented alongside non-price instruments so as to drive forward the development of energy efficient technologies on the demand-side, and energy efficient and low- and zero- (LZC) carbon technologies on the supply-side.

It is generally accepted that any mix of price and non-price instrument should be one that fares well when assessed against the three criteria of *effectiveness* (does the mix allow the chosen emissions target to be met?), *equity* (does the mix reduce

¹⁰⁷ This terminology is derived from Krause (1996). Taxes are clearly price instruments and as, in economic theory, trading and taxes are seen as equivalent, trading is also included under this label. Non-price instruments are those whose influence is not dependent upon directly changing the price of carbon.

¹⁰⁸ Foxon (2003, p18)

emissions in a fair manner?) and *efficiency* (does the mix reduce emissions in a cost-effective manner?)

7.5 Deep emissions cuts and feasibility

It is important to remember the scale of the emissions reduction that policy instruments are required to bring about under the scenarios set out in Sections 5 and 6. By the end of the scenarios in 2050, emissions are 90% lower than at the beginning of the scenarios in 2004.¹⁰⁹ However, between 2004 and 2010, carbon emissions actually rise from 168MtC to 174MtC. This occurs as a result of increases in international aviation and shipping emissions, with emissions from other sectors declining very slightly from 152.9 to 151.2MtC.¹¹⁰

Emissions continue to rise until 2012 (177MtC) and then decline 161MtC to 16MtC in 2050 (figure 2.1). This reduction is equivalent to an average annual reduction in emissions between 2013 and 2050 of around 6%.¹¹¹ Given that, throughout the scenarios, the economy is growing at 2.5% per annum, this means an average annual reduction in the carbon intensity of GDP over this period of around 8.3%.

Some of the instruments and implementation timetables described below may strike some as unfeasible. However, given the very large annual reductions required in both emissions and carbon intensity, it is important to consider all possible instruments that meet the criteria of effectiveness, equity and efficiency set out above. And, in terms of the speed of policy implementation, it may well be necessary to substantially extend the boundaries of what is currently regarded as politically feasible.

7.6 Emissions trading

Set out in Section 7.7 are various instruments that could be applied to the four sectors into which this report divides the economy: households, services, industrial and transport. However, given that emissions trading is clearly regarded as an important emissions reduction instrument, both within the UK and the EU, we first discuss the variety of schemes that have been proposed as potential policy options.

¹⁰⁹ And also around 90% lower than emissions levels in 1990.

¹¹⁰ Note that this estimate of 151.2MtC for emissions from sectors other than international aviation and shipping is in marked contrast to the government's estimate of 132-137MtC - a difference of 14.2-19.2MtC or 10.4-13.1%. The reasons for this divergence are set out in Section 2.

¹¹¹ In other words if emissions in each year of the period 2013-50 were 6% lower than in the previous year, the cumulative emissions in this period would be equal to the cumulative emissions under the scenarios in this report.

7.6.1 EU ETS: A key instrument

In October 2005, the Council of the European Union noted that

the EU ETS will remain an essential instrument in the EU's medium and long-term strategy to tackle climate change.¹¹²

And in June 2006, the European Union's High Level Group on Competitiveness, Energy and the Environment

confirmed its preference for a well-functioning ETS as a central instrument for reducing greenhouse gases.¹¹³

The European Commission notes that, whilst the scope of the EU ETS was intentionally limited during its initial phase in order to build up experience of emissions trading,

trading has the potential to involve **many sectors of the economy and all the greenhouse gases controlled by the Kyoto Protocol** (CO₂, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride).¹¹⁴

The UK government is a supporter of expanding the EU ETS and, in its 2006 Climate Change Programme, stated its intention to

work with EU partners to secure agreement to further action in the EU, in particular by extending and strengthening the Emissions Trading Scheme and the Clean Development Mechanism to make them key regional and global tools for emissions reductions beyond 2012.¹¹⁵

7.6.2 Expanding EU ETS

¹¹² CEU (2005b, p2)

¹¹³ HLG (2006)

¹¹⁴ European Commission (2005a). Emphasis added.

¹¹⁵ Defra (2006, p4)

In September 2005, the Commission adopted a Communication recommending the inclusion of aviation within EU ETS¹¹⁶ and in December 2005 the European Council supported this recommendation stating that

from an economic and environmental point of view, the inclusion of the aviation sector in the EU Emissions Trading Scheme (EU ETS) seems to be the best way forward, in view of emissions trading already having been implemented within the EU and it holding greater potential for application internationally than other policy alternatives.¹¹⁷

The LETS Update project assessed the feasibility of expanding the sectors and gases covered by EU ETS and a recent report concluded that CO₂ from the production of ammonia, fertilisers and petrochemicals could be included in Phase III. It also concluded N₂O from adipic and nitric acid plant could be included during Phase II and definitely by Phase III. And, in addition, methane from active coal mines, and CO₂ and PFCs from aluminium production could be included in Phase III.¹¹⁸

7.6.3 Trading alongside EU ETS

There have been a number of proposals for trading schemes that operate alongside EU ETS. For example, in its submission to the Climate Change Programme Review and Energy Efficiency Innovation Review, the Carbon Trust proposed a UK consumption-based emissions trading scheme (UK CETS). According to the Trust

this instrument has significant potential coverage. Even if initially restricted to the existing coverage of half-hourly meters, it could span baseline emissions of ~20MtC split roughly equally between less energy intensive manufacturing and the service sector, and encompass around 14,000 companies and public sector organisations (occupying 91,000 sites).¹¹⁹

A March 2006, report prepared for the Swedish Environment Protection Agency,¹²⁰ investigated the potential for the transport sector to be covered by emissions trading, either by including it within an expanded EU ETS or by setting up separate schemes.

¹¹⁶ European Commission (2005b)

¹¹⁷ CEU (2005c)

¹¹⁸ AEA Technology Environment and Ecofys UK (2006)

¹¹⁹ Carbon Trust (2005, p12)

¹²⁰ SEPA (2006)

It concluded that separate trading schemes for road and maritime emissions that ran alongside EU ETS would be feasible. It also concluded that a separate trading scheme for transport as a whole would be feasible. In addition, the report recommended further investigation of the inclusion of the entire transport sector within the EU ETS, but also considering alternatives for the sector such as a carbon tax.

The UK Government has also been examining the potential for including surface transport within emissions trading, noting in its 2006 Climate Change Programme that

drawing on the work we have already carried out, we will engage with key stakeholders, the European Commission and other EU member states to help develop a robust evidence base on the costs and benefits of including surface transport in CO₂ emissions trading at an EU level. We will also continue to investigate the desirability of introducing surface transport CO₂ emissions trading at a UK level, either as preparation for EU-wide adoption or as a self-standing measure.¹²¹

7.6.4 Alternative approaches to emissions trading

In Section 7.4, it was noted that any suite of emissions reduction instruments should aim to reduce emissions in an equitable manner. In its 2000 report on energy and climate change, the RCEP took the view that the most equitable approach to emissions reduction was one under which

every human is entitled to release into the atmosphere the same quantity of greenhouse gases.¹²²

A number of emissions trading schemes that embody this approach to emissions reduction have been proposed and are briefly discussed below.

1. Domestic Tradable Quotas

¹²¹ Defra, (2006, p70)

¹²² RCEP (2000, p2)

Domestic Tradable Quotas (DTQs) were proposed by David Fleming in 1996¹²³ and have been the subject of an assessment by the Tyndall Centre for Climate Change Research.¹²⁴ Under DTQs, emissions rights covering emissions from energy use are allocated to all energy end-purchasers. In any given year, emissions rights (or *carbon units*) equivalent to that year's cap on energy emissions, are divided between adult individuals and organisations. Carbon units are allocated to adult individuals free and on an equal per capita basis, whilst organisations must purchase the units they require on a national carbon market. The proportion of carbon units going to individuals is equal to the proportion of total energy emissions arising from their purchase of fuel and electricity (currently around 40% in the UK). The remaining units are auctioned onto the national carbon market where they can be purchased by organisations and by individuals who wish to emit at a level above that permitted by their initial allocation of units. Individuals with surplus units can sell them onto the national carbon market, thus earning themselves some additional income. Research by the Tyndall Centre has concluded that such a personal carbon trading scheme is technologically feasible and that transaction costs would not be prohibitive.

Box 7.1 discusses the potential for EU ETS to evolve into a personal carbon trading scheme such as DTQs.

Box 7.1 Domestic Tradable Quotas and EU ETS

Emissions trading schemes can be upstream, downstream or a mixture of the two (hybrid). In upstream schemes, the holders of emissions rights are fossil fuel suppliers. Downstream schemes are classified as either *direct* or *indirect* and these terms are briefly explained.

An individual or organisation emits directly when they combust fossil fuel. And an individual or organisation emits indirectly whenever they consume goods or services whose production involved the combustion of fossil fuel by another organisation. Hence if an electricity generator combusts coal to produce electricity, its emissions are direct. However, those same emissions can be regarded as the indirect emissions of the customers who consume the electricity, as these emissions arise in order to satisfy the customers' demand for electricity, and they "emit" these greenhouses indirectly through their consumption of the electricity.

¹²³ Fleming (1996, 2005)

¹²⁴ Starkey and Anderson (2005)

Under EU ETS, emissions rights are allocated to selected *emitters* (large electricity generators and other large industrial emitters). And as explained above, under DTQs, emissions rights are allocated to all energy *end-purchasers*. However, there is a considerable overlap between these two groups as it is only in the electricity sector that end-purchasers are not emitters. It is this distinction between emitters and end-purchasers in the electricity sector that means EU ETS is a downstream *direct* scheme (emissions rights to the generator) and DTQs is a downstream *indirect* scheme (emissions rights to the customers of the generator).

If EU ETS were expanded to include all emitters currently not covered then, in terms of the allocation of emissions rights, the two schemes would differ only with regard to the electricity sector. Hence, if, within EU ETS, allocation of rights in this sector was shifted from allocating to electricity generators to allocating to their customers, then in terms of rights holding, the schemes become equivalent. And hence, if DTQs proved to be a sufficiently attractive idea, then there is an evolutionary route that could be taken to realise the scheme.

Allocating carbon units directly and on an equal per capita basis quite literally makes individuals equal environmental stakeholders by awarding them an equal stake or share of the atmospheric sink. If the public regards this equal share to be fair, and if fairness is a condition for public acceptability, then the equal stakeholder approach of DTQs may promote greater public buy-in to the task of bringing about very large reductions in emissions.

2. Ayres proposal

With the possible exception of those that are very high emitters, organisations under DTQs will not buy carbon units directly at auction. The majority of units would be purchased by market makers (e.g. high street banks and the post office) that would then sell them on to organisations and to individuals who wished to buy additional units. Market makers would also purchase carbon units from individuals who wish to sell their surplus.

The scheme proposed by Ayres¹²⁵ is similar to DTQs in that all end-purchasers of fuel and electricity (both individuals and organisations) are required to surrender

¹²⁵ Ayres (1997)

carbon units. However, the schemes differ in how carbon units are allocated. Under DTQs (and using UK figures) 40% of units are allocated to individuals on an equal per capita basis and 60% auctioned by government. In contrast, under the Ayres proposal, fully 100% of units are allocated to individuals on an equal per capita basis. Under both schemes, organisations will purchase emissions rights from market makers. However, whilst under DTQs, market makers obtain the majority of units from one source, the auction,¹²⁶ under the Ayres scheme, market makers must buy rights solely from the tens of millions of individuals holding a surplus in order to sell them on to organisations.

3. Sky Trust and Feasta

Sky Trust is a proposal for an upstream emissions trading scheme under which emissions are auctioned by the government to fuel suppliers and importers.¹²⁷ The revenue from the auction is then shared out equally amongst eligible individuals. So whilst under the Ayres proposal it is emissions rights that are allocated to individuals on an equal per capita basis, under the *Sky Trust* proposal it is the revenue from the sale of these rights that is allocated in this way.

A variant of the *Sky Trust* proposal has been proposed for the EU by the Irish NGO, *Feasta*.¹²⁸ Under this proposal, emissions rights are not auctioned directly to fuel suppliers but are allocated once a year and on an equal per capita basis to individuals who then sell them on to fuel suppliers via market makers. *Feasta* argues that the initial allocation of rights to individuals is important, for as the rightful owners of emissions rights, it is important that they actually have possession of them, rather than the government simply auctioning them on their behalf.

7.7 Policy instruments by sector

It is assumed that each of the four sectors – households, industry, services and transport – are brought under some sort of emissions trading scheme or are subject to some sort of carbon tax (or increased carbon tax) at the earliest opportunity. A number of possible scenarios can be envisaged. For example EU ETS could be expanded to include aviation with the rest of the economy falling under a carbon tax. Or EU ETS could be expanded to include aviation, with, say, separate emissions trading schemes implemented for surface transport and for the commercial sector

¹²⁶ And, in addition, obtain some from below-allocation emitters.

¹²⁷ Barnes (2001). See also the *Sky Trust* website at www.uskytrust.org.

¹²⁸ *Feasta* (2006)

and a carbon tax applied to all other sectors. Or EU ETS could be gradually expanded into an economy-wide personal carbon trading scheme.

From the point of view of public acceptability, it will be important to point out to the public that revenue raised under a carbon tax or through auctioning of emissions rights under a trading scheme, will not represent a wholesale rise in overall taxation levels, as all, or at least a significant proportion, will be recycled, leading to a reductions in, for example, income tax or National Insurance contributions.¹²⁹

The various price and non-price instruments to be implemented in these sectors are listed below and are divided into those that can be implemented in the short-term (today to 2010) and the medium-term (2011-2030). It is assumed that in the long-term (2031-2050) there is simply a continuation of policies put in place in the short- and medium-term.

It is important to emphasise that decisive policy action is needed in the short-term to create the momentum to achieve the substantial emissions reductions required in the medium and long-term. Such decisive action is most quickly and easily achieved in the short-term by utilising existing policy instruments and, hence, the approach taken here is to use and build on the current mix of instruments wherever possible.

7.7.1 Households

7.7.1.1 Households and price instruments

Whilst the policy aim under these scenarios is to bring all sectors under a price instrument as quickly as possible, work by the Policy Studies Institute (PSI) shows that within the UK it is currently not possible to levy a carbon tax on households or place them under an emissions trading scheme without disadvantaging some household in fuel poverty.¹³⁰

PSI's research investigated the effects of a carbon tax on household energy use and sought to show that

poorer households could be compensated by distributing the tax revenues, through the benefit system or otherwise, in such a way that

¹²⁹ Some revenue may be used to fund, for example, the implementation of energy efficiency measures in low-income households.

¹³⁰ Dresner and Ekins (2004)

the tax would not leave them worse off and would therefore not increase fuel poverty.¹³¹

However, the research found that due to the very substantial variation in energy use and carbon emissions within income deciles it is was not possible to recycle the revenue from the tax in such a way as to leave no households in the lowest income deciles worse off than prior to the implementation of the tax. Whilst revenue recycling was progressive on average, a significant percentage (20-30%) of households in the lowest income deciles were actually made worse off.

In order to levy a tax on households whilst leaving none in the lowest income deciles worse off, it is necessary either to improve the energy efficiency of the dwellings of those in fuel poverty or at least to have specific information about them so as to be able to accurately target compensation. However, according to PSI, currently “nothing is known about the thermal characteristics of a particular address”.¹³²

To tackle fuel poverty, PSI proposes a 10 year programme that significantly expands the government’s Warm Front scheme. At the end of this 10-year programme most dwellings of those in fuel poverty would have been brought up to around SAP 70. Although, a number of solid wall houses with electric heating would not have been improved, all these dwellings would have been identified so as to allow rebates under a tax or trading scheme that would not leave them worse off.

Given that a carbon tax could not be levied on the household sector during this 10 year programme to tackle fuel poverty, Dresner and Ekins proposed a concurrent ten-year scheme for other households that would require them to undertake an energy audit and implement all cost-effective measures identified by the audit or face a surcharge on their council tax.¹³³ Such a scheme, would, they estimate, save 7.3MtC and save households £19.7bn. Subsequently a carbon tax could be imposed on all households to prevent household energy use and carbon emissions from increasing with rising incomes.

7.2.1.2 Improving the thermal efficiency of the housing stock

¹³¹ Ekins and Dresner (2004, p6)

¹³² Ekins and Dresner (2004, p7)

¹³³ This is a stronger proposal than the voluntary scheme put forward by the Energy Savings Trust which advocates a reduction in Council Tax if energy efficiency measures are implemented.

In the scenarios described in this report, the number of dwellings increases from 25 million in 2004 to 27 million in 2050. As well as this new-build of 2 million, there is the additional new-build required to replace those existing dwellings demolished between now and 2050. Total space-heating energy demand in 2050 will therefore be determined by the number of existing properties demolished, the refurbishment of existing properties left standing and the efficiency of new-build. In line with the assumptions in *The 40% House* project, demolition within these scenarios focuses on the least thermally-efficient properties and demolition rates are substantially increased from those of today.¹³⁴ And, again, in line with the assumptions in *The 40% House* project, building regulations will ensure an increase in thermal efficiency of new-build such that by 2020 energy demand for space heating in new housing is close to zero.

¹³⁴ In the 40% House project scenario, 3.2 million dwellings are demolished between now and 2050 (Boardman et al, 2005).

7.7.1.3 Household sector policies

Short-term

- Increase efforts to tackle fuel poverty through Warm Front and the Energy Efficiency Commitment (EEC)
- Introduce PSI-type household audit scheme
- Halt sale of incandescent light bulbs
- Increase efficiencies for household appliances using minimum efficiency standards¹³⁵
- Increase the *Low-carbon Buildings Programme* to build the market for micro-generation
- Introduce easy-to-read gas and electricity bills which clearly show the amount of carbon emitted
- Introduce a public information campaign on energy efficiency and conservation
- Transform energy labels so as to use absolute consumption as the basis of the label, thus discouraging the trend towards bigger appliances
- Introduce home energy ratings (required by Energy Performance in Buildings Directive and to be incorporated in Home Condition Report of Home Information Pack)
- Tighten building regulations in line with the *Code for Sustainable Homes*
- Regulate to ensure most efficient appliances are specified for those pre-fitted by builder in new-build
- Make necessary changes to planning regulations to enable increased rates of demolition
- Significantly increase the funding of Energy Savings Trust (EST)

¹³⁵ The 40% House report notes that with regard to the consumer electronics field, “[w]hilst minimum standards would guarantee the savings, strong voluntary agreements may be more appropriate due to the fast rate of change in this sector” (Boardman et al, 2005, p57).

Medium-term

- Having solved fuel poverty issues, place households under carbon tax or emissions trading scheme
- Install smart metering in all dwellings by 2012
- Introduce minimum efficiency standards for all appliances
- Further tighten building regulations to specify that by 2020, new-build should
 - have (close to) zero heating demand
 - contain only LED fittings
 - incorporate LZC technologies for heating and/or electricity generation
- Amend planning regulations to specify that all new-build above a certain density requires community CHP

7.7.2 Industry

Over the course of both scenarios, the trend in the industrial sector is toward industrial ecology with its “closed loop” manufacturing systems. In both the energy-intensive and non-intensive sectors, a reduction in carbon intensity occurs as a result of decarbonising the electricity grid and a substitution from gas and coal to LZC hydrogen for process heat. Hydrogen from gas and coal is produced using CCS and so production is centralised and a distribution network is required. However, hydrogen is also produced on-site by electrolysis, using electricity from wind power and PV.

Short-term

- Increase in Climate Change Levy (CCL) and removal of exemptions relating to firm size so as to cover entire sector
- Make Climate Change Agreements (CCA) more challenging
- Significantly improve funding of Carbon Trust to assist industry in making emissions reductions
- Introduce energy performance certificates for new-build (required by Energy Performance in Buildings Directive)

- Tighten energy efficiency requirements in building regulations for new-build industrial plant¹³⁶

Medium-term

- Increase CCL or bring the industrial sector under an emissions trading scheme
- Amend planning regulations to encourage the development of industrial ecology

7.7.3 Services

Under both scenarios, the long-term historical trend of increasing energy consumption within the commercial sector is reversed in the short-term, whilst current rates of improvement in the public sector are maintained. Improved energy efficiency in building fabric, appliances and air conditioning reduces energy demand, which, combined with a progressively decarbonising grid, reduces emissions.

Short-term

- Increase in Climate Change Levy (CCL) and removal of exemptions relating to firm size so as to cover entire sector
- Tighten energy efficiency requirements in building regulations for new-build commercial buildings¹³⁷
- Amend building regulations to specify the incorporation LZC technologies for heating and/or electricity generation in commercial and public sector new-build¹³⁸
- Introduce minimum energy efficiency standards for office equipment
- Widen scope of list of processes/products eligible for enhanced capital allowances (ECAs) to include building fabric, lighting and energy services
- Reduce VAT on selected energy efficient products and services
- Introduce energy performance certificates for new-build (required by Energy Performance in Buildings Directive)
- Significantly improved funding of Carbon Trust to assist industry in making emissions reductions

¹³⁶ This could, for example, be based on the BREAM (Building Research Establishment Environmental Assessment Method) for industrial units.

¹³⁷ This could, for example, be based on the BREAM (Building Research Establishment Environmental Assessment Method) for industrial units and offices.

¹³⁸ Local authorities may currently “include policies in local development documents that require a percentage of the energy to be used in new residential, commercial or industrial developments to come from on-site renewable energy developments” (ODPM, 2004, p10)

- Significantly expand and heavily promote the interest free loan scheme for SMEs
- Extend the Energy Efficiency Commitment (EEC) into the commercial sector

Medium-term

- Increase CCL or bring services sector under emissions trading scheme
- Continue to tighten building regulations so that there is a strong presumption against electrical air conditioning in new-build. Where air conditioning is necessary, regulations must ensure that it is delivered in the most efficient manner e.g. adsorption CHP cooling

7.7.4 Transport

As explained in Sections 5 and 6, the major difference between the two scenarios lies in the passenger transport sector. Vehicle efficiency improves in both scenarios. However, in the *Static Mobility* scenario, vehicle kilometres for the transport sector as a whole decrease out to 2050. With regard to individual transport sectors, vehicle kilometres travelled decrease in private road transport and remain static for rail. They increase in domestic and international aviation up to 2010, with domestic aviation then declining to 2004 levels and international aviation declining to below 2004 levels by 2050. In public road transport, they decrease slightly until 2030 before rising to above 2004 levels in 2050. By contrast, total vehicle kilometres in the *Mobility Plus* scenario increase out to 2050, when they are almost exactly 1.5 times greater than in 2004. In domestic aviation, vehicle kilometres increase until 2010 and then remain at approximately this level until 2050. In all other transport sectors vehicle kilometres increase out to 2050.

In the *Static Mobility* scenario, total passenger kilometres across all transport sectors are the same in 2050 as in 2004, having increased slightly in the interim. Passenger kilometre increase over time for rail and public road travel, but in international aviation and private road, passenger kilometres peak at 2010 and then decline to below 2004 levels by 2050. In domestic aviation, passenger kilometres peak in 2030 before declining to below-2004 levels in 2050. In contrast, in the *Mobility Plus* scenario, total passenger kilometres increase across the period and in 2050 are just over double what they were in 2004. In relation to individual transport sectors, passenger kilometres increase out to 2050 in all sectors other than international aviation where they then peak in 2030 before declining to 2004 levels in 2050.

The greater number of vehicle kilometres travelled in the *Mobility Plus* scenario compared with *Static Mobility* is explained by a greater use of both fossil fuel (including hydrogen from fossil fuel) and renewables (in the form of biofuels and renewably generated hydrogen). For example, by 2030 biomass consumption in transport is almost 2Mtoe higher in the *Mobility Plus* scenario and by 2050 almost 7Mtoe higher. In 2050, this difference in biomass use for transport explains the difference in biomass use as a whole under the two scenarios. Hence there is a greater policy emphasis on building biomass capacity, both at home and abroad, under *Mobility Plus*.

7.7.4.1 Aviation

Between 2004 and 2010, annual average emissions growth in both scenarios is 6.2% which is slightly lower than is likely under business as usual. Although aviation emissions decrease between 2011 and 2050, the average annual percentage decrease is (along with shipping) significantly lower than in other sectors. This means that, over time, aviation is responsible for an increased percentage of carbon emissions. In 2004 aviation was responsible for 5.4% of total emissions. In the *Mobility Plus* scenario, aviation is responsible for 22.8% of emissions in 2030 and 34.6% in 2050, whilst in the *Static Mobility* scenario, the figures are somewhat lower, but still significant, at 13.4% for 2030 and 19.8% in 2050.

In 2002 the RCEP conducted a study of the opportunities available to the aviation industry to minimise its impact on climate.¹³⁹ With regard to fuel, the study concluded that fewer options were available for reducing the climate impact of aviation than for surface transport. For example, there are greater barriers to using hydrogen in aircraft as, unlike with cars, a complete redesign of aircraft is necessary to allow hydrogen use. The RCEP concluded that hydrogen was not likely to be used to fuel planes before 2050 and that that bio-kerosene or mixing bio-diesel with fossil-fuel-derived kerosene are likely to be the only practical alternatives for this industry. This conclusion forms the basis for the aviation fuel-mix in these scenarios. Note that bio-diesel and bio-kerosene can, with relatively minimal adjustments, be used in current aircraft, though further research is required to make bio-diesel of practical use in the cold conditions experienced by aircraft at altitude.

¹³⁹ RCEP (2002). The environmental effects of civil aircraft in flight. Special report of the Royal Commission on Environmental Pollution. R. C. o. E. Pollution.

Short-term

- Implement moratorium on runway building
- Increase tax on flying
- Announce that aviation will enter EU ETS in 2012
- Increase funding for public RD&D
- Require airlines to provide emissions data to passengers regarding their flight

EU legislation permits the taxing of aviation fuel used in domestic flights. However, taxation of aviation fuel used in international flights is less than straightforward and the Commission currently takes the view that

the wider application of energy taxes to aviation can not be relied upon as the key pillar of a strategy to combat the climate change impact of aviation in the short- and medium-term.¹⁴⁰

Hence, whilst for domestic flights, the tax levied on flying could be a fuel tax, a tax on aircraft themselves or air passenger taxes, only the latter two taxes can be applied to international flights. Given the Commission's view on the taxation of aviation fuel for international flights, and given the political momentum currently behind aviation joining EU ETS (see 7.6.1), it is announced in 2007 that aviation will join in 2012. Huge political effort is made through the International Civil Aviation Organisation (ICAO) to ensure that there is international agreement that non-EU carriers will participate in the scheme.

Under a cap, the aviation industry can thrive only through increased energy efficiency and future use of biodiesel and biokerosene. The announcement stimulates a big increase in private R&D into energy efficiency by the aviation industry and is coupled with significantly increased government funding for public RD&D.¹⁴¹

¹⁴⁰ European Commission (2005b, p7). See Section 5.3 on the difficulties associated with taxation of fuel used in international flights.

¹⁴¹ Note that reductions in fuel efficiency and CO₂ brought about by the suite of policy measures for aviation are consistent with the target of the Advisory Council for Aeronautical Research in Europe (ACARE) to reduce fuel consumption and CO₂ emissions per passenger kilometre in 2020 by 50% from 2000.

Particularly within the *Mobility Plus* scenario, a significant growth in UK biomass production is required and government puts in place programmes to ensure that this occurs (see biomass section).

In order to raise awareness of the carbon impact of flights, airlines are required to provide passengers with information on or accompanying their tickets regarding the carbon emissions associated with their flight.

Medium-term

- Include all flights arriving and departing the EU (both EU and non-EU carriers) within EU ETS in 2012.
- Institute a presumptive ban on flights that are less than half-full.
- Reduce flying speeds on domestic and intra-EU flights at a lower level than today. This not only increases the energy efficiency of flights by substantially reducing drag but encourages modal shifts to fast rail travel.

7.7.4.2 Private Road

Substantially reducing emissions in the private road passenger sector whilst slightly reducing vehicle kilometres travelled (*Static Mobility* scenario) or substantially increasing vehicle kilometres travelled (*Mobility Plus* scenario) is achieved by demand management (taxes or trading), increased vehicle efficiency and the development of low/zero-carbon fuels – biomass, LZC hydrogen and LZC electricity for battery electric vehicles.

Particularly in the *Mobility Plus* scenario, improvements in vehicle efficiency are pushed using vehicle emissions standards. In 1998-9, the EU signed voluntary agreements with the automobile manufacturers under which they committed to bring average fleet emissions down to 140g/km CO₂ by 2008-9.¹⁴² Under these scenarios, the voluntary agreement becomes a mandatory target in 2012 of <120g/km.¹⁴³ The development of LZC fuel will be depend on government policies to build biomass and to develop a LZC hydrogen economy (see 7.12). The combination of policy

¹⁴² The agreements were signed with European, Japanese and Korean Manufacturers Associations (ACEA, JAMA and KAMA). ACEA committed to achieve the 140g/km target by 2008 and JAMA and KAMA by 2009.

¹⁴³ The voluntary agreement with ACEA includes the possibility of extending it to include an emissions level of 120g/km by 2012.

instruments in the short- and medium-term leads to intensive innovation within the automotive industry to develop “hypercar” technology.¹⁴⁴

Short-term

- Substantially increase Vehicle Excise Duty on less efficient vehicles.
- Reinstate fuel duty escalator¹⁴⁵
- Decrease speed limit on motorways to 60mph, on A-roads to 50mph and in residential areas to 20mph
- Teach “green” driving techniques for driving test
- Increase funding of public R&D
- Implement government programme to increase UK biomass production
- Implement government programme to build renewables capacity
- Implement government programme to develop the hydrogen economy

Medium-term

- Increase taxation or incorporation road transport within emissions trading
- Minimum fleet emissions standards of below 120g/km by 2012
- Mandate for zero emissions/hydrogen vehicles

7.7.4.3 Public road

In both scenarios, car access to city centres is substantially reduced and access is instead mainly through park and ride schemes. This encourages increased use of buses for commuting. In addition, government works closely with private bus operators to substantially increase the level of rural and semi-rural bus services.

Note that the policy measures set out for private road travel also apply here. In addition, the following policies are implemented.

Short-term

- Introduce comprehensive network of bus lanes within towns and cities

¹⁴⁴ See, for instance, Lovins and Cramer (2004)

¹⁴⁵ Clearly this will need to be reviewed in the light of further sharp rises in the price of oil.

- Put in place regulations that require local governments to implement park and ride schemes
- Offer incentives to private bus operators to substantially increase level or rural and semi-rural bus services

7.7.4.4 Rail

The rail sector and the public road sector are the only transport sectors where passenger kilometres travelled increase in both scenarios. Regulation restricting flying speed on domestic and intra-EU flights, the higher cost of aviation as a result of its entry into EU ETS and the increased speed of intercity travel facilitates major modal shift to rail for not only domestic travel but some European travel.

Short-term

- Implement carbon tax to drive efficiency improvements in fleet
- Invest heavily in track improvements to enable introduction of larger high-speed and double-decker trains to travel between major urban centres.

Medium-term

- Increase taxation or bring under emissions trading scheme
- Continue investment in track improvements

7.7.4.5 Shipping

Biofuel and hydrogen constitute over two-thirds of fuel used in shipping by 2030. This, coupled with improvements in engine technology and loading practices reduces emissions in this sector.

Short-term

- Carbon tax on fossil fuel used in shipping
- Increase RD&D into
 - hydrogen use in shipping
 - Reintroduction of sail ships

- reducing drag in shipping¹⁴⁶
- environmentally sound ships¹⁴⁷

Medium-term

- Continue RD&D

7.7.4.6 Cycling and walking

In the *Static Mobility* scenario, with its constraint on the growth in passenger kilometres, it is important to provide opportunities for walking and cycling.

Short-term

- Begin the introduction of an extensive network of cycle routes throughout the UK
- Regulate to ensure organisations provide increased cycle storage facilities
- Support *Safe Routes to School* initiative that aims to enable children to walk and cycle to school safely
- Reduce residential speed limit to 20mph, thus increasing pedestrian safety

7.8 Supply

7.8.1 Biomass

In these scenarios, biomass is used in transport, CHP and for co-firing with coal linked to CCS. It constitutes an increasingly large part of primary fuel over time, accounting, by 2050, for 11% and 14% in the *Static Mobility* and *Mobility Plus* respectively

Short-term

- Introduce banding approach within Renewables Obligation to support biomass
- Introduce Renewable Heat Obligation
- Introduce grant scheme for farmers to switch to biomass production
- Introduce waste regulation to require local authorities to collect green waste (for use in CHP or to produce biogas)

Medium-term

- Use Clean Development Mechanism to develop biofuel infrastructure overseas

¹⁴⁶ Thwaites (2006)

¹⁴⁷ Harrison (2005)

- Increase the percentage of renewable fuel required under the Renewable Transport Fuel Obligation above 5% after 2011.

7.8.2 Other renewables

Under the *Static Mobility* and *Mobility Plus* scenarios, renewables other than biomass account, respectively, for 13% and 15% of primary fuel in 2030 and 32% and 29% in 2050.

Short and medium-term

- Increase percentage of renewable electricity required under the Renewables Obligation
- Extend lifetime of Renewables Obligation to capture longer-term technologies such as tidal stream, tidal barrages, wave and deep sea wind
- Increase funding for public RD&D

7.8.3 Hydrogen

Hydrogen plays an important role within the scenarios. Under *Static Mobility* hydrogen is responsible for 17% of final energy demand in 2030 and 29% in 2050. Under *Mobility Plus*, hydrogen is responsible for 18% of final energy demand in 2030 and 27% in 2050. In order to develop the hydrogen economy, technological advances are required in the production, distribution and storage of hydrogen and in fuel cell production. The evolution of the hydrogen economy is heavily dependent on the development of renewables and CCS.

The Government intends to set up a Hydrogen Coordination Unit and, given importance of hydrogen in scenarios, government spending on hydrogen RD&D is increased by an order of magnitude. Private investment is stimulated by the announcement of LZC hydrogen transport obligation

Short-term

- Set up Hydrogen Coordination Unit
- Develop a clear transition strategy to the hydrogen economy to provide confidence and reduce uncertainty
- Substantially increase funding for public RD&D into the various aspects of the hydrogen economy including the feasibility of using the gas pipeline network for distributing hydrogen

- Introduce enhanced capital allowance for private hydrogen RD&D

Medium-term

- LZC hydrogen transport obligation to stimulate the market
- Increase gas storage capacity for methane reformation
- Mandate for zero emissions/hydrogen vehicles

7.8.4 CCS

Within these scenarios, the LZC electricity and hydrogen produced using CCS complements the electricity and hydrogen produced from renewables. Indeed, in the *Mobility Plus* scenario using CCS in conjunction with the co-firing of biomass, makes the process into a carbon sink. According to the Government

Current evidence suggests that the cost of capture and storage of carbon dioxide from new power plants is around \$40-60 per tonne of carbon dioxide, which can be expected to fall as the technology matures. This is comparable with other major abatement options, and suggests that the technology could have a major role in mitigating emissions. The rate of deployment is constrained by uncertainties over economics (cost of capture technologies, and emissions trading eligibility) and legal status of subsea-bed storage under the London and OSPAR Conventions, which are designed to protect the marine environment.¹⁴⁸

Cross-party commitment to the emissions reduction trajectory set out in Fig 2.1, the fact that the entire economy is subject to either a carbon tax or emissions trading and government announcements that CCS is to play a role in emissions reduction create an economic signal to stimulate private investment in this technology. Various specific policy measures suggested to support CCS include: incorporating within EU ETS, a CCS obligation, contracts for differences, an auction avoided allowances, a non fossil fuel obligation (NFFO) model and feed in tariffs¹⁴⁹ (ref).

Short-term

- Continue efforts to resolve the legal issues surrounding CCS

148 Defra 2006, p187

149 Chapman, J. 2006

- Significantly increase funding for RD&D
- Make regulatory changes to enable CCS to be combined with enhanced oil recovery in the North Sea
- Consider various policy options outlined above

8. CONCLUSIONS

The following conclusions have been drawn from this report and the accompanying research, allied with the experience and judgement of the reports authors, all of whom are researchers within the Tyndall-Manchester energy and climate change programme. Friends of the Earth and The Co-operative Bank commissioned the research on the understanding that it both focus on a 2°C future and adhere to a suite of explicit and stringent constraints on energy supply. Consequently, whilst the authors have been completely free to draw their own conclusions from the research, the conclusions have nevertheless been dependent on the initial constraints; in particular the limitations on available renewable and biomass resources, constrained electricity consumption and a moratorium on new nuclear capacity.

The key message to policy makers

The UK has reached a 'tipping point'! If the Government's carbon dioxide targets are to actually have meaning, the Government must act now to curb dramatically the nation's carbon dioxide emissions. The message from this research is that stark. In waiting for technology or the EU ETS to offer a smooth transition to a low-carbon future, we are deluding ourselves. It is an act either of negligence or irresponsibility for policymakers continually to refer to a 2050 target as the key driver in addressing climate change. The real challenge we face is in making the radical shift onto a low-carbon pathway by 2010-12, and thereafter driving down carbon intensity at an unprecedented 9% per annum, for up to two decades.

The urgency with which we must make the transition to a low-carbon pathway leaves no option but to instigate a radical and immediate programme of demand management. It is incumbent on government to initiate, maintain and monitor this programme whilst simultaneously facilitating a phased transition to low-carbon demand and supply technologies.

8.1 A realistic climate debate

8.1.1 450ppmv CO₂ – a move in the right direction

The central tenet of the report has been to illustrate how the Government can direct the UK towards a low-carbon pathway in accordance with its stated objective of “prevent[ing] the most damaging effects of climate change”, which it quantifies in relation to “a global average temperature increase of no more than 2°C above the pre-industrial level”.¹⁵⁰ As discussed in Section 2, correlating the 2°C figure with an atmospheric concentration of carbon dioxide and, subsequently, a national cumulative emissions target is fraught with scientific and political uncertainties. Within this report, and for the reason outlined in Section 2, the analysis has been developed for a 450ppmv CO₂¹⁵¹ stabilisation level. Whilst this offers a substantial improvement on the probability of not exceeding 2°C over a 550ppmv level, the latest science suggests it is still likely to provide a medium-to-high probability of exceeding 2°C. The decision to focus on a 450ppmv CO₂ future, as opposed to a lower concentration, was one of practicality.

- 450ppmv CO₂ will demand a dramatic and rapid transition from the current carbon trajectories. It will require the incumbent and any subsequent Government to explicitly engage with the public in designing effective means to foster and, to some degree engineer, social change.
- The increasing acknowledgment amongst policy makers that 2°C correlates with a 450ppmv CO₂ future, or less, suggests the necessary political and social inertia to support a 450ppmv future may exist, whilst it is likely a 400ppmv future may, *ceteris paribus*, be considered too extreme.
- The short-term trajectory (up to five years) for 450ppmv CO₂ stabilisation would not, arguably differ substantially from that for 400ppmv CO₂. Consequently, putting the UK onto a path towards 450ppmv would not preclude a transition to a 400ppmv trajectory provided that transition occurred within the next five years.

8.1.2 Towards a real 2°C limit

Whilst a genuine transition to a 450ppmv trajectory requires a radical departure from the scale of carbon reductions envisaged by many climate change stakeholders, the magnitude of change necessary to put the UK on a 400ppmv CO₂ trajectory has received no detailed examination, and would likely be dismissed by many policy

¹⁵⁰ Dti 2006, p. 24

¹⁵¹ See the earlier discussion in Section 2 about carbon equivalence.

makers as too far-reaching to contemplate. However, the latest scientific understanding of correlations between concentration and temperature suggest that even at 400ppmv CO₂, there is, approximately, a 50% chance of exceeding the 2°C target. The implications of this emerging scientific consensus for the UK's stated position on climate change are difficult to exaggerate. Unless the UK and the EU are to abandon their commitment to 2°C, they must continue to either fudge¹⁵² the implications, or acknowledge that "*aiming for a global average temperature increase of no more than 2°C*" demands that they establish targets in line with stabilising atmospheric concentrations of CO₂ at levels as close to 400ppmv as possible. It is important to recognise that according to current scientific understanding, to have a very high probability of not exceeding 2°C would require a complete cessation of carbon emissions from today.¹⁵³

Whilst this report has focussed on a 450ppmv CO₂ future, it nevertheless provides some pointers as to how the UK could reduce its 2000-2050 emissions below the 4.6GtC cumulative limit discussed in Section 2. Clearly going beyond this already highly demanding limit would require the "*the greatest threat we face*" be taken at literally and afforded the gravity, urgency and resources necessary to meet the challenge. If such a situation were to arise, it would be possible to reduce still further the 4.6GtC, by, for example:¹⁵⁴

- The very low-carbon energy supply system of *Mobility Plus* meeting, with some modification, the energy supply needs of the *Static Mobility* scenario, with consequent and modest savings in carbon emissions from the lower passenger and vehicle kilometres travelled within *Static Mobility* compared with *Mobility Plus*.
- A phased reduction in economic growth and an corresponding shift in the balance between materialism and alternative forms of value.
- The acceptance of a wider portfolio of low and zero-carbon energy supply options and fuels.

¹⁵² It is hard to draw any other more polite conclusion than this. The UK Government have, at varying events, been made aware of how the science of climate change has progressed, and yet even within the documentation accompanying the 2006 Energy Review and the 2006 Climate Change Programme the message remains unclear. In the latter document, for example, it is acknowledged that 2°C may correlate with lower concentrations (p.13), perhaps even below "*450ppm*" (it is unclear whether this is for CO₂ or CO₂eq). It subsequently refers to the EU Council, "*driven by EU leaders*", reiterating, in March 05, their aim of "*limiting average global temperature to an increase of no more than 2°C*" (p.20).

¹⁵³ According to Meinshausen 2006 it would be necessary to go below 350ppmv CO₂eq to ensure 2°C was not exceeded, with 350ppm CO₂eq Meinshausen estimates a 0% to a 31% chance of exceeding 2°C. Currently the concentration is 380ppmv CO₂ and approximately 425ppmv CO₂eq.

¹⁵⁴ The examples provided here are simply the important drivers of energy growth identified in the scenarios. The inclusion of the drivers in this list is to illustrate how it would be possible, should the circumstances arise, to go beyond the 450ppmv CO₂ future.

- The introduction of major structural adjustments to the relationship between Government and the citizenry.
- The introduction of macro-engineering options for increasing and producing new carbon sinks, including raising the level of biomass/coal co-firing with CCS – as outlined in the scenarios.

8.1.3 A comprehensive and up-to-the-minute inventory

The Government's reporting of carbon emissions is both partial and not sufficiently up-to-date. The scale of the problem demands the UK's carbon inventory be fully inclusive of all sectors and be regularly updated. Arguably such updates should be at six-monthly intervals to enable the impact of policies to be tracked, with some policies likely requiring regular fine tuning to mitigate undesirable rebound.¹⁵⁵ Mirroring a reliable, robust, and comprehensive carbon inventory should be a similar inventory for the remaining basket of six gases, and, arguably indirect greenhouse gases such as N₂O and sulphur.

8.1.4 Co-ordination of carbon-related¹⁵⁶ strategies and policies.

It is imperative a fully integrated strategy be developed to foster, guide and police 'joined-up' thinking within and between all ministries and tiers of central, regional and local government. Cross-party support is necessary for primary legislation committing the Government to deliver sustained and absolute year-on-year emissions cuts.

8.1.5 Urgent and unprecedented – 9 to 13% p.a decarbonisation¹⁵⁷

As stated above, establishing a fundamental sea change in society's attitude towards carbon emissions between now and 2010-14 is a prerequisite for achieving the 4.6GtC target. However, essential though this period is, the real decarbonisation begins in around 2014 and proceeds at a mean reduction in carbon intensity of approximately 11.5% p.a for almost two decades, before gradually relenting from 2030 onwards. Analysing the numbers in a little more detail serves only to re-iterate the discrepancy between the rhetoric of the Government's 2°C target and the reality of the policy initiatives proposed to reduce emissions. Assuming emissions can actually be stabilised by 2010 (as per Figure 2.1), the mean annual reduction in carbon intensity between 2010 and 2030 is in the region of 9%, with the decade

¹⁵⁵ For example where the financial benefits of fuel savings from energy efficiency measures are used, for example, to purchase a cheap weekend city break by plane.

¹⁵⁶ Some of these may not relate directly to carbon emissions; for example, legislation and guidelines on migration, divorce, second homes, congestions charges, and tourism.

¹⁵⁷ All the figures in this section include a GDP growth rate of 2.5% p.a. To convert the figures from reductions in carbon intensity to approximate reductions in absolute emissions, simply subtract 2.5%

between 2020 and 2030 requiring a drastic 13% reduction in carbon intensity year on year.

8.2 Scenario conclusions

A number of key conclusions emerged from the scenarios particularly in relation to behavioural change and demand management, innovation and technology and finally resources. These are outlined below.

8.2.2 Behaviour

No time for delay

The emissions trajectory curve described in Section 2 clearly illustrates the fallacy of the view that low-carbon energy supply and high-efficiency energy demand will provide the necessary reductions in carbon emissions. Whilst such options are certainly necessary, the curve demonstrates that we do not have the luxury of waiting for such supply and demand technologies to become widespread. Urgent action is necessary *now* to both curtail our escalating aspirations for more high-carbon emitting activities and to establish the policy framework for the transition to a rapidly decarbonising society from 2014 onwards.¹⁵⁸

No hope without substantial demand management

Demand management measures are absolutely essential to achieving a 450ppmv future. Insufficient technical options exist and, where they do, they are generally unable to respond with the immediacy necessary. Demand management and low-carbon technologies should be considered as providing synergistic low-carbon benefits over and above their individual low-carbon impacts

8.2.3 Innovation

Hydrogen in a carbon-fuel constrained world

Hydrogen penetrates the energy markets during the medium-term. This is a partial consequence of several factors. The necessary decommissioning of many power stations and the growth in electricity leaves the electricity supply industry with a major replacement and new-build programme with little surplus electrical capacity. Moreover, existing steam reformation of natural gas offers the knowledge, technology and experience necessary to produce hydrogen on a large scale by 2030.

¹⁵⁸ Whilst emissions no longer rise after 2010-11, the threshold between gradual and rapid decarbonisation can reasonably be described as occurring around 2014.

Limited budgets and constrained choices

Limited resources and the scale of the problem force government and industry to focus on core activities anticipated to provide reliable low-carbon outcomes domestically and sales of equipment and knowledge internationally. The highly limited budget and policy framework in terms of RD&D must be dramatically increased and must be focused on a suite of constrained choices.

Pursuing step and incremental change

The rapid decarbonisation illustrated in Figure 2.1 will necessitate technical, behavioural, operational and institutional step and incremental changes in all forms and modes of energy demand and supply. For example, step changes in transport fuel infrastructure to facilitate the market penetration of hydrogen, large incremental change in the uptake of all scales of renewable technologies, step change reductions in aviation growth and moderate incremental improvements in the energy efficiency of the existing housing stock.

Second order impacts of wider policy

Wider policy measures must guard against constraining low-carbon innovation, and explicit innovation policies will be required to preferentially guide innovation towards low-carbon options (e.g. the renewables obligation). The reciprocal of this is that explicit carbon reduction instruments, be they regulatory, taxation or emissions trading should be designed to avoid overly-constraining broader competition and innovation.

Transport infrastructure

If there is to be little or no increase in transport infrastructure required for the increased vehicle kilometres travelled under the *Mobility Plus* scenario, then a careful assessment of the most effective and efficient ways to use existing infrastructure will be required.

8.2.4 Resources

Biofuels and aviation

The constraints on fuel and energy use under which the research was conducted, essentially forced the aviation industry to adopt biofuels as the primary technical route for improving their relative carbon performance. The carbon emissions within both scenarios arise from oil and gas consumption (without CCS). Gas has insufficient density to compete with liquid fuels for aviation. Consequently, the industry is required to pursue demand management options, radical improvements in efficiency, and the substitution of hydro-carbon for bio-kerosene.

Careful use of the fuel and carbon permit limited transport growth

The scenarios illustrate that within both the severe carbon limits imposed by a 450ppmv future and the fuel/energy constraints placed on the research, it is still possible to envisage substantial increases in mobility, including via aviation. However, it should be noted that in the case of aviation, the rate of growth underwent a substantial step change, downwards, even in the *Mobility Plus* scenario. Moreover, the industry was required to pursue step changes in fuel (biofuel) as well as broader incremental technical and operational efficiency improvements. It is highly likely the increased transport within the *Mobility Plus* scenario will invite legitimate concern over its environmental sustainability implications (land-use for biofuels, local air pollution, noise, etc)

Nuclear power is not a prerequisite of low-carbon futures

Nuclear power is not a prerequisite of the UK meeting its climate change objectives – namely, making its ‘fair’ contribution to not exceeding a 2°C future. However, the relatively narrow remit of the research makes it difficult to envisage how, without major structural reform of the existing social and economic system, the scenarios could avoid large scale carbon capture and storage technologies.

8.3 Policy conclusions

The scenarios require a portfolio of policies if they are to achieve their goal of directing the UK on a path to decarbonisation. These conclusions are highlighted below, many in relation to the short-, medium- and long-term.

Taxing bads not goods

Public support for the very large cuts in emissions required is more likely if such cuts do not equate with large hikes in the overall level of taxation. Additional revenue – quite possibly in substantial quantities - will be raised from carbon taxes and from emissions trading schemes in which the emissions permits are auctioned. Whilst the government may use some of the revenue, for instance to implement energy-efficiency measures in low-income households, it should make it clear that a significant portion of this revenue will be returned to the public in the form of, for instance, cuts in income tax or lower taxes on jobs. Whilst the public is likely to accept a slight rise in their taxes if it understands and supports the uses to which its extra payments are to be put, it can be assured that it will not face a substantially greater burden of tax.

8.3.1 Short-term

Integrated transport strategy

Transport is a key sector within these scenarios and a truly integrated transport system is required that not only safeguards the climate but is safe, efficient, and affordable. Under the scenarios, transport policy ensures an appropriate balance between public and private modes, proper coordination between the various modes of public transport and, in a departure from today, explicitly includes both international aviation and shipping.

Cross-party consensus and public acceptability

Measures to achieve the very large emissions reductions implied by the cumulative emissions budget of 4.6GtC will be much easier to implement if there is a cross-party consensus to be bound by this emissions budget. The Government endorses the position of the Council of the European Union that emissions cuts of 60-80% are required by 2050 and the other major political parties have signed a joint statement acknowledging that emissions cuts of at least 60% are needed by 2050. In these scenarios, this consensus on “60% or greater” rapidly transforms into a consensus

on “90% by 2050”. However, more important than consensus over the mantra of “90% by 2050” is the consensus that emerges around the mantra of “70% by 2030” as the period between now and 2030 is the one in which the steepest reduction in emissions must occur.

Clearly, public acceptance of and support for “70% by 2030” and “90% by 2050” is necessary for the implementation of policy measures to achieve these targets. With the nation’s politicians all singing from the same hymn sheet, and putting on a united front with respect to emissions reductions required, it will undoubtedly be much easier to gain public acceptance and support for the robust climate change policy regime required.

Combination of instruments required

At the earliest opportunity, all sectors of the economy should be brought under a carbon tax or an emissions trading scheme. However, whilst a “taxing and trading” approach can limited demand and stimulate low-carbon innovation, other policy mechanisms are also required, from minimum efficiency standards for appliances and dwellings to interest-free energy-efficiency loans for SMEs to increased RD&D for hydrogen and CCS.

Build on what we’ve got

The size of emissions cuts required and the urgency with which they need to be made means that a shift in the policy regime is required as of now. Given this, the general approach adopted here has been to build on what we’ve got, tightening existing instruments in the short-term whilst considering new instruments in the medium-term. Vigorous policy action in the short-term will put in place a policy regime that provides a solid foundation for driving forward the 120MtC reduction in emissions (from 170MtC to 50MtC) in the medium-term.

8.3.2 Medium-term

Aviation and the EU ETS

In order to halt the rapid increases in aviation emissions and to bring emissions down, international aviation enters the EU ETS in 2012 under a stringent cap.

Trading for all?

There is the opportunity to implement innovative approaches to emissions trading such as implementing schemes running parallel to EU ETS or expanding EU ETS into an economy-wide personal carbon trading scheme.

New vision for supply

Under the scenarios, the energy supply model changes towards one of more decentralised supply. Deployment of CCS is required to start by 2015 and should be widespread by 2025 so as to coincide with the decommissioning not only of many nuclear power stations but also the old coal-fired plant. In addition, it is important to capitalize on the cost-effective opportunity for combining CCS with enhanced oil recovery in the North Sea. Deployment of hydrogen needs to begin around 2020 and be widespread by 2030.

8.3.3 Long-term

The hard work's been done

By 2030, the policies that have been put in place since the beginning of the scenarios have driven down emissions to 50MtC and their continued implementation enables the continued driving down of emissions to 17MtC in 2050.

Finally, if there is one important message we want to re-iterate from the research, it is the absolute urgency with which we must act to curb dramatically our carbon emissions. It is an act either of negligence or irresponsibility for policymakers to continually refer to a 2050 target as the key driver in addressing climate change. The real challenge we face is in directing society towards a low-carbon pathway by 2010-12, and thereafter driving down carbon intensity at an unprecedented 9% per annum (around 6% per annum in terms of absolute carbon emissions), for the following two decades.

9. References

AEA Technology Environment and Ecofys UK (2006) *LETS Update: Decision makers summary*, Bristol: Environment Agency

Anderson, K. (2001). Reconciling the electricity industry with sustainable development: backcasting – a strategic alternative, *Futures*, **33**: 607-623

Anderson, K., Shackley, S., Mander, S and Bows, A. (2005). *Decarbonising the UK: Energy for a climate conscious future*. The Tyndall Centre for Climate Change Research. Technical Report Number 33

ATAG (2000). European air traffic forecasts 1985-2015. IATA.

Aviation (2005). A strategy towards sustainable development of UK aviation. S. AOA, BATA, NATS.

Ayres, R (1997) Environmental market failures: Are there any Local Market-based Corrective Mechanisms for Global Problems, *Mitigation and Adaptation Strategies for Global Change* **1**, pp289-309

Barnes, P (2001) *Who Owns the Sky? : Our Common Assets and the Future of Capitalism*, Washington DC: Island Press

Berkhout, F., Hertin, J., and Jordan, A. (2002). Socio-economic futures in climate change impact assessment: using scenarios as learning machines. *Global Environmental Change* **12**, 83-95.

Boardman, B, Darby S, Killip,G, Hinnells, M, Jardine, C, Palmer, J and Sinden G (2005) *40% House*, Oxford: Environmental Change Unit

Bows, A., K. Anderson and P. Upham (2005). *Growth Scenarios for EU & UK Aviation: Contradictions with Climate Policy*. Tyndall Centre for Climate Change Research, Working Paper Number 84.

Bows, A., K. Anderson and P. Upham (2006). *Contraction & Convergence: UK carbon emissions and the implications for UK air traffic*. Tyndall Centre for Climate Change Research, Technical Report Number 40.

Bristow, A., Pridmore, A., Tight, M., May, A., Berkhout, F., Harris, M. (2004). *How can we reduce carbon emissions from transport?* Tyndall Centre for Climate Change Research, Tyndall Centre Technical Report 15,

BWEA (2006) *Offshore Wind: at a Crossroads*, British Wind Energy Association, April,

CAA (2004). *Main outputs of UK airports*. C. A. Authority.

Carbon Trust (2005) *The UK Climate Change Programme: Potential evolution for business and the public sector – executive summary*, London: Carbon Trust

Carbon Trust. (2003) *Building options for UK renewable energy*.

Carbon Trust. (2005) *Future Marine Energy*

CEU (2005a), *Climate Change: Medium and longer term emission reduction strategies, including targets - Council conclusions*, 7242/05, 11 March
<http://register.consilium.europa.eu/pdf/en/05/st07/st07242.en05.pdf>

CEU (2005b), *Council conclusions on climate change*, 17 October
http://ue.eu.int/ueDocs/cms_Data/docs/pressData/en/envir/86625.pdf

CEU (2005c) EU Council Conclusions – Reducing climate change impact of aviation, 2 December, http://europa-eu-un.org/articles/fr/article_5400_fr.htm

Chapman, J (2006). *The need for incentives to take CCS from RD&D into commercial stage*. Presentation at IEA workshop, Oil and Gas Innovation in the Fossil Fuel Future, Brussels, 22-23 February
http://iea.org/textbase/work/2006/resources/Day2/14_JChapman.pdf

Department of Trade and Industry. (1999) *Environmental Futures*. Office of Science and Technology, Department of Trade and Industry, London

Department of Trade and Industry. (2000) *Energy Paper 68*,
<http://www.dti.gov.uk/files/file11257.pdf>
<http://www.british-energy.com/article.php?article=99>
http://www.foe.co.uk/resource/evidence/bright_future_data.pdf

Department for Transport. (2003) *The Future of Air Transport*. Government White Paper, DfT London.

DEFRA (2006). *Climate change: The UK Programme 2006*. DEFRA. London.

DfT. (2005). *Images of the Future: New Market or Smart*. Visioning and Backcasting for UK Transport Policy (VIBAT), The Bartlett School of Planning and Halcrow Group Ltd, Stage 2 Working Paper

DfT (2005). *Transport Statistics Great Britain*. TSGB. N. Statistics. London.

DfT (2005). *Transport Statistics Great Britain*. Transport Statistics Great Britain. TSO. London, Department for Transport.

Dresner, S and Ekins, P (2004) *The Social Impacts of Environmental Taxes: removing regressivity – Economic Instruments for a Socially Neutral National Home Energy Efficiency Programme* (PSI Research Discussion Paper 18), London: Policy Studies Institute

DTI (2003). *Our energy future - creating a low-carbon economy*, Energy White Paper. DTI, Stationery office, London.

DTI (2006). *Our energy challenge: securing clean, affordable energy for the long-term*. DTI. London.

EEA (2002). TERM 2002 29 EU - Occupancy rates of passenger vehicles. Indicator Fact Sheet. E. E. Agency.

Ekins, P and Dresner, S (2004) *Green taxes and charges: reducing their impact on low-income households*, York: Joseph Rowntree Foundation

European Commission (2005a) *EU action against climate change: EU emissions trading - an open scheme promoting global innovation*, Brussels: European Commission

European Commission (2005b) *Reducing the Climate Change Impact of Aviation*, Comm (2005) 459 final

Feasta (2006) *The Great Emissions Rights Give-Away*, Dublin: Feasta
<http://www.feasta.org/documents/energy/emissions2006.pdf>

Fleming, D. (1996) Stopping the Traffic, *Country Life* **140**, 19; 9 May, pp 62-65

Fleming, D. (2005) *Energy and the Common Purpose: Descending the Energy Staircase with Tradable Energy Quotas (TEQs)*, London

Forster, P. M. d. F., K. P. Shine and N. Stuber (2006). It is premature to include non-CO₂ effects of aviation in emission trading schemes. *Atmospheric Environment* **40**(6): 1117-1121.

Foxon, T. (2003). *Inducing innovation for a low-carbon future: drivers, barriers and policies*, London: Carbon Trust

Gough, C., Shackley, S and Cannell, M. (2002). *Evaluating the Options for Carbon Sequestration*. Tyndall Centre for Climate Change Research, Tyndall Centre Technical Report 2.

Harrison, D. (2005). Unveiled: the clean queen of the sea, *Daily Telegraph*, 14 March 2005

HLG (2006) Press Release (IP/06/729)
<http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/06/729&format=HTML&aged=0&language=EN&guiLanguage=en>

Interdepartmental Analysts Group (2002) Unpublished document, DEFRA/DTI, London

IPCC. (1999). *Aviation and the global atmosphere*. Cambridge, Cambridge University Press.

IEA (2001) *Dealing with climate change: policies and measures in IEA member countries*, Paris: IEA

Krause, F. (1996). The costs of mitigating carbon emissions: a review of methods and findings from European studies, *Energy Policy* **24**, (10/11) pp. 899-915

Lib Dems (2006) *Joint Statement on a Cross-Party Approach to Climate Change*,
<http://www.libdems.org.uk/environment/issues/>, accessed 20 May

Lovins, A and Cramer, D (2004) Hypercars[®], hydrogen, and the automotive transition, *International Journal of Vehicle Design* **35**, (1/2)

McDowall, W. and Eames, M. (2006). Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: a review of the hydrogen futures literature. *Energy Policy* **24**

Meinshausen, M. (2006). What does a 2C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates *Avoiding Dangerous Climate Change* **Chapter 28**.

ODPM (2004) *Planning Policy Statement 22: Renewable Energy*, London: ODPM

ONS. (2003). *Greenhouse gas emissions from transport*. ONS. London.

ONS (2005). *United Kingdom National Accounts, The Blue Book*. New York, Palgrave MacMillan.

Performance and Innovation Unit. (2002). *The Energy Review*, Performance and Innovation Unit, Cabinet Office, London.

RCEP (2000) *Energy – The Changing Climate* (Twenty-second Report, Cm. 4749), London: The Stationery Office

RCEP (2002). The environmental effects of civil aircraft in flight. Special report of the Royal Commission on Environmental Pollution. R. C. o. E. Pollution.

Sausen, R., I. Isaksen, I. (2005). Aviation radiative forcing in 2000: An update on IPCC (1999). *Meteorologische Zeitschrift* **14**(4): 555-561.

Saynor, B., Bauen, A., Leach, M. (2003). *The potential for renewable energy sources in aviation P. F. Report*. London, Imperial College Centre for Energy Policy and Technology.

SEPA (2006) *Dealing with transport emissions: An emission trading system for the transport sector, a viable option?*, Stockholm: Swedish Environmental Protection Agency
<http://www.naturvardsverket.se/bokhandeln/pdf/620-5550-X.pdf>

SMMT. (2005). *UK New Car Registrations by CO2 Performance*. T. S. o. M. M. a. T. Ltd.

SRA (2001). Rail Emission Model. S. R. Authority, AEA Technology.

Starkey, R and Anderson, K. (2005). *Domestic Tradable Quotas: A policy instrument for reducing greenhouse gas emissions from energy use*. Tyndall Centre for Climate Change Research. Tyndall Technical Paper 39

Thwaites, T (2006) Ocean Flyer, *New Scientist*, 18 Feb 2006, pp46-8

UKCIP. (2001) *Socio-economic scenarios for climate change impact assessment: A Guide to their use in the UK*, Office of Science and Technology, Department of Trade and Industry, London

Watson, J. (2003). *UK Electricity Scenarios for 2050*. Tyndall Centre for Climate Change Research, Tyndall Centre Working Paper Number 41.

Williams, V., Noland, R.B., Toumi, R. (2003). Air transport cruise altitude restrictions to minimize contrail formation. *Climate policy* **3**: 207-219.